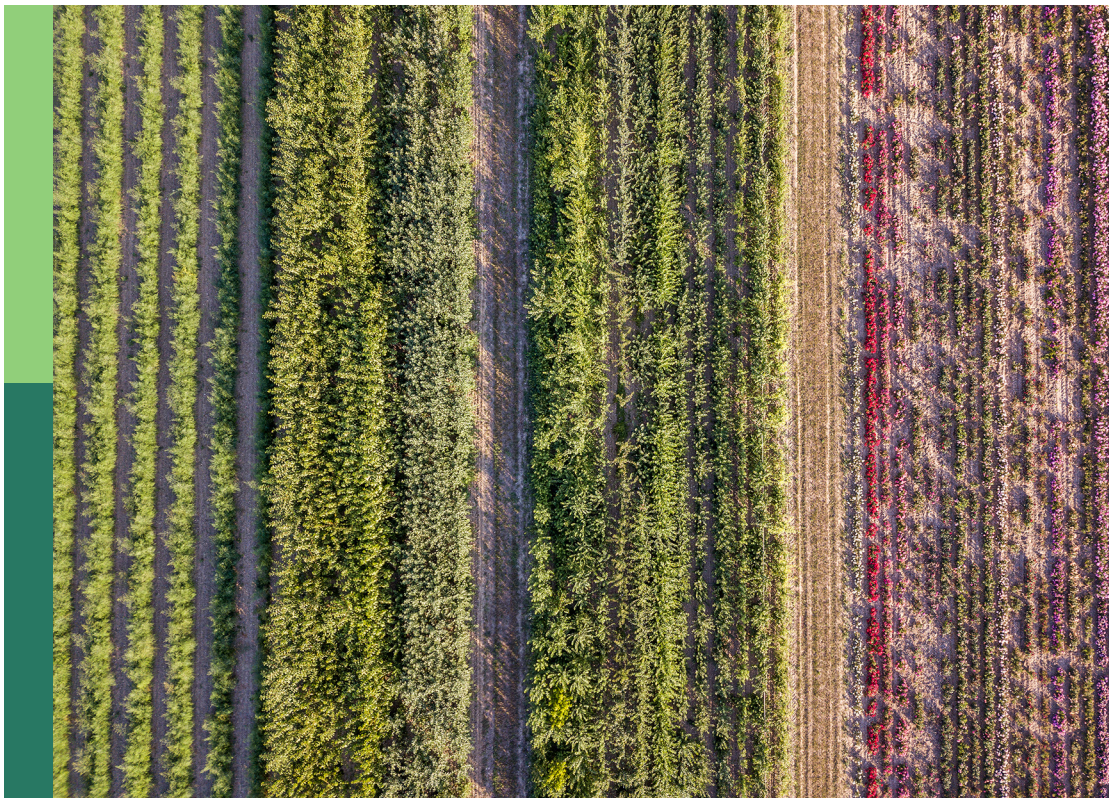
frontiers | Research Topics

Achieving food system resilience & equity in the era of global environmental change

Edited by
Albie F. Miles, Valarie Blue Bird Jernigan, Philip Dobie, Anja Gassner, Casey Hoy, Noa Kekuewa Lincoln, Kathleen Merrigan, Jennifer Sowerwine and Samina Raja

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Achieving food system resilience & equity in the era of global environmental change

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Editorial: Achieving food system resilience and equity in the era of global environmental change

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Editorial on the Research Topic
Achieving food system resilience and equity in the era of global environmental change

National governments and international agencies are forcefully warning that society is in the midst of a global climate crisis with grave risks to human welfare and natural systems (Pörtner et al., 2022). Recent IPCC reports have issued what has been called a "code red for humanity," delivering, once again, dire warnings of the profound risks of unmitigated anthropogenic climate forcing on human welfare, the limitations of ecosystems and human societies to adapt to climate change, and the risks to social and ecological stability (Sellers et al., 2019; IPCC, 2021, 2022). Further, recent analyses support the conclusion that the current national climate targets and international policy efforts are insufficient to limit anthropogenic warming to 1.5°C above pre-industrial global temperatures (Kemp et al., 2022; Matthews and Wynes, 2022). The full extent of the potentially catastrophic impacts of climate destabilization remains to this day scientifically underexplored and poorly understood (Kemp et al., 2022).

Food systems will continue to play a defining role in global environmental change, human welfare and socio-economic stability. The world's agri-food systems are a primary driver of global ecological change and negative public health externalities while simultaneously being vulnerable to the impacts of climate destabilization (Steffen et al., 2015; Meybeck and Gitz, 2017; Willett et al., 2019; Benton et al., 2021; Crippa et al., 2021; Slater et al., 2022). Severe weather events and their impacts to global agriculture, fisheries, and related food system infrastructure have steadily increased over the last decade and are projected to increase in severity over the remainder of this century (Brown et al., 2015; Watts et al., 2021; de Perez et al., 2022). Such negative impacts on yields from crop, livestock and fisheries, as well as damage to food processing, storage, transportation, and retail infrastructure could significantly diminish the security of the global and regional food supplies, drive food price spikes, and negatively impact the availability of high-quality foods, especially to low-income countries and marginalized and vulnerable communities, exacerbating food insecurity and malnutrition (Myers et al., 2017; Harris and Spiegel, 2019; Romanello et al., 2021; IPCC, 2022; Pörtner et al., 2022).

Deadly pathogens emerging from and amplified through agriculture are also anticipated to increase along with human population and the expansion and intensification of production strategies (Rohr et al., 2019; Wallace et al., 2021; Brooks et al., 2022; Trivellone et al., 2022). The global syndemic of climate destabilization, chronic illness, the COVID-19 pandemic, food insecurity, economic shocks, and the loss of ecosystem services must be simultaneously

accounted for in attempts to transform food systems to achieve stability, health, equity, resilience, and sustainability (Fanzo, 2020; Webb et al., 2020; Petersen-Rockney et al., 2021; Zurek et al., 2022).

Even with significant and coordinated efforts to limit global greenhouse gas emissions, all regions must plan for climate-induced shocks from more frequent and severe weather events resulting in the disruption of agricultural production, fisheries and supply chains, food price spikes, increased food insecurity, and the catastrophic loss of livelihoods, property and infrastructure (Harris and Spiegel, 2019; Duvat et al., 2021; Hasegawa et al., 2021). How food systems are planned, structured, and managed will, therefore, have a profound influence on the ability of society to sustain critical ecosystems services, mitigate and adapt to climate change, respond to future social and ecological crises, and ensure food security, public health, human rights and social stability into the future (Agyemang and Kwofie; Sampson et al.; Rockström et al., 2020; Rosenzweig et al., 2020; Queiroz et al., 2021; Watts et al., 2021).

With the possibility of significant destabilization of the Earth's climate system this century (Mora et al., 2013; Trisos et al., 2020; IPCC, 2022) educators, researchers, NGO leaders, planners, and elected officials must work together on transdisciplinary research, education, state and regional food system planning and policy efforts toward building more healthy, equitable, resilient, and ecologically sustainable food systems that are strategically aligned with state, national, and UN Sustainable Development Goals (Eyhorn et al., 2019; Valentini et al., 2019; Fanzo et al., 2021).

Food system resilience is the capacity over time of a food system to provide sufficient, appropriate and accessible food to all (i.e., food security) in the face of various and unpredictable biophysical, social, or economic disturbances (Tendall et al., 2015; Schipanski et al., 2016; Chodur et al., 2018; FAO, 2020). Food system resilience requires both sufficient stability to maintain needed capacity through disturbances as well as sufficient adaptive capacity to alter system structure and function when environmental changes render existing structure and function incapable of maintaining needed capacities (Hoy, 2015). Therefore, existing food systems can be hypothesized to be more or less resilient only to known or expected shocks and disturbances, but we can't say they are resilient until capacity has been maintained after disturbances occur. The performance of current food systems during the COVID-19 pandemic leaves some doubt about their resilience. Food system equity is a goal, outcome or condition of the food system where the benefits and risks of how food is grown and processed, transported, distributed, and consumed are shared equitably by society (Allen, 2010; Gottlieb and Joshi, 2010; Alkon and Agyeman, 2011; Smith, 2019). Based on the concept of resilience described above, equity could be viewed as both an essential condition for food system resilience and sustainability and an outcome of sustainable and resilient food systems. Achieving food system resilience and equity in the era of global environmental change will require integrated and reinforcing research, education, public policy, investment, and normative goal setting (Blay-Palmer et al., 2021; Zurek et al., 2022), all of which exist within varying cultural, political, and economic systems.

The objective of this Frontiers Special Research Topic is to provide academics, elected officials, government agencies, urban and regional planners, community leaders, and other food system practitioners with an up-to-date scientific analysis of the systemic risks of anthropogenic climate destabilization and other stochastic shocks to agriculture, food security, human health, and economies. Papers submitted to address this topic provide key theories principles, case studies and actionable strategies for achieving food system resilience and equity (Figure 1).

The articles throughout the special edition have enriched the conceptual and practical definitions of resilience and equity in food systems, consistent with the description above. A particular focus of a review of published resilience studies in the Indo-Pacific region (Friedman et al.) was in how resilience was defined or described, compared with standard definitions in previous literature. The conceptual views most prevalent in the papers reviewed were adaptation, adaptive capacity and response to disturbance, although only about half of the papers selected for analysis cited specific definitions. Although resilience is more than response to disturbance and environmental change, the importance of climate change in stimulating studies of food system resilience was clearly evident. Papers that identify observable qualities or operational/mechanistic characteristics of food systems to propose metrics or indicators give further insight into evolving models and definitions and how they can be operationalized in research and practice.

In multiple submissions, the measurable qualities of resilience and equity were focused on one of a few key food systems concepts: sustainability, sovereignty or security, and in some cases all three, as in the human right to food. Although many of the papers describe metrics and/or indicators, several articles in the collection focused on them specifically. For example, Jernigan et al. propose a series of indicators and sub-indicators of food sovereignty with a particular focus on the food systems of indigenous communities, and which are potentially generalizable to a wide range of cultural contexts. Agyemang and Kwofie selected 5–6 indicators from the literature for each of 4 areas that are important in food system failure analysis: production, nutrition, social equity, and environmental damage mitigation. In contrast, Sampson et al. focus on particular characteristics of equity, food sovereignty and the human right to food, and test their association with food security, an outcome of sustainable and resilient food systems. Rather than propose specific indicators, Springer et al. propose a malleable workflow for selecting the indicators and issues that are most useful and relevant to a particular community or context in measuring food system sustainability. Remaining papers in the special edition, case studies of both challenges to resilience or equity and of food system qualities that may favor resilience and equity, collectively enrich the conceptual understanding of key concepts and the metrics and indicators used to measure and compare specific systems and geographic regions.

Structural obstacles to food system resilience and equity were a major focus of papers describing resilience-related research in the Indo-Pacific region (Friedman et al.), where climate change and environmental disturbance were the most prevalent forms of disturbance appearing in the literature analyzed. Likewise, climate change impacts and adaptation strategies were a focus of a comparison between rural communities in the global north and south by Raj et al. in this collection. However, several other important challenges appear in the articles published in this special edition. Hutchins and Feldman, for example, compared individual farmer responses to COVID-19 in Hawaii. Industry conditions, such as consolidation or lack of diversity in both production (Howard et al.), and supply chain components or actors (Miller) were described as key

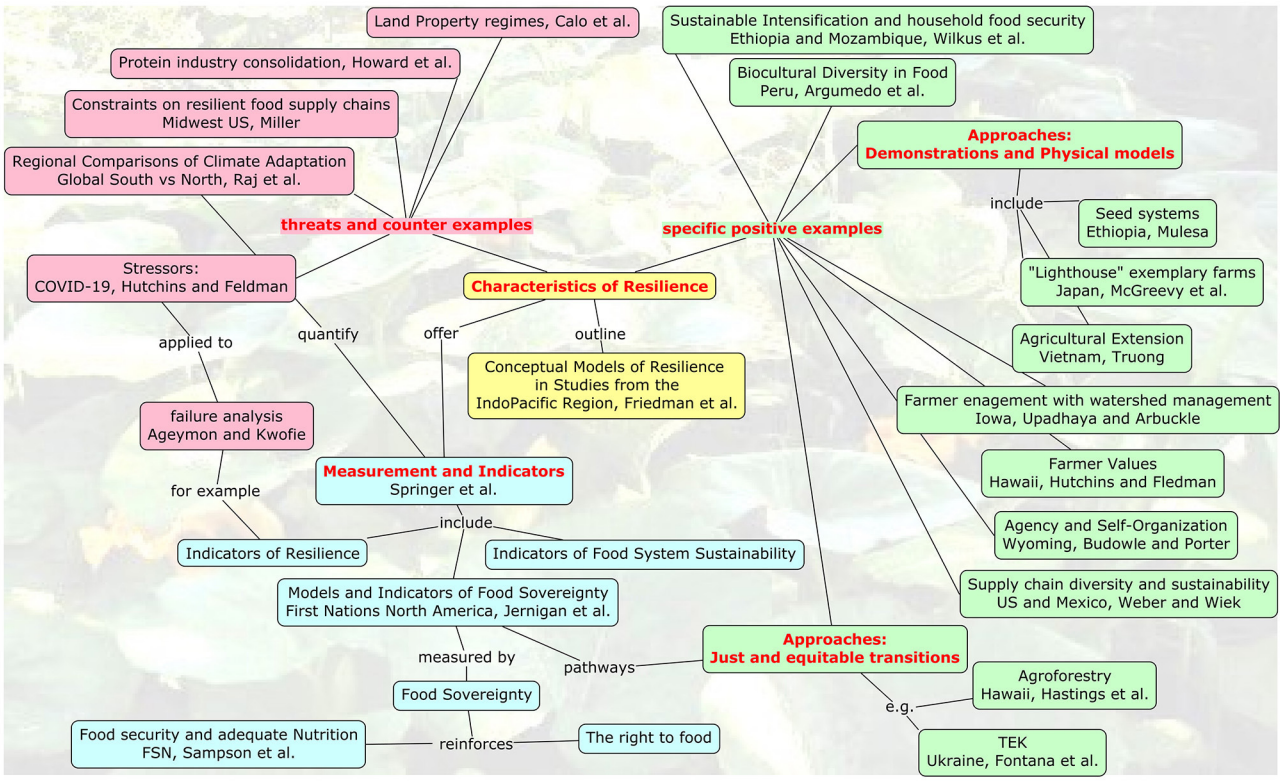


FIGURE 1
Concept map of the papers submitted to address the special Research Topic on food system resilience and equity under global environmental change.

constraints to realizing food system resilience and equity, in each case with diversification as a clear means of addressing these challenges. As a serious obstacle to both food system resilience and equity, Calo et al. examined dominant land property regimes, which can have a direct bearing on both food sovereignty and security.

Finally, approximately half of the papers in this special Research Topic described case studies of system qualities that are expected to be positively associated with food system resilience and equity. These include examples of environmental, social, and economic elements of food systems, as well as transition pathways within each of these three important dimensions of food system sustainability. Production ecosystem-oriented examples include biocultural diversity (Argumedo et al.) and sustainable intensification (Wilkus et al.) with programmatic transition pathways (Fontana et al.; Hastings et al.; McGreevy et al.; Mulesa) proposed through similar traditional knowledge and agroecological approaches. Social dimensions of food systems were addressed through analysis of farmer values (Hutchins and Feldman), collaborative approaches to watershed scale management (Upadhaya and Arbuckle), and agency for self-organization (Budowle and Porter), with extension educational programs among the transition pathways analyzed (Truong). An example of supply chain diversity (Weber and Wiek) is given to support the proposed solutions (e.g., Miller) for more resilient economic elements of food systems.

Overall, the special edition contains examples and points of view from all hemispheres and from various perspectives on key aspects of food system resilience and equity. The papers collectively help to clarify conceptual definitions of food system resilience and equity as well as operational processes and observable, measurable qualities associated with those conceptual definitions. We hope that the collection will both enable and encourage more focused research on resilience and equity in food systems internationally and across cultures.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Cooperating With "Open Cards"—The Role of Small Intermediary Businesses in Realizing Sustainable International Coffee Supply

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Despite improvements, international food supply in general and coffee supply in particular continue to cause significant greenhouse gas emissions, economic inequities, and negative impacts on human well-being. There is agreement that dominant economic paradigms need to change to comply with the sustainability principles of environmental integrity, economic resilience, and social equity. However, so far, little empirical evidence has been generated to what extent and under which conditions sustainable international coffee supply could be realized through small intermediary businesses such as roasteries, breweries, and/or retailers. This case study reports on a collaborative project between a small coffee brewery and its customers in the U.S. and a small coffee roastery and its suppliers in Mexico that demonstrates how sustainable coffee supply could look like and explores under which conditions it can be realized. A research team facilitated the cooperation using a transdisciplinary research approach, including field visits and stakeholder workshops. The project (i) assessed the sustainability challenges of the current supply and value chains; (ii) developed a vision of a joint sustainable coffee supply chain; (iii) build a strategy to achieve this vision, and (iv) piloted the implementation of the strategy. We discuss the project results against the conditions for sustainable international coffee supply offered in the literature (why they were fulfilled, or not). Overall, the study suggests that small intermediary coffee businesses might have the potential to infuse sustainability across their supply chain if cooperating with "open cards." The findings confirm some and add some conditions, including economic resilience through cooperation, problem recognition, transparency, trust, and solidarity across the supply chain. The study concludes with reflections on study limitations and future research needs.

Keywords: global food supply, value chains, small businesses, fair prices, transformation, transdisciplinarity

INTRODUCTION

Globally, 60 million people are involved in the annual production of 8.5 million tons of green coffee (Eakin et al., 2017), with the large majority being exported to the U.S. and Europe (International Coffee Organization, 2019). While coffee sales amount to tens of billions of dollars (e.g., 19 billion USD in 2017; United Nations Statistical Division, 2020), there are significant imbalances in the financial flows, e.g., only a small percentage of the purchase price for green coffee remains in the countries of production (Jaffee, 2007; Beshah et al., 2013). Low incomes for coffee farmers are often linked to low access to health services and schools as well as to migration to cities (Samper and Quiñones-Ruiz, 2017). Economic constraints also drive coffee rust epidemics (Villarreyna et al., 2020), a major economic and ecological challenge for coffee production, in particular in South America (Avelino et al., 2015). In addition, intensification of coffee production contributes to biodiversity loss due to deforestation (Philpott et al., 2008), as well as climate change due to greenhouse gas emissions (van Rikxoort et al., 2014).

Over the past decade, the coffee sector has seen the rise of voluntary sustainability standards, e.g., Fairtrade, 4C, UTZ, or Rainforest Alliance, among others (Pierrot et al., 2010). Some of these practices offer incremental improvements to the sustainability performance of coffee production (Zerbe, 2014; Winter et al., 2020). However, while about 25% of coffee traded globally is certified in one way or the other (Lernoud et al., 2018), this often does not improve smallholder farmers' livelihoods (Chiputwa et al., 2015), but rather benefits roasters or retailers (Valkila et al., 2010; Kolk, 2013; Dragusanu and Nunn, 2018). While there is evidence that some certificates perform well under specific circumstances (e.g., Parrish et al., 2005), there are often trade-offs between economic and environmental outcomes (Vanderhaegen et al., 2018). In short, certifications do not result in the "fundamental transformation of the global food system" (Zerbe, 2014) necessary to align with the sustainability principles of environmental integrity, economic resilience, and social equity (FAO, 2014; Levy et al., 2016).

Approaches that pursue sustainable coffee supply, other than certifications, are alternative trade arrangements (Rathgens et al., 2020), e.g., direct trade of coffee and relationship coffee models (Jaffe and Bacon, 2008; Edelmann et al., 2020). Key players in these arrangements are intermediary coffee businesses between producers and consumers, i.e., roasteries, breweries, and retailers. Direct trade of coffee relies on a connection between a coffee producer on the one hand, and a roaster, brewer, and/or a retailer, on the other, who "seek to build a sustainable, long-term and mutually beneficial relationship to grow, process and market outstanding coffee" (Borrella et al., 2015, p. 34). This study intentionally focused on small intermediary businesses as an under-researched supply-chain actor group as studies on alternative trade arrangements in international food supply mostly focus on producers or consumers (Rathgens et al., 2020). While alternative trade arrangements might infuse sustainable practices across the coffee supply chain, they mostly focus on the pursuit of economic fairness and resilience (Gerard et al., 2019). Conditions that enable alternative trade arrangements include, among others, direct contacts, trust, transparency, accountability, and commitment (Gerard et al., 2019; Edelmann et al., 2020; Weber et al., 2020), all indicative of cooperating with "open cards" as a summative condition to advance sustainability across the supply chain.

Against this background, two objectives were derived:

- First, to explore the *extent* to which small intermediary coffee businesses can induce sustainable practices across their supply and value chains.
- And second, to explore the *conditions* conducive to such efforts.

These objectives were pursued through a study on a transdisciplinary project between a research team and two small intermediary coffee businesses, a brewery from the U.S. and a roastery from Mexico. The project (i) assessed the sustainability challenges of the current supply and value chains; (ii) developed a vision of a joint sustainable coffee supply chain; (iii) built a strategy to achieve this vision, and (iv) piloted the implementation of the strategy. We discuss the project results against the conditions for sustainable international coffee supply offered in the literature (why they were fulfilled, or not). Thereby, we explore the extent to which small intermediary coffee businesses, through cooperation, can induce sustainable practices across their supply and value chains.

While limited in generalizability due to the case-study nature, the results from this study could inform intermediary coffee businesses and policy makers interested in advancing sustainable international coffee supply. We would also hope that this study stimulates more research and theory building on the role of small intermediary businesses in creating sustainable supply chains. The project finally could inform researchers how to conduct transdisciplinary research to advance positive change in international food supply.

RESEARCH DESIGN

The project was conducted between September 2018 and November 2019 as a transdisciplinary collaboration between the *Sustainable Food Economy Lab* at Arizona State University and two coffee businesses, *Considerate Coffee Company* and *Catando Ando Coffee Rosters*. Considerate Coffee was a processing company for bottled cold-brew coffee in Phoenix, Arizona. Founded in 2017 and run by two co-owners, the company brewed coffee sourced from Ethiopia and roasted in Phoenix and distributed the bottled coffee drink mostly to restaurants and hotels. The company closed in 2020 due to private reasons. Catando Ando is a local coffee business with a roaster and coffee shop in Xalapa, Veracruz, Mexico. Founded in 2014 and run by two co-owners and four employees, the company roasts green coffee sourced from local farmers and distributes it in Mexico.

The selection of suitable project partners was informed by previous research on sustainable practices of intermediary

businesses in international food supply (Weber et al., 2020). For this case study, the researchers were looking for businesses that were (i) small intermediary businesses in international food supply; (ii) committed to sustainable business practices and models; and (iii) interested in piloting some of the practices not adopted yet. The researchers conducted semi-structured interviews with eight potential businesses – and eventually selected Considerate Coffee and Catando Ando. Both businesses were active as intermediary businesses, showed high commitment to sustainability, and were willing to experiment with new sustainable practices. In addition, we considered (iv) spatial proximity (Phoenix and Mexico) for feasible site visits and direct exchange; (v) existing contacts (to both businesses) for productive collaboration; and (vi) available expertise (coffee trade expertise) for accelerated project results. The main motivations of the businesses for participating in this collaboration was to advance sustainability and transparency across the supply and value chains; to broaden market access and livelihood opportunities for coffee farmers; and to cooperate with like-minded people and to learn from each other. The businesses did not receive any compensation for the collaboration. The project team consisted of the two co-owners and one employee from Catando Ando, the two co-owners of Considerate Coffee, and two researchers from the Sustainable Food Economy Lab (the authors).

The research team used an established transdisciplinary approach that guides researchers and practitioners in developing evidence-based solutions to sustainability problems (Lang et al., 2012; Wiek and Lang, 2016). The researchers developed relationships to both businesses through conversations and by personally visiting the businesses in Phoenix and in Xalapa. They then established the contact between the two businesses and facilitated the collaborative process, described below. Similar to participatory action research projects with smallholder farmers in coffee supply chains (e.g., Jaffe and Bacon, 2008; Méndez et al., 2017) the researchers and the coffee businesses collaborated closely in (1) understanding the current challenges in the coffee supply chains (assessment); (2) developing a vision for a joint sustainable international coffee supply chain; (3) building a strategy for achieving this vision; and finally (4) testing vision and strategy through a demonstration project (**Table 1**). Thereby, the researchers adopted different roles, namely, as process facilitator, knowledge generator, and knowledge broker (Wittmayer and Schäpke, 2014).

In the first phase, the current coffee supply and value chains of the two coffee businesses were mapped out and analyzed (cf. Castello Branco and dos Santos, 2018). Additional information about the current business practices was compiled and assessed against a comprehensive set of sustainability principles (cf. Weber et al., 2020), based on the Sustainability Assessment of Food and Agriculture (SAFA) framework of the United Nations Food and Agriculture Organization (FAO, 2014). Data was collected through document reviews, two semi-structured interviews (one per businesses) and five individual working sessions with the business owners (two with Catando Ando, three with Considerate Coffee), as well as two site visits (one at each business site). Details on the price calculations for the value chains can be found in the **Supplementary Material**. In the second phase, a vision for a sustainable joint coffee supply chain was developed and refined based on a set of quality criteria, including coherence and plausibility (Iwaniec and Wiek, 2014). The vision process also included that participants shared their motivations and expected benefits of the collaboration to build trust and ownership for the process (Ostrom, 2003; Luederitz et al., 2017). In the third phase, a strategy (action plan) was developed on how to achieve the vision (Kay et al., 2014). Data for vison and strategy was collected through two 3-h all-hands working sessions, in which all seven team members joined, two individual meetings (one with each businesses), frequent email exchange, literature review, and reflections by the researchers (documented after each meeting). Some of the information was obtained by the intermediary businesses, who—due to short supply chain structures—had direct contact with farmers and consumers, respectively. For example, all upstream prices of the envisioned value chain were informed by Catando Ando's conversations with the coffee farmers. Catando Ando participated online in the working sessions. Main working language was English, with one of the researchers translating between English and Spanish as needed. In the fourth phase, based on the action plan, Considerate Coffee and Catando Ando piloted the joint supply and value chain. The process was documented with pictures and notes taken by the businesses. The researchers facilitated bi-monthly online meetings to share recent developments and address emerging issues. After the pilot project had ended (October 2019), the researchers facilitated a transfer workshop for coffee businesses in Phoenix (Weber and Wiek, 2020).

DESIGN PRINCIPLES FOR SUSTAINABLE INTERNATIONAL COFFEE SUPPLY

Incremental improvements do not suffice to address current sustainability challenges in international coffee supply (Zerbe, 2014). Approaches are needed that restructure international coffee supply in ways that align with a comprehensive set of sustainability principles (Samper and Quiñones-Ruiz, 2017; Castello Branco and dos Santos, 2018). The SAFA framework (FAO, 2014) provides a robust sustainability assessment framework for food systems. We made a few adaptations to fully reflect the nature of an international coffee supply chain with its variety of participating actors and entities. In addition, such principles are best formulated as design principles with clear direction of what to aspire to and applicable to what small intermediary businesses can do. The set of principles is most convincing (plausible) when grounded in existing pioneering practices (cf. Weber et al., 2020). We therefore indicate an exemplary coffee business that complies with the respective principle. The ten design principles used in this study are summarized in **Table 2**, below. They are adapted

TABLE 1 | Phases of the project.

Phase	(1) Current state assessment	(2) Sustainability visioning	(3) Strategy development	(4) Demonstration project	(5) Transfer workshop
Output	Current-state model of coffee supply and value chains	Vision of sustainable coffee supply and value chain	Strategy (action plan) to achieve the vision	Piloted sustainable coffee supply	Capacity in coffee businesses
Time period	Sep–Oct 2018 (4 weeks)	Oct–Nov 2018 (4 weeks)	Nov–Dec 2018 (2 weeks)	Dec 2018–May 2019 (6 months)	Oct 2019 (1 day)
Methods	Document review, interviews, site visits	Workshops and data analysis	Workshops and data analysis	Photo documentation, online meetings, reflections	Workshop and data analysis

from previous research (Weber et al., 2020), which provides the supporting literature.

RESULTS

Sustainability Problems Along the Current Coffee Supply Chains

The assessment exposed a number of sustainability challenges along the supply chains of Considerate Coffee and Catando Ando (**Table 4-A**).

Considerate Coffee's annual production volume was around 8,706 liters (or kg) cold brewed coffee, brewed from around 544 kg roasted coffee. Their customers, mostly restaurants and hotels, were located in Phoenix. Considerate Coffee's supply and value chain is illustrated in **Figure 1**. The coffee was transported more than 14,500 km from Ethiopia to Arizona with associated emissions (*Long distance/high CO_2 emissions*). There was a large number of actors ($n = 13$) involved in the supply chain (*Long complex supply chain*). The coffee was roasted in Arizona, not in the country of origin (*Value extracted from the country of origin)*. Prices were unknown for most of the upper part of the value chain. Considerate Coffee was able to identify only a few prices, based on the closest business relationships and common knowledge, e.g., for exported Fairtrade certified green coffee. Based on current studies (Valkila et al., 2010; e.g., Chiputwa et al., 2015), we assumed that even Fairtrade prices could have been unfair (too low), at least for some supply chain actors (*Prices do not meet socio-economic needs*). Similarly, one has to assume—considering common practices—that coffee farming and processing were not based on organic, energy-efficient, and water-efficient technologies and practices (*Resource-intense production and processing techniques*); nor might they have supported equity efforts (*Lack of empowering women and minorities*). Finally, there were major gaps in information across the supply chain. Considerate Coffee only knew the two actors based in Arizona personally (retailer, roaster) and the names of two others (larger importer, farm site); yet, did not know any specifics about the life and work circumstances of any supply chain actors upstream. This translated into gaps in product information provided (*Insufficient product information*). With little/no knowledge, supply chain actors also displayed little/no support, assistance, and solidarity for each other (*Lack of caring professional relationships*). However, Considerate Coffee also displayed some positive sustainability features, for example, they purchased Fairtrade-certified coffee which might have secured workers' health and safety (*Good working conditions*), and they produced coffee bio-char from coffee grounds and used only recycled material for their brewing equipment (*Resource-efficient processing techniques*).

There were fewer sustainability challenges related to Catando Ando's supply and value chain (**Figure 2**). Catando Ando operates and distributes in Mexico (*Short distance/low CO_2 emissions*), in direct contact to all six supply-chain actors, and with knowledge about prices associated with each element of the value chain. Knowing the farmers' life and work conditions and being in regular contact with them *(Caring professional relationships/Good working conditions)*, Catando Ando indicates as a sustainability challenge that farmers and coffee pickers do not receive a fair price, at least 20% too low (*Prices do not meet socio-economic needs*): "Farmers get 3 pesos per kg [coffee cherries] as an average price. We pay [at least] 3.5 to 4 pesos per kg [coffee cherries]. This should be increased to 5 pesos to be fair." (Catando Ando, Visioning Workshop, 2018/11/08, for green coffee equivalents see **Figures 2**–**4**). Catando Ando is often not able to pay higher prices because its specialty coffee does not achieve adequate prices in Mexico. At the time of the project, Catando Ando was therefore exploring export markets, e.g., to Vietnam – with the implications of significantly higher food miles (*Long distance/high CO_2 emissions*) and more supply-chain actors involved (*Long complex supply chain*). While Catando Ando collaborates with coffee farmers on improving production and processing techniques in order to increase the quality of coffee cherries and green beans, most contracted farmers still use conventional coffee farming practices, e.g., using chemical pesticides against the fungus that causes coffee leave rust (*Unsustainable production and processing techniques*). Catando Ando uses a packaging that displays the famer's name, the coffee bean variety and the exact location of the coffee farm (*Relevant product information*).

The vision for a joint sustainable coffee supply chain

The vision reflects the desire to address the sustainability problems revealed in the assessment, starting with merging the two coffee supply chains of Considerate Coffee and Catando Ando. While this leverages their complementarities (**Table 4-A**), both companies were willing to explore additional efforts to enhance the sustainability performance of the joint supply chain.

TABLE 2 | Design principles for small intermediary businesses for sustainable international coffee supply, adapted from Weber et al. (2020), with correspondence to SAFA criteria and exemplary coffee businesses that have implemented the respective principle.

Principle	Definition (*SAFA Criteria*)	Example
Pay prices that satisfy socio-economic needs	Compensate every person working in the coffee supply chain, including temporary field workers (e.g., coffee pickers), a price that allows them to satisfy their socio-economic needs. This ensures that all supply-chain actors can live a decent life with sufficient levels of housing, food, health, education etc. (*Decent livelihood; Fair Trading Practices; Investment; Vulnerability; Local Economy*)	*Teikei Coffee*, Germany
Reduce number of supply-chain actors	Remove intermediaries, e.g., importers, exporters, trade associations, especially those, who do not add value to the coffee product. This reduces costs, enhances transparency, and allows for closer relationship building across the supply chain (*Accountability; Participation*)	*Peixoto Coffee*, USA
Shorten geographical distance	Reduce food miles along the coffee supply chain through partnering with actors located in regions as close as possible to each other. This reduces CO_2 emissions and allows for closer relationship building across the supply chain (*Atmosphere; Participation*)	*Considerate Coffee & Catando Ando*, USA/Mexico
Add value in the country of origin	Shift value-added production steps from coffee importing countries to the country of origin, e.g., roasting and packaging the coffee in the country of origin. This ensures higher revenue generation in the country of origin where it is often needed most *(Fair Trading Practices; Local Economy)*	*Solino*, Ethiopia
Secure gender and race equality	Empower women and minorities through qualifications for entrepreneurship and management, e.g., through financing training courses. This helps women and minorities to become independent, as well as gain higher satisfaction in work environments (*Equity; Cultural Diversity*)	*Femcafe*, Mexico
Develop caring professional relationships	Get to know the partnering supply-chain actors, communicate (frequently) with them, share insights with them, appreciate their products/services, and recognize their needs. This facilitates collective decision-making, solidarity, assistance, and support across the supply chain (*Participation*)	*Pachamama Coffee*, USA
Secure good working conditions	Grant all supply-chain actors basic rights of safety, health, and participation, beyond existing legislation, if necessary (no slavery, exploitation, dominance). This ensures that all supply-chain actors are treated in accordance with human rights and other basic rights (*Labor Rights; Human Safety and Health; Participation; Rule of Law*)	*La Revancha*, Nicaragua
Disclose all relevant information about the coffee product	Compile and share all relevant information about the coffee product, including ingredients, production and processing steps, potential health implications, involved supply chain actors, value chain, etc., beyond existing legislation, if necessary. This ensures that supply-chain actors and in particular consumers are aware of all important features of the coffee product and can take an informed decision on participating in the supply chain, e.g., by purchasing the product (or not) *(Accountability; Rule of Law; Product Quality and Information)*	*Quijote Kaffee*, Germany
Apply resource-efficient production and processing techniques	Apply organic and other production, processing, and distribution technologies and practices that conserve soil, water, energy, and biodiversity, beyond existing legislation, if necessary. This ensures to not overexploit natural resource stocks and contributes to mitigating climate change *(Atmosphere; Water; Land; Biodiversity; Materials and Energy; Rule of Law)*	*Coopedota*, Costa Rica
Offset CO_2 emissions	Offset remaining CO_2 emissions caused during production, processing, and distribution, e.g., through financing reforestation projects. This contributes to mitigating climate change *(Atmosphere; Materials and Energy)*	*Jumarp*, Peru

The vison was therefore crafted to comply with the full suite of design principles for sustainable international coffee supply (**Table 4-B**).

The joint sustainable supply chain between Considerate Coffee and Catando Ando (**Figure 3**) envisions: Prices are truly fair and transparent to all supply-chain actors, who know and care for each other. This is facilitated by a reasonable number of supply chain actors ($n = 8$) with Catando Ando and Considerate Coffee being exporter and importer, respectively. All supply-chain actors are located in reasonable proximity from each other (Arizona, USA & Mexico) and stay in regular contact. Short transportation, organic farming practices, resource-efficient processing equipment, and offsetting remaining CO_2 emissions through reforestation projects in the regional mountain forest protect the environment.

The first core element of the vision are truly fair prices paid to *all* supply-chain actors, that means, that all supply-chain actors "are paid in such a way that they can cover their needs and live a decent life far away from poverty" (Sotiropoulou, 2012). The project partners co-defined "living far away from poverty" as follows: all supply-chain actors (i) have sufficient food, clothing, and shelter, as well as access to education, health, and other social services; (ii) are empowered to participate in decision-making processes; and (iii) feel hopeful about the future (cf. UN-SDG2). Fair prices for all elements and actors of the value chain reflect differences in needs and decent-life costs across the regions and countries where supply chain actors reside. For example, the higher payments would allow coffee pickers to afford healthcare and education for their families; or coffee farmers would be incentivized to continue farming as opposed to abandon their land and migrate to the city. The prices are significantly higher compared to Considerate Coffee's current value chain; for example, as compared to the envisioned 6.14 USD/kg roasted coffee for the individual farmer, currently, a farmers cooperative receives the standard Fairtrade price of 4.41 USD/kg, with individual farmers likely receiving even less

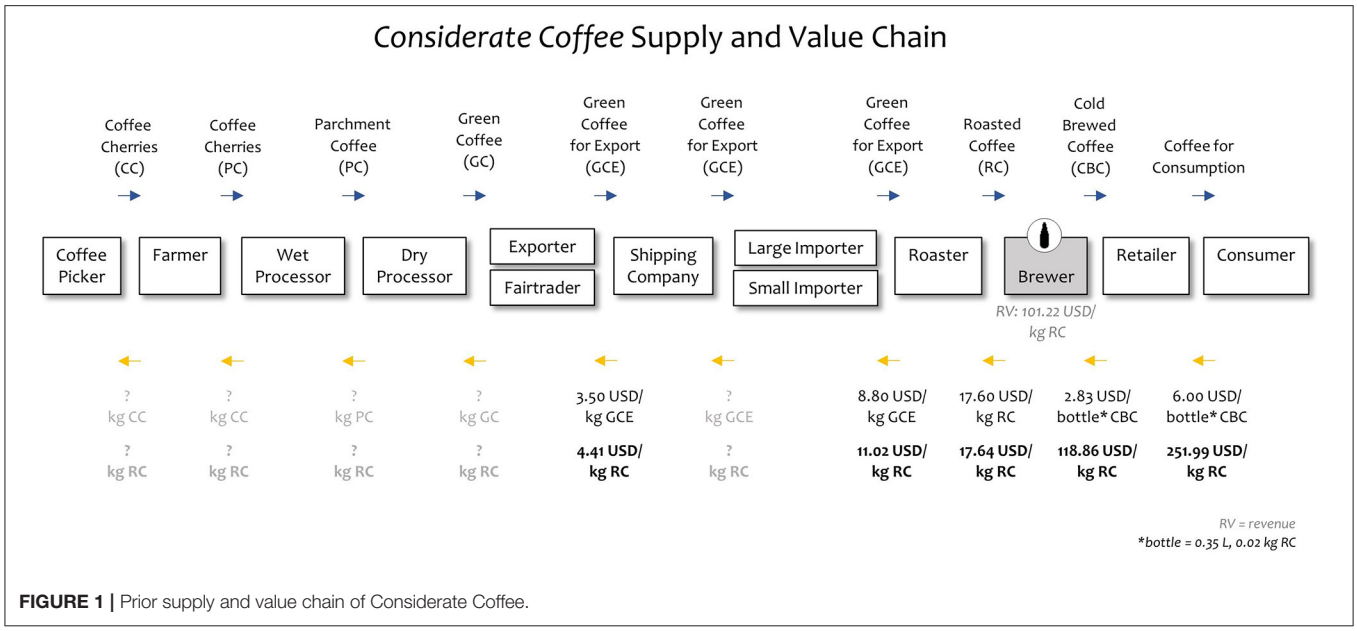


FIGURE 1 | Prior supply and value chain of Considerate Coffee.

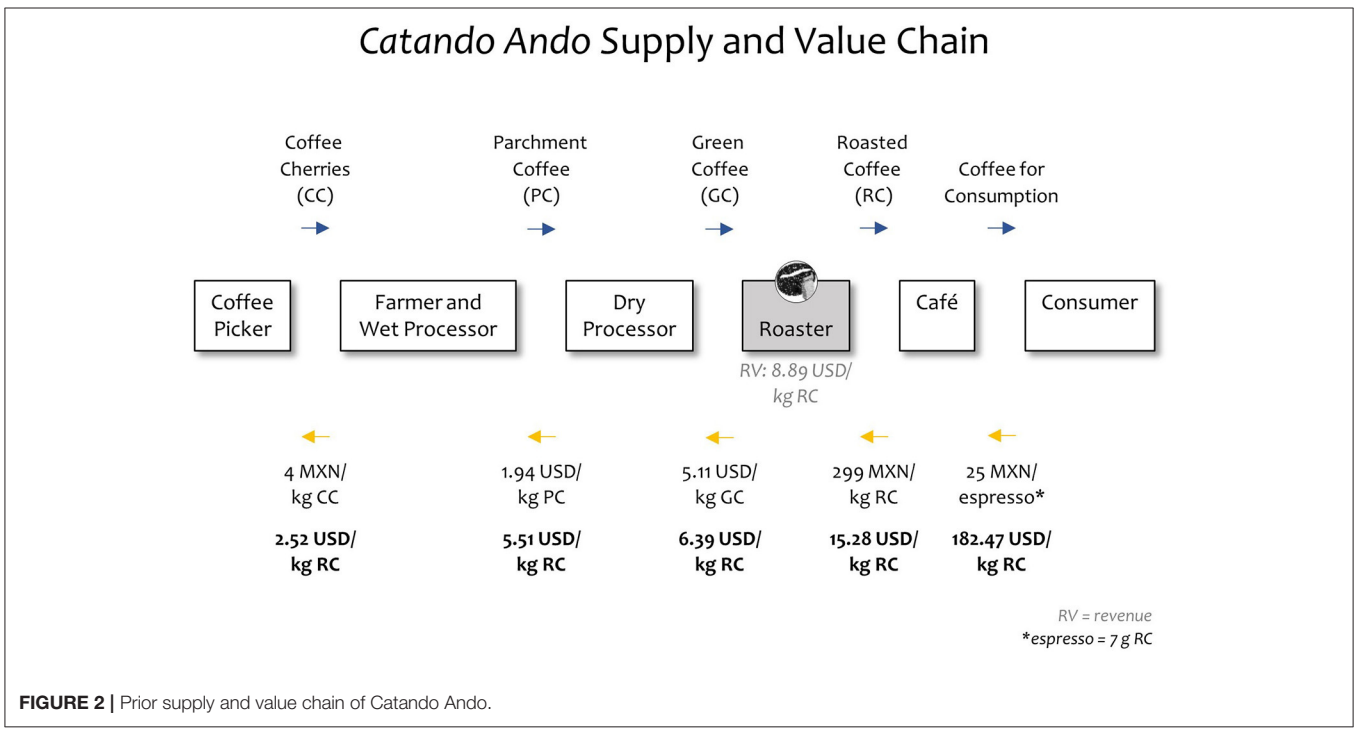


FIGURE 2 | Prior supply and value chain of Catando Ando.

(Chiputwa et al., 2015). This is indicative of the fact that Fairtrade prices often do not keep up with increased cost of living, as suggested in other studies (Bacon, 2010).

The second core element of the vision is the short supply-chain structure with Catando Ando operating as the exporter, Considerate Coffee as the importer, a customs broker taking care of the paperwork, and a shipping company transporting the coffee (annual exporter/importer certification fees and shipping costs are included in the value chain). This facilitates close and caring professional relationships across the entire supply chain with regular (online) contact and occasional visits, as well as achieving transparency and securing good working conditions across all stages of production, processing, and distribution. Striving for full transparency includes disclosing all relevant information on the product, e.g., coffee variety, locations, people, and payments, to all supply chain actors, including consumers, through personal communication, product packaging, and company websites.

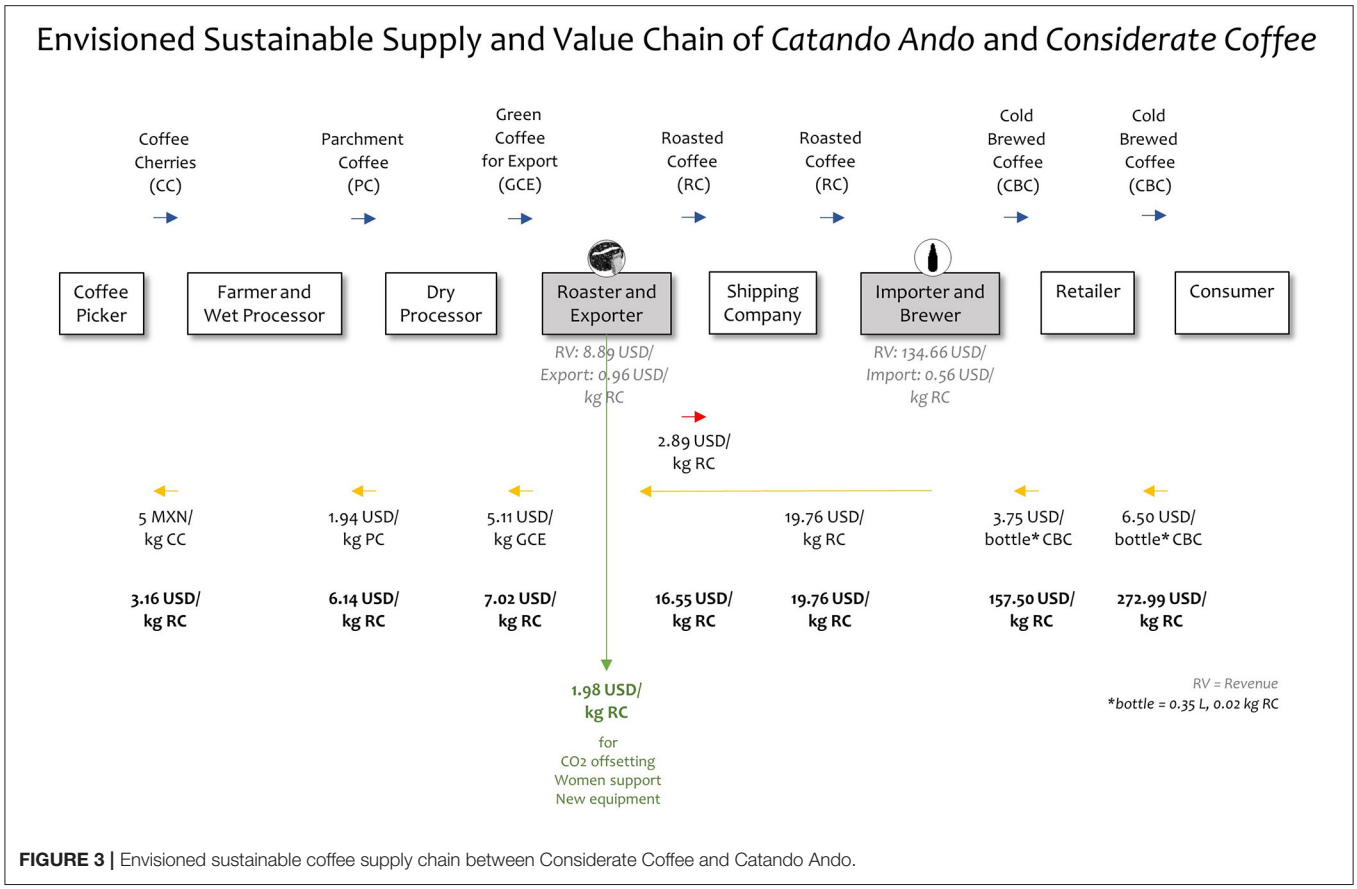


FIGURE 3 | Envisioned sustainable coffee supply chain between Considerate Coffee and Catando Ando.

Sourcing roasted coffee from Mexico to Arizona instead of green beans from Ethiopia significantly reduces food miles (from 14,500 to 2,600 km) and CO_2 emissions, while adding value in the country of origin. Both businesses agreed on investing up to 10% of the sales price between both companies into supporting gender equality, resource-efficient production and processing techniques, as well as offsetting CO_2 emissions. Catando Ando's women employees would receive training to become certified as specialty coffee barista; coffee farmers would be 100% organically certified; and the wet processer would operate with a new, water-efficient wet processing machine, which would reduce water input by a factor of 10; and remaining CO_2 emissions would be offset through reforestation projects by a local NGO in the mountain forest within the coffee-growing region (Cofre de Perote). An annual volume of 720 kg supplied coffee would allow to finance 1 ha of planted trees per year (Catando Ando, Strategy-Building Workshop, 2018/12/05).

The Strategy (Action Plan) for Achieving Sustainable International Coffee Supply

The strategy to achieve the vision of a sustainable supply chain between Catando Ando and Considerate Coffee is structured into three main phases (**Table 3**), namely, initiation, acceleration, and consolidation, following the standard order of key components of transition strategies (Rotmans et al., 2001; Kay et al., 2014).

The first phase (initiation) is about piloting the strategy and setting up the cooperation. Key activities are negotiating and agreeing on fair prices across the supply/value chain, and then conducting a pilot project on this base to test as many cooperation elements as possible (see next section, below). Using the insights from the pilot project, final adjustments can be made, contracts need to be issued among all supply-chain actors (incl. for shipping and for offsetting), and additional core cooperation elements, e.g., exporter/importer application, need to be completed. Finally, necessary expansion of Considerate Coffee (facility, equipment, staff) need to be initiated (fundraising, etc.).

In the second phase (acceleration), the cooperation becomes fully operational. Acceleration activities advance the cooperation, with focus on completing Considerate Coffee's expansion, broadening caring professional relationships, adding new infrastructure at Catando Ando (wet processing machine, packaging system), establishing trainings (organic farming, barista). Regular evaluation and adjustments secure continuous improvement of the cooperation.

The third phase (consolidation) allows for expanding the cooperation based on long-term contracts among all key supply-chain actors and for standardizing processes through certifications (e.g., organic), new business model (worker cooperative), and advanced professional procedures (monitoring, identification of new opportunities).

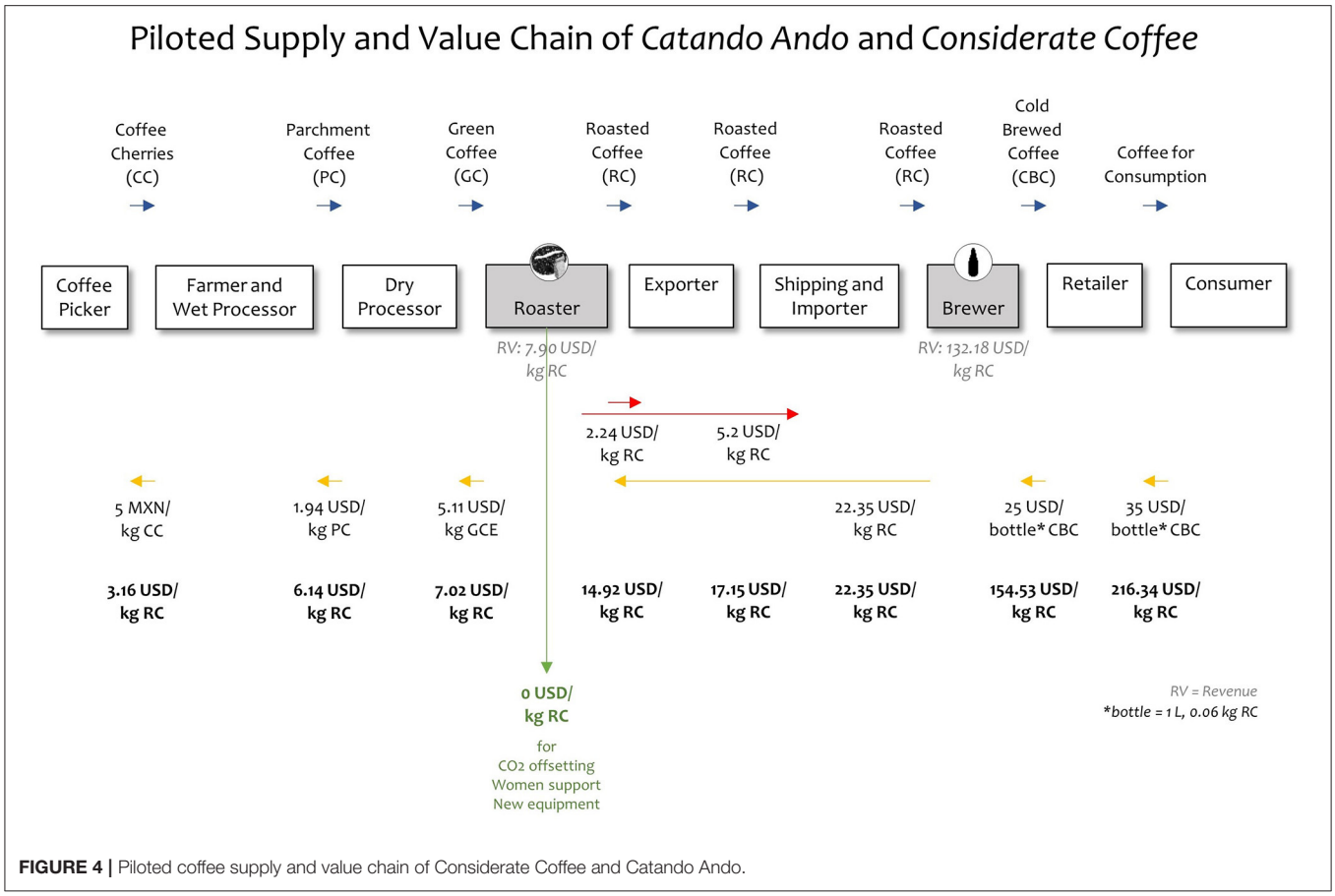


FIGURE 4 | Piloted coffee supply and value chain of Considerate Coffee and Catando Ando.

Regular evaluation and adjustments continue to improve the cooperation.

Piloting Sustainable International Coffee Supply

The first phase of the action plan included execution of steps 1–5 (**Table 3**) with a focus on carrying out a pilot or demonstration project on the new supply and value chain (**Figure 4**). Catando Ando roasted green coffee (received from the dry processor after the last coffee harvest in 2017/2018), and shortly thereafter, on December 26, 2018, sent 20 kg with UPS to Considerate Coffee in Phoenix, where it arrived on January 8, 2019. The sales price was 447 USD. Considerate Coffee cold-brewed 4.5 kg of Catando Ando's roasted coffee and filled 28 1 L-bottles of cold brew coffee. These bottles were sold at a tasting event to their main clients on February 14, 2019. The event offered an opportunity to explore their clients' satisfaction with the new product and their willingness-to-pay (price range). The marketing approach of the event was communicating the achievements of the new supply chain, including increased payments for coffee pickers, reduced CO_2 emissions, offsetting remaining emission caused by transport, and building caring professional relationships to the roaster in Mexico, among others.

The demonstration project yielded a number of positive results (**Table 4-C**): Considerate Coffee was able to significantly reduce food miles and CO_2 emissions by importing coffee from Mexico instead of Ethiopia. Importing roasted coffee from Catando Ando instead of green coffee beans added value in the country of origin (Mexico). Through regular (online) meetings between Considerate Coffee and Catando Ando caring professional relationships started to develop. Other vision elements were at least partly achieved. The pilot project reduced the number of supply-chain actors to 9 (from 13, for Considerate Coffee). As indicated in **Figure 4**, higher prices were paid and they made a difference for the most vulnerable supply-chain actors (i.e., the coffee pickers). Information on the product and the mission behind it was disclosed to the majority of supply-chain actors (from producers to consumers).

However, during the project, partners also encountered several obstacles that resulted in diversions from the vision (**Table 4-C**) and yielded important insights for the strategy implementation. First, the export and import activities had to be provided by external services due to the short timeframe of the pilot vs. the long approval process for exporters and importers. As soon as there approval processes are completed, supply-chain complexity can be further reduced and efforts can begin to familiarize *all* supply-chain actors with each other. Second, the pilot shipment of a small amount of coffee (20 kg) incurred relatively high costs for shipment and import (5.2 USD/kg roasted coffee) that resulted in compromising other

TABLE 3 | Strategy (action plan) for the new supply chain between Considerate Coffee and Catando Ando.

(1) Initiation (Year 1)
1. Verify and update critical information (shipping, fees, etc.)
2. Negotiate and agree on fair prices across the supply/value chain
3. Plan pilot project
4. Carry out pilot project
5. Make adjustments to vision and strategy based on results from pilot
6. Re-negotiate and agree on fair prices across the supply/value chain
7. Develop and sign mid-term contracts among key supply-chain actors
8. Contract shipping company
9. Contract offsetting organization
10. Complete process of becoming an exporter/an importer (admin, fees, etc.)
11. Raise funds for necessary physical expansion of Considerate Coffee (facility and equipment)
12. Recruit and hire additional personnel for expanded Considerate Coffee's operations
(2) Acceleration (Years 2–3)
1. Transition into full operations
2. Complete expansion of Considerate Coffee (facility and equipment)
3. Establish regular visits across the supply chain
4. Expand consumer contacts and relations (incl. experiential marketing & capacity building)
5. Contract and carry out trainings in organic farming and other sustainable practices
6. Purchase and start using new wet processing machine
7. Introduce new packaging practices across the supply chain (refund, reuse, and recycling systems)
8. Participate in barista certification course (women employees)
9. Convert Considerate Coffee into a worker cooperative (or employee ownership)
10. Regularly evaluate process and outcomes
11. Make adjustments as necessary
(3) Consolidation (Years 4–8)
1. Develop and sign long-term contracts among key supply-chain actors
2. Expand operations
3. Obtain organic and other sustainability certifications
4. Expand offsetting activities (incl. LCA assessment, identifying additional offsetting project opportunities)
5. Regularly evaluate process and outcomes
6. Make adjustments as necessary

vision elements (e.g., offsetting CO_2 emissions; barista training for women employees). An annual volume of at least 720 kg supplied coffee would be needed to realize the vision elements omitted in the pilot. However, 720 kg roasted coffee is still a little amount compared to the more than 165,000 tons of green coffee produced in Mexico in 2019 (FAO, 2020). This higher minimum volume of 720 kg (compared to 544 kg Considerate Coffee had processed previously) and aspired additional expansion contracts would require securing a larger brewing facility and additional (or new) brewing equipment for Considerate Coffee. This aligned with aspirations to convert from a microbrewery (2 owners) to a small brewery (∼10 employees). An alternative (partnership with a brewery in California that produces shelf-stable kegs of cooled-down hot-brewed coffee using liquid nitrogen instead of bottling cold-brewed coffee) was considered but rejected due to the additional CO_2 emissions from transportation and packaging (kegs from California vs. bottles from Phoenix) as well as a more energy intense cooling process. Third, despite the increased premium, conversations with coffee pickers revealed that even these higher prices did not allow them to sufficiently satisfy their socio-economic needs. Fully accounting for their needs would require to further increase the premium (>5 MXN/kg coffee cherries). The main reason for arriving at a sub-sustainable price level was that commodity prices still served (even if indirectly) as reference point for price negotiations (see also Sotiropoulou, 2012). A way out is to engage "honest brokers" and decouple price negotiations from commodity prices and focus on socio-economic needs. While conceptually reasonable, the pilot indicated that this is a major paradigm shift that has to go through major "growing pains." Fourth, the timeframe of the demonstration project was too limited to go through the change from conventional to organic farming practices. This requires extensive re-training and, at least in part, new material and/or equipment. As indicated in **Table 3**, related actions are planned for the acceleration phase, with full conversion in the consolidation phase. Finally, the tasting event at Considerate Coffee yielded the insight that some of Considerate Coffee's clients still demanded the previous product brewed from the Ethiopian coffee. Potential solution to this challenge include: convincing the clients of Considerate Coffee's new vision/mission (more compelling story); recruiting new clients open to the new vision/mission of Considerate Coffee; or exploring and securing other coffee varieties from Mexico that satisfy the demand of Considerate Coffee's existing clients.

DISCUSSION

The project assessed the current state of two small intermediary coffee businesses' individual supply and value chains; generated a vision and a strategy for a joint sustainable supply and value chain between the two businesses; as well as piloted the joint supply and value chain through a demonstration project. The results of each project stage are summarized in **Table 4** regarding the extent to which they comply with the sustainability principles presented in section Design Principles for Sustainable International Coffee Supply, above.

Comparing the vision to the current state assessment, the results show that a cooperation between small intermediary coffee businesses has the potential to infuse sustainability into their supply and value chain to a much larger extent than currently done operating independently: there is a potential change from at least partly complying with 2 and 7 principles, respectively, to full compliance with all 10 sustainability principles. The demonstration project showed that this can actually be implemented to a large extent: at least partly complying with 8 of the 10 principles. However, the demonstration project revealed that compliance with some sustainability principles is difficult to achieve despite good intentions. The demonstration project also showed that at least one of the vision elements ("Pay prices that satisfy socio-economic needs") was insufficiently developed and needed revision.

In the following, we discuss the presented project results against the *conditions* that enable small intermediary coffee

TABLE 4 | Compliance of current state, vision, and demonstration project with sustainability principles.

Sustainability Principle	(A) Current State		(B) Sustainability Vision	(C) Demonstration Project
	Compliance Considerate Coffee	Compliance Catando Ando	Compliance of envisioned supply chain Considerate Coffee and Catando Ando	Compliance and diversion from the vision during the pilot (20 kg roasted coffee)
Pay prices that satisfy socio-economic needs	No	No	Some (revised after pilot) (main change: 5 MXN for coffee pickers)	Some (5 MXN still not enough)
Reduce number of supply-chain actors	No	Yes	Yes (8 supply chain actors who know each other)	Some (9 supply chain actors; not all know each other)
Shorten geographical distance	No	Yes	Yes (reduced food miles; personal visits)	Yes (reduced food miles)
Add value in the country of origin	No	Yes	Yes (purchasing *roasted* coffee from Mexico)	Yes (purchasing *roasted* coffee from Mexico)
Secure gender and race equality	(N/A)	No	Yes (barista training female employees)	No
Develop caring professional relationships	No	Yes	Yes (frequent, direct online exchanges; visits)	Yes (frequent, direct online exchanges)
Secure good working conditions	Yes	Yes	Yes	Yes
Disclose all relevant information about the coffee product	No	Some	Yes (packaging and website; info for producers and consumers)	Some (tasting event for clients; conversations with coffee pickers)
Apply resource-efficient production and processing techniques	Some	Some	Yes (water-efficient wet coffee processing; organic farming; etc.)	Some
Offset GHG emissions	No	No	Yes (offsetting through local reforestation projects)	No

businesses to infuse sustainability into their supply and value chains through cooperation, namely by explaining how these conditions have worked out (or not) in the project. Key factors seem to be economic resilience through cooperation, problem recognition, transparency, trust, and solidarity across supply-chain actors – in short, cooperating with "open cards."

Small Intermediary Businesses Are Willing to Enhance Their Economic Resilience Through Cooperation

Infusing sustainable practices into the supply chain primarily depends on the small intermediary companies staying in business. While small businesses demonstrate some advantages in pursuing sustainability compared to large companies (Burch et al., 2016), they are also vulnerable due to their small size. Changes in business partnerships, new career aspirations, personal crises, sickness, accidents, and other human (resources) factors can quickly turn into an existential threat to the business (Cooper and Burke, 2011). In this project, both businesses were run by entrepreneurs and staff of <5 people. And indeed, a major personal disturbance led to the closure of Considerate Coffee and, by extension, to the dissolution of the cooperation described. Economic resilience cannot be achieved through a cooperation, as the one demonstrated in this project, alone. Potential solutions, apart from growing the individual businesses in size, might be offered by advanced forms of cooperation and collaboration (Nidumolu et al., 2014), including support structures of alternative food networks, or different forms of cooperative businesses, including multi-stakeholder cooperatives, or peer-learning networks (Jaffee, 2007; Burch et al., 2016; Weber and Wiek, 2020). To avoid negative side-effects, such advanced forms of cooperation still need to adhere to the other sustainability principles, including short supply chain structures (participation, accountability).

Supply-Chain Actors Are Willing to Recognize Sustainability Challenges and Take Action

Awareness and readiness to act are key conditions to address sustainability challenges along the coffee supply chain. In this project, the collaborative sustainability assessment of the current supply and value chains helped facilitate collective problem recognition by identifying tangible sustainability strengths and weaknesses. The conversations among the entrepreneurs revealed that personal experiences with issues of unsustainability motivates to take action toward sustainability, as indicated in other studies (e.g., Handy et al., 2002), too. Nguyen and Sarker (2018) report that coffee farmers who experienced negative effects such as soil erosion and water shortages are more willing to participate in sustainability programs. Raynolds (2009) suggests that intermediary coffee businesses adopt fair trade practices to counteract global socio-ecological problems caused

by externalizing socio-ecological costs (cf. Clapp, 2015). Yet, problem awareness alone is often not sufficient for taking action. Limited time, capital, workforce, and expertise are factors that can hinder small businesses to take action despite problem recognition (Burch et al., 2016). This indicates the necessary *interplay* of the conditions discussed here.

Supply-Chain Actors Are Willing to Openly Share Value Chain Information

Openly sharing value chain information challenges the still prevalent "value chain secrecy" in favor of broad transparency and empowerment of *all* supply-chain actors (Mol, 2015). Transparency is widely considered a key principle of direct trade arrangements (MacGregor et al., 2017) and relationship coffee models (Vicol et al., 2018). In this project, disclosing all relevant value chain information, after some hesitation, enabled the entrepreneurs to collectively identify insufficient payments along the entire supply chain, and eventually move toward paying fair prices to all supply chain actors. However, Gardner et al. (2019) point out that transparency should be considered a *means* toward sustainable supply chains, not an end in itself. It is a necessary, yet, not a sufficient condition for ensuring fair prices are being paid along the entire value chain. But even if transparency meets willingness to pay higher prices, it might just not be enough. The demonstration project points to the importance of validating adjusted prices with all supply chain actors, which might reveal the need for additional adjustments (as was the case in this project – see comment about prices paid to coffee pickers). Transparency is often facilitated by trust, as disclosing value chain information might reveal unsustainable business practices and affect business image. Thus, alternative trade arrangements for coffee build trust in pursuit of transparency (Vicol et al., 2018; Edelmann et al., 2020) – see next condition.

Supply-Chain Actors Trust and Commit to Each Other

In supply-chain relationships trust is a special quality that facilitates reciprocity and accountability in following through with obligations and granting benefits (Castello Branco and dos Santos, 2018). It has been identified as a key factor in successful (sustainable) coffee supply chains (Cuong, 2019). There is agreement in the literature that trust and commitment are key conditions for successful alternative trade arrangements (Edelmann et al., 2020), even more important than contracts, in some cases (Borrella et al., 2015). In this project, trust enabled the development of caring relationships and was initially built through continuous constructive conversations that revealed similar values and commitment toward sustainability, as well as mutual cultural sensitivity. Indicative of the latter was, for example, that both businesses showed an honest interest in learning about the cultural context in which the other business operated as well as undertook efforts of learning to communicate in both languages (English and Spanish). Trust was further built through the demonstration project, which was considered successful by both cooperating partners.

Supply-chain actors Are willing to Act in solidarity across the supply chain

This condition refers to an attitude that places "more importance on people than on capital and profit" (Sahakian and Dunand, 2015, p. 3). Applied to sustainable supply chains, this condition has four dimensions. First, *consumers are willing to pay adequate prices*. Mission-driven coffee businesses (Raynolds, 2009) seem to attract mission-driven consumers. And Weber et al. (2021) show that if consumers understand the sustainability mission of a coffee business, they are willing to pay a higher price for the product. However, convenience or routines might still get in the way of sustainable consumption choices (Rathgens et al., 2021). The demonstration project yielded some insights into retailers' or consumers' willingness to pay higher prices, namely, that they were not willing to pay significantly more, only 2% and 8%, respectively, more per bottle cold brewed coffee. As a consequence, additional investments for CO_2 offsetting, women support, or new equipment, which had been envisioned earlier, could not be realized (**Figure 4**). Second, *supply-chain actors are willing to pass on profit*. This is a condition for fair payment of all supply-chain actors, including temporary field workers and other vulnerable supply-chain actors, which is the main objective of alternative trade arrangements (Bacon et al., 2008; Vicol et al., 2018). Intermediary coffee businesses play a critical role in demonstrating this solidarity with the upstream coffee producers (Borrella et al., 2015). In this project, trustful relationships facilitated open conversations about prices and confirmed the commitment to adequate distribution of benefits, as demonstrated in the iterative increase of payments for the coffee pickers. Third, *supply-chain actors' are willing to use profit for enhancing the environmental performance of the supply chain*. Current global food supply chains externalize environmental costs (Clapp, 2015). Sustainable supply chains, on the contrary, seek to internalize such costs, e.g., through offsetting and compensation mechanisms, if negative environmental effects are not directly being avoided (Weber et al., 2020). In this project, using or even producing solar energy instead of burning gas in the roastery seemed cost-prohibitive (and there were some other considerations about taste); instead, paying for projects that reforest the surrounding mountain forest was considered an economically viable option and thus was included into the vision. Yet, it was not practiced in the demonstration project after all due to reemerging economic concerns (willingness not sufficient, maybe). This points to the need for policies and financial incentives that ensure internalizing of environmental cost across the supply chain (Ding et al., 2016). However, research calls for a more proactive approach, namely, to adopt sustainable practices that avoid environmental costs from the beginning and thus make compensation schemes obsolete (Montabon et al., 2016). Fourth, *supply-chain actors are willing to compensate for negative systems effects*. Changing supply chain structures might have negative effects on previously involved supply chain actors. In this project, substituting coffee produced by Ethiopian farmers with coffee produced by Mexican farmers could negatively affect livelihoods in Ethiopia. Hence, the sustainability

assessment ought to adopt a systems perspective that accounts for distal socio-environmental feedbacks or telecoupling (Eakin et al., 2017). Mitigation strategies could include diversifying cooperation networks without significantly enlarging the supply chains. While this solidarity facet was briefly discussed in this project, it was not pursued due to the complex nature of such a system-wide compensation endeavor (willingness not sufficient, maybe).

Limitations

Despite the achievements, the presented study has limitations, too. First, transferability of practices and insights depend on specific contexts. Some of the sustainability principles might be easier to adopt than others depending on the specifics of a given supply and value chain, as well as the preferences of the supply-chain actors. In any case, the proposed iterative process from assessment to piloting should allow for context-specific re-design of coffee supply chains to enhance their sustainability through cooperation. Second, some findings of the study are not conclusive, for instance, if the multiple-adjusted prices across the value chain indeed allow for a decent life for *all* supply-chain actors. Additional evaluative research is needed to verify those numbers over the mid-term. Third, some information was provided by the intermediary businesses as the researchers were unable to interview coffee farmers working with Catando Ando (although the researchers had conversations with other coffee farmers in the region). Primary data collection would be needed for full verification. Fourth, this demonstration project was realized with a very small quantity of coffee (20 kg), which by itself had no impact on larger issues such as poverty alleviation. Additional research would be needed to demonstrate the scale that would be required to succeed on such issues. Fifth, findings are based on a demonstration project with small intermediary food businesses in a short supply chain, which might have less validity for conventional supply chain structures. For that, rigorous certification continues to be a promising approach, despite pitfalls and setbacks. However, the conversion of small supply chains, as demonstrated in this study, is equally viable – as a different approach to amplify the positive impact of sustainable practices (Lam et al., 2020). Such efforts, however, call for significant changes in consumer behavior, business education, and governmental incentives; and as such, they need many coordinated efforts over long periods of time. Sixth, the tasks of the research team consisted of designing the project, identifying potential partners, forming the partnership, facilitating the project (collecting technical information preparing and facilitating workshops, etc.), collecting and analyzing research data, and reflecting on the processes. While researchers can and often need to take various roles in transdisciplinary sustainability projects (Wittmayer and Schäpke, 2014), this comes with benefits and costs. Being deeply involved in all facets of the cooperative project provided in-depth insights into sustainability challenges and opportunities that small intermediary food businesses face. Yet, it also affected the accompanying research, which needed to be organized pragmatically, and, at times, was deemphasized in favor of the cooperative partnership.

CONCLUSIONS

This study explored extent and conditions under which sustainable international coffee supply could be realized through small intermediary businesses such as roasteries, breweries, and/or retailers. Using the case of a cooperation between two intermediary coffee businesses the study shows that there is great potential of infusing sustainability across the supply chain, including paying prices that meet socio-economic needs, simplifying the supply chain, and reducing food miles, amongst others. Based on these findings, the study identified conditions for infusing these practices into the supply chain including economic resilience through cooperation, problem recognition, transparency, trust, and solidarity across supply-chain actors. Some of these factors have been detailed in the literature and are confirmed here; others are nuanced or added through this study. For example, while transparency and trust are widely discussed as key factors in sustainability-oriented direct trade and coffee relationship models, solidarity has been less nuanced in the literature (focusing on the willingness to pass on profit). Also, problem recognition has been recognized as a motivational condition for producers, which is here confirmed for intermediary businesses, too. All of these confirmed, nuanced, and added conditions seem to point to the importance of *cooperating with "open cards"* as the summative condition to advance sustainability across the supply chain. Further research is needed on effective political and financial support for small intermediary food business to infuse sustainability into the supply chain; cooperative arrangements that help small intermediary food businesses to increase their economic resilience; and how to account and compensate for systems-wide negative effects of redesigning supply chains.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Office of Research Integrity & Assurance, Arizona State University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

HW and AW designed the research project together and structured the paper and wrote the manuscript together. HW did the field visits, data collection and analyses. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.663716/full#supplementary-material

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REVIEW
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Response-to-Failure Analysis of Global Food System Initiatives: A Resilience Perspective

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International food system initiatives have led the efforts to combat the threats to global food security resulting from the failure of the current food systems. This study set out to investigate and assess the contributions of global food system initiatives in tackling the food system challenges. In assessing the food system initiatives, we develop a three-step methodology for Food System Initiative (FSI) selection and then conduct a qualitative evaluation using relevant indicators based on food system failure narratives. Furthermore, the authors synthesize present literature in the context of the extent to which coronavirus disease 2019 (COVID-19) pandemic has compounded food system challenges and, together with the response-to-failure analysis, recreate a resilient transformational framework, which will be an invaluable tool to FSI during and after the COVID-19 era, and guarantee we build back better. The findings show that while considerable effort is being made in addressing food system failures, the current COVID-19 pandemic has exacerbated the challenges and would require a paradigm shift not only in the implementation of conventional food system initiatives but also in the role of food system actors. The food system resilience framework presented provides useful pathway in expanding the understanding of the role of all key stakeholders and in identifying tipping points for building the desired resilience moving forward.

Keywords: resilient, framework, paradigm shift, food system initiatives, food system failure

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INTRODUCTION

In the last few decades, there has been a surge of interest from international organizations, governments, industries, and cooperate bodies to implement initiatives that ensure the United Nations Agenda on food security and nutrition are met.

The support for this agenda began in the late 1990's through the launch of a globally agreed mandate, the Millennium Development Goals (MDGs), and then in 2015, it was followed by the Sustainable Development Goal (SDG number two), which advocates for "zero hunger." Although the global policy (MDGs) seemed to achieve its target, a broader understanding of the existing pathways to ensure food security was not accounted for. More importantly, the discovery of the multidimensionality (dimensions, time, and space) of the food system became aspects of increased importance. This led to a revision in priority indicators as well as additional indicators in championing SDG number two (Murray, 2015; Gil et al., 2019).

Whereas some countries across the globe currently produce enough food to feed their citizens, others are not. The key players in the global food supply chain have an enabling environment (such as government subsidies, taxes, and regulations) to produce more and hence have access to a global environment to dictate the pattern of food trade. Yet, others with less financial muscle (minor players) to dictate the trade directions leave the poorest consumers in their country to food and nutrition insecurity. Aside from factors such as trade policy and market performance, other factors including infrastructural capacity contribute to this disparity.

According to the 2019 Food and Agriculture Organization's (FAO's) report on the global state of food security, close to two billion people experience severe food insecurity, well more than one billion people are overweight and just over 820 million people go hungry today, which threatens the achievability of the "Zero Hunger" target by 2030 (FAO, 2019). It is imperative to establish that this goal aims not only to "eradicate hunger," but also to "ensure access by all people across the United Nations member countries, to safe, nutritious, and sufficient food all year round" (SDG Target 2.1) and to "eradicate all forms of malnutrition" (SDG Target 2.2) (Bizikova et al., 2020).

Notwithstanding, within the research and policy development domain on food security and nutrition, numerous innovations to address food system challenges and policy intervention programs have been implemented to strengthen our food system. This is evidenced by the abundance of literature, reporting on initiatives, strategies, action plans, and on the current global status in combating hunger and improving nutrition (El Bilali et al., 2019). Despite these major efforts to eradicate hunger, the current food systems have fueled negative outcomes such as environmental degradation, biodiversity loss, excessive greenhouse gas emissions to which it accounts for ∼30% of the total global emissions (Macdiarmid et al., 2011; Vermeulen et al., 2012), and a staggering increased rate of persistent malnutrition and hunger (Beddington, 2011; FAO, 2014). More disturbingly, the failure of the food systems to provide balanced nutrition has been a significant root cause of many global illnesses, diseases, and inability to build immunity to infections (Mozaffarian, 2016; Kuyper et al., 2017).

To this end, the Food and Agricultural Organization in partnership with government and non-governmental bodies have launched key innovative initiatives and agendas including Climate Smart Agriculture (Venkatramanan and Shah, 2019), Regenerative Agriculture (Duncan, 2016), Agricultural intensification (Matson et al., 1997; Tscharntke et al., 2005), Precision farming (Auernhammer, 2001), and Circular Economy (Kirchherr et al., 2017) to drive the food system toward sustainability in the rural and periurban space. These agendas have promoted soil health, improved biodiversity, reduced cost in farm inputs, and, more importantly, delivered nutritious farm produce. Furthermore, they have provided knowledge, information, and expertise, which have boosted agriculture and the food system.

Similarly, food system transformational initiatives such as the Global Alliance for the Future of Food, UN Environment Programme food system initiative, Netherlands Food Partnership, Food Action Alliance (FAA), Food System Dialogue, C40 Cities, Food System Network, and Food & Business Knowledge Platform (F&BKP), among others, have presented comprehensive solutions and strategies that support and speed up food transformation to feed 10 billion people by 2050.

Moving beyond the unsustainability challenges identified in earlier paragraphs, the current coronavirus disease 2019 (COVID-19) pandemic has caused all stakeholders to reflect on the sustainability and resilience of the food system to this unprecedented shock (Devereux et al., 2020).While existing food system initiatives and programs considered shocks, such as climate change and natural disasters, and stresses, such as corruption and political instability, COVID-19 was unanticipated. As argued by Seekell et al. (2017), to sustainably ensure food security to the human population, the food system and, in particular, the supply chain must adapt to disruptions. However, this has not been the case, COVID-19 crisis has laid bare the overarching vulnerabilities within our global food system from a resilient perspective, stimulating the necessity to build back a better one (Galanakis, 2020). Some of these include restricted access to nutritious food at affordable prices and the collapse of small and medium food enterprises (Henry, 2020). Indirectly, COVID-19 has exposed diverse fragilities in the food system that were never envisioned. Perhaps, an increased emphasis on resilience of food system to buffer against external shocks and guarantee food security that does not elude the world's population is the key (Schipanski et al., 2016).

This challenge coupled with multiple concerns of food insecurity, malnutrition, and food inequality highlights the need to focus on a healthy, circular, and more efficient food system. Also, these trends reiterate the gap that exists in achieving SDG 2 and affirm that our current food system is failing us. The broad use of the term "food system failure" as discussed in the literature and mentioned in earlier paragraphs refers to "the inability of the current food system to provide the expected need to meet full societal well-being" (Rosin et al., 2013).

Taken together, the food system resilience is under continuous threat and therefore calls for a need to innovate key strategies, technologies, and robust systems on a large scale to simultaneously meet the world's growing food requirements, as well as staying within the planet's safe operating boundaries. This also calls for the need to evaluate our current actions and initiatives in addressing food system challenges to identify points of failures to develop pragmatic and robust routes to ensure a more resilient food system.

Considering the above gaps, this article provides insights into the contributions of global Food System Initiative (FSI) and potential partners within the global and regional landscape and identifies key donor landscape for healthy, diverse, and circular food systems. The authors evaluate the progress made by existing food system initiatives in addressing the current narratives of food system failure. To gain further understanding, the study synthesizes the results of the evaluation along with a map of the impact of COVID-19 on the food system, to the extent to which, we develop a novel pragmatic transformational framework for redesigning food system moving forward. Again,

the authors extend the conventional literature reporting mindset to an innovative analytical mindset, thereby improving the efficiency of the information gathered. However, the evaluation and assessment of the impacts of initiatives by tracking indicators against predefined transformational goals are far from being able to achieve the desired change within our food system. The overall structure of the study takes the form of four sections including the introduction. In the second section, we present the methodology. Here, we (1) give an overview of the conceptual framework used in this study, (2) present the current perspectives of food system failure, (3) identify indicators and metric for assessing initiatives, and (4) develop a three-step methodology in selecting the initiatives. Subsequently, in *Results and Discussion*, we present the results of the study. Also, here, we (1) provide a brief description of selected food system initiative, (2) analyze the performance of these initiatives using the metrics developed, (3) map out the disruptions and impact of COVID-19 on the food system, and (4) present a reflective reconstruction of the food system based on the lessons learned. The final section gives a summary and critique of the findings of the study.

METHODOLOGY

The Conceptual Framework for the Study

Figure 1 displays the conceptual framework used in this study, which consists three main stages. In the first stage, the authors begin by discussing four distinct narratives on food system failure in the light of food insecurity, malnutrition, social inequality and inequity, and environmental degradation. There are certainly opportunities to explore the dimensions of food insecurity (availability, access, utilization, and stability) as distinct areas of failure; however, they do not holistically capture the different failures within the entire food system. The current failure narrative adopted in this study are reported in a large number of literatures and looks beyond issues of food security, which is but one of dimensions of food system challenges (FAO, 2016; Haddad et al., 2016; Beal et al., 2017).

Next, we move on to develop a methodology to select and qualitatively assess the efforts of existing global food system initiatives in tackling the challenges of the failure. The next stage of the study focuses on how the unprecedented shock, COVID-19, has impacted our current food system, laying bare the persistent failures. As displayed in **Figure 1**, COVID-19 has resulted in higher food insecurity, nutritional insecurity, food inequality, and environmental implications. These heightened implications on the existing narratives of food system failure are as a result of the lockdown, unemployment, trade restrictions, and closure of production systems associated with COVID-19 pandemic. As of the time this study was conducted, there has been little information in the literature discussing the impact of the pandemic on the environmental dimension of the food system, save for its implications on postharvest losses.

Because of the devastating impact of the COVID-19 pandemic, there is a consensus that our food system needs deep reforms and reconstruction. Others (Cattivelli and Rusciano, 2020; Shilomboleni, 2020) argue that the current initiative activities need to be intensified. Therefore, in the final stage of the conceptual framework, the authors present a novel food system transformation framework that can be used by food system initiatives to achieve their objectives and action plans in the context of a pandemic. The COVID-19 pandemic, like many other shocks, has forced significant changes in every fabric of the food system. Regardless of how the food system performs now, if it is unable to withstand any shock thrown at it, then that is a failure of the system. As a result, the ultimate objective of the framework is to achieve a resilience food system. To wit, circular economy [refers to reducing the amount of waste generated, reuse of food, byproduct and food waste, and nutrient recycling (Jurgilevich et al., 2016)] and sustainable manufacturing strategies would help build resilience to the vulnerabilities across the different dimensions. Although it has not reached a breaking point yet, all stakeholders including consumers, governments, and corporations alike concur that a resilience food system must deliver a nutritious and healthy diet, the corollary amounts to a failure of the food system. It is expedient to understand that transformational frameworks provide a route through which action plans of food system initiatives can be assessed and implemented successfully taking into account health, social inclusion and circularity, and planetary boundaries, covering farm-based, value chain, finance, policy, and market interventions.

Food System Failure Analysis Metric

Food System Failure Perspective

As indicated previously, it is clear that our food system is failing. Several narratives have been reported in the literature, highlighting the inability of the current food system to meet the food security and malnutrition challenge (Rosin et al., 2013). The first dimension of the failure is captured as the inability to produce enough food to feed the global population. In this light, West et al. (2014) attempted to define leverage points that can provide enough calories to meet food-insecurity challenges for more than three billion people while addressing many environmental impacts. The second generally accepted dimension focuses on the nutritional gap that persists. Likewise, to this, Hawkes and Ruel (2011) demonstrated that food value chain concepts can be exploited to meet nutritional challenges. On the other hand, the challenge of social inequality and inequity has been frequently reported in the literature. This challenge was highlighted by Mooney (2017), who focused on the proportionate amount of the global population that continues to experience hunger and inappropriate allocation of power, which introduces food inequality and inequity in the food system. Following this further, D'Odorico et al. (2019) expounded on the inequality that exists in terms of the distribution of natural resource for agricultural production and in food availability due to economic potential and trade patterns.

While Amundson et al. (2015) helped distinguish the final challenge as the authors in his dissertation assessed the implications of human activities, especially agriculture on soil ecology and the recent global advances in understanding, and replenish it. Deductively, there exist four perspectives in discussing the issue regarding food system failure as

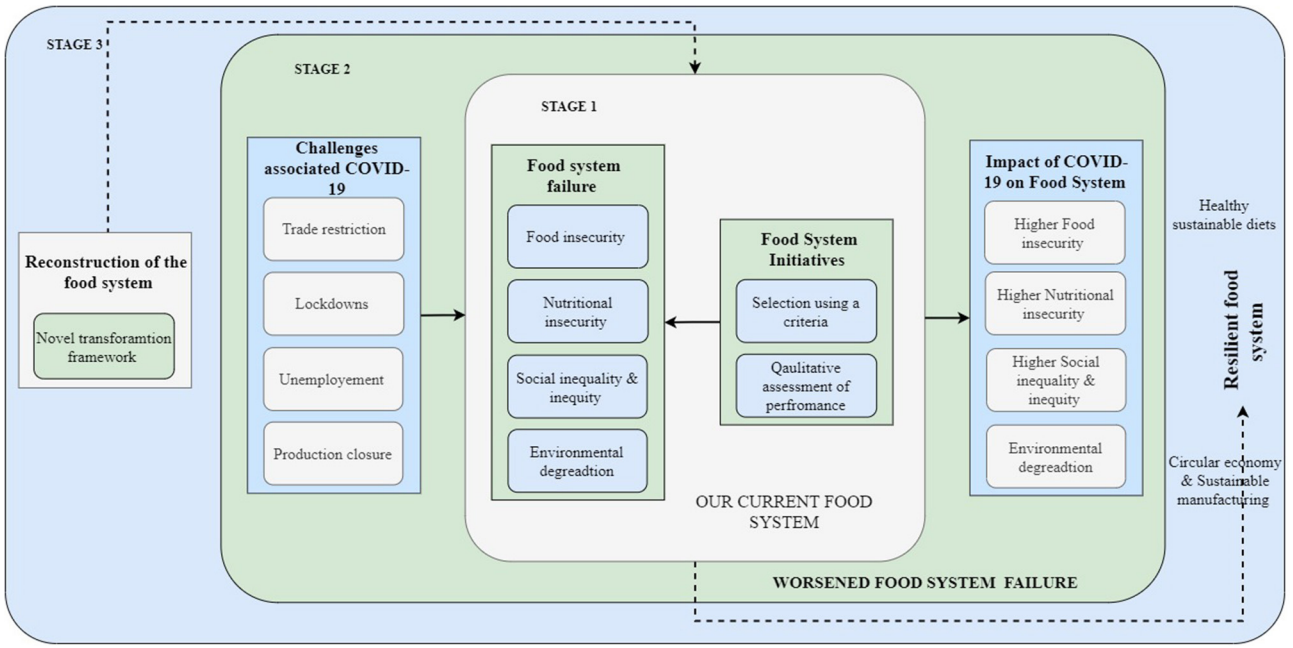


FIGURE 1 | Conceptual framework of the study.

TABLE 1 | Different narratives about the failure of the food system [extracted from Béné et al. (2019b)].

Food system failure	What is threatened and needs to be fixed?
The inability of the system to feed the future world population	Food availability
The inability of the system to deliver a healthy diet	Nutrition security and health
The inability of the system to produce equal and equitable benefits	Social justice, democratic process, small scale actors
The depletion of the natural resources and environment upon which the food system depends	Natural resource agrobiodiversity, energy–water–carbon efficiency

demonstrated in the reports of the aforementioned authors. A detailed review and discussion of the different narratives regarding the failure of the food system are discussed extensively by Béné et al. (2019a). **Table 1** presents a summary of the four narratives that describe the overarching problem of the failure of the food system.

The narratives presented in **Table 1** can also be said to capture four dimensions of the food system challenges, namely, food production, malnutrition, social inequality and inequity, and environment impact. Closing the yield gap through sustainable and efficient agricultural production, nutritional gap, food decentralization, and reducing the footprint of the food system on the environment are the respective actions needed to address the gap that has created failures within our food system. These actions are necessary because for every dollar spent on food, society pays $2 in health, environmental, and economic costs. It is important to note that the narratives provide strategic directions for transformations. Obviously, by explicitly providing nutritious and sustainable diet in light of these challenges, a critical part is formed in achieving resilient food system.

Metrics for Evaluating Food System Initiatives

To present a thorough evaluation of the performance of FSI in ameliorating food system failure, we adopt indices or indicators that characterize the different perspectives of food system failure. These indicators have been extracted from the following references (Feenstra et al., 2005; Pham and Smith, 2014; HLPE, 2017). Also, to ensure consistency and coherency with global sustainability metrics for food systems, the indicators presented in this study are similar to those commonly used to assess the progress made in the achievement of SDG 2 targets by the World Health Organization. Other indicators described in this section were selected from Béné et al. (2019a), who built a sustainability matrix by using a rigorous protocol. Incorporating these indicators will allow a thorough and consistent evaluation of FSI to create sustainable value. These indicators also serve as matrices to monitor what precisely needs to be fixed within the food system and whether food system initiatives are closing the gap to meet the 2030 agenda.

Turning now to the first narrative in which the challenge remains as to "how to close the yield gap," the global consensus within this domain is to sustainably intensify agricultural

TABLE 2 | Indicators to measure support for food production.

Performance indicator	Description	Objective	References
Improved seed variety	It reflects the support to provide hybrid seeds that increase yield and are climate resilient	To provide farmers with hybrid seed that improve crop yield	Hamukwala, 2012
Digital technology	It reflects the support to advance digital technology and innovations that improve farming practices	To provide and promote digital technologies that accelerate agriculture	D'Odorico et al., 2018; Kamilaris et al., 2019
Application of fertilizer/pesticides	It measures assistance in subsidizing the cost of fertilizer	To provide subsidized fertilizers that increase yield	Rasul and Thapa, 2004; Dantsis et al., 2010
Mechanization	It measures the degree of support in providing machinery in agriculture production	To provide machinery that reduces the labor intensiveness of agriculture	Thompson and Blank, 2000
Alternative practices such as agroecology	It measures the advocacy for the adoption of environmentally friendly agricultural practices	To support the adoption of agroecology, circular economy and regenerative agriculture	Sherwood and Uphoff, 2000; Hathaway, 2016
Training (Communication and knowledge sharing)	It measures the amount of training and workshops to educate farmer groups and another stakeholder on sustainable production practices	To communicate and share knowledge on sustainable agricultural protocols	Van Cauwenbergh et al., 2007

TABLE 3 | Indicators to measure the support to mitigate malnutrition.

Performance indicator	Description	Strategic Objective	References
Training and policy toward nutrient-rich food	It expresses the level of education on sustainable food consumption	To promote sustainable food consumption	Sanchez, 2020
Prevalence of stunted	It reflects the percentage of stunting among children aged 0–5 years	To prevent malnutrition in all forms (undernutrition, overweight, micronutrient deficiency, and stunted)	Abarca-Gómez et al., 2017; Achicanoy et al., 2019
Prevalence of overweight and obesity	It reflects the percentage of a defined population with a body mass index (BMI) of 30 kg/m^2 or higher		
Wasting	It reflects a recent and severe process of substantial weight loss associated with caloric deprivation (dietary energy deficiency) or disease		
Non-communicable diseases	It is the measure of the prevalence of diet-related diseases such as cancer and diabetes	To reduce diet-related communicable diseases such as cancer, diabetes, coronary heart disease	Hugenschmidt, 2016; Sabanayagam et al., 2016; Achicanoy et al., 2019
Diet diversification	It expresses the low energy supply (in kcal/caput per day) provided by cereals, roots, and tubers as a percentage of the total Dietary Energy Supply (DES) (in kcal/caput per day)	To ensure equal share of dietary energy supply derived from cereals, roots and tubers (%) (3-year average)	Elmadfa, 2005

production; therefore, we consider factors that directly contribute to intensification, rather than expansion. Agricultural expansion, on the one hand, would require additional land use change, ecological habitat destruction, and CO_2 emissions. A summary of the indicators is presented in **Table 2**. The second narrative focuses on how to alter the current production systems to meet the nutritional requirements both locally and globally. Once again, the challenge is "how to close the nutritional gap." Therefore, the key indicators selected for this narrative focus on how the current food system can provide nutritious and healthy food to feed the global population and limit foods that lead to obesity and diet-related diseases. A summary of the indicators is presented in **Table 3**. At this point, the authors would like to draw the attention of the readers to the fact that the indicators, wasting and stunting, are usually classified as underweight. Moving on, we consider the third narrative, which focuses on economic and social inequalities and inequities that the food system has generated. **Table 4** presents a summary of the indicators used to describe this narrative. Finally, the fourth narrative, as discussed earlier, addresses the negative impact that the current food system has on the natural resources and environment. We selected indicators that measure the detrimental effect of the food system on the environment. **Table 5** presents a summary of the selected indicators.

TABLE 4 | Indicators to measure the support to mitigate economic and social inequality and inequity.

Performance indicator	Description	Strategic objective	References
The concentration of food distribution and marketing activities	It measures the level of quality, safety, and sustainability in food distributions across a demography	To ensure equitable distribution of food	Akkerman et al., 2010
Fair trade	Fair trade is an alternative approach to conventional trade based on a partnership between producers and traders, businesses, and consumers	To promote inclusiveness in fair trade networks	Dubuisson-Quellier and Lamine, 2008
Food policy influence	It is a call for people's right to shape and craft food policy	To advocate for a multisectoral approach in shaping and crafting food policies	Windfuhr and Jonsén, 2005; Patel, 2009
Labor force participation, female (% of female population aged 15+)	It is the proportion of the population aged 15 years or older that is economically active: all people who supply labor for the production of goods and services during a specified period	To promote equal labor force participation	Achicanoy et al., 2019
Employment in agriculture (% of total employment)	It measures the stimulation of innovative activities that create employment in agriculture	To support, expand, and invest in business innovation within the agricultural value chain, thereby creating employment	New Zealand, 2015; Achicanoy et al., 2019
Gini index of land distribution and tendency	It measures the inequality in agricultural land distribution measured, which ranges from 0 (indicating perfect equity) to 1 (total inequity)	To ensure equal distribution of agricultural land	Achicanoy et al., 2019; D'Odorico et al., 2019

TABLE 5 | Indicators to measure the support to mitigate the environmental damaged caused by the activities of the food system.

Performance indicator	Description	Strategic objective	References
Food loss	A measure of postharvest and preconsumer food loss as a ratio of the total domestic supply of crops, livestock, and fish commodities, in tons	To reduce food loss	Lipinski et al., 2013; Irani et al., 2018
Renewable resource	It refers to the adoption of alternative sustainable energy resources to replace the use of fossil energy in agricultural production	To improve the use of renewable resources in agricultural production	Fluck, 2012; Liu et al., 2017
Gas emission (CO_2eq) in gigagrams	It measures the emissions of greenhouse gases (GHGs) by gas	To mitigate/reduce GHG emissions	Achicanoy et al., 2019
Resource consumption/agricultural land as % of arable land	It measures the total areas under temporary crops, meadows and pastures and lands temporary fallow	To reduce superfluous resource consumption	Van Doorn and Bakker, 2007
Irrigation/agricultural water withdrawal	It measures the percentage of the total freshwater withdrawn for agricultural purposes	To reduce the depletion of freshwater resource for irrigation	Molden et al., 2010

Food System Transformation Initiatives

Food System Initiatives Selection

Given the continuous reappearance of food system challenges, there exist promising food system partnership to realize a healthy and circular food system transformation (Candel, 2018). The authors developed a three-step process to facilitate the selection of prominent transformational initiatives.

First, two keywords, "food system transformation" and "food system initiative," were used to search for expert reports and documentation and peer-reviewed articles from international organizations and agencies, Google Scholar, and the open web. It is important to note that previous studies by Davidson et al. (2019) and BCFN, MUFFP (2018) considered single initiatives, which does not provide a holistic overview in assessing the efforts of global initiatives. Therefore, this study is the first of its kind in considering a sampled size of 17 global food system initiatives. Additionally, the regions of operations of the initiatives were captured. In the second step, we evaluate the regions in the world in which the sampled initiatives operate or have conducted projects. As at 2018, almost 260 million people in Africa (90% living in

Sub Saharan Africa), more than 500 million people in Asia, and 42.5 million in Latin America and the Caribbean were undernourished and continue to experience other prevalent food system challenges (FAO, 2019). This motivated the screenings of food system initiatives per their operations within the aforementioned regions. Next, a strict inclusion/exclusion protocol of operating in at least two of the demographic regions was employed. After carefully subjecting the selected FSI to the inclusion/exclusion protocol, 10 were selected. In the final step, we filter the FSI from the second step per the availability of appropriate documentation of activities between 2010 and 2019. This step proved crucial as it contributes to the reproducibility of the study. The stepwise results of the methodology discussed above are presented in **Table 6**.

RESULTS AND DISCUSSION

Brief Profile of the Selected Food System Initiatives

This section presents an overview of the selected FSI by considering multiple attributes including core objectives; key interventions; key public, private, and science partners involved; core funders of the initiative; documented or delivered impact; regional focus; and association with different food system initiatives.

One Planet Sustainable Food Systems Programme

The One Planet Sustainable Food Systems Programme was launched in October 2015 as one of the sectoral programs of action by the One Planet network with a core objective of "catalyzing more sustainable food consumption and production patterns through multistakeholder action." It was formed to implement the commitments of the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns (10YFP), which was adopted at the United Nations Conference on Sustainable Development (Rio+20) in 2012 (Bortoletti and Lomax, 2019). The key actors and partners within the program include Switzerland, Costa Rica, and World Wildlife Fund, in collaboration with Multistakeholder Advisory Committee that consists of 20 members from five different stakeholder clusters, namely, (1) Government agencies such as US Department of Agriculture; (2) Civil society organizations such as IFOAM-Organic International; (3) Research and technical institutions; (4) UN agencies and other international organizations, such as the FAO; and (5) private sector such as Nestle and Food Networks (Hatt et al., 2016). The initiative is involved in numerous projects, with the most notable one being the Pesticide Risk Tool, which has been used by the Red Tomato Eco Apple program. The program has recorded a 50% reduction in the average number of high risks per pesticide application since 2004 and a corresponding 35% pesticide reduction since 2010. More recently, the tool has been adopted by major food retailers to monitor, analyze, and identify major risk-related areas in their supply chain to ensure pesticide risk reduction (Solon et al., 2018).

Food Action Alliance

The FAA was launched in 2019 at the third world economic forum with the support of the International Fund for Agricultural Development, Rabobank and the World Economic Forum in partnership with the Alliance for a Green Revolution in Africa, the African Development Bank, the International Center for Tropical Agriculture, the World Business Council on Sustainable Development, and many others from business, civil society, and international organizations (World Economic Forum, 2019). The initiative aims to nurture the next generation of value chain partnerships for large-scale food system transformation, bringing together a coalition of partners from all sectors—government, business, civil society, international organizations, and farmers' associations. The FAA is strategically positioned to serve as a platform that will deliver in-country action, supporting a vision of sustainable food systems that deliver better, faster, and at scale on food security and nutrition, inclusive growth and decent jobs, and environmental sustainability and climate resilience—in line with the UN SDGs 2030 Agenda (World Economic Forum, 2020). The initiative is involved in flagship programs in Latin America, India, Southeast Asia, and Africa (initial programs in Ghana and Togo).

The Milan Urban Food Policy Pact

Taking into account the challenges such as resource scarcity that threatens the food system, the Milan Urban Food Policy Pact was initiated to "coordinate international food policies and engage major cities to identify their contributions toward making positive changes." The policy pact was promoted by the Mayor of Milan in September 2014 and signed in October 2015 by 140 cities. It currently holds the signatories of more than 210 cities across the globe. The core objective of the pact is "to increase the overall sustainability of the food system and consistently drive it toward a circular economy by diminishing food losses and food waste." Some of the recommended actions of the policy pact include (1) reducing surplus and food waste, through education of citizens on healthy eating and food waste management and (2) promoting the recovery of surplus food by devising redistribution channels for sharing it with other operators in the value chain. Additionally, the pact addresses food system sustainability dimensions, such as (1) governance, (2) sustainable diets and nutrition, (3) social and economic equity, (4) food production, (5) food supply and distribution, and (6) food waste. So far, Copenhagen's Food Council has led the way by mandating that 90% of the food served in their canteens must be organic. The initiative works in collaboration with experts, institutions, and foundations such as the FAO, C40 Cities, Ruaf Foundation, Ellen Macarthur Foundation, and the Cuny Urban Food Policy (BCFN, MUFFP, 2018; Candel, 2019).

Global Alliance for the Future of Food

It was formed in 2012 by a strategic alliance of philanthropic donors with a core objective "to accelerate the transition toward agroecology as the core solution to the future of food system." The core founders of the initiative include David Rockefeller Foundation, McKnight Foundation, and many

TABLE 6 | The three-step methodology for selecting FSI.

S/N	Step 1a (identify FSI)	Step 1b (identify their regions of operation)	Step 2	Step 3
1	One Planet Sustainable Food Systems Programme	Africa (346), Australia (391), Middle East (223), Europe (55), North America (222), South America (349)	√	√
2	Food Action Alliance	Latin America, India, Southeast Asia and Africa	√	√
3	The World Food System Center at ETH Zürich (ETHZ WFSC)	South Africa, Switzerland, Cote D'Ivoire, Congo	X	
4	The Milan Urban Food Policy Pact	Europe, Africa, Latin America	√	√
5	The FAO–UN Environment Programme Sustainable Food System Programme	Ghana, Mozambique, and South Africa	X	
6	Netherlands Food Partnership (NFP)	Niger, Mali, Burkina, Uganda, Tanzania he Sahel, Horn of Africa and the Middle East and North Africa (MENA)	X	
7	Global Alliance for the Future of Food	Central America and Cameroon, Madagascar	√	√
8	Global Alliance for Nutrition and Health	USA, Brazil, Argentina, the Netherlands	X	
9	Feed the Future	Africa, Asia, and Latin America and the Caribbean (Bangladesh, Ethiopia, Honduras, Ghana, Niger, Nigeria, Kenya, Mali, Nepal, Uganda, Guatemala, Senegal)	√	√
10	C40 Cities Food System Network	North America, Latin America, Africa, Europe, Central East Asia East, Southeast Asia and Oceania, and South and West Asia	√	√
11	Global Alliance for Improved Nutrition	Ethiopia, Kenya, Rwanda, Tanzania, Mozambique, Nigeria, Bangladesh, Pakistan India and Indonesia	√	√
12	UN Food Systems Summit,	Not an initiative, convening of leaders to discuss food-related issues	X	
13	Food System Dialogue	Africa (Ghana, Addis Ababa) Asia (Jakarta, New Delhi, Europe (Davos, Stockholm), America (New York), South America (Bogota)	√	X
14	Future Food Network	Europe (Madrid, Amsterdam, Berlin, Bologna), South Asia (Shanghai, Tokyo, Bangkok, Mumbai) and North America (Toronto)	X	
15	Future Food Commons (Alternative Food Network)	Germany	X	
16	Feed Back Global	Kenya, Senegal, South Africa, United States, Brazil, Peru, Spain, Germany, Italy, Austria, Poland, Ireland, Belgium, UK	√	X
17	World food program	Latin America, Africa, Southern Asia	√	√

√, *Meets requirements; X, Does not Meets requirements.*

others. The activities of the initiative are focused on three impact areas, agroecology, health and well-being, and true cost accounting. Members of the initiative are engaged in a range of supportive actions such as system approach for the transition of a biodiversified agroecosystem, which is currently studying different sites such as the production of rice in Madagascar and Agroforestry system in Central America and Cameroon. Other key intervention also addresses the vulnerabilities experienced by a small and marginalized farmer in India. Through its strong collaboration with the Biovision Foundation for ecological development, it has initiated the beacon of hope, which was launched in 2019. The initiative is supporting global initiatives such the Valley Organic, North East Slow Eat Food and Agrobiodiversity, the Milan Food Pact, and World Food Center ETH Zurich "to accelerate the transformation of sustainable food systems."

Feed the Future

Feed the Future emerged in 2010, after one of the most devastating food shortages across the globe in 2007 and 2008, to "equip partner countries and communities with the skills and knowledge to feed themselves," hence alleviating poverty and hunger. The initiative is in partnership with the US Government and agencies such as USAID, universities, businesses, and nonprofit organizations (Briggs, 2016). Throughout the years, the initiative has supported a multitude of global shocks including the Ebola outbreak in West Africa and armyworm invasion in Africa. For example, in Ghana, it has achieved a 12% reduction in poverty between 2012 and 2015 and 17% reduction in stunting among children younger than 5 years within the same time frame. So far, in all its regions of operation, 23.4 million people live above poverty, 3.4 million more children live free from stunting, and 5.2 million more families live free from hunger. Currently, the initiative has activities going in Africa (Ethiopia, Ghana, Niger, Nigeria, Kenya, Mali, Uganda, and Senegal), Asia (Bangladesh and Nepal), and Latin America and the Caribbean (Honduras and Guatemala) (America and Fund, 2016).

Global Alliance for Improved Nutrition

One in every three people worldwide is malnourished; therefore, the Global Alliance for Improved Nutrition (GAIN), a Swiss-based organization, was established in 2002 with the core

objective to "galvanize efforts by the public and private sectors to end malnutrition." Aside from reaching out to more than 600 million people with nutritious food as of the first decade of its establishment, the organization has expanded with new programs to include maternal, infant, and young child nutritional improvement agendas. Through its numerous partnerships with government, philanthropic organizations, business and civil societies, and international organization, GAIN has experienced positive results. Through its fortification of maize meal and wheat flour with folic acid, the organization has reduced Neural tube defect in South Africa by 30%. Similarly, through its fortification of soy with iron in China, anemia levels have dropped drastically by more than 30%. Currently, the key focus of the organization is to tackle issues of malnutrition in countries such Ethiopia, Kenya, Rwanda, Tanzania, Mozambique, Nigeria, Bangladesh, Pakistan, India, and Indonesia, where it is very prevalent. The program is in partnership with different food system initiatives such as the Amsterdam Initiative Against Malnutrition, business platform for nutrition research, commercialization of biofortified crops, Global Fortification Data Exchange, and the SUN Business Network (Moench-Pfanner and Van Ameringen, 2012; Geissler and Powers, 2017).

C40 Food System Network

The Food System Network was set up by the mayor of London, Ken Livingston, in 2005 with an initial membership of 18 cities. The network was formed to address "bureaucratic and political obstacles to the effective delivery in urban-focused climate initiatives" (Acuto, 2013). Through this core objective, C40 aims to help the world's big city practitioners to improve and accelerate climate actions. The network boasts of more than 94 affiliated city partners and members from the largest cities in Africa, Asia and Oceania, North and Latin America, and Europe, covering close to 650 million people (Bortoletti and Lomax, 2019; Watts et al., 2019). The network works in strong partnership with united cities and local government, World Resource Institute, the World Bank, and Clinton Foundation. Core funders of the initiative include Johnson & Johnson, the UK Government, Clean Air Fund, and Citi Foundation. A broad overview of the past decade of activities and agendas by the C40 Food System Network is reported extensively by Davidson et al. (2019).

World Food Programme

The World Food Programme (WFP) is an international program set in 1963, with the objective of "delivering food assistance in emergencies and working with communities to improve nutrition and build resilience." Governments, corporate bodies, and individuals are the core funders of this initiative. The WFP works in collaboration with other United Nations organization agencies (such as the World Health Organization), over 1,000 Non-governmental agencies (such as World Relief and Islamic Vision), global food system initiatives (such as GAIN and Scale-Up Nutrition), private sectors (such as the Mastercard Foundation), and researchers (such as the International Food Policy Research Institute). Remarkably, in 2019, the WFP aided more than 97 million people in 88 countries in Africa, Latin America, and Asia with food relief programs. Similarly, the initiative's school meal and nutritional programs reached 17.3 million and 17.2 million beneficiaries, respectively.

In summary, **Table 7** presents an overview of the different food system initiatives discussed. The summary and overview shown in **Table 7** suggest that although some of these initiatives address only a subset of the dimensions and elements of the food system, they all contribute toward more sustainable food systems.

Analysis of the Global Food System Initiative Through the Lens of Food System Failure

Table 8 presents a qualitative assessment of initiatives in their support for tackling food system failure. The highlighted green sections indicate an initiative that has undergone projects that measure the corresponding indicators. The orange sections indicate initiatives that have the indicators mentioned in their policy document; however, the authors could not identify any explicit report or information from online resources demonstrating that it had carried out a project in light of their documented policies. On the other hand, the gray sections demonstrate initiatives that do not support or have any published report relating to the highlighted indicators of food system failure. At this point, the authors would like the readers to note that the assessment presented was based on research papers and published reports on completed and ongoing projects, as well information displayed on the respective initiative websites. For example, an extensive study on the different strategies by signatories policy instruments for deploying these strategies and their current impact under the Milan urban food policy pact has been discussed by Candel (2019).

From **Table 8**, five interesting observations can be made: (1) all selected FSIs discussed above tend to address the challenge of malnutrition, which implies that it is of great interest across the globe; (2) issues regarding the environmental impact of food systems are widely tackled; (3) there exist similarities in terms of goals across the initiatives (this is probably due to how they all tend to address food-insecurity challenges); (4) food production and food security insecurity and inequality are scarcely discussed [a possible reason for this observation is the spillover effect, which is widely held by FSIs when defining objectives; this idea refers to a situation where FSIs set a single objective with the assumption that while achieving it, other objectives will be met because of their independencies; in reality, this is often not the case, hence the observed patterns in the **Table 8**]; (5) While the initiatives are doing immense work in some areas, it is very clear that the focus has not been on closing the yield. This is because the initiatives are working in countries where there is small-scale farming; hence, the focus has been on empowering and alleviating poverty. To achieve agricultural intensification, new initiatives working with other government will need to be established, or perhaps existing initiatives can restructure their implementation strategies. In summary, a considerable progress is being made in championing SDG 2.

In summary, we have reviewed eight major FSIs and provided a summary of their key interventions, as well as a high-level analysis of their efforts, to critically transform our food system in

TABLE 7 | Summary of the different initiatives in relation to sustainable food system.

S/N	Initiative	Main sustainability dimension(s) addressed	Main food system element addressed	Key interventions or food system outcomes	Shortcomings due to COVID-19 disruptions	Affiliated donor landscape
1	One Planet Sustainable Food Systems Programme	Environment and food nutrition and security	Production and consumption, food loss and waste	A shift toward sustainable consumption and production	➢ Concerns for food system actors and the difficulties that has led to gaps in food production, access, and availability ➢ Role of diet in heightening the health impact of COVID-19	International Fund for Agriculture Development (IFAD) Global Nature Fund
2	Global Alliance for the Future of Food	All dimensions	All elements	The transition toward agroecology for sustainable food system	➢ Mobilization of diver agents of change to better comprehend the current system, develop solutions and communicate actions to community ➢ Structural inequality at the heart of the food system	Christensen Fund Clerence E. Heller Foundation David Rockefeller fund Cariplo Fondazione McKnight Foundation Swift Foundation
3	World Food Programme	Food nutrition and social equality and inequality	Food consumption	To provide emergency food relief and improve nutrition	Resourcing situation (funds to continue to scale up COVID response)	Government, Non-Governmental agency, Private individuals
4	Food Action Alliance	Nutrition security	Food value chain	To strengthen the agriculture value chain to produce food efficiently and sustainable	Food insecurity spreading to everyone's plate	International Fund for Agriculture Development (IFAD) Rabobank African Development Bank
5	C40 Cities Food System Network	Environment	Food and climate	To introduce consumption interventions to reduce food-related emissions	Food access to vulnerable population	Bloomberg philanthropies Children Investment Fund Foundation Clean Air Fund Citi Foundation
6	Milan Food Systems Pact,	Social, economic, food safety and security, nutrition	Food waste, training and knowledge, food distribution	A drive toward a circular economy to reduce food waste and loss	Food access to the vulnerable groups	Ellen Macarthur Foundation Rauf Foundation
7	Global Alliance for Improved Nutrition	Nutritional security	Consumption	To improve the consumption of nutritious food and safe food especially by the most vulnerable	Protecting the nutritional status of the population most threatened by COVID-19	Bill and Melinda Gate Foundation The Rockefeller Foundation The Waterloo Foundation Good ventures Children's Investment Fund Foundation
8	Feed the Future	Food security	Production, marketing, consumption	To equip people with the tools to feed themselves	Prevent widespread hunger, malnutrition, and poverty	US Government

TABLE 8 | Comparison of food system initiatives in addressing food system failures.

Food system initiative	Dimensions of food system failure																					
	Food production						Food insecurity and malnutrition						Social inequity and inequality						Impact on environmental and natural resource				
	FP1	FP2	FP3	FP4	FP5	FP6	FM1	FM2	FM3	FM4	FM5	FM6	SQ1	SQ2	SQ3	SQ4	SQ5	SQ6	EN1	EN2	EN3	EN4	EN5
One planet sustainable food systems programme																							
Global alliance for the future of food																							
World food programme																							
Food action alliance																							
C40 cities food system network																							
Milan urban food policy pact																							
Global alliance for improved nutrition																							
Feed the future																							

Initiative is working | The initiative does not support this driver | No explicit information although stated in core objectives

FP1, Chemical fertilizer; FP2, Agroecology; FP3, Improved seed; FP4, Digital technology; FP5, Mechanization; FP6, Training.
FM1, Education and train; FM2, Stunting; FM3, Overweight/obesity; FM4, Wasting; FM5, Non-communicable disease; FM6, Diet diversification.
SQ1, Gini index; SQ2, Fair trade; SQ3, Food distribution; SQ4, Employment; SQ5, Labor participation; SQ6, Food sovereignty.
EN1, Gas emission; EN2, Natural resource; EN3, Resource consumption; EN4, Food loss and waste; EN5, Agricultural water.
Initiative is working (green); the initiative does not support this driver (grey); No explicit information although stated core objectives (orange).

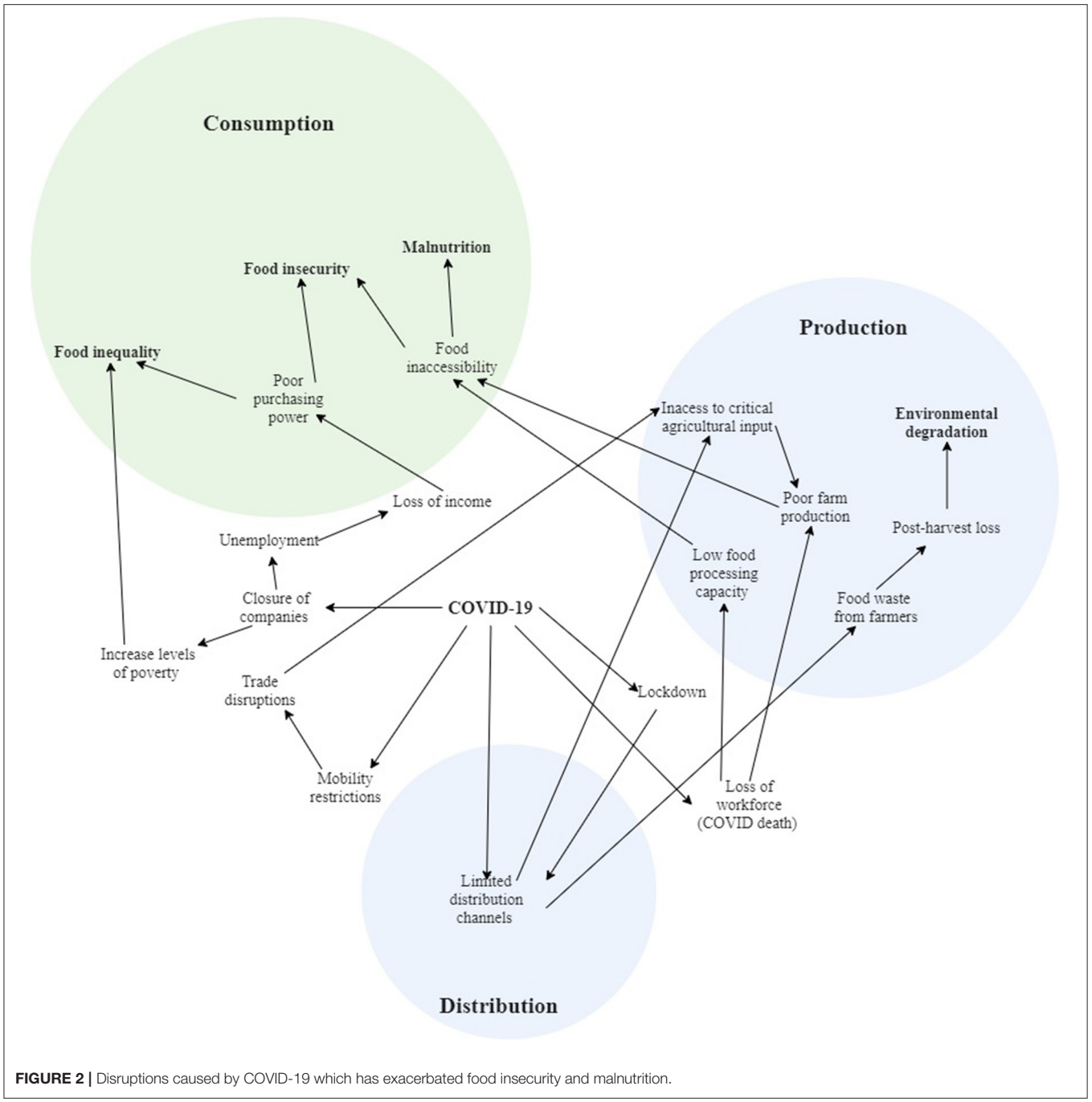


FIGURE 2 | Disruptions caused by COVID-19 which has exacerbated food insecurity and malnutrition.

the face of a rapidly changing world. In the section that follows, we discuss an account on the influential theories on building food system resilience in the context of a pandemic from literature and present a framework that can serve as navigation to global FSI in achieving their objective.

In the wake of the COVID-19 pandemic, access to healthy and nutritious food has never been more critical. Between 2016 and 2019, this number of people experiencing food insecurity increased at a lower rate, that is, from 108 to 135 million, which is fewer than 30 million people. This was attributed to climate change, conflict, and economic downturn. Although the World Food Program had predicted the number to rise to 140 million people, COVID-19 exacerbated food security crisis to 265 million people at the end of 2020 (Husain and Agamile, 2020). Vulnerable groups such as women, smallholder farmers, and the urban poor will be the hardest-hit. Therefore, the subsequent subsections are pivotal in navigating global FSI to build a resilient food system in the era of the COVID-19 crisis. The following section presents tipping points within the food system as a result of the impact of the COVID-19 pandemic, in which specific

TABLE 9 | Innovative strategies to integrate into the current food system.

Strategic component	Opportunities	References
Innovative technology and mechanization	• Breakthrough technology for harvesting crops • Technologies and facilities for storing food	Altieri and Nicholls, 2020; Fadele et al., 2020; Savary et al., 2020
Advanced transport and distribution channels	• Opportunities also arise in using delivery services to transport directly from the farm to consumer homes (short food supply chain) • Technologies capable of delivering foods to consumers without human intervention	Hobbs, 2020; Singh et al., 2020
Improved education	• Education on the intake of a balanced diet and food supplements through social media for urban areas and communities' groups for areas with limited access to the internet • Building capacity of farmers through smallholder farmer groups to adopt the technologies and transition to new distribution channels	Belanger et al., 2020; Yancy, 2020
Financing	• Financial support will be required for manufacturing and acquisition of technologies and delivery systems, research, education • Support will also be required to expand the innovative distribution channels as well as scale up the technologies	Amjath-Babu et al., 2020; Ragasa and Lambrecht, 2020
Revised policies	• Opportunity to reorient policies that influence food system performance as well as build better resilience to pandemics such as COVID-19	Galanakis, 2020; Klassen and Murphy, 2020; Ragasa and Lambrecht, 2020

changes can be implemented by FSIs to achieve specific changes that improve the resilience of the food system.

How COVID-19 Has Disrupted Our Food System

At the beginning of the twenty-first century, there came SARS (severe acute respiratory syndrome), which emerged in China, and then bovine spongiform encephalopathy, which peaked in the United Kingdom; later, the H1N1 influenza pandemic struck certain parts of Asia, from the Middle East respiratory syndrome (also known as MERS) to Ebola, which affected some parts of West and Central Africa, without the rest of the world experiencing any detrimental effect. Now, the novel coronavirus (COVID-19) has impacted the 7.8 billion people on the planet from a multifaceted angle. It has revealed weaknesses that exist not only within our food system, but also the health system, and has raised alerts on personal hygiene activities, which up to now were neglected. The one question that arises is: "How did COVID-19 have an enormous impact on our food system?" Perhaps it is because the food supply chain is one of the most complicated systems with diverse actors and complex interactions with other systems, hence the most vulnerable/susceptible to disruptions.

In response to the COVID-19 pandemic, measures such as social distancing, mobility restrictions, and closure of public and some workplaces were imposed by governments to contain the spread of the virus. However, these measures, as per the reports of the FAO (June 2020), have increased the levels of acute food insecurity and malnutrition in some parts of the world. This has stimulated various discourses within the stakeholders of the food value chain on how to intensify the provision of nutritious, healthy, and safe food to the world population.

Figure 2 illustrates a causal link that maps out the impacts of COVID-19 in increasing food insecurity, malnutrition, food inequality, and environmental degradation. It is apparent from the figure that low processing capacities due to shutdowns, as well as transportation restrictions, resulted in farmers discarding their produce (Kumar et al., 2020; Laborde et al., 2020). Also, loss of workforce due to COVID death and a lack of access to vital agricultural inputs due to trade disruptions have resulted in low agricultural production (Zhang et al., 2020). Pu and Zhong (2020) studied how the government's efforts to mitigate the spread of the virus not only hinders the availability of agricultural inputs, such as fertilizers and machinery, but also blocks production flows/channels, ultimately underpinning the production capacity of countries.

Moreover, the loss of income, which exacerbated the poor purchasing power of people, was mainly due to layoff and shutting-down of some companies. This has further increased the poverty and hunger levels in some parts of the world and crippled household and the more vulnerable populations' resilience to food insecurity and malnutrition (Gralak et al., 2020; Laborde et al., 2020; Stephens et al., 2020). In summary, the disruptions have limited food accessibility in areas already affected by food insecurity (Valdramidis et al., 2020). Power et al. (2020), reported on how COVID-19 has also exposed food inequality, reaffirming how fragile our food system is. Likewise, Ragasa and Lambrecht (2020) investigated the effect of the pandemic and proposed opportunities for gender equality in the current food system. Recent work by Béné (2020) has established the disruptions caused by the pandemic on the different actors on the food value, juxtaposing the effects of the direct and indirect impact on food insecurity. The impacts mentioned previously were mainly caused by the lockdown and mobility restrictions

TABLE 10 | Redesign of the contributions of key actors in building a resilient food system against COVID-19.

Actors	Contributions	References
Research and thought community	• Engage in a coordinate effort with other stakeholders to investigate and introduce diverse market channels to distribute food • Conduct research that focuses on the health and nutrition implications of the pandemic	Pérez-Escamilla et al., 2020
Government (policymakers)	• Reevaluate/reorient and strengthen policies regarding food prices to avoid price hikes • Restructure existing trade policies to allow safe passage of food commodities and agricultural inputs across the border • A collaborative effort with all stakeholders to expand food banks	Laborde et al., 2020; Reardon et al., 2020
Civil society groups	• Intensify the organization of food charity programs at the national and community levels in very deprived communities to meet the less privileged • Advocate for the adoption of a short and intertwined food supply chain • Improve and amplify education about a balanced diet and the inclusion of food commodities or ingredients that provide the necessary nutrients that enhance the immune system • Advocate for hygienic practices	Ivanov and Dolgui, 2020; Rowan and Galanakis, 2020
Private sectors/donor landscape	• Intensify the adoption of remote working strategies and implement strict safety protocols • Identify essential ingredients that will be in short supply during pandemics and store them or develop alternate ingredients for the manufacturing of their products/ modified recipes • Increase funds to expand food banks and support charity food programs • Provide financial support for scientific research	McKee and Stuckler, 2020; Pérez-Escamilla et al., 2020
Development partners (technology manufacturers)	• Accelerate efforts for the development of innovative technologies that reduce the overdependence on labor for agricultural production • Support the transition toward Industry 4.0 in food processing companies • Increase support and investment into storage facilities on farms to avoid food waste	Hobbs, 2020

imposed by governments and local authorities. The effects of these disruptions and current trend strongly indicate we will not meet the SDGs 2 by 2030.

Again, in middle- and low-income countries, the COVID-19 pandemic forced consumers to purchase staple and nonperishable foods, leading to waste of perishable foods in markets. Also, the mobility restrictions resulted in reduced number of people in markets, consequently leading to an increased postharvest loss. In situations such as these, all resources (land, energy, labor, and capital) used to produce the food are wasted (Galanakis, 2020).

In summary, as illustrated in both **Figures 1**, **2**, COVID-19 has heightened many fragilities in our food system, increasing food insecurity and malnutrition and social inequality and inequity. In the long run, COVID-19, economic recessions, climate change (heavy rains), deterioration of soil quality, stresses (pest invasions such as locust infections and the emergence of pathogens), and increased subjection of arable land for industrial, residential, and animal feed have put our food system to test.

Reflective Reconstruction From the Lessons Learned

To tackle the challenges introduced by COVID-19 pandemic on the current food system, several researchers (Harris et al., 2020; Stephens et al., 2020) have reported numerous intervention strategies, whereas other authors (Ahmed et al., 2020; Farrell et al., 2020) have convincingly shown pathways for a potential policy response to build resilience toward the pandemic. Drawing on an extensive range of sources on the realigning our food system during the pandemic, the authors set out to synthesize these studies, identify overarching recommendations, and develop an innovative transformation model that guarantees we build back better.

Although the World Health Organization declared that the COVID-19 pandemic will persist for the next 5 years, there still exists a high degree of uncertainty on the pandemic time duration. Therefore, there will be a need for a systematic transformation framework that can be adopted immediately by FSI to achieve healthy sustainable diets and circular and

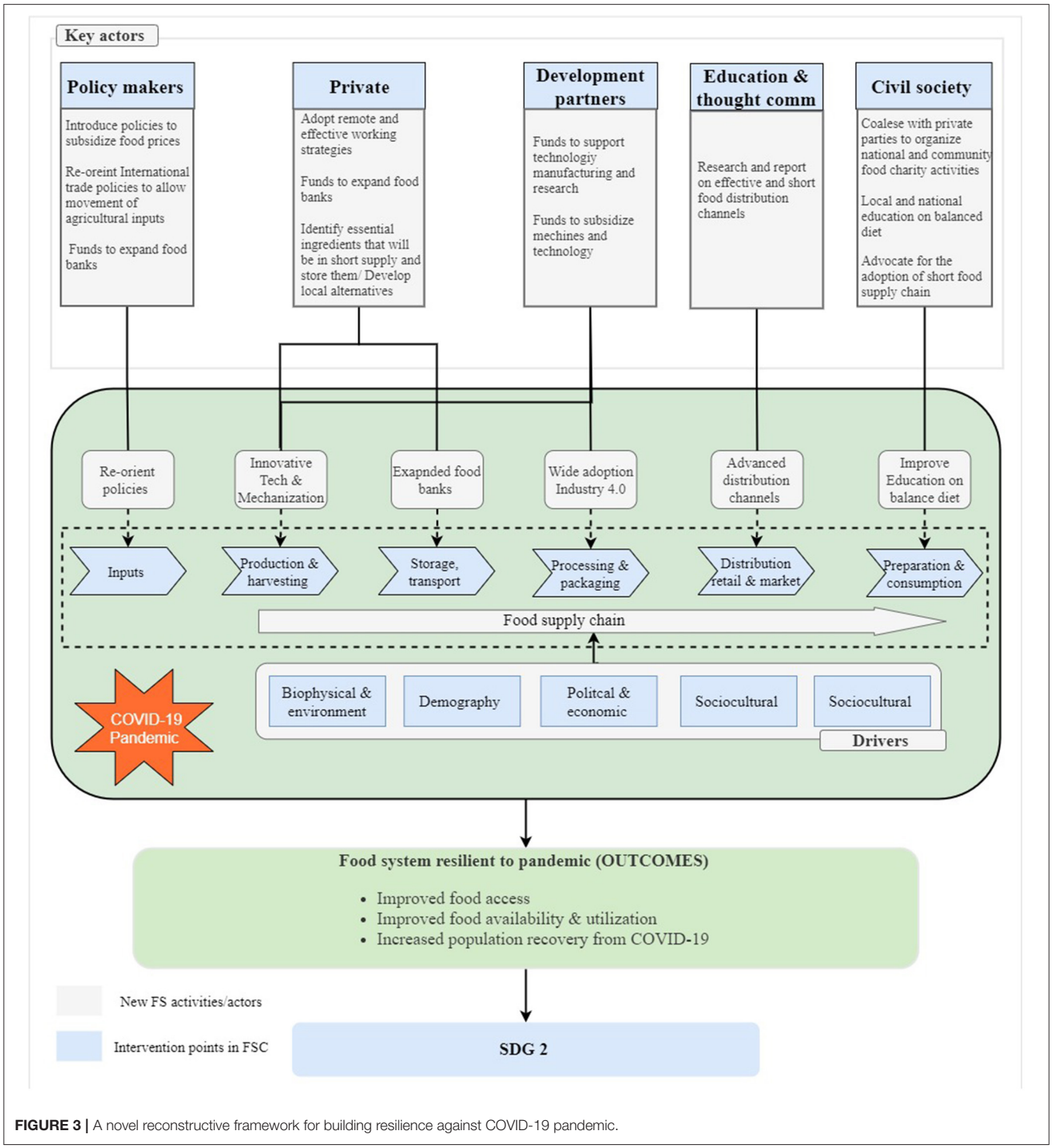


FIGURE 3 | A novel reconstructive framework for building resilience against COVID-19 pandemic.

sustainable manufacturing. It is imperative to understand that before these transformations can be achieved there is a need to identify tipping points or leverage points that will trigger actions. As presented by Galanakis (2020), Laborde et al. (2020), and Tamru et al. (2020), the current pandemic has offset and disrupted the food supply chain enormously. Therefore, given the nature and severity of the COVID-19 crisis, new adaptations are desired across the entire supply chain including recycle and reuse of waste, which minimizes physical contact but ensures that nutritional requirements are met (Aldaco et al., 2020). Also, the components of the supply chain present timely intervention points, which when prioritized could be enablers of business

innovation. All things considered, now is the time to strategically redesign our supply chain to be both resilient and agile to shocks from the supply and demand perspective (Reardon and Swinnen, 2020).

Moving on, we present two narratives that represent a summary of the different proponents in the literature to address the COVID-19 food supply challenge. The first considers key innovation strategies that can be integrated into the current supply chain to drive long-term sustainable impact. Under this narrative, the main components include technologies and mechanization, education, advanced transport, and distribution channels and increased financial support and policies. These five components will significantly reduce food insecurity, nutritional insecurity, and food inequality associated with COVID-19. **Table 9** presents an elaboration of the innovative components to be integrated into the current food system and the opportunities they present to ensure the resilience to COVID-19 pandemic is achieved.

Successfully integrating these five components into the current food system to build resilience against COVID-19 will require a multisectoral approach, which inadvertently disregards the convention silo-syndrome approach of tackling food system challenges. Hence, the second narrative focuses on the mobilization of key stakeholders in the food system. **Table 10** outlines important insights into the role of key food system actors to build back better.

Populating the strategic components above on the food supply chain, we present **Figure 3**, a new transformational model for building food system resilience during the COVID-19 pandemic. The transformational model can be adopted by the global food system initiative to guide their action plans to achieve healthy sustainable diets and circular and sustainable manufacturing. The important aspects of the framework are that (1) it highlights areas of technological adaptions to improve production, as well as distribution; (2) it identifies new routes to share light on education about a balanced diet and the inclusion of food commodities or ingredients that provide the necessary nutrients that enhance the immune system; and (3) maps out an improved and more efficient distribution channels of food items.

The authors hope that the framework presented will reorient future food system initiative by providing an opportunity for them to identify tipping points to implement their actions. The adoption of the proposed framework will not only enable food systems to build resilience not only in the current context but also in future pandemics that have not yet been envisaged. Ultimately, weaknesses within the food system can be eradicated as we continue to build capacities within our food system.

It is important to mention that initiatives such as the WFP have already responded to the pandemic with emergency response programs in African countries such as Ghana, Democratic Republic of Congo, and Syria. Although the efforts are laudable, moving forward, the global community ought to pursue food system transformation in a coordinated manner considering the threats of COVID-19 on food security. Failure to act now could prolong the achievability of the "zero hunger" agenda by 2030.

CONCLUSION

The present study was designed to assess the contributions of global FSI in addressing food system challenges. Indeed, considerable efforts are being made by FSI to address multiple food system concerns ranging from environment, inequity, nutritional insecurity, to food insecurity. Contrarily, the analysis presented revealed that significant attention is given by FSIs to tackle nutritional insecurity. As a result, it is critical for FSIs to also adopt a systemic approach that considers all dimensions of food system concerns.

Another significant finding was the compounded impact of COVID-19 on food system challenges. The mapped-out COVID-19 impact shows disruptions that heightened malnutrition and food inequality and inequity and calls for the reconstruction of the resilience pathways for food systems. The proposed reflective reconstruction framework provides a pathway toward new paradigm. First, it highlights domains in the food value chain for technological adaptations that ensure efficient food production and distribution; second, it identifies opportunities to intensify education on sustainable consumption patterns. This covers areas around balanced diet and the inclusion of food ingredients that provide the necessary nutrients and, finally, mapped out an improved and more efficient distribution channels that promote food safety. Additionally, the result enhances our understanding of the role of key stakeholders and leverage points within the supply chain to implement strategic proponents for transformation. A careful consideration of the framework presented will reorient future FSIs by providing not only an opportunity for them to identify tipping points in the value chain but also key strategic proponents that could be integrated into their action plans.

AUTHOR CONTRIBUTIONS

Conceptualization was done by EK and PA wrote initial draft with inputs from EK. EK reviewed and edited the manuscript. Both authors read and approved the final manuscript.

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Understanding Factors Influencing Farmers' Engagement in Watershed Management Activities

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Studies have pointed to a positive relationship between farmers' active engagement in watershed management (WM) and soil and water conservation practice adoption. If farmers' involvement in WM leads to more conservation, what predicts WM participation? This study seeks to answer that question through binomial logistic regression analysis of data from a survey of 6,006 Iowa farmers conducted to support the implementation of the Iowa Nutrient Reduction Strategy (NRS). Results indicate that public and private sector information sources, awareness of and attitudes regarding nutrient loss reduction strategies, farm contiguity to water bodies, and cost-share and technical assistance were positive predictors of farmers' engagement in WM, while lower agronomic self-efficacy, farm press as an information source, greater age, and higher farm sales were negative. Findings point to several potential actions to improve farmer involvement in WM: (1) more effectively engage with the farm press to disseminate information about the benefits of WM, (2) increase outreach to larger-scale farmers, and (3) focus on nutrient loss management capacity building. Further, a continued emphasis on awareness and attitudes related to the NRS and related actions, such as watershed management, may guide efforts to recruit farmers into watershed groups to help improve soil and water conservation outcomes.

Keywords: watershed management, conservation, water quality, farmers, extension

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INTRODUCTION

Loss of nutrients from agricultural fields has resulted in a greater amount of nutrients in surface and ground water resources globally (Tilman et al., 2011). Flow of nutrients through terrestrial and aquatic systems is also linked with many of the United Nation's Sustainable Development Goals (SDGs) (Ladha et al., 2020) (also see https://www.un.org/sustainabledevelopment/sustainable-development-goals/). Due to runoff from agricultural nutrient applications, impaired water quality has become a major concern with its associated ecological and environmental challenges (Alagele et al., 2019). In addition, excessive tillage practices have also led to soil and water degradation globally (Tilman et al., 2002; Smith et al., 2019). Implementation of strategies for reducing the use of these harmful practices while sustaining agricultural productivity at high levels is a significant priority (Tilman et al., 2011).

As states across the U.S. Midwest have struggled to meet nutrient loss reduction goals from agriculture through traditional individual-focused programs and approaches (Secchi and Mcdonald, 2019), watershed management groups have come to be seen as a promising strategy to catalyze effective action (Church and Prokopy, 2017). Because agriculture is the predominant source of nonpoint source pollution in the region and the main driver of harmful algal blooms (HABS) (Brooks et al., 2016), gulf hypoxia (Rabotyagov et al., 2014; Lee et al., 2018), and impaired waterways (Alagele et al., 2019), watershed management activities that actively engage farmers are of particular interest (Morton and Brown, 2011). Watershed management, which includes water resource utilization control, water pollution control, and economic policies, is an effective means of dealing with these issues at the watershed scale (Heathcote, 2009). A strong global consensus has begun to evolve that effective land and water management must start at the watershed level, and that land and water management actions must be taken in the context of watersheds and the human communities in them (Heathcote, 2009; Ramsar Convention Secretariat, 2010).

Thus, watershed management groups that strive to engage farmers have become increasingly central to water quality improvement efforts across the Midwest (Fishers Farmers Partnership, 2020; Indiana Watershed Initiative, 2020; Iowa Agriculture Water Alliance, 2020; Minnesota Association of Soil Water Conservation Districts, 2020; Natural Resources Conservation Service, 2020). Owing to the complexity of watersheds, uncertainty is one of the key factors influencing watershed management programs as successful management depends upon changes in human behaviors (Floress et al., 2015). These individual behaviors are influenced by a variety of social, economic, institutional, psychological, and biophysical attributes (Floress et al., 2015). Understanding how these factors may influence farmers' decisions to join watershed management groups is important as little is known about farmers' decisions to join such groups.

Although little research on the effectiveness of engaging farmers in such approaches exists, the few studies that have examined the impacts of farmer involvement in watershed groups point to improvements in soil and water conservation outcomes (Morton, 2008; McGuire et al., 2013; Church and Prokopy, 2017; Lee et al., 2018). Lee et al. (2018) found that farmers' active involvement in watershed management (WM) activities had strong direct and indirect relationships with their use of cover crops, a highly effective and heavily promoted nutrient loss reduction practice for farmland (Christianson et al., 2018). At the same time, however, the study found that only 27% of surveyed farmers were involved in organized watershed management activities. As recruiting farmers into watershed groups requires time, effort, money, and other resources (Church and Prokopy, 2017), improved understanding of predictors of watershed management involvement could lead to enhanced farmer participation and achievement of nutrient loss reduction goals. Given that farmer involvement in watershed management appears to lead to improved conservation outcomes, this study asks the question: what factors influence farmers' engagement in watershed management activities?

METHODS

Data Collection

The data for this analysis were collected through a 5-year survey of Iowa farmers conducted to support the implementation of the Iowa Nutrient Reduction Strategy (NRS) (Nowatzke and Arbuckle, 2018). The NRS is a science and technology-based framework aimed to reduce nutrient loads through waterways to the Gulf of Mexico (INRS, 2017). The strategy sets a goal of reducing agricultural nonpoint and point source generated nitrogen (N) and phosphorus (P) loads by 45% in the waterways across Iowa that are transported to the Gulf of Mexico (INRS, 2020). The survey measured farmers' attitudes, behaviors, and knowledge related to nutrient loss reduction through soil and water conservation practice use. The survey was stratified by six HU6 watersheds (**Figure 1**) and sent to 14,139 farmers between 2015 and 2019. We received completed surveys from a total of 6,006 farmers, for a response rate of 42%.

Variables in the Model and Data Analysis

The dependent variable is a binary measure of farmers' engagement in watershed management activities. The survey posed the question, "Are you involved in organized watershed management activities?" in the watershed where their farm operation is located. Farmers who reported involvement in watershed management were assigned 1 and 0 if not.

To guide our selection and construction of the 21 explanatory variables in the model (**Table 3**), we drew on two related conceptual frameworks developed to guide research to inform successful water resources management efforts. The multilevel community capacity framework, outlined by Davenport and Seekamp (2013), and the change through stakeholder engagement framework proposed by Eaton et al. (2021), both posit that research and engagement for effective watershed management should consider individuals (in this case, farmers) as embedded within multi-level social and ecological communities and their institutional and biophysical contexts. We focus on several key concepts that are common to both frameworks and also overlap with the major behavioral change frameworks diffusion of innovations and the theory of planned behavior (Prokopy et al., 2008, 2019).

First, at the individual level, we employ explanatory variables measuring farmers' awareness of watershed management activities, attitudes toward the NRS, an institutional structure promoting behavior change, and efficacy, or capacity to engage in water quality improvement efforts. Also at the individual level we include demographic characteristics such as age, education, and gender. Another set of explanatory variables focused on farmer integration into what Davenport and Seekamp (2013) term "relational networks" that facilitate knowledge sharing: the information channels through which farmers had learned about the NRS, the influence of information sources on their nutrient management decisions, and interaction with providers

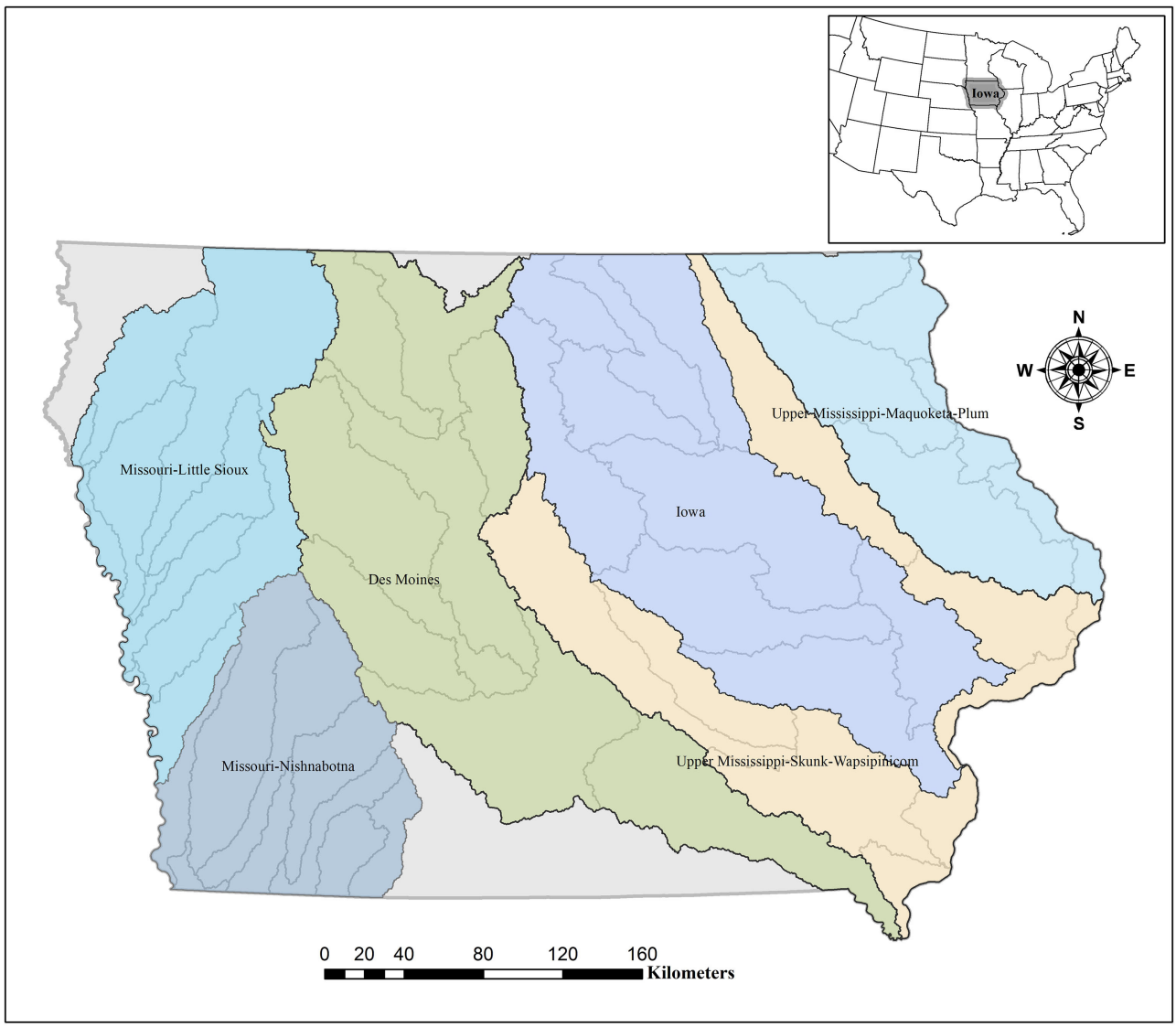


FIGURE 1 | Six HUC6 watersheds surveyed between 2015 and 2019 in Iowa.

of cost-share and/or technical assistance for conservation. A fourth set of explanatory variables measured farm characteristics, including acres of crops and pasture, percentage of cropland rented, gross farm sales, and the presence of water bodies within or contiguous to the farm.

Individual-Level

Awareness and Attitudes

Awareness of environmental impacts related to agriculture and attitudes toward potential solutions are among the most consistent predictors of conservation practice adoption (Prokopy et al., 2019). The awareness variable (*Awareness*) is a measure of farmers' awareness of the NRS and its goals. The survey described the Iowa NRS and its goals, then asked, "Before reading the description above, how knowledgeable were you about the Iowa Nutrient Reduction Strategy?" They were asked to answer this question through a five-point knowledge scale ranging from not at all knowledgeable (1) to very knowledgeable (5). The attitude scale (*Attitudes*) was created from four items measuring farmers' attitudes toward the NRS. Farmers were asked to rank each attitude item on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5). The scale was calculated by summing the four items, then dividing by the number of items (**Table 1**).

Self-Efficacy/Capacity

In recent years, as the Theory of Planned Behavior (Ajzen, 2002) has become a commonly used conceptual framework in

TABLE 1 | Factor scores and reliability tests for farmers' attitudes toward the Iowa nutrient reduction strategy.

Survey items	Factor score	CARC*	KMO*	Bartlett's test
Please provide your opinion on the following statements related to the NRS				
Attitudes				
I would like to improve conservation practices on the land I farm to help meet the nutrient reduction strategy's goals.	0.746	0.731	0.759	0
Helping to meet the nutrient reduction strategy's goals is a high priority for me.	0.751			
I would be willing to have someone help me evaluate how my farm operation is doing in terms of keeping nutrients out of waterways.	0.769			
Iowa farmers should do more to reduce nutrient and sediment runoff into waterways.	0.714			

**CARC, Cronbach's alpha reliability coefficient; KMO, Kaiser-Maier-Olkin test.*

the examination of conservation practice adoption, measures of capacity to act, also termed self-efficacy, are frequently included in analyses (Reimer et al., 2012; Arbuckle and Roesch-McNally, 2015; Wilson et al., 2018). A question set assessed farmers' perspectives regarding their perceived economic and agronomic capacity to implement different practices for water quality improvement in Iowa. Farmers were asked to rank seven potential barriers to water quality improvement on a five-point agreement scale ranging from strongly disagree (1) to strongly agree (5). We created two summated scales, "*Capacity.Econ*" and "*Capacity.Agron*" which measure perceived economic capacity and perceived agronomic capacity, respectively (**Table 2**).

Farm and Farmer Characteristics

We include a number of farm and farmer characteristics that are typically used in adoption studies. The farmer characteristics, age, gender, and education were included in the model (**Table 3**). We also include acres of cropland [*TotalAc.Crops(log)*], acres of pasture [*TotalAc.Pasture (log)*], gross farm sales (*GrossSales*), and percent of cropland rented (*PerRent.Crop*) in our model. A variable measuring whether any of the farmers' cropland bordered any water bodies such as creeks, streams, rivers, or lakes (*WaterBorder*) was also included.

Relational Networks

Information Sources and Awareness

The source from which farmers receive information is a relatively consistent predictor of soil and water conservation behavior (Carlisle, 2016; Prokopy et al., 2019), and entities that raise common awareness of water issues and potential solutions set the stage for collective action (Davenport and Seekamp, 2013). We were particularly interested in where farmers received information about soil and water conservation, so we asked farmers to indicate whether they had learned about the Iowa NRS from any of eight different sources. Those eight options included: three private-sector information sources: Seed company representative, Agricultural retailer (e.g., fertilizer, agricultural chemical dealer), Independent/ private crop adviser or agronomist; and three public sector information sources: Iowa State University Extension and Outreach, Natural Resources Conservation Service (NRCS) or Soil and Water Conservation District, and another government agency (e.g., Iowa Dept of Agriculture and Land Stewardship). Lee et al. (2018) noted that these public and private sector entities had promoted the NRS through different activities such as workshops, field days, press releases, and other means of extensions. Two mass media source options were provided: the farm press (i.e., magazines, radio, TV programs, websites, that focus on agriculture) and the popular press (i.e., general-interest newspaper, TV programs, radio, magazines). We created four information source variables using a simple count of the information sources from which farmers had heard about the NRS, resulting in four-point count variables (0–3) for the private sector (*Info.Priv*) and public (*Info.Pub*) source groups and binary variables (0–1) for the farm press (*Farm.Press*) and popular press (*Pop.Press*) sources.

Influential Actors

Similar to information sources, different agricultural actors have been found to influence soil and water conservation behavior (Prokopy et al., 2019). For example, Lee et al. (2018) found that farmers who rated private sector actors as influential were less likely to use cover crops, while public sector entity influence was positively related to cover crops use. Our influence variables measure various stakeholders' influence on farmers' nutrient management practices and strategies. Farmers were asked to rate 14 different agricultural stakeholders on an influence scale ranging from no influence (1) to very strong influence (5). Using factor analysis, these 14 entities were grouped into four different categories, and scales were generated by summing the items' responses within each group and dividing by the number of items (**Table 4**). The 14 entities represent four different agricultural stakeholder groups: public sector, private sector, organizations that sponsor on-farm research and demonstrations, and family/landlords (**Table 4**). The public sector stakeholders (*Infl.Pub*) are NRCS or county Soil and Water Conservation District, Iowa Department of Agriculture and Land Stewardship, Iowa Water Quality Initiative (WQI), and Iowa State University Extension. Private sector entities (*Infl.Priv*) are seed companies, local agricultural retailers (e.g., fertilizer, agricultural chemical dealer, co-op), custom operator/applicator, and independent/private crop adviser/agronomist. On-farm research and demonstration groups (*Infl.On-farm*) are Practical

TABLE 2 | Factor scores and reliability tests for farmers' economic and agronomic capacity to implement different water quality improvement practices in Iowa.

Survey items	Factor score	CARC*	KMO*	Bartlett's test of sphericity
Please indicate your disagreement or agreement with the following statements about the potential barriers				
Perceived economic capacity (Cap.Econ)		0.777	0.7	0
I can't afford to implement more conservation practices	0.803			
Many farmers don't have the economic resources to adopt sufficient conservation practices	0.799			
There is not enough cost-share and other support available from government agencies	0.726			
Pressure to make profit margins makes it difficult to afford conservation practices	0.688			
Perceived agronomic capacity (Cap.Agron)		0.787	0.609	0
Nutrient loss is difficult to avoid in corn-soybean production systems	0.767			
Nutrient loss is difficult to avoid in tile-drained fields	0.756			
Many conservation practices have negative impacts on yields	0.595			

**CARC, Cronbach's alpha reliability coefficient; KMO, Kaiser-Maier-Olkin test.*

TABLE 3 | Descriptive statistics for the independent variables used in the analysis.

Variables	Description (scales)	Min/Max	Mean	SD
Attitudes, efficacy				
Awareness	Self-reported knowledge of the NRS (Knowledge)	1/5	2.948	0.966
Attitudes	Support for NRS (Agreement)	1/5	3.593	0.519
Cap.Econ	Perceived economic capacity (Agreement)	1/5	3.352	0.759
Cap.Agron	Perceived agronomic capacity (Agreement)	1/5	2.824	0.683
Farmer characteristics				
Age	Farmer age (Number)	20/96	57.94	11.907
Gender	Farmer gender (Male/Female)	0/1	0.979	0.14
Education	Education level (1:H.S or Less; 2:Some College; 3:Bachelors; 4:Grad School/Prof Degree)	1/4	2.046	0.971
Farm characteristics				
TotalAc.Crops	Log of Total Acres of Crop Land (Acres)	0/9.553	6.232	1.023
TotalAc.Pasture	Log of Total Acres of Pasture (Acres)	0/7.938	1.766	2.13
GrossSales	Gross Farm Sales None=1; <$50k=2; $50K-$150k=3; $150K-$250k=4; $250K-350K=5; $350K-500K=6; $500K-$1000K=7; >1000K=8	1/8	5.043	1.818
PerRent.Crop	Percentage of rented crop land (%)	0/100	48.07	37.266
WaterBorder	Waterbodies border farm (Yes/No)	0/1	0.801	0.399
Relational networks				
Info.Pub	Public sector sources of information about NRS (Count)	0/3	1.685	1.12
Info.Priv	Private sector sources of information about NRS (Count)	0/3	0.594	0.918
Farm.Press	Farm press as sources of information about NRS (Count)	0/1	0.812	0.39
Pop.Press	Popular press as source of information about NRS (Count)	0/1	0.508	0.499
Infl.Pub	Public sector influence on nutrient management practices (Influence)	1/5	2.45	0.914
Infl.Priv	Private sector influence on nutrient management practices (Influence)	1/5	2.092	0.818
Infl.On-farm	On-farm research groups influence on nutrient management practices (Influence)	1/5	1.705	0.826
Infl.Fam	Family, peers, and landlords influence on nutrient management practices (Influence)	1/5	2.324	0.888
CS.TA	Received cost share or technical assistance for conservation (Yes/No)	0/1	0.577	0.494

Farmers of Iowa, Iowa Learning Farms, and the Iowa Soybean Association. The Family/Landlords group (*Infl.Fam*) consists of family members, landlord/farm management firm, and other farmers (**Table 4**).

Cost Share and Technical Assistance Providers

Integration in conservation networks is another key predictor of conservation behaviors (Prokopy et al., 2019), as they can serve to increase farmer capacity to engage in individual and collaborative pro-environmental behaviors (Davenport and Seekamp, 2013). To measure farmer's contact with conservation-related agencies and organizations, we constructed a binary variable (*CS.TA*) from responses to the following questions: "In the last 5 years, have you received conservation technical assistance from a state or federal agency (Soil and Water Conservation District or NRCS/FSA)?"; "In the last 5 years, have you received conservation technical assistance from a non-governmental organization (e.g., Soybean Association, Pheasants Forever)?"; In the last 5 years, have you received cost-share to help you fund conservation practices?" Farmers who responded "yes" to at least one of these questions were assigned a "1" and the rest a "0." More than half of the respondents (57%) reported that they had received cost-share and/or technical assistance to support conservation.

The data were analyzed using the Statistical Package for social sciences (SPSS-IBM) software, version 22, and R software (R Core Team, 2020). Due to the dependent variable's binary nature measuring participation in watershed management activities (WM), a binary logistic regression model was used (Hardle and Simar, 2014).

RESULTS

Of 4,534 valid responses, 1,250 farmers (27.57%) reported that they were involved in watershed management activities in their area (**Table 5**). Our results show that 12 out of 21 variables were statistically significant at the $p < 0.05$ level or lower. The MacFadden, Cox and Snell, and Nagelkerke pseudo-R^2, three common measures of goodness of fit, were 0.15, 0.26, and 0.29, respectively, indicating that the model explains a substantial amount of variance in the dependent variable. The binomial regression model correctly classified 74% of observations, indicating a relatively good fit of the model to the data set (**Table 5**).

The variables measuring farmers' awareness of (*Awareness*) and attitudes toward (*Attitudes*) the NRS were positive and significant (**Table 5**). The odds ratio statistic indicates that a one-unit increase in the 5-point awareness and attitude scales corresponded to an increase in odds of WM engagement of 16% and 35%, respectively.

One of the two perceived capacity variables had a significant negative effect on farmers' participation in WM. The variable measuring perceived lack of agronomic capacity (*Capacity.Agron*) was significant and negatively related to farmers' participation in WM, with a one-unit increase in the scale (indicating higher perceived agronomic barriers to nutrient loss reduction) corresponding to a 13% decrease in odds of participation in WM (**Table 5**).

Among farmers' demographic and farm characteristics, age (*Age*) and the 8-category measure of gross farm sales (*GrossSales*) were negatively related to farmers' engagement in WM. The odds ratio statistic indicated that a one-unit increase in age corresponds to a decrease in odds of engagement in WM by 1%, and one unit increase in gross farm sales corresponds to a 6% decrease in odds of engagement in WM (**Table 5**). The strongest predictor among the farmer and farm characteristics was the variable measuring presence of a stream, lake, or similar water body. Farmers who farmed land bordered a water body (*WaterBorder)* were 2.02 times more likely to report participation in WM. Other farm characteristics-crop acres, pasture acres, and percent rented cropland-were not significant.

Three out of four information channels through which farmers had learned about the NRS were significant (**Table 5**). Learning about the NRS through public *(Info.Pub)* or private (*Info.Priv*) information sources were positively significant, with a one-unit increase in the number of the public sector and private sector sources associated with a 22% and 27% increase in odds of participation in watershed management activities. The third information channel, the farm press, was significantly and negatively related, with farmers who checked that source being 30% less likely to report engagement in watershed management activities. Popular press sources (*Pop.Press*) was not significant.

Among the four variables measuring the influence of different actors on nutrient management decisions, influence of public sector actors such as the Natural Resources Conservation Service (*Infl.Pub*) was positively related to WM. In contrast, the influence of agricultural on-farm research and demonstration groups (*Infl.On-farm*) was negative and significant, with a one-unit increase in *Infl.Pub,* resulting in a 30% increase in odds and a one-unit increase in *Infl.On-farm* resulting in a 16% decrease in odds (**Table 5**). Private sector entity (*Infl.Priv*) and family and landlords (*Infl.Fam*) influence were not significantly related to WM involvement.

The cost-share and technical assistance variable was the strongest predictor of involvement in watershed management activities from among the network-related variables. The coefficient for whether or not a farmer received cost-share or technical assistance to help with conservation practices (*CS.TA*) was positive and significant. The corresponding odds ratio statistic indicates that farmers who received cost share or technical assistance were more than twice (2.51) as likely to report participation in WM (**Table 5**).

DISCUSSION

Establishment of watershed management groups that involve farmers has become a more common strategy in Midwestern water quality improvement efforts (Fishers Farmers Partnership, 2020; Indiana Watershed Initiative, 2020; Iowa Agriculture Water Alliance, 2020; Minnesota Association of Soil Water Conservation Districts, 2020; Natural Resources Conservation Service, 2020). This has raised interest in improving our understanding of predictors of farmers' participation in such groups. Our analysis identified 12 variables that appear to

TABLE 4 | Factor scores and reliability tests for different agricultural stakeholders that influence farmers' nutrient management practices and strategy decisions.

Survey items	Factor scores	CARC*	KMO*	Bartlett's test of sphericity
Please indicate how much influence the following sources of information have on your decisions about nutrient management practices and strategies.				
Public sector (Infl.Pub)		0.854	0.816	0
NRCS or county soil and water conservation district	0.834			
Iowa department of agriculture and land stewardship	0.821			
Iowa water quality initiative (WQI)	0.754			
Iowa State University Extension (e.g., field days, workshops, publications, videos)	0.753			
Private sector (Infl. Priv)		0.767	0.765	0
Seed company	0.826			
Local agricultural retailer (e.g., fertilizer, agricultural chemical dealer, co-op)	0.802			
Custom operator/applicator	0.753			
Independent/private crop adviser/agronomist	0.882			
On-farm research groups (Infl.On-farm)		0.821	0.794	0
Practical farmers of Iowa	0.848			
Iowa Learning Farms	0.821			
Iowa soybean association	0.778			
Family and landlords (Infl.Fam)		0.766	0.753	0
Family members	0.837			
Other farmers	0.683			
Landlord/farm management firm	0.743			

**CARC, Cronbach's alpha reliability coefficient; KMO, Kaiser-Maier-Olkin test.*

positively or negatively and significantly influence Iowa farmers' engagement in watershed management activities.

Results suggest that the type of information source from which farmers learned about the Iowa Nutrient Reduction Strategy was related to WM behavior. Much effort has gone into NRS-related outreach, with public sector actors such as university extension targeting both individual farmers and the private sector entities such as agricultural retailers that farmers rely on for agronomic advice (INRS, 2020). The results showing that farmers who learned about the NRS through public and private sector sources of information were more likely to participate in WM suggest that those efforts may have directly or indirectly influenced some farmers' decisions to join organized WM efforts. On the other hand, farmers who cited the farm press as an information source were less likely to participate in watershed management activities. A possible explanation for this may be that the farm press tends to focus articles on productivity-related themes (Walter, 1996). It is possible that coverage of conservation practices skews toward on-farm production-related practices rather than off-farm collective approaches to soil and water conservation such as watershed management. Rust et al.'s (2021) findings that farmers did not view the farm press as a credible source of information about sustainable agricultural practices, perhaps because of perceived bias toward agribusiness, support this interpretation. This may point to a need for proponents of watershed management groups to develop communication and outreach strategies that bring their work to farm press outlets' attention.

A second major finding identified associations between entities that influence farmers' nutrient management decisions and WM involvement. Farmers who attributed higher levels of influence to public sector entities such as NRCS were more likely to report WM action. Combined with the finding that farmers who had received cost-share or technical assistance were twice as likely to be involved in WM activities, this offers evidence that public-sector groups' intensive efforts to promote conservation action positively impact farmer participation in WM. These findings align with Davenport and Seekamp's (2013) emphasis on relational and formal networks and support Church et al.'s (2019) recommendation that conservation agency involvement in watershed projects, especially combined with the promotion of cost-share and technical assistance, can play a key role in encouraging farmers' adoption of conservation practices to reduce impaired water quality.

One surprising result was the small negative relationship between influence of organizations that facilitate on-farm research and demonstration and WM involvement. Given the major role that such organizations play in promoting farmer conservation practice adoption, this result was perplexing. It may be that the specific groups that comprise the factor—Practical Farmers of Iowa, Iowa Learning Farms, and the Iowa Soybean Association—tend to focus their on-farm production and conservation practices research and demonstration work on individual farms and farmers rather than group-based watershed management. While these groups certainly support involvement in watershed groups, it could be that farmers who cite them as influential may be more focused on on-farm practices rather than off-farm, collective activities.

The strong positive relationship between farmers' awareness of the NRS and attitudes toward the strategy and its water quality

TABLE 5 | Binomial logistic regression of farmers' participation in watershed management activities on selected variables.

Variables	Coefficient	SE	Z	Odds ratio	*P*-value
(Intercept)	−3.667	0.594	−6.175	0.026	0.000
Attitudes, efficacy					
Awareness	0.151	0.045	3.4	1.163	0.001
Attitudes	0.302	0.078	3.889	1.353	0.000
Cap.Econ	0.027	0.05	0.55	1.028	0.583
Cap.Agron	−0.14	0.056	−2.513	0.869	0.012
Farmer characteristics					
Age	−0.009	0.003	−2.605	0.991	0.009
Gender	0.433	0.294	1.474	1.541	0.141
Education	−0.066	0.038	−1.721	0.936	0.085
Farm characteristics					
TotalAc.Crops(log)	0.008	0.062	0.136	1.008	0.892
TotalAc.Pasture(log)	0.013	0.107	6.576	1.013	0.441
GrossSales	−0.056	0.017	0.771	0.945	0.053
PerRent.Crop	0.001	0.029	−1.927	1.001	0.536
WaterBorder	0.706	0.001	0.619	2.025	0.000
Relational networks					
Info.Pub	0.195	0.038	5.09	1.215	0.000
Info.Priv	0.235	0.04	5.838	1.265	0.000
Farm.Press	−0.346	0.102	−3.406	0.707	0.001
Pop.Press	−0.006	0.076	−0.074	0.994	0.941
Infl.Pub	0.26	0.058	4.481	1.297	0.000
Infl.Priv	−0.03	0.054	−0.558	0.97	0.577
Infl.On-farm	−0.165	0.057	−2.885	0.848	0.004
Infl.Fam	0.054	0.049	1.104	1.056	0.27
CS.TA	0.921	0.082	11.258	2.511	0.000
MacFadden Pseudo R^2	0.148				
Cox and Snell (ML) Pseudo R^2	0.256				
Nagelkerke (Cragg and Uhler) Pseudo R^2	0.297				
Correct prediction %	0.739				
n	4,534				
WM Participant (%)	27.57				
Non-Participant (%)	72.43				
Model x^2	577.3				0.000

improvement objectives and their engagement in watershed management action is encouraging. A central tenet of the Iowa NRS is that efforts to increase awareness and change attitudes will lead to behavior change. These results, which align with our conceptual frameworks and previous research (Prokopy et al., 2019), suggest that, at least in terms of farmer involvement in WM, the focus on shifting awareness and attitudes may be effective.

Another result that we wish to highlight is the negative relationship between the agronomic capacity variable and involvement in watershed management. Results show that farmers who reported a lower perceived capacity to reduce nutrient loss in their cropping systems were less likely to engage in WM activities. This finding is important because watershed groups that involve farmers often focus on helping them to surmount their perceived capacity barriers through peer-to-peer learning and other assistance (Morton, 2008; McGuire et al., 2013). Thus, this result indicates that watershed management groups and other stakeholders should continue to focus on increasing farmer confidence in their capacity to address nutrient loss, and specifically take self-efficacy challenges into account in farmer WM recruitment efforts. These findings and recommendations align with those suggested in previous studies (Arbuckle and Roesch-McNally, 2015; Burnett et al., 2018; Lee et al., 2018).

Another negative predictor of involvement in WM activities that requires discussion is gross farm sales. Farm sales is a proxy of farm size, so the result indicates that larger-scale farmers may be less likely to become involved in watershed management. Because larger-scale operations farm a disproportionate amount of land relative to their numbers (USDA ERS, 2020), their engagement in soil and water conservation efforts is critically

important. Efforts to bring more larger-scale farmers into WM and similar conservation efforts should be increased.

Finally, the result indicating that farmers whose farm operations were bordered or bisected by streams and other water bodies were twice as likely to be involved in WM has major implications for outreach. This finding suggests that watershed planning efforts that employ GIS, remote sensing, modeling, and innovative tools such as the Agricultural Conservation Planning Framework to facilitate watershed-level conservation planning and action (Ranjan et al., 2019) may find such farmers to be more receptive to targeted outreach.

CONCLUSION

Despite major financial and other investments in individual-focused traditional programs and approaches, agricultural production practices across the U.S. Midwest still lead to major environmental challenges, including harmful algal blooms (Brooks et al., 2016), gulf hypoxia (Rabotyagov et al., 2014), biodiversity loss, and impaired waterways (Alagele et al., 2019), and nutrient loss reduction goals are far from met (Secchi and Mcdonald, 2019). As individual-focused programs have faltered, voluntary collective actions such as watershed management groups have become increasingly central to water quality improvement efforts across the Midwest (Church and Prokopy, 2017). In most agricultural regions, farmers manage the majority of the land, and how they manage it largely determines watershed health. Because farmers' engagement in watershed management appears to directly or indirectly affect the adoption of key practices (McGuire et al., 2013; Lee et al., 2018), results presented in this paper can serve to inform ongoing and increasing efforts to involve farmers in WM activities.

Our findings have broad relevance given the increasing role that watershed management planning and action plays in working toward improved water quality, which it turn makes a vital contribution to social, economic and ecological benefits and services. Diverse countries including the U.S. have agreed upon goals like the United Nations Sustainable Development Goals (SDGs) in an integrated manner (see https://www.un.org/sustainabledevelopment/sustainable-development-goals/). Policy and decision-makers are increasingly looking for policy options that will help them achieve these agreed upon goals (McElwee et al., 2020). It is suggested that many land challenges such as clean water and sanitation (SDG 6), Life under water (SDG 14) and Life on land (SDG 15) can be met with a range of response options readily available, such as reducing the alteration of natural ecosystems and increasing adoption of conservation practices that reduce nutrient loss to surface water (McElwee et al., 2020). Our study, by identifying factors associated with farmers' participation in watershed management activities, can also assist decision-makers to craft policy and goals setting for achieving different SDGs including SDGs 6, 14, and 15.

In summary, this research points to several key levers to help increase farmers' involvement in watershed management activities. Specifically, it highlights the importance of engaging with the information sources and influential actors that can be related to farmer proclivity to take part in WM, as well as the critical role that awareness of water quality issues and attitudes toward amelioration efforts can play. Extension and outreach efforts should continue to focus on raising awareness and attitudes and further align information sources and influential actors, including watershed groups themselves, on working to recruit farmers into watershed management groups and collective efforts to improve water quality.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because our Institutional Review Board human subjects research protections make it difficult to share primary survey data. Requests to access the datasets should be directed to J. Gordon Arbuckle, arbuckle@iastate.edu.

ETHICS STATEMENT

This research involving human participants was reviewed and approved by the Iowa State University, Institutional Review Board (IRB).

AUTHOR CONTRIBUTIONS

SU and JA conceived the idea for the manuscript and wrote the manuscript. JA designed the survey and collected the data. SU conducted the data analysis. All authors contributed to the article and approved the submitted version.

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"Protein" Industry Convergence and Its Implications for Resilient and Equitable Food Systems

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Recent years have seen the convergence of industries that focus on higher protein foods, such as meat processing firms expanding into plant-based substitutes and/or cellular meat production, and fisheries firms expanding into aquaculture. A driving force behind these changes is dominant firms seeking to increase their power relative to close competitors, including by extending beyond boundaries that pose constraints to growth. The broad banner of "protein" offers a promising space to achieve this goal, despite its nutritionally reductionist focus on a single macronutrient. Protein firm strategies to increase their dominance are likely to further diminish equity in food systems by exacerbating power asymmetries. In addition, the resilience of food systems has the potential to be weakened as these strategies tend to reduce organizational diversity, as well as the genetic diversity of livestock and crops. To better understand these changes, we visually characterize firms that are most dominant in higher protein food industries globally and their recent strategic moves. We discuss the likelihood for these trends to further jeopardize food system resilience and equity, and we make recommendations for avoiding these impacts.

Keywords: protein, consolidation, diversity, political ecology, visualization, equity, resilience

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INTRODUCTION

Over the past decade, a significant restructuring has been underway across food systems. After a spate of mega-mergers sparked unprecedented consolidation in the seed, agrichemical, fertilizer, animal genetics, and farm machinery industries (IPES-Food, 2017), a similar convergence toward monopoly is occurring under the umbrella of *protein*. Nearly all of the largest meat and dairy processing firms, for example, have announced they are investing in or developing plant-based substitutes, and Unilever has set a target of €1 billion in annual sales of these foods by 2028 (Wood, 2021). In addition, the largest catch fisheries firms have expanded into aquaculture (Uzunca and Li, 2018), and dominant food processors are increasing their size and scope to offer numerous higher-protein foods—these include microbial proteins, insects and cellular (lab-grown or cultured) meat and fish (Mouat et al., 2019). This broader emphasis is highlighted in the language of several leading meat processors—Cargill and Maple Leaf Foods now describe themselves as "protein companies," and Tyson Foods has gone so far as trademarking the phrase "The Protein Company."

A growing body of research has analyzed the impacts of global livestock and fish production, particularly in regards to animal-source foods' effects on public health, the environment, and social and animal welfare (Pauly et al., 2002; Steinfeld et al., 2006; Worm et al., 2006; Rockström et al., 2009; HLPE, 2014; Bowles et al., 2019; Ryschawy et al., 2019; Willett et al., 2019; FAO, 2020b).

Investor organizations have also sought to reduce their risks by analyzing the sustainability of animal source food industries. A notable example is FAIRR (Farm Animal Investment Risk and Return), a network of institutional investors currently representing US$29 trillion in assets. The organization has developed an extensive "protein producer index" that focuses on the 60 largest beef, dairy, pork, poultry/eggs, and farmed fish firms (FAIRR, 2019). This index scores firms by impacts on greenhouse gases, deforestation, water scarcity, waste and pollution, antibiotics, animal welfare, working conditions, and food safety.

While per-capita meat consumption is predicted to fall globally by nearly 3%, according to a recent report of the Food and Agriculture Organization of the United Nations (FAO, 2020a), sales of meat substitutes have been rising in many countries during the last year (Watson, 2020). This is partially a result of disruptions in the availability of meat products due to the COVID-19 pandemic, as well as the impacts of African swine fever on pork supplies in Asia and Europe. It also stems from a steady change in consumers' preferences and consumption patterns, especially in high-income countries. The meat substitute market is expected to reach annual sales of US$12 billion by 2025 and $17 billion by 2027, with an annual growth rate of 15–18% expected from 2020 to 2025 (Meticulous Research, 2020). This represents more than double the annual growth rate of the global processed poultry and meat market, estimated to increase at a rate of 7% during the same period and expected to reach $1.65 trillion annually by 2025 (Joseph et al., 2020; Research Markets, 2020). The popularity of meat analogs among consumers seeking protein alternatives and sustainable food is particularly high in Germany, France, the Netherlands, the United Kingdom, Italy, and Sweden (Kyriakopoulou et al., 2019). Europe is currently the largest market for these products and consumed the world's greatest share in 2017 (39%), but the Asian market is the fastest growing (Mordor Intelligence, 2020).

As the biggest players in the food industry are shifting their emphases from meat, dairy, and eggs to the macronutrient of *protein,* there is a need to understand who is changing, what is changing and how those changes will impact equity and resilience—questions that have yet to receive significant attention from food systems researchers. It is also crucial to understand the degree to which the industry convergence around higher-protein foods is a response to consumption and impact trends, and how much it is a catalyst of them. The answers to these questions have important implications for suggesting pathways to avoid negative impacts on food systems.

This paper analyzes how the convergence of investors and industry executives on protein may potentially exacerbate power asymmetries and increase the fragility of food systems. Below we first describe our theoretical perspectives, which suggest that these strategies may reduce organizational diversity, as well as the genetic diversity of livestock and crops. We then describe our methods, which visually characterize firms that are most dominant in higher protein food industries globally and their recent strategic moves. We conclude by discussing the likelihood for these trends to further jeopardize food system resilience and equity, and we make recommendations for avoiding these impacts.

THEORETICAL PERSPECTIVES

To analyze drivers of changes involving higher protein food industries we use the perspective of Capital as Power (Nitzan and Bichler, 2009). To analyze the impacts of these changes on equity and resilience we complement this framework with perspectives from the political ecology of food literature. We also explore the interactions between drivers and impacts, which have the potential to reinforce negative outcomes, and decrease the opportunities for addressing them in the future.

Capital as Power is a framework that views capitalism not as a mode of production nor of consumption, but a mode of power. It seeks to connect changes in capitalists' quantitative, consensus estimates of power to the qualitative strategies of firm "owners and directors to shape and reshape politics, society, and culture (Di Muzio, 2013, p. 6). This approach, which views the accumulation of power as capitalists' ultimate goal, problematizes conventional dichotomies between politics and economics, as well as finance capital and material capital (Hager, 2013).

Market capitalization is viewed as measure of future expectations of power in current monetary valuations, while also adjusting for perceived risks. The theory emphasizes that top executives at large corporations are constantly trying to beat the average, as measured by benchmarks such as the S&P 500. Importantly, it suggests that capitalists are willing to strategically sabotage rapid growth—they will even accept negative growth rates, particularly if this leads to declining more slowly than other firms and results in a net differential increase in their power (Bichler and Nitzan, 2014).

There are numerous strategies that capitalists use to restructure society to increase their power relative to others. The market capitalization of Amazon (one of just five firms that exceeds $1 trillion), for example, is not based only on current economic performance, but also investor expectations of future success for its aggressive strategies—these include rapidly increasing spending on research and development, which is expected to lead to additional patent-protected monopolies (Watanabe et al., 2020). Although these strategies are constantly resisted, capitalists are quite flexible, which complicates the analysis of predominant approaches. One strategy that is typical for beating the average, however, is to "successively break its 'envelopes,' spreading from the industry, to the sector, to the national economy, and ultimately to the world as a whole" (Nitzan and Bichler, 2009, p. 332).

Although this might also occur *via* internal growth, it is easier and less risky to "bolt on" growth *via* acquisitions, particularly for firms that have the means to make buyout offers. Executives who fail to increase their firm's power relative than others may themselves become vulnerable to takeover. Regulations that previously hindered these strategies became less of a barrier beginning in the 1970s, due to the influence of "Chicago School" antitrust theories, and most notably the arguments of legal scholar Robert Bork (Lynn, 2010; Olson,

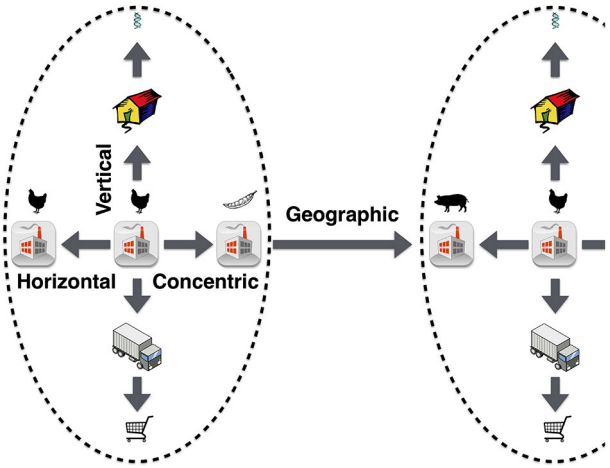


FIGURE 1 | Directions of breaking ownership envelopes by firms to overcome constraints to growth.

2014). Antitrust laws have been reinterpreted by judges and regulators to emphasize efficiency gains and lower prices that may potentially result from mergers and acquisitions (Aron et al., 1994), particularly in the United States and the European Union, which has enabled increasing concentration in numerous industries (Howard, 2016a). By 2012, for example, the US Department of Justice detailed abuses of power by dominant firms in food and agricultural industries, including bid rigging, market manipulation and one-sided contracts. The agency suggested that it could not address these issues, however, because they were outside of the scope of antitrust laws, due to precedents in recent decades (Khan, 2012; USDOJ, 2012).

Breaking ownership envelopes may proceed in multiple directions, as shown in **Figure 1**. Horizontal integration involves mergers or acquisitions with close competitors, such as a chicken processor acquiring another chicken processor in the same region. Another direction is to integrate vertically, or to acquire upstream suppliers or downstream customers. For this same chicken processor, for example, it might involve acquiring a poultry genetics firms upstream, or a distributor downstream. A third potential direction is to expand concentrically by acquiring firms in related industries, such as a pork processor or a pea protein processor. The fourth direction in which envelopes may be broken is geographic, such as expanding into new regions, nations or continents.

Geographic expansion is increasing in importance for food and agricultural firms, which are experiencing level or declining sales in high-income countries. One striking example is Nestlé's use of boats on the Amazon River tributaries in Brazil, as well as door to door sales *via* contractors in poor urban neighborhoods in this nation, to reach potential new consumers (Mulier and Dantas, 2010). Because the size of our stomachs is limited, there are significant barriers to increasing food and beverage sales in comparison to goods and services without such biological constraints. Per capita consumption of dairy, beef, and pork products in North America and Europe, for example, are high relative to many other parts of the world but have not increased in recent decades. Food firms have responded by shifting demand toward their products at the expense of other foods, or by encouraging the purchase of more highly processed and/or branded foods, which may command higher prices. These efforts have contributed to "meatification," or increased consumption of animal source foods (including dairy) in areas where these products have traditionally been less central to diets, and particularly in households with rising incomes (Weis, 2013; Hoelle, 2017; Schneider, 2017; Clay and Yurco, 2020; Hansen and Jakobsen, 2020).

Increasing food sales is also a challenge in regions where more people are directly engaged in agriculture and have the capacity to produce or process their own food. These constraints may be overcome by reducing this capacity, such as supporting policies that lead to depeasantization (Araghi, 1995) and deskilling for those still engaged in farming (Stone, 2007). Deskilling leads farmers to become more dependent on corporations in upstream segments, such as animal genetics, or downstream segments, such as meat processing, and may be reinforced by regulations—food safety requirements for meat and dairy processing, for example, have created significant barriers to market access for smaller-scale producers (GRAIN, 2012).

Deskilling is also an important strategy that is applied to consumers (Jaffe and Gertler, 2006). Marketing by dominant firms has become more sophisticated and more effective in reducing knowledge and abilities with respect to food preparation. Hormel, for example, hired a corporate anthropologist who helped develop a ready to eat sandwich aimed at teenagers, with a goal of enabling them to consume it with one hand on their smartphone. This product has a 70-day shelf life, and it has been one of the most successful recent introductions in the food industry (Stock, 2016).

Dominant food firm marketing strategies increasingly promote the consumption of "protein." This reductionist focus on a single macronutrient (Clapp and Scrinis, 2017) is not justified by nutritional requirements, as the majority of adults in high-income countries currently exceed the recommended daily protein intake (Mittendorfer et al., 2020). Even in low-income countries, where dietary diversity is generally low, interventions to reduce hunger that focused heavily on protein have been ineffective (Waterlow and Payne, 1975). This marketing emphasis, however, is used to convince consumers to replace animal source foods with highly processed and proprietary substitutes—frequently with the promise of comparable protein levels—rather than toward more diverse, less processed and less profitable foods (Clay et al., 2020; Santo et al., 2020).

A Capital as Power perspective views decreasing equity and self-reliance as an intended outcome, and the result of capitalists' influence on the redistribution of income and assets. It is not surprising that dominant firms increase prices for consumers (even going so far as price signaling or price-fixing) or drive down prices for sellers, and wages for workers. Protein-focused firms have been prominent in recent cases of alleged price-fixing, including tuna, beef, pork, chicken, turkeys, and peanuts (Demetrakakes, 2021). COVID-19 increased awareness of the vulnerability of low paid workers employed by dominant meat

and seafood processors, many of whom were at greater risk of infection due to long working hours, and inadequate access to safety protections and health care (Middleton et al., 2020). Processors such as Tyson and JBS are also extending their contract model, which drastically reduced incomes and decision-making power for chicken growers in the southern US, to other regions, and to more species of livestock (Constance, 2008; Leonard, 2014; Stull, 2019). From an equity standpoint, concentration in food systems has made farmers increasingly reliant on a handful of suppliers and buyers, further squeezing their incomes and eroding their ability to choose what to grow, how to grow it, and for whom (IPES-Food, 2017; Hendrickson et al., 2019).

Many additional negative consequences of these trends could be viewed as collateral damage from a Capital as Power framework—they are unintended impacts of the strategies used to increase dominance (Cochrane, 2010). Most ecological impacts fall into this category, and political ecologists are prominent among researchers detailing these impacts empirically. These are typically described as "externalities" by economists, reducing costs for firms by displacing them onto society or the environment. Because firms that operate in the same political economic context frequently behave in ways that are similar to each other, these cost cutting strategies may be replicated throughout an industry (Nitzan and Bichler, 2009).

The growth of firms converging under the banner of protein (meat, dairy, and animal feed processors) has contributed to what political ecologists describe as an increasingly global "grain-oilseed-livestock complex." This complex is characterized by "oceans of monocultures" of coarse grains (mostly maize) and oilseeds (mostly soybeans), and islands of concentrated animal production (mostly chickens, pigs and cows) (Weis, 2013). The growing intensification and separation of crop and livestock production results in a much heavier ecological footprint (or "hoofprint") for these products, as well as the loss of multiple functions of livestock in more integrated contexts (e.g., labor, transport, hides, wool, fertilizer, fuel). Impacts such as pollution and soil damage are typically addressed with short-term technological fixes in an attempt to override them, but in the longer-term these approaches further undermine sustainability (Weis, 2010).

Breeding efforts have focused on an increasingly narrow range of crops and livestock, as noted above, which has contributed to the extinction of nearly one in six livestock breeds within a 100-year period (Tisdell, 2003). Genetic diversity within these species has also been reduced by focusing on a small set of traits (Khoury et al., 2014; IPES-Food, 2016). This leads to what a Tanzanian botanist described as a "monoculture within monoculture" (Thompson, 2007, p. 563). Industry consolidation is an important factor in these trends (Neo and Emel, 2017), such as the elimination of all North American turkey breeding stock after an acquisition made by a European firm, EW Group in 2004 (Walker, 2009). This firm, along with Hendrix Genetics, accounts for ∼99% of the global breeding stock for turkeys, and 94% for laying hens (ETC Group, 2013). The seed industry has also experienced declining diversity in conjunction with dramatically increased concentration—four firms control more than half of commercial sales globally (Howard, 2020).

Reduced genetic and species diversity hampers the capacity of farming systems to mitigate risks related to shocks and stresses (IPES-Food, 2016). Highly concentrated monocultures of livestock, for example, remove "immune firebreaks" that would slow disease transmission in more diverse populations—particularly when (1) production conditions suppress immune systems, (2) life cycles are shorter and more uniform, (3) there is no on-site reproduction to evolve resistance, and (4) global trade increases the exchange of pathogens (Wallace, 2016, 2021). Intensive livestock production has demonstrated substantial vulnerability to epidemics such as those caused by avian influenza, PEDv, and numerous other pathogens. China, for example, lost 37% or more of its swine herd due to an outbreak of African swine fever in 2019 (FAO, 2019).

A key effort to counter these trends is agroecology, which has been demonstrated to be an important strategy to shift food systems in more resilient and equitable directions (IAASTD, 2009; Rosset et al., 2011; Altieri et al., 2015). Agroecology is the application of the science of ecology to sustainable food systems, integrated with practice and social movements. There is strong evidence of these systems' ability to deliver robust and stable outputs, based on maximizing biodiversity and minimizing external inputs (IPES-Food, 2018). In numerous contexts, the ability of diverse agroecological systems to maintain yields, reduce losses, and allow recovery in the face of environmental stresses and shocks has been noted (Holt-Giménez, 2002; Mijatovic et al., 2013; Wezel et al., 2020). Diversified systems, in particular, have shown the ability to boost production in areas where more food is urgently needed, addressing both resilience and equity goals.

Resilience is also being weakened, however, by changes in organizational diversity that accompany the rising power of dominant firms. An increasingly large-scale and centralized food system has reduced diversity in both scale and forms of organization, and has become more vulnerable to disruption, such as from natural disasters, pandemics, resource depletion, or social unrest (Hendrickson, 2015). With fewer smaller- and medium-scale organizations there is less flexibility and adaptability to respond to change, as well as less redundancy and a growing number of chokepoints (Bailey and Wellesley, 2017). COVID-19 dramatically illustrated the fragility of just-in-time supply chains, with so much food flowing through a very small number of processing plants—shutdowns resulting from outbreaks led to product shortages and forced farmers to euthanize their livestock (Hendrickson, 2020). In the US, for example, more than half of beef production is processed in just 13 plants (FAIRR, 2020). The demands of large firms for uniformity reinforce these trends by shutting out more participants, as "only the big can serve the big" (Hannaford, 2007, p. 30).

Interactions between the drivers and impacts described above are also resulting in feedbacks that further threaten equity and resilience. The disruption of fragile supply chains, for example, leads to firms charging higher prices to cover increased costs, and in concentrated industries, prices are "sticky"—they tend to decline more slowly and only partially when supply

chains recover (Shields, 2010). Another interaction occurs when alternative food initiatives form in response to the social and ecological impacts of dominant firms—examples include organic and fair trade labeling schemes—but the most successful of these may be co-opted and redirected as new growth opportunities for dominant firms (Jaffee and Howard, 2010; Bichler and Nitzan, 2020).

METHODS

Our analytic method focuses on visualization, which aids in cognition and reduces burdens on short-term memory, particularly for complex data sets (Card et al., 1999). This approach frequently improves understanding and recall in comparison to text or tables alone (Mayer, 2014). Visualization is especially useful for studying complex, industry-wide changes that are the collective result of the decisions of numerous specific firms. We collected information from secondary data sources to determine the largest firms involved in industries considered to be protein-focused, and to analyze the strategies they are employing to increase their dominance.

The data we selected included annual sales, ownership changes (primarily acquisitions and joint ventures), and market capitalization figures for the most recent 10-year period, 2011–2020. In addition, we collected data on investments in cellular meat and seafood startups to analyze actors involved in attempts to commercialize these products. Finally, we collected more detailed data on ownership changes (dates, locations, sale prices, and brands controlled) for one firm, JBS. We selected this firm as a case study due to its rapid growth *via* acquisitions to become the world's largest meat processor, as well as the more recent public disclosure of the illegal strategies that contributed to this dominance (Freitas et al., 2017; Wasley et al., 2019).

Data sources were diverse, and included annual reports, company websites, press releases, trade journals, business articles, and non-profit and trade association reports. A key source of data for annual sales was the Food Engineering Top 100 Food and Beverage Companies (2020), but four additional firms were added based on figures from their annual reports (CP Foods, Tönnies, Mowi, and Thai Union). All data points except for the Food Engineering annual sales figures were corroborated with at least one additional document, unless they were announced directly by the firm that was involved.

We applied five types of visualizations to best represent the data we analyzed, guided by our theoretical framework. These included a treemap, a multi-variable plot, a timeline, a network diagram and a cartographic map (Howard, 2009). All of these visualizations were produced with OmniGraffle (The Omni Group, Seattle, WA), although initial layouts of the treemap and multi-variable plot were first produced with RAW Graphs (Mauri et al., 2017), and then revised with OmniGraffle. Data were encoded with color, form, and spatial position to take advantage of "pre-attentive" processing, or the capacity of the sense of vision to take in large amounts of information faster than possible when paying conscious attention (Tidwell, 2010).

RESULTS AND DISCUSSION

In this section we present the results of our analysis, which includes visualizations of the current scope and recent changes in "protein" industries. We also discuss what they reveal about protein industry strategies to increase power, and the likelihood of these trends continuing in the near future.

The largest protein firms by sales, focus, and headquarters are shown in **Figure 2**. The rectangle sizes are proportional to 2019 food sales—Nestlé was highest at US$76.8 billion and the lowest shown is Land O'Lakes with $4.0 billion. Rectangles are also colored by the firm's primary commodity focus, although some firms increasingly emphasize multiple higher protein commodities as the boundaries between them become more blurred. As a result, a gradient of two colors is used to represent Cargill's focus on both meat and animal feed, Kraft Heinz's focus on meat and dairy, and Charoen Pokphand (CP) Food's focus on seafood and meat.

This figure indicates that dominant protein firms globally are most likely to focus on dairy, followed by those focusing on meat and animal feed. Although four firms focused on seafood are shown, their food sales are smaller relative to the other sectors. This figure should be interpreted with some caution, because it is based on total food sales, and some firms are selling foods in categories that are broader than "protein." Nestlé, for example, is not only a dairy processor, but dominant in other commodities such as coffee, candy, and bottled water, as well as pet food and pharmaceuticals—dairy sales account for less than one-third of the food sales represented in **Figure 2** (Ledman and van Battum, 2020). Also note that in 2020 most of the assets of Dean Foods were acquired by Dairy Farmers of America (DFA) in a bankruptcy sale, therefore the division between these firms for 2019 food sales is portrayed as less distinct than others.

Some geographic differences are evident, with meat firms concentrated in North America and South America, dairy firms concentrated in Europe, animal feed firms concentrated in North America, and seafood firms concentrated in Asia. The reasons for these differences are complex, but include cultural, ecological and historical factors, as well as government supports for dominant firms—examples include government-backed financing for meat firms headquartered in Brazil, and subsidies for animal feed crops in the United States (Howard, 2019).

Next we selected a subset of the firms shown in **Figure 2**, with a focus on the largest publicly traded firms. This resulted in excluding privately held (e.g., Cargill) and cooperatively held (e.g., FrieslandCampina) firms, for which market capitalization figures are not available. We then plotted 15 firms with a market capitalization of more than US$10 billion as of December 31, 2020 by their percentage change in market capitalization since December 31, 2010, with size proportional to annual sales in 2019. The results are shown in **Figure 3**, with the change in the S&P 500 during the same 10-year period (199%) included as a point of reference—as mentioned above, this is a benchmark that top executives frequently seek to exceed.

Two dairy-focused firms, Nestlé and Unilever, stand out as having the highest market capitalization figures ($343.7 billion and $156.6 billion, respectively), which suggests strong

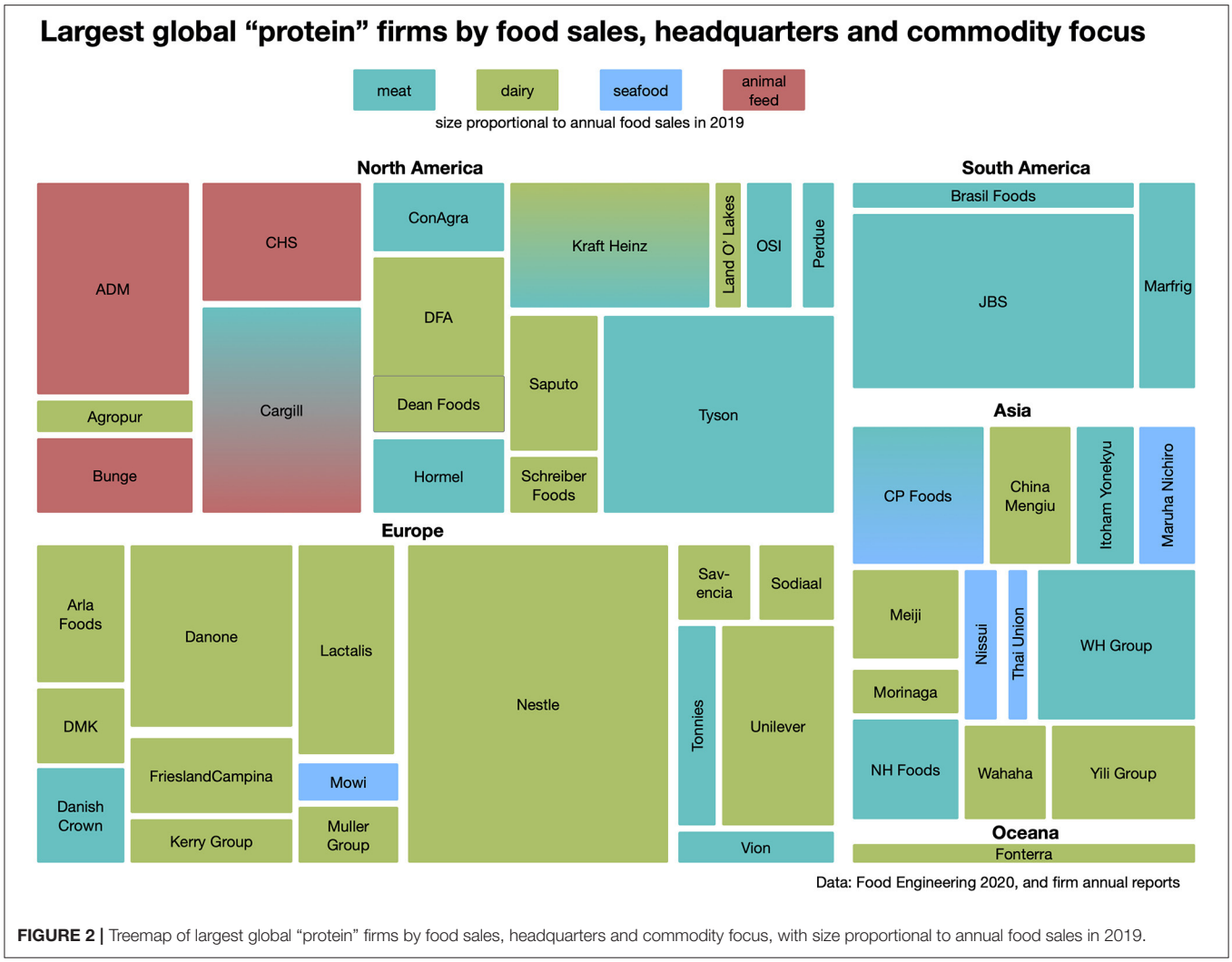


FIGURE 2 | Treemap of largest global "protein" firms by food sales, headquarters and commodity focus, with size proportional to annual food sales in 2019.

expectations from investors that these firms will be profitable in the future. Both firms, however, are diversified into other products—Nestlé's diversity is noted above, and Unilever is dominant in personal care and home care products.

Another cluster of firms is identified by growth rates that equaled or exceeded the S&P 500 over the previous 10 years. These are led by two dairy firms headquartered in China, Yili Group and China Mengniu (growth rates of 783 and 414%, respectively), followed by the more diversified Ireland-headquartered dairy firm Kerry Group (334%). In late 2020, Kerry Group reportedly hired advisors to consider selling its consumer food units, in order to fund acquisitions in food ingredients and flavors—a market in which it is more dominant (Nair et al., 2020). As Yili Group and China Mengniu have increased their sales and market share, encouraged by government policies, China has transformed from a nation that once shunned dairy as a "barbarian" food to the third-largest dairy producer in the world (Böhme, 2021). Milk suppliers have increased in size, as well as expanded their use of more genetically uniform foreign breeds of cattle—there are now more than 40 farms in China with herds of 10,000+ cows (Sharma and Rou, 2014).

The high growth group also includes three meat processors, Hormel, Tyson, and JBS, as well as one seafood/aquaculture firm, Mowi. Hormel, Tyson, and JBS, along with WH Group and other dominant firms in the US have faced multiple accusations of anti-competitive behavior, facilitated by sharing data with the firm AgriStats. This includes driving up prices for distributors, retailers, and consumers, and driving down wages for workers and the prices paid to contract farmers. Although Tyson and JBS have paid hundreds of millions of dollars in fines or settlements for some of these claims, a number of legal actions are still ongoing, including federal indictments of 10 poultry firm executives—five from JBS subsidiary Pilgrim's Pride, and one from Tyson (Secard, 2020).

Mowi is notable for its high market capitalization relative to annual food sales of just $4.6 billion, which is substantially lower than the other firms shown in **Figure 3**—this indicates investor expectations of strong future growth. Mowi is positioned to increasingly dominate the rapidly growing industrial aquaculture

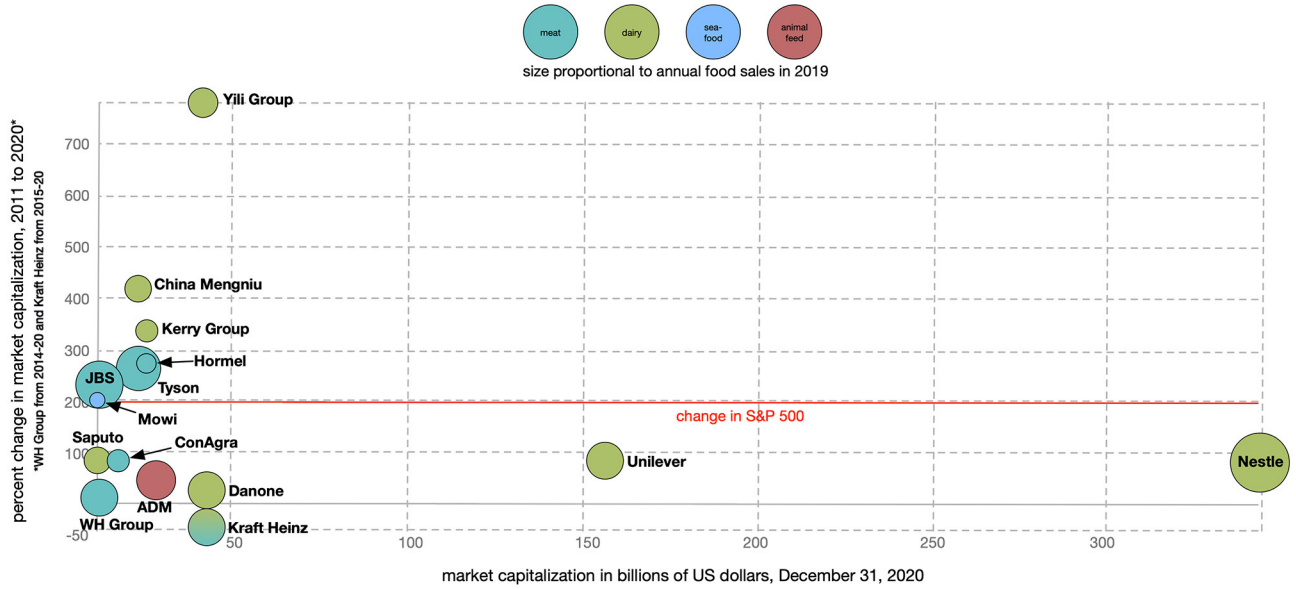


FIGURE 3 | Multi-variable plot of dominant publicly traded "protein" firms: market capitalization, growth rate relative to the S&P 500 from 2011 to 2020, and annual food sales in 2019.

sector—although catch and consumption of wild caught seafood has been stagnant for decades (Pauly, 2019), aquaculture has reported growth rates exceeding 5% annually since the year 2000 (Edwards et al., 2019). Approximately half of fish consumed by humans is now derived from aquaculture (Rousseau et al., 2019). Mowi is vertically integrated into fish breeding, relying on the same strain of Atlantic salmon since 1964. The firm's growth is not only increasing genetic uniformity for farmed salmon, but may also threaten wild salmon populations when introgression occurs with escaped fish (Glover et al., 2017).

Even higher expectations of growth are evident for the plant-based meat alternative firm Beyond Meat. This firm had a market capitalization of $7.8 billion at the end of 2020, which was not high enough to reach the threshold for inclusion in **Figure 3**. Although its food sales totaled just $298 million in 2019, this valuation indicates investors are confident that future sales are likely to eventually exceed most other close competitors. Just a month later, for example, the market capitalization briefly reached $12 billion. Early investors included Tyson, which sold its 6.5% stake before Beyond Meat's initial public offering in 2019, followed by introducing its own "plant-based protein" brand, Raised & Rooted. The packing and marketing of both of these firms' products prominently display their high protein content. Beyond Meat also emphasizes this macronutrient to the exclusion of all others by stating, "part of our vision is to re-imagine the meat section as the Protein Section of the store," and trademarking the phrase "The Future of Protein" (Beyond Meat, 2021).

A third cluster of firms, with growth rates below that of the S&P 500 and a market capitalization of $43 billion or less, includes the animal feed firm ADM, as well as other meat and dairy firms. ADM recently agreed to pay $45 million to settle a civil lawsuit, which alleged price-fixing with other peanut processors (Bunge, 2021). Kraft Heinz recorded the lowest growth among firms in **Figure 3**—its market capitalization declined 52% since two namesake firms merged in 2015, and the resulting entity has since attempted to simplify the strategic focus. In addition to selling a peanut division, as mentioned below, Kraft Heinz sold part of its cheese division to Lactalis in late 2020 for $3.2 billion.

We selected a subset of nine firms in **Figure 3** to visualize acquisitions and joint ventures from 2011 to 2020, focusing on the largest and fastest growing firms by market capitalization. The results are shown in **Figure 4**. The colors represent the commodity focus, and they indicate that all firms were making horizontal acquisitions during this time period. Mengniu, for example, paid ∼$1 billion to acquire Bellamy, an organic infant formula firm in Australia, with a goal of expanding to more international markets with this premium brand (Ferreira, 2019). The firm also formed a joint venture with Coca-Cola named "KeNiuLe" in 2020 to leverage the latter's brand influence and increase chilled milk sales in China—an analyst suggested this product "was purchased by just 29 percent of Chinese families and hence has huge growth potential" (Yan, 2020).

Four of the nine firms have also concentrically acquired plant-based protein firms: Nestle acquired Sweet Earth, Unilever acquired The Vegetarian Butcher, Kerry Group acquired a majority stake in Ojah, and Hormel acquired two peanut firms, Skippy and Justin's. In addition, shortly after the end of the study

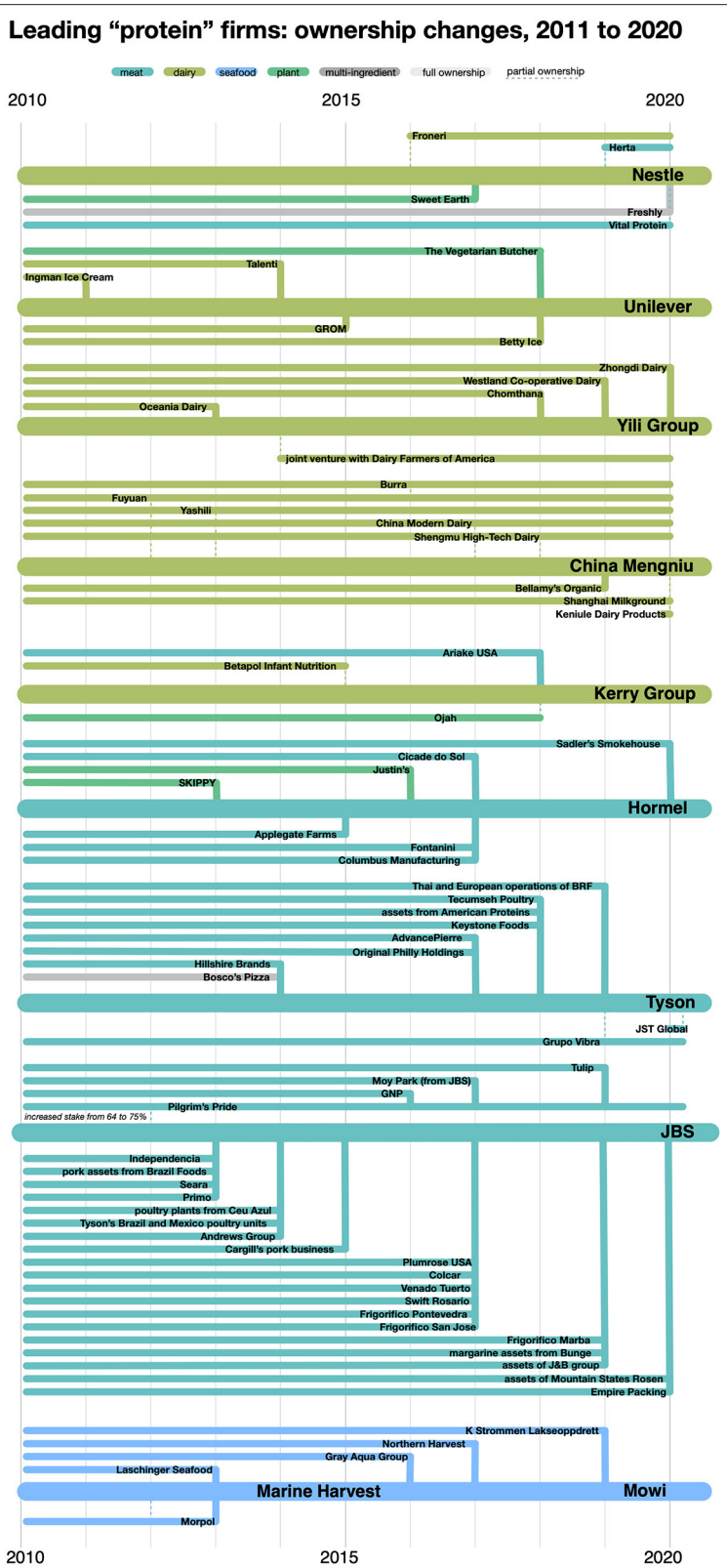


FIGURE 4 | Timeline of leading "protein" firms: ownership changes, 2011–2020.

period, Hormel acquired the Planters peanut brand from Kraft Heinz for $3.35 billion.

Nestlé also integrated vertically by acquiring the prepared meal delivery firm Freshly, while Tyson acquired the multi-ingredient (and branded) frozen food firm Bosco's. Not shown in the figure is Marine Harvest's vertical integration into aquaculture shipping vessels *via* a joint venture in 2016—the firm was renamed Mowi in 2020, the same year that it divested this joint venture, with a net gain of ∼$65 million (McDonagh, 2020). The name change was motivated by an increasing emphasis on branding—the firm has hired a former Coca-Cola executive to lead a €35 billion effort to "establish loyalty and habits" for a product that was previously an unbranded commodity (Berge, 2018). If successful, this will create more barriers to entry for smaller firms in this industry.

The meat processor JBS has been most active of the firms in **Figure 4**, as measured by number of acquisitions. JBS took a 64% stake in Pilgrim's Pride in 2009, and then increased the amount of equity to 75% in 2012 (it has since increased to 78%). When JBS was forced to sell Moy Park in 2017 to pay a $3.2 billion corruption fine, the sale was made to the Pilgrim's Pride subsidiary.

Figure 4 also indicates the reduction in organizational diversity that occurs with industry consolidation. Although it focuses on just a subset of firms in this study, it illustrates the declining number of firms that account for an increasing proportion of sales. This results in larger and more centralized organizations, with decision-making concentrated in fewer hands. It also leads to the loss of more diverse forms of organization, such as smaller firms and cooperatives, either through acquisitions or exiting these industries.

Figure 5 shows the investments in cellular meat and fish startups by key actors through the end of the study period, December 31, 2020. These firms are developing cellular technologies to produce meat or fish *via* stem or satellite cells from an organism's muscle, and growing them with the aid of nutrients, hormones and growth factors in an appropriate culture medium (Warner, 2019; Chriki and Hocquette, 2020; Guan et al., 2021). One firm, Eat Just, recently received regulatory approval to sell a cell-cultured chicken product to consumers in Singapore, although the high costs of production make it likely that entry to retail outlets will be slow (Scipioni, 2020). The convergence of firms with a focus on protein is evident, with investments made by meat firms, including Tyson and Cargill, as well as seafood, dairy and plant-based protein firms (Pulmuone controls the tofu brands Nasoya, Pulmuone and Wildwood). In addition to the investments made during the study period, in early 2021, BlueNalu announced an investment from Thai Union, Aleph Farms announced a partnership with Brasil Foods, and Future Meat Technologies announced investments from ADM, Rich's and Müller Group. Additional investors (not shown) include venture capitalists, who seek to beat the average rate of return by wide margins, typically with an exit strategy of an acquisition by a dominant firm. Investments in this sector have exceeded $350 million since 2014 (Khan, 2020), even though most of these firms are likely years away from commercialization.

These trends raise concerns that cellular meat and fish will be quickly monopolized by dominant firms, thus maintaining or even increasing power asymmetries in food systems (Santo et al., 2020). An emphasis on providing cellular alternatives may actually increase consumption of the non-cellular meat and seafood products sold by these firms, due to reinforcing the belief that such foods should be a central part of diets (Lonkila and Kaljonen, 2021). The utopian promises of new technologies frequently lead to overestimates of their potential impacts (Chiles, 2013), but substantial growth in this sector may threaten the livelihoods of livestock producers and harm rural communities. Such critiques are raised infrequently in mainstream media coverage, because these outlets rely heavily on industry sources and present overwhelmingly positive perspectives (Painter et al., 2020).

Figure 6 shows a global map of acquisitions and brands controlled by JBS. The time period selected is slightly extended in comparison to **Figure 4**, and instead begins in 2005—this was the first year that JBS expanded internationally by acquiring the firm Swift-Armor in Argentina. Not only has this firm been more active than other "protein" giants in terms of acquisitions, its strategy has received significant support from the government of Brazil, where it is headquartered. Other dominant meat firms based in this country, Marfrig and Brasil Foods, also had access to state-backed financing for foreign acquisitions but did not receive as preferential treatment as JBS. In 2017 a government investigation uncovered that the firm had bribed nearly 2,000 politicians, spending nearly $250 million (Wasley et al., 2019). Two brothers who controlled the firm admitted to these crimes as part of a plea bargain, and later served prison sentences for insider trading. One of them, Joesley Batista, said that without these bribes, "It wouldn't have worked. It wouldn't have been so fast" (Freitas et al., 2017).

JBS has made acquisitions throughout South America, North America, Australia, and Europe, and currently sells in more than 150 countries. Although the firm does not yet have a presence in Asia *via* acquisitions or joint ventures, it does have alliances in China to sell its branded meat products. These include agreements with e-commerce giant Alibaba, and the government-owned meat processor and grain trader COFCO.

The center of the figure names nearly 100 brands controlled by JBS globally. This is not unusual—Dean Foods offered more than 40 brands of milk in the US before its bankruptcy, for example (Howard, 2016a), and ConAgra has more than 70 highly recognized brands for meat and other processed foods. For all products, Unilever owns more than 400 brands and Nestle owns more than 2,000 brands (Wood, 2021). These ownership patterns are not transparent to consumers, however, which presents an illusion of greater organizational diversity. JBS, for instance, now offers brands in the categories of organic (Acres Organic, Spring Crossing, Just BARE), grass fed (Grass Run Farms, Little Joe), and plant-based substitutes (OZO). After acquisitions, dominant firms typically maintain profitable and fast-growing brands, and discontinue less successful brands. The numerous consumer options that do remain, however, may obscure the much lower diversity embodied in their ingredients, as well as in the breeds and seeds used to produce these ingredients (Howard, 2016b).

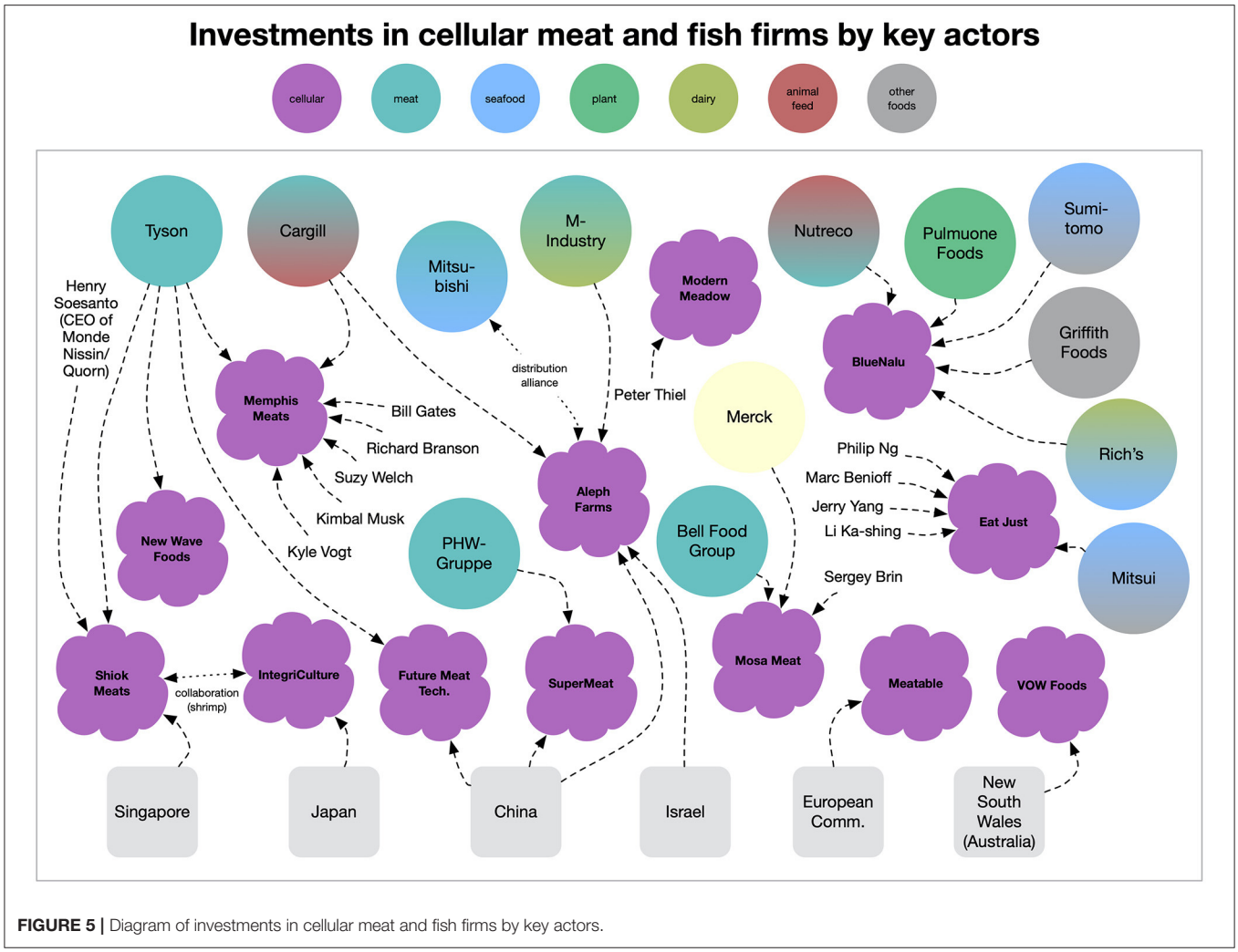


FIGURE 5 | Diagram of investments in cellular meat and fish firms by key actors.

There has been very little response by governments to slow or prevent the types of acquisitions described above—JBS has continued to make acquisitions after receiving financial penalties, and due to the dominance established relative to smaller competitors, will likely continue to do so. Regulators in the US allowed JBS to acquire a lamb processing facility, from the cooperative Mountain States Rosen, at a bankruptcy auction in 2020. JBS, which imports all of its lamb products in the US, immediately announced it was converting the plant to beef processing. This action removed one of the few remaining processors for sheep producers in Colorado and surrounding states, and is expected to drive many of them out of business (Campbell, 2020). Such an impact would increase inequity and reduce farm organization diversity, and potentially reduce breed diversity.

Another meat processor headquartered in Brazil, Marfrig, was allowed to acquire ~82% equity in the US firm National Beef in 2018, moving it into the second ranked position globally for beef processing. Then, in early 2021, Marfrig became the largest shareholder in Brasil Foods by acquiring 31.66% of its shares. Although calls for more aggressive antitrust enforcement are becoming more common, particularly with respect to dominant technology firms (e.g., Amazon, Alphabet/Google, Apple, Facebook), this has not yet translated to significant actions in food and agricultural industries.

CONCLUSIONS AND RECOMMENDATIONS

The convergence of previously separate industries under the umbrella of "protein" is contributing to increasing market capitalization values for the world's most dominant meat, dairy, animal feed, and seafood processors, as well as removing more of the remaining boundaries between them. Investors are therefore demonstrating confidence that these firms will continue to increase their power relative to other members of society. Some of these firms have used illegal tactics to decrease equity by driving up prices for customers, driving down prices for suppliers, and suppressing wages for workers. Even legal strategies to achieve these goals, however, have been quite successful over the past decade, and have contributed to increasing inequality. Vertical,

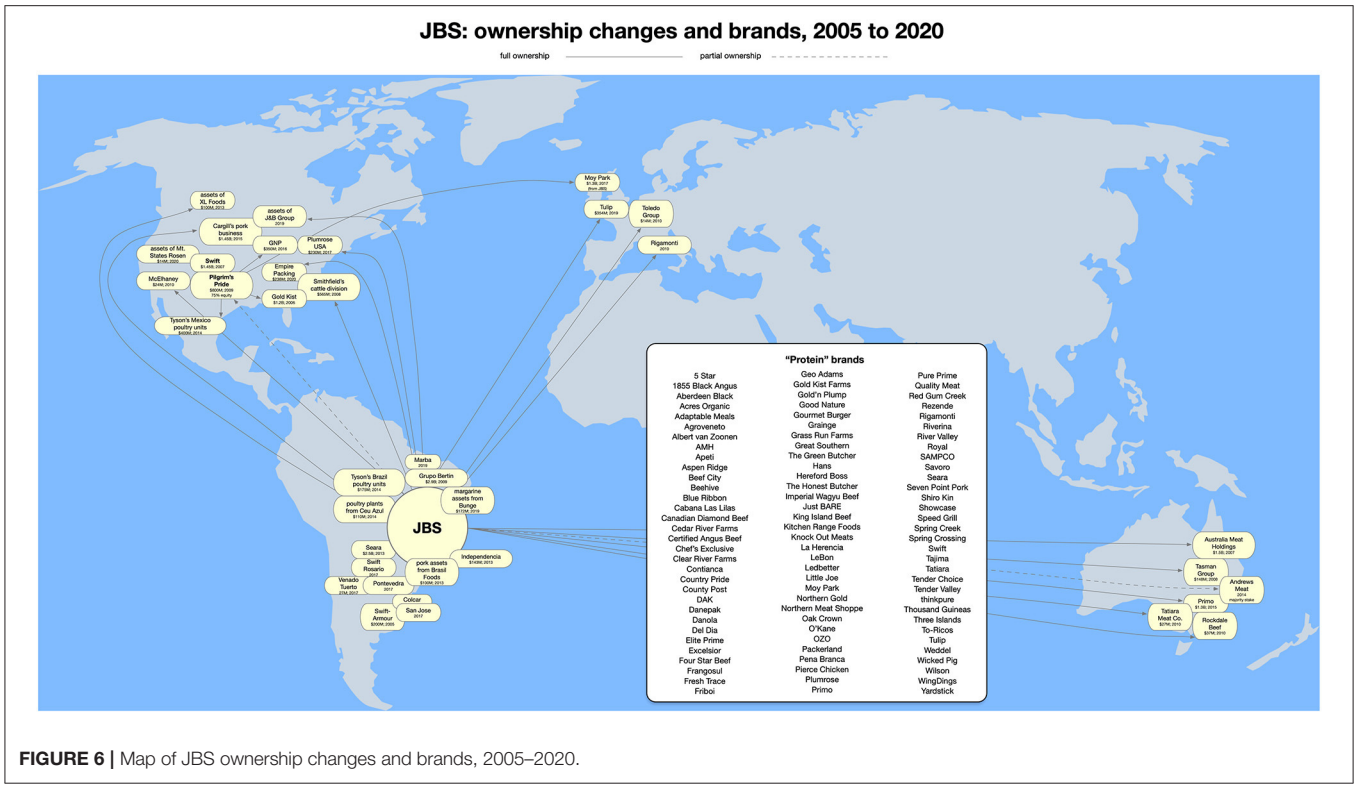


FIGURE 6 | Map of JBS ownership changes and brands, 2005–2020.

horizontal, concentric and geographic growth strategies have also reduced the number of firms and their organizational diversity, resulting in less adaptability to respond to disruptions. Furthermore, the actions of these firms are contributing to declining species and genetic diversity, such as in dairy cattle and farmed Atlantic salmon, which amplifies the risks of pandemics.

The strategy of breaking ownership envelopes to achieve growth is also giving these firms control over what may appear to be alternatives to their products, such as plant-based substitutes and organic brands. These alternatives are frequently promoted as solutions to sustainability problems, but their rapid absorption by the most dominant firms indicate they pose little threat to business as usual and may actually reinforce their power. In addition, the strategic focus of dominant firms on "protein" has contributed to inflating the nutritional importance of this macronutrient, as well as to deflecting attention from the high degree of processing for many of their products.

The continued ability of dominant firms to restructure society and amass power suggests that efforts to improve equity and resilience will not be successful in the long term unless they also address the drivers of power concentration, which underlie and reinforce numerous other lock-ins of unsustainable, industrial food systems (IPES-Food, 2016). Government inaction to slow consolidation results in a vicious circle of increasing firm size, which leads to a greater ability of these firms to influence policy. One recommendation is therefore to redefine anti-competitive practices and extend the scope of antitrust rules—this should be accompanied by measures to fundamentally realign incentives in food systems and allow for transnational oversight (IPES-Food, 2017), while also implementing stronger enforcement of national competition laws to avoid unfair trading practices (Kelly, 2018). More broadly there is a need to strengthen food sovereignty, allowing individuals and communities more agency to define their own food and agriculture systems. Achieving this goal will involve the challenging tasks of mobilizing social movements and forming more diverse coalitions (Sharma and Daugbjerg, 2020).

A transition toward sustainable, healthy and fair food systems could also be achieved through greater support for both agroecology and increased organizational diversity (Hendrickson et al., 2020). This would require public governance reform through integrated food policies (IPES-Food, 2019) that allow for a level playing field for agroecology, and for shorter and more redundant supply chains to emerge and develop (HLPE, 2019). Public governance reform should also guarantee a shift in subsidies and investments from industrial production systems and powerful companies to instead support agroecological practices and research (Miles et al., 2017), and re-localized food systems. Some initial measures might include public procurement (de Schutter, 2014; Chandler et al., 2015), incentivizing innovative distribution and exchange models (Berti and Mulligan, 2016), and increasing land access and tenure (Peterson-Rockney et al., 2021). Moreover, agricultural subsidies could also be shifted to privilege sustainable food systems indicators that go beyond yields per hectare or productivity per worker and include price premiums for managing multi-functional landscapes with a continuum of wild and cultivated species (IPES-Food, 2016). Such practices could encourage increased species and genetic diversity of crops and livestock,

as well as on-site reproduction to evolve greater resistance to pathogens (Wallace, 2021).

Lastly, more research could be conducted on the convergence of meat, dairy, animal feed, seafood, and plant-based alternatives industries, particularly from a food systems perspective. Such research could better characterize the social and ecological impacts of the growing power of these firms in specific contexts, and potentially inform more place-specific policy recommendations. As one example, the marketing efforts that have accompanied these trends frequently promote one-size-fits all or "neoliberal diets," which may homogenize previously diverse food cultures, as well as increase consumption of less nutritious, ultra-processed products (Winson, 2013; Otero, 2018). In conjunction with multilateral trade agreements that favor dominant firms (Wood et al., 2021), such changes contribute to loss of domestic producers and increases in the prices that consumers pay for less processed domestic foods (Werner et al., 2019). A better understanding of the constraints on individuals and households to make dietary choices that reflect their values, and the role of dominant firms in structuring food access and availability to enact such constraints, is needed (Hendrickson and James, 2016).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

PH wrote the first draft of the manuscript and led the analysis and the production of visualizations. FA and MY wrote sections of the manuscript. AC conducted a systematic search of academic databases. All authors reviewed and contributed to manuscript drafts and approved the submitted version.

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Amplifying Agroecological Farmer Lighthouses in Contested Territories: Navigating Historical Conditions and Forming New Clusters in Japan

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Individual agroecological farms can act as lighthouses to amplify the uptake of agroecological principles and practices by other farmers. Amplification is critical for the upscaling of agroecological production and socio-political projects emphasizing farmer sovereignty and solidarity. However, territories are contested spaces with historical, social, cultural, and economic contexts that can present challenges to the effectiveness of farmer lighthouses in catalyzing localized agrarian change. We explore these amplification dynamics through fieldwork in a particular region of Japan employing interviews and data derived from an assessment of nine farms using ten amplification indicators. The indicators include social organization, participation in networks, community leadership, and degrees of dependency on policies or markets among others, as well as degree of adoption of on-farm agroecological practices, all of which capture farmer lighthouses' potential to amplify territorial upscaling. At the same time, we trace the historical development of a previous generation of Japanese farmer lighthouses practicing organic agriculture in alignment with agroecological principles that experienced, to varying degrees, push-back, co-option, and successful territorialization in rural communities. We find that many of the same social and cultural territorial dynamics are still influential today and affecting the amplifying effect of agroecological farmer lighthouses, but also find examples of new clustering around lighthouses that take advantage of both the historical vestiges of the previous generation's efforts as well as contemporary shifts in practice and agrarian orientation. This research calls for a detailed dissection of the dynamic and contrasting processes of agroecological territorialization and the ways in which diverse contexts shape agroecological upscaling.

Keywords: farmer lighthouses, agroecology, upscaling, amplification, new entry farmers, farmer-to-farmer networks

INTRODUCTION

Agroecology has been identified as one of the main solutions to addressing environmental unsustainability, food security, and socio-economic inequity in contemporary agriculture and food systems (Altieri et al., 2012; Wezel et al., 2016; FAO, 2018; Lamine and Dawson, 2018; Frison and Clément, 2020). Successful examples of agroecological farms and farmer networks, particularly based in Latin America, have fueled interest in the study of how such farms and networks thrive despite the lack of formal policy support. Research into what hinders the spread of agroecological uptake and drives upscaling processes has flourished in recent years (Mier y Terán Giménez Cacho et al., 2018; Bergez et al., 2019; Magrini et al., 2019; Wezel et al., 2020). The lack of financial incentives or subsidies, absence of support for niche markets or sales mechanisms, and the dearth of funding for research and extension, as well as political-economic control of genetic, technological, and information resources are just some of the factors that hamper agroecological upscaling (Holt-Giménez, 2006; Duru et al., 2015; IPES-Food, 2016; Giraldo and Rosset, 2017; Holt-Giménez et al., 2021; Muñoz et al., 2021). While these structural issues are important and need addressing in their own way, there is also a need for more investigation into how agroecological practices are initiated and scaled up and out at the farm, community, and regional levels (Wezel et al., 2016; Mier y Terán Giménez Cacho et al., 2018; Nicholls and Altieri, 2018; Magrini et al., 2019; Dale, 2020). We describe this process as the amplification of agroecology. Amplification is critical for the upscaling of agroecological production and socio-political projects emphasizing farmer sovereignty and solidarity.

Amplification catalyzes agroecological knowledge and on-the-ground practices to thrive and spread, to involve or recruit more farming families, and to eventually lead to scaling out and territorialization. The focus of this study is on one type of amplification pathway or "amplifier" for agroecology: agroecological lighthouses (Nicholls and Altieri, 2018). Individual agroecological farms can acting as lighthouses become centers of learning and influence to amplify the uptake of agroecological principles and practices by nearby farmers and those from surrounding territories. Studies have shown that farmer lighthouses, such as demonstration farms and NGO-led operations, are effective in providing models of agroecological practices in action and in educating farmers and visitors (Warner, 2007; Laforge and Levkoe, 2018; Nicholls and Altieri, 2018; Ryschawy et al., 2019). Research has also revealed how *campesino a campesino* networks create opportunities for farmer-to-farmer learning and spread agroecological practices and principles, as farmer lighthouse leaders can demonstrate and share successful examples with others (Holt-Giménez, 2006; Holt-Giménez et al., 2010; Rosset et al., 2011).

Despite these success stories, rural and agricultural territories are contested spaces with historical, social, cultural, and economic contexts that can present challenges to the effectiveness of farmer lighthouses in catalyzing localized agrarian change. This research explores these amplification dynamics through two questions. First, what is the amplification potential of farmer lighthouses and how can we assess it using a farm-level set of evaluation indicators? Evaluative frameworks to assess agroecological practices at the farm-level have already been developed (Mottet et al., 2020; Nicholls et al., 2020). Equally important in determining the amplification potential of farmer lighthouses is the degree to which farmers are integrated with social networks, their ability to demonstrate leadership in the community, and their level of autonomy in relation to policy, markets and external inputs. An evaluative framework that incorporates all of these elements would provide a useful tool in investigating amplification dynamics. Second, how do farmer lighthouse leaders overcome or negotiate contestation to agroecological territorialization? We know that scaling processes are not linear and regimented, but are unfixed and dynamic, simultaneously contested and championed by various societal actors (Levidow et al., 2014; Rivera-Ferre, 2018; Giraldo and McCune, 2019; Muñoz et al., 2021). The process of establishing agroecological lighthouse farms, how farmers are able to create and maintain networks of knowledge sharing and influence, and how these efforts merge to re-territorialize rural farming communities and surrounding regions where conventional agriculture is dominant are all questions that require more inquiry. Research in this area is largely based on examples from Latin America, with only limited examples in Asia and the Global North (Castella and Kibler, 2015; Wezel et al., 2018; Anderson et al., 2019b; Carlisle et al., 2019; Ong and Liao, 2020). This research focuses on the amplification dynamics of territorialization processes and how they play out in the context of Japanese agriculture and rural society.

Rural Japan, like many Global North countries, is undergoing pronounced depopulation and farmer aging. The agricultural sector is experiencing both a de-agrarianization of family farming alongside a mixed process of re-agrarianization (Hisano et al., 2018). Conventional, highly specialized agriculture is being encouraged while at the same time interest in diverse forms of small-scale sustainable agriculture are growing. Japan has a history of organic farming movements and other forms of agroecological production that have developed and evolved over decades, and multiple generations of agroecological farmers are now interacting and territorializing rural space in unique ways, including clustering (Zollet and Maharjan, 2021).

In this paper, we developed a rubric of ten amplification indicators and used it to assess the amplification potential of lighthouse farms and farmers in the Japanese context. Through fieldwork and retracing the historical development of the organic movement in Japan, we find that Japanese farmer lighthouses purposefully create cooperative relationships in their local communities to minimize social friction, form inclusive knowledge networks, encourage diverse forms of resilient production, and take advantage of unique cultural contexts to enable clusters of support. This approach builds on the past experiences of successful agroecological lighthouse farmers and further develops the discussion on the dynamic and contrasting processes of agroecological territorialization and the ways in which diverse contexts shape agroecological upscaling.

LITERATURE REVIEW

Amplification and Territorialization Processes

Agroecological scaling processes have been a target of study for some time and have provided a rich vocabulary to describe the various ways agroecological practice and knowledge can spread (**Box 1**; Ferguson et al., 2019). In general, scaling up portrays the process of grassroots agroecological principles traveling to the level of public and private institutions and scaling out is the process by which more people (farmers, families, communities) in greater physical areas are aware of or practice agroecological principles (Rosset and Altieri, 2017; Mier y Terán Giménez Cacho et al., 2018). Amplification and territorialization capture scaling up and scaling out as interlinked processes, but target different scales of focus.

Amplification targets person-to-person interaction as amplifiers, such as lighthouses and traditional farming, and how agroecological knowledge and practices move through individual and community networks and enable the creation of supportive policies and markets (Nicholls and Altieri, 2018). The ways in which knowledge and local resources are utilized and practices are performed and reproduced by individuals and networks, and how these activities influence society and policy are of particular focus. Territorialization is an overhead view of a physical area or territory and describes how different symbolic and material characteristics come to dominate or contest a territory (Guzmán Luna et al., 2019). As Guzmán Luna et al. (2019, p. 765) state, "territorialization is never definite," which highlights the role of diverse actors, food systems, markets, values, and policies simultaneously contesting space (Maye et al., 2016; Berti, 2020). We argue that amplification and territorialization are complementary processes that integrate aspects of both scaling up and scaling out in a constructive way.

The integration of amplification and territorialization processes is consistent with the creation of "agroecological territories" (Wezel et al., 2016). Wezel et al. (2016, p. 140) define agroecological territories as territories "where (a) a transition toward sustainable agriculture based on agroecological practices exists, (b) biodiversity and resource conservation is taken into account, (c) territory-linked embedded food systems exist, and (d) stakeholders support the transition toward sustainable agricultural and food systems." We would add that these agroecological territories and the embedded knowledges, practices, and stakeholders therein are likely standing in opposition to the constellations of actors, practices, markets, and policies that compose contemporary food systems and industrial agriculture. This resonates with the importance given in agroecology to traditional farming systems and landscapes, which are often characterized by greater functional diversity and resilience compared to agrarian landscapes patterned by industrial or monoculture production (Altieri et al., 2015). Moreover, such landscapes can produce the goods and services humans need for their sustenance and well-being in a sustainable way (Plieninger et al., 2018). Agroecological territories therefore link individual farm-scale activities with the surrounding ecological and socio-cultural landscape and the local food system in order to amplify agroecology and further territorialize and re-territorialize in the face of pressures from contemporary food systems.

Two additional concepts are relevant to the discussion on amplification and territorialization: territorial resilience and territorial mediators (McCune et al., 2017; Guzmán Luna et al., 2019). As agroecological amplification and territorialization occurs, agroecological-territories develop resilience or "the collective capacity of the actors to continue to facilitate the development of territorial responses to external disturbances" (Gilly et al., 2014, p. 596, cited in Guzmán Luna et al., 2019). Guzmán Luna et al. (2019) identify six variables for territorial resilience: agrobiodiversity maintenance, food sovereignty, learning and innovation, resistance to depeasantization, and social, economic, and political aspects of territoriality. These variables are essential for successful agroecological amplification and territorialization. In addition, McCune et al. (2017, p. 354) center their attention on how social movements drive territorialization by creating politically, socially, and culturally significant elements, termed territorial mediators, that "facilitate the rooting of agroecological social processes in a given territory." Territorial mediators have pedagogical significance for individuals and might be particular "moments or activities experienced by learners, or certain people or mentors" that influence one's sense of political identity (McCune et al., 2017, p. 359). We see similarities between territorial mediators and agroecological amplifiers in the form of lighthouses and farmer leaders. In both instances, farmer-to-farmer learning and the presence of charismatic leadership can amplify agroecological knowledge and practices throughout a given territory. Territorial resilience and mediators provide unique lenses to analyze amplification dynamics as part of broader processes of agroecological territorialization.

Agroecological Lighthouses, Amplification Dynamics, and Territorialization

The focus of this paper is agroecological lighthouses and their ability to amplify the uptake of agroecological principles and practices by other farmers from surrounding territories. Agroecological lighthouses are diversified farms that serve as models on how to "design and manage farms based on agroecological principles" (Nicholls and Altieri, 2018, p. 7). Equally important are the farmers of lighthouse farms, who play a key role in promoting agroecological principles in the surrounding community and amongst farmers from other regions. For the purposes of this paper, the lighthouse farm and lighthouse farmer are inseparable, as the design and operation of a lighthouse farm is contingent upon the ability and orientation of the lighthouse farmer. A single lighthouse can provide an inviting and protective space for agroecological farming to develop, as well as influence farmers in nearby geographical areas to adopt or, at the least, be accepting of agroecological production. As an actual lighthouse radiates light against dark ocean nights, so too do agroecological lighthouses provide pathways alternative to the industrial agricultural model.

BOX 1 | Key words and their definitions relevant to agroecological scaling processes.

(De-)(Re-) agrarianisation: De-agrarianisation refers to the process through which the reproduction of strictly agrarian and land-based livelihoods (particularly small-scale and/or family farming) becomes increasingly difficult, due to changing social, material and biophysical conditions. Re-agrarianisation refers to the reversal of this process, with an increase of the agrarian-based economy and agrarian-related activities (Hebinck, 2018).

Amplification: the process through which agroecological practices are initiated and scaled up and out at the farm, community, and regional levels. Amplification refers specifically to processes occurring through social interaction (e.g., the expansion of agroecological knowledge and practices through individual and community networks). It also concerns the way in which this expansion enables the creation of policies and markets supportive of agroecology.

Cluster: the concept of cluster emerged in the field of economics, where a cluster is defined as a "geographically proximate group of interconnected companies and institutions in a particular field, linked by commonalities and complementarities" (Porter, 1998, p. 199). A cluster is characterized both by spatial proximity and by knowledge- or resource-sharing, collaboration and competition.

Agroecological lighthouse: an individual agroecological farm representing a model of agroecological practices in action and acting as a center of learning and influence to amplify the uptake of agroecological principles and practices.

Scaling out (Outscaling): the horizontal process through which the awareness and/or practice of agroecological principles extends to more people over a wider geographical area.

Scaling up (Upscaling): the vertical process of grassroots agroecological principles traveling from the grassroots to the institutional (public and private) level. It is worth noting that the "scaling" of agroecology is often meant as a combination of scaling up and out processes (Mier y Terán Giménez Cacho et al., 2018).

Territorialization: similar to scaling and amplification in that it refers to the process leading increasing numbers of people over increasingly vast territories to practice agroecology and/or engage in the consumption of agroecologically produced food, but with a specific focus on the physical area or territory where the process occurs. Also describes how different symbolic and material characteristics come to dominate or contest a territory.

Agroecological lighthouses and lighthouse farmers promote agroecological principles through networking, leadership, and teaching, and through the demonstration and dissemination of production and managerial practices at the farm level. There is an expanding literature on transformative learning (Anderson et al., 2019b), farmer's knowledge networks (Laforge and Levkoe, 2018), peasant-to-peasant processes of horizontal learning (Val et al., 2019), "wisdom dialogues" (*dialogo de saberes)* (Anderson et al., 2019b), and communities of practice (Dolinska and d'Aquino, 2016) that detail the different ways agroecological knowledge is passed from farmer-to-farmer. We argue that agroecological lighthouses and lighthouse farmers are critical links in farmer-to-farmer chains as well as amplifiers in disseminating agroecological knowledge and practices within and beyond territories. Beyond dissemination of knowledge and practices, agroecological lighthouses and lighthouse farmers possess and create social capital in rural communities and can utilize this capital to create relationships with different local and extra local actors. Lighthouse farmers are effective leaders and use different types of social capital (such as bonding, bridging, and linking) to build trust and leverage cooperation, connect disparate networks to engage in collaboration, and create links between sections of society in which formal or institutionalized power play a role (Cofré-Bravo et al., 2019).

The importance of social capital for lighthouses' ability to amplify agroecology places emphasis on understanding what social and cultural factors might be influential in amplification and territorialization processes. The presence of social institutions or organizations that are part of a larger social movement is consistently seen as a powerful force for agroecological upscaling. For example, Mier y Terán Giménez Cacho et al. (2018) identify the presence of social organization and social movements as a critical factor for upscaling agroecology across five cases based around the world, including the *Campesino a Campesino* movement in Latin America. Nicholls and Altieri (2018) profile four different NPO-led lighthouses in Latin and South America that each receive thousands of visitors annually. Zero Budget Natural Farming in India is also an example of a successful agroecological upscaling due to "a social movement dynamic...charismatic and local leadership… (and the) generation of a spirit of volunteerism among members (Khadse et al., 2018, p. 192). Magrini et al. (2019) point to the importance of shared values between farmers and consumers as well as co-determining rules and protocols that can support niche markets and institutionalization of agroecological principles in the community. Finally, Dale (2020, p. 3) argues that building social and political alliances is critical in the advancing of "counter-hegemonic agroecology." Beyond social movements and organizations, charismatic leadership, shared values among actors, and the formation of alliances are also decisive factors in amplifying agroecology via lighthouses.

Taking these examples from the literature into account, there are still many gaps in understanding about agroecological lighthouses and the ways in which amplification dynamics play out in rural communities, as well as how lighthouse amplification ultimately impacts territorialization processes. Little is known on how agroecological lighthouse farms and farmers become established nexus points of learning and how lighthouses eventually provide "space" for agroecological territorialization to be successful. Agroecological territories are created over a period of time—What role do lighthouses play in recruiting new settler farmers or in creating enclaves of agroecological farms within the dominant, contemporary food system. How do these pockets form, grow, stagnate, then kick off again? Is there evidence of lighthouse pioneers from one territory moving elsewhere to establish another locus of influence? In one of the few studies that focuses on agroecological scaling in Japan, Zollet and Maharjan (2021) examined the phenomenon of clustering of new entry sustainable farmers. They define a cluster as being

both a "spatial co-location" and having active elements such as knowledge mobilization, collaboration and competition that allow clusters to develop and evolve over time (Beckie et al., 2012, as cited in Zollet and Maharjan, 2021 p. 4). Important factors leading to the formation of clusters included local acceptance of the style of small-scale farming for self-sufficiency and the presence of pioneer farmer leaders as "attractors" (Zollet and Maharjan, 2021, p. 16). This paper aims to build on this work and further explore the relationship between lighthouse formation and clustering.

In addition, territorialization is articulated in diverse ways based on socio-cultural and environmental contexts. The literature on agroecological territorialization is largely based in Latin America and there is a need to examine how the process unfolds in other locations. The forms of territorial resilience (Guzmán Luna et al., 2019) and territorial mediators (McCune et al., 2017) that can aid or diminish amplification processes for lighthouses may be different in different contexts, requiring further elaboration. For example, Peano et al. (2020) share the example of school gardens as demonstration agroecological farms in urban African cities as important places to share food culture, environmental conservation, and reimagine the urban food economy. We research how lighthouse farms help to create agroecological territories in the context of Japan.

Strong and vocal social movements and social organizations have also been key in the upscaling of agroecology in Latin America and places in Asia, such as India (Khadse et al., 2018). How essential are social movements and social organizations for lighthouse farms and farmers in amplification and territorialization processes? In Japan, there is a history of social movements associated with organic farming, but it can be argued that these have not been as vocal or influential as those seen in the *La Via Campesina* movement in Latin America (Hatano, 2008; Kondoh, 2014). As the next section describes, the Japanese organic farming movement was started a generation ago and continues today. At the same time, there is an increase in new entrant farmers wanting to practice sustainable forms of agriculture who are less motivated to become part of an existing social movement, than to escape the drudgery of modern society (McGreevy, 2012; McGreevy et al., 2019). What role does the previous generation of lighthouse farms and farmers, established as part of the organic movement, play in amplifying and territorializing agroecology in Japan?

History of Amplification and Territorialization: Interfacing Environmental Movements, Lighthouse Farmers, and Local Community

Before the 1970s, several citizen movements were organized to speak out against numerous cases of widespread environmental pollution resultant of Japan's post-war industrialization, but the connection between chemical pollution and food production wasn't made until the establishment of the Japan Organic Agricultural Association (JOAA) (Tabeta and Masugata, 1981; Ichihara Fomsgaard, 2014). The JOAA is a nationwide network, established mainly by medical scientists, agronomists, and people involved in agricultural and consumer cooperatives. At first, the association was more of a place for researchers and information exchange, but as agricultural pollution and pesticide contamination became social issues, it gradually absorbed producers involved in non-chemical farming and consumers seeking safe food, and developed into a driving force for alternative agriculture and the organic farming movement in Japan (Ichihara Fomsgaard, 2014; Kondoh, 2014).

We should note that the term agroecology has only recently been introduced into Japan, but agroecological principles are largely embodied in the organic agriculture and natural farming movements and captured by the JOAA in its Prospectus document published at its establishment in 1971. In that document, the importance of maintaining the health of farmers, consumers, and the natural environment is emphasized, as is the need for farmers to improve and develop alternative methods from those in conventional agriculture (JOAA, 1971). The organic farming movement also advocated for self-reliant and self-sufficient localities with farms being ecologically and functionally complex and integrated into the local natural environment. This can be connected to the preservation and revitalization of Japan's traditional, pre-modernization agricultural landscape, called *satoyama* (Takeuchi et al., 2003). *Satoyama* is a production landscape shaped through the interactions between people and nature and characterized by high levels of biodiversity, resilience and self-sufficiency (Takeuchi et al., 2016). Furthermore, agriculture is seen as a civic partnership, essential to the health and survival of society, and that these elements should be prioritized over economic rationalization (JOAA, 1971). *Teikei*, solidarity-based partnerships between farmers and consumers where food is purchased directly (much like community-supported agriculture or CSA), are the embodiment of the organic movement and are run democratically under the aim of mutual assistance (Kondoh, 2014).

As farmers began to realize the harm caused by high-input agriculture, organic farming spread, and a few examples of successful territorialization took hold, including those led by young farmers groups (Matsumura and Aoki, 1991), agricultural cooperatives (Takeyoshi et al., 1988), and local governments (Kohmoto, 2005; Masugata, 2008), as well as those led by lighthouse farmers. Two lighthouse cases in particular stand out: Ogawa Town in Saitama Prefecture and Kisuki Town in Shimane Prefecture.

Yoshinori Kaneko started Shimosato Farm, an organic farm producing vegetables, fruit, rice, wheat, and some animal products, in 1971 in Ogawa Town, Saitama Prefecture. He questioned the industrialization and commercialization of conventional agriculture and was eager to find alternatives. A few years after establishing his farm, he began to form direct marketing relationships with consumers (*teikei*) and attract and accept trainees. Inspired by farm schools in Europe, Kaneko created farm tours and farm stay options for trainees to learn through first-hand experience (Shimoguchi et al., 2015). Kaneko's farm averages about 10 trainees per year and approximately half of them continue on as independent farmers (Shimoguchi et al., 2015). Throughout the 1980s, trainees began to settle and

farm in Ogawa Town. In addition, cooperation within the region developed between organic farms and local food manufacturers, as agricultural produce was processed into various organic products, for example tofu. These economic relationships became so strong that in the 2000s, some local conventional farmers converted to organic farming in order to sell their products through the sales channels developed by Kaneko (Oguchi, 2012). As a result of Kaneko's pioneering leadership in developing independent sales channels, cooperation with local industries, and training successors, Ogawa Town is now well-known throughout Japan as an organic farming town.

Around 1960, dairy farmers in Kisuki Town, Shimane Prefecture, began to consider chemical fertilizers and agricultural chemicals as a potential hazard when their cows displayed poor health. Chukichi Sato confronted this issue and worked with his fellow farmers to introduce wild grass-based feed and regulate the use of pesticides and chemical fertilizers on grass. In 1972, the Kisuki Organic Farming Study Group was established to promote organic farming in the region. Sato was also the president of a company called Kisuki Dairy, which was jointly established by a number of dairy family farmers in the town. The company aimed at small-scale, agroecological dairy farming as a means of self-sufficiency in mountainous regions. From the perspective of quality rather than quantity, the company has been producing pasture-raised milk and natural cheese since the 1980s, and has become known nationwide as a manufacturer of high-quality dairy products. Kisuki Dairy employees have access to social insurance and various welfare programs like any company. In Kisuki Town, the activities of two groups, the Organic Farming Study Group and Kisuki Dairy, interacted with each other and many initiatives were undertaken. In the process, the town government began to actively promote organic farming, and cooperation with conventional farmers expanded in the 1990s. Finally, in 1999, the town created a multi-faceted farm incorporating various small-scale food processors and businesses around the concept of slow food. The farm also accepts new organic farming trainees. At the same time, organic food manufacturers such as wineries, tofu shops, and bakeries have gathered together and formed an agroecological and high-quality food cluster (Masugata, 2008; Iguchi, 2013).

One notable aspect we can derive from these examples of first-generation lighthouse farmers is their ability to build economic and social relationships with the local community. In Japan, after World War II, the Allied government redistributed farmland and many small-scale autonomous farmers were born. Agricultural cooperatives were institutionalized as farmers' organizations to bring these new farmers together and democratically promote agricultural productivity, efficiency and improve the status of farmers. Japan Agricultural Cooperatives (Nokyo or JA) provided a variety of services, such as joint purchase of materials, joint shipment of agricultural products, instruction in farming techniques, finance, and insurance in case of crop failure. The JA became, and in many places still is, a core institution within rural communities. In the 1960s, chemical pesticides and fertilizers were promoted to improve productivity and contribute to the modernization of agriculture. Overall, the JA actively promoted the use of high-input conventional farming methods. Technical guidance, material sales, and purchase of agricultural products were provided as one-stop services. In this social context, practicing agroecological farming methods meant taking a different path from the farmer groups that formed the local community. This not only created the risk of social conflicts, but also meant that they would have to purchase materials, learn techniques, and market their products on their own. The Japan Organic Agriculture Association and teaching centers, such as the Natural Farming Research Center in Nagano Prefecture, were able to provide support for technical guidance and sales channel development. However, building relationships with local communities was a serious challenge for all farmers, especially in the beginning stages.

In both the Ogawa and Kisuki cases, the farmers tried to integrate into the local community, cooperated where they could, and continued to work agroecologically at their own farm. While small-scale conventional farming was becoming harder to sustain nationwide, in both towns, it became clear that successful organic farming represented a business advantage. As a result, the conventional farmers in the area came to recognize the economic rationale for agroecological farming. The two towns have now formed viable value chains with agroecological farming at the core, leading to the revitalization of the region.

Policy Environment Lacking Support

Supportive policies are often cited as a way to bolster agroecological upscaling through the establishment of financial incentives or viable markets. However, organic agriculture in Japan has received limited policy support from both the Ministry of Agriculture, Forests, and Fisheries (MAFF) and JA. When the JOAA was formed in 1971, many agronomists as well as the government and JA criticized the organic farming movement. They regarded the organic farming movement as regressive to the modernization of agriculture, and no support was offered through policy or research (Adachi, 1991).

In the 1980s, more and more businesses began to specialize in organic produce, and co-ops began to expand their direct marketing operations. There was also a trend for high-end supermarkets and department stores to carry organic produce as a featured product. MAFF finally began to take up organic farming as a policy topic in the late 1980s, mainly in view of the high value-added nature of organic agricultural products. The causes of this were a reevaluation of organic farming, influenced by the agricultural policy shift in Europe and the U.S. to focus on environmentally friendly agriculture and a rise in domestic demand for healthy and gourmet food (Masugata, 1994). At the same time, there was an increase in the distribution of agricultural products claiming to be organic and the Fair-Trade Commission pointed out the confusion in labeling. The JAS organic certification scheme was established in 1999, but the costs and administrative hurdles associated with the process limited its use to large-volume producers, dissuading the majority of small-volume organic farmers from using it (Hatano, 2008). JOAA has been consistently critical of such certification regulation by MAFF and its reluctance to place *teikei* as the core market mechanism for organic agriculture. Although attention to organic farming and environmental conservation agriculture

has increased, support by JA cooperatives has also remained weak. Many JA cooperatives are engaged in joint shipments to wholesale markets and, by the JA's logic, the fact that organic agricultural products vary widely in appearance and quality make them unsuitable for this system (Oba and Otahara, 1999).

Nearly 40 years after the establishment of the JOAA, a law on organic agriculture was finally enacted in 2006: The Act on the Promotion of Organic Agriculture. JOAA and the Japan Society of Organic Agriculture actively participated in the policy development and drafting process. However, although MAFF actively promoted organic farming immediately after the enactment of the law, as time went by, the attitude that organic farming should be regarded only as a high value-added production again became the mainstream, and the law has largely been criticized due to lack of enforcement (Nakajima, 2017; Taniguchi, 2017). For example, an initiative to create organic farming model towns (*Yukinogyo Moderu Taun*) was launched in 2009, and a few municipalities were able to take advantage of the system (including Ogawa Town), but funding was cut shortly after the Cabinet deemed the impact to be too limited (Honjo, 2017). In 2017, MAFF estimated that there were 23,000 hectares devoted to organic farming in Japan, making up only 0.5% of total agricultural land (Ministry of Agriculture, Forestry, and Fisheries (MAFF), 2019).

Currently, MAFF is pursuing an agricultural policy that would see Japanese farmers increase exports of high-valued niche products through high-tech, monoculture production. Previously barred from the agricultural sector, non-farm corporations have been allowed in, signaling a shift to a corporate farming model for agriculture (Jentzsch, 2017; Hisano et al., 2018). Pressured to take action to decarbonize all sectors of its economy, the Japanese government has agreed to implement a new "Green Food System Strategy" by expanding organic agriculture to 25% of total agricultural land area, as well as significantly reduce chemical use (Ministry of Agriculture, Forestry, and Fisheries (MAFF), 2021). Looking closely at the plan, however, reveals that it is driven by high-tech infrastructure, capital-intensive investments in AI and robotics, and GMO crops, which are in opposition to agroecological principles by creating dependencies on external resources, marginalize local and traditional knowledge, decrease diversity and ecological synergies, and, on the whole, promote further corporatization of the sector.

METHODS

We set out to examine the ways agroecology was being amplified by nine lighthouse farmers in west-central Japan in two ways: (1) Through on-farm assessments and in-person interviews using a set of ten amplification indicators during the summer of 2019 and (2) by performing follow-up online interviews in January 2021 to validate the assessment and deepen our understanding of amplification and territorialization processes experienced by the farmers.

The amplification indicators used in this study are listed in **Table 1** and were selected because of both their presence in the literature on agroecological upscaling and ability to capture particular aspects of successful lighthouse farms. The indicators closely mirror key drivers for agroecological upscaling put forth by Mier y Terán Giménez Cacho et al. (2018) but diverge to emphasize individual farmer and on-farm dimensions.

The indicators were arranged into an assessment rubric that provides three levels of detail for each indicator to aid in the assessment, shown in **Table 2**. For example, indicator C. Participation in networks for sharing experiences and knowledge shows for the lowest score (1) "Don't engage in knowledge exchange"; for the middle score (2.5) "Occasionally participates in knowledge exchange, sharing practices, technical information"; and for the high score (5) "Actively participates in farmer to farmer exchanges, open to visitors, engages in training (own farm or other places to teach), is a promoter." Using the rubric, each indicator can be scored on a scale from 1 (low) to 5 (high) depending on how well the criteria are adhered to by the farmer.

The rubric was used as part of a pilot survey on nine farms in the summer of 2019. Representatives from organic farming networks were contacted via social media or professional networks and asked to identify exemplary organic farmers in the area who were highly respected by their peers as farmer leaders. Five farmers were identified in Kyoto, three in Hiroshima, and one in Hyogo Prefectures. All farms self-identified as either organic or following natural farming precepts, while two were certified as organic. Following the cultural standard of farm (household) representation, all farm representatives we interviewed were male, of ages ranging between 35 and 60, with a minimum of 10 years of farming experience (some were more established with more than 30 years of experience). All except farmers 4 and 6 are first generation farmers, meaning they had no familial heritage in farming and initiated their farm on their own. Such farmers predominantly rented their land (average farm size 1.5 hectares). Farmers 4 and 6 are farm successors with full ownership of their land. All farmers were self-employed, specializing in vegetable production for mostly urban consumers, and the majority of their total income came from their farming activities. A summary of agroecological farming practices by the farmers can be found in **Appendix 1**.

Farm visits were conducted in the summer of 2019 and the assessment rubric was used to score each indicator. During the farm visits, farmers were interviewed informally, with the rubric as a guide. Each farm visit included a tour of the farm and the whole engagement lasted ∼2 h each. Farms were scored by four researchers and scores were discussed together after the visit to arrive at the final assessment.

After the survey using the rubric, scores were analyzed and the four farmers with the highest scores were selected as the most successful lighthouse cases and asked for a follow-up interview. Due to COVID-19 precautions, these interviews were conducted online. The interviews lasted for 1 to 2 h and aimed at validating the effectiveness of the assessment tool from the farmers' perspective and to deepen our understanding of processes and dynamics of agroecological amplification and territorialization in connection to lighthouse farmers. A set of open-ended interview questions (**Appendix 1**) was used to facilitate the conversation and covered topics such as the farmer's relation to their surrounding community, the process of initiating

TABLE 1 | Ten indicators to assess the amplification potential of selected farms and farmers.

Indicators	Description	Identified in the literature
1. Motivations to search for alternatives	What are the farmer's motivations? Are they primarily motivated by economic profit (associated with a low score), or is the health of the farm's agroecosystem and surrounding environment, as well as the wellbeing of the rural community and society at large a concern?	Mier y Terán Giménez Cacho et al., 2018; Nicholls and Altieri, 2018
2. Level of social organization	To what degree is the farmer an active member of farmer organizations at either a local, regional, or national level? Are they isolated or only concerned with their own practice?	McCune et al., 2017; Khadse et al., 2018; Mier y Terán Giménez Cacho et al., 2018; Dale, 2020
3. Participation in networks for sharing experience and knowledge	To what degree is the farmer engaged in farmer-to-farmer knowledge exchange, hosting students, interns or trainees, otherwise open to visitors who want to learn?	Laforge and Levkoe, 2018; Anderson et al., 2019a; Val et al., 2019
4. Use of effective, efficient and accessible traditional and modern agroecological practice	To what degree is the farmer respectful and/or incorporate diverse forms of knowledge (traditional, local) and practice relevant to their own agroecosystem? Is emphasis placed mainly on rationalizing agriculture and external inputs?	Altieri and Nicholls, 2012; Nicholls and Altieri, 2018; Mestmacher and Braun, 2020
5. Autonomy: Dependency on external inputs, markets and policies	Does the farmer have control over their terms of engagement in the marketplace, to determine prices and their methods of farming?	Nicholls and Altieri, 2018; Anderson et al., 2019a
6. Leadership (mobilizing discourse, encourages and influences community by example, generates enthusiasm in community)	Does the farmer play a role in mobilizing discourse, encouraging, and influencing different communities (both agricultural and local) by example?	Khadse et al., 2018; Cofré-Bravo et al., 2019; Zollet and Maharjan, 2021
7. External allies (working linkages with Universities, NGOs, extension agents, etc)	To what degree does the farmer work in collaboration with external allies such as universities, non-profit organizations, or extension agents? Are they networked with relevant potential partners?	Wezel et al., 2018; Anderson et al., 2019a; Cofré-Bravo et al., 2019
8. Benefits from local/national conducive policies	Does the farmer take advantage of relevant policies to benefit their practice or farm?	Mier y Terán Giménez Cacho et al., 2018; Nicholls and Altieri, 2018; Nicol, 2020
9. Favorable markets (participates in alternative food networks, direct links with consumers, etc.)	Does the farmer participate in alternative food networks with direct links to consumers? Do they form economic relationships based on solidarity, rather than depend on mainstream markets over which they have limited control?	Mier y Terán Giménez Cacho et al., 2018, Magrini et al., 2019, Berti, 2020; Nicol, 2020
10. Focuses on principles and processes rather than technologies and "magic bullets"	Is the farmer knowledgeable of and practicing agroecological principles? Or are they attached to recipes, "magic bullet" solutions, or the use of specific techniques or ingredients that do not take into account the uniqueness of each farm?	Nicholls and Altieri, 2018; Wezel et al., 2020

their farms, and their own conceptualizations of lighthouse farmers. The interviews were then transcribed and answers were compiled according to the ten indicators to assess the amplification potential of selected farms and farmers.

RESULTS

In the following section, we share results on each of the ten indicators from the survey and content from follow-up interviews of farmers to highlight significant elements of farmer lighthouses in the Japanese context. We then use the same data to describe the establishment process of agroecological lighthouse farms, how farmers were able to create and maintain networks of knowledge sharing and influence, and how these efforts merged to territorialize rural farming communities and surrounding regions. All farmers surveyed in the study will be referred to by a number.

Amplification Potential Assessment

Motivation to Search for Alternatives

This was the highest scored indicator for all farmers surveyed with an average score of 3.83 out of 5. This can be attributed to the fact that organic agriculture has historically been rooted in a critique of modern industrial agriculture and is generally understood as being based on coexistence with the natural environment and way of living over a set of techniques (Nakajima et al., 2010). Farmer 7 emphasized the importance he places on recycling locally available resources to coexist within the surrounding ecosystem distinguishing himself from organic farmers who merely purchase off-farm organic inputs. Similarly, Farmer 5 described his agricultural practice as abiding by a traditional "*satoyama*-style," reflecting the conscious embedding of their practice in the landscape, through, for example, active use of forest leaf litter and limiting his use of livestock manure, which he felt might have heavy metals and other toxins. Farmer 9 also relies on leaf litter collected from nearby forest as

TABLE 2 | Set of ten indicators used as an agroecology amplification assessment rubric.

Indicator	Scoring criteria		
	Value 1 (Low)	**Value 2.5 (Medium)**	**Value 5 (High)**
1. Motivations to search for alternatives	Just economically/profit motivated	Both economic and environmental. Maybe focused on their own farm	Deep reasons, human/social, autonomy, well-being. Concern extended to the community
2. Level of social organization	Individual, isolated, work alone, don't connect with the community	Well-connected in community, but not connected with outside. Well-connected outside of the community, but not locally	Well-connected with the local community and outside of the community (regional/national/international)
3. Participation in networks for sharing experience and knowledge	Don't engage in knowledge exchange	Occasionally participates in knowledge exchange, sharing practices, technical information	Actively participates in farmer to farmer exchanges, open to visitors, engages in training (own farm or other places to teach); is a promoter
4. Use of effective, efficient and accessible traditional and modern agroecological practice	IPM, ignores traditional knowledge (i.e., old knowledge is a practice of ignorance); rationalization of external inputs; combine organic and conventional	Input-substitution	Highly advanced agroecological farming practices, blending different forms of knowledge/techniques (traditional/scientific/modern), farm redesign
5. Autonomy: Dependency on external inputs, markets and policies	Debt, high dependency on external schemes/subsidies, depend on intermediaries (middlemen), don't set their own price	Sometimes there is control over these factors; external inputs purchasing happens occasionally, sometimes deal with middlemen	Control over the terms of engagement with the market (); determine prices themselves, no use of external inputs, not dependent upon subsidies/extension
6. Leadership (mobilizing discourse, encourages and influences community by example, generates enthusiasm in community)	Not a leader in any way. Follower, not inclusive	Has a discourse, can mobilize enthusiasm, but not followed by practice or vice versa; limited impact on neighbors/local community	Motivate and influence communities, charismatic leaders, has disciples (guru-student); has a philosophy AND technique (discourse matched with practice); make special effort to be inclusive (youth, women, local authorities); impacts policy making processes, impacts local farmers/neighbors
7. External allies (working linkages with Universities, NGOs, extension agents, etc)	No allies, no relationship with groups who might be allies Not open to working with scientists, other experts Actively dismissing science	Limited allies, connectivity with external allies, not the best allies Open to science collaboration, but not active in the research co-design (i.e., "Just tell me the results")	Close ties with universities, NGOs, extension Relationships have palpable outcomes/outputs that solve problems/enhance practices etc Open to participatory science collaboration (Co-creation processes visible)
8. Benefits from local/national conducive policies	Don't take advantage of policies that they could use; completely ignorant of policy options that might help; actively against policy interventions; only act if there is a policy option	Sometimes take advantage of policy, but don't fully implement the practice; Just in it for the monetary reasons	Strategically, take advantage of policies; results are obvious
9. Favorable markets (participates in alternative food networks, direct links with consumers, etc)	Depends on mainstream markets solely; market determines their sales circuits	Varied, one products in mainstream markets, another in an alternative (i.e., coffee farmers, cash crop farmers)	Actively involved in local, alternative markets (by-passing the mainstream markets/options); strong solidarity relationships with consumers
10. Focuses on principles and processes rather than technologies and "magic bullets"	Dogmatically attached to recipes and magic bullets; secret ingredients	Mixed, apply certain principles Open to other options, but some reliance on magic bullets Limited understanding of agroecological processes Enacting practices without understanding the underlying effects	Deeply understands agroecology, skeptical of claims of magic bullets; Don't work with recipes; flexibility in their approach because they understand principles/processes

Indicators were assessed and assigned a value between 1 and 5 according to the criteria described for each indicator (1 corresponding to poorest performance, 2.5 a medium value, and 5 indicating high performance).

organic amendments in his soils, as was the practice before the introduction of chemical fertilizers. In general, each farmer lighthouse saw their farming practice as being more than a process of growing commodity crops but, as Farmer 7 put it, a "way of thinking" about how to better interact with the larger environment.

Level of Social Organization

This indicator had the second lowest overall score on average (2.81). Those who scored high for this assessment were all active members of farmer study groups, both in their own communities as well as across multiple communities. Several were in study groups that had taken advantage of a government supported funding scheme to expand eco-friendly agricultural production in Japan (Farmers 3, 5, and 10). If organic farmer colleagues were nearby, they actively communicated on what others were growing, what kind of fertilizers they were using, and coordinated when necessary (Farmer 7). Also connected to indicator 1, all of the farmer lighthouses emphasized the importance of interacting with local conventional farmers. Many conventional farmers in the community produce vegetables for self-consumption and have significant place-based and traditional knowledge that can be accessed if cultural norms (deference for the elderly, etc.) are navigated effectively (McGreevy, 2012). Both new farmers originally from outside the community as well as local farmers demonstrate preferences for certain kinds of knowledge that can create misunderstanding and lack of knowledge exchange for the less socially adept (McGreevy, 2012). Farmer lighthouses were also affiliated with regional organic agricultural associations (Farmer 3 and 5) and actively participated in online seminars to learn about the latest technologies and discourses around organic agriculture. Despite COVID-19 induced restrictions, social ties have been maintained and, in some cases, strengthened due to the normalization of online exchanges and seminars.

Participation in Networks for Sharing Experience and Knowledge

Farmers with overall high scores had either initiated or played a key role in farmer-to-farmer study groups. Farmer 9 organized weekly study groups among local hobby farmers or gardeners who tend to be more open to organic techniques. Others organized study groups for any and all farmers in their local communities that aimed at expanding "ecologically friendly" practices.[1] By casting the net widely, rather than explicitly making it exclusively an organic group, Farmer 7 intended to strengthen production capacity and improve the community's environmentally-friendly image. He clarified, however, that it was possible to do that in his community because there were fewer full-time conventional vegetable farmers, who he suspected would not be as open to alternative methods of production. All farmer lighthouses had one to two trainees who stayed and learned under them for at least 1 year and all attracted trainees to their farms without active recruiting. Trainees often settled and started their own farms in communities nearby where the lighthouses were located.

Use of Effective, Efficient, and Accessible Traditional and Modern Agroecological Practice

The overall score for this indicator was slightly above average among surveyed farmers (3.11). Both farm visit observations of farming practices and interviews contributed to the score. All of the lighthouse farmers were very open to different forms of knowledge and methods of agriculture, and were very active in trying to incorporate knowledge from their neighbors, as well as maintaining active exchange with relevant research institutions and organizations that hold online seminars on agricultural techniques, as described in the description for indicator 2.

Dependency on External Inputs, Markets, and Policies

All farmers cited that they had control over how they engaged agricultural markets due to the fact they were all utilizing box schemes or B2B direct consumer sales channels where they can determine their own price. Farmer 9, for example, sells directly to his customers and has full control over the price at which he sells. Dependency on external inputs, however, was evident as many were dependent on plastic mulch, manure or organic amendments procured from off-farms, which may explain the relatively low average score of 2.72.

Leadership

Leaders are often described as being charismatic and many people would come to learn their techniques and philosophy. Effective leaders are inclusive, opening up their farm to anybody who comes independent of their age, gender, nationality, or social position and create new communities of exchange and interaction. In such a way, they are often able to impact policy making processes. To this point, all of the lighthouse farmers receive many visitors on their farm, ranging from consumers, vendors, middlemen, students, as well as local politicians. They try to value diverse perspectives and people from all walks of life, and as a result, there are constant requests for people who want to visit and people who want to come and train under them. According to Farmer 9, one way to maintain their social and political influence in their communities was to obtain organic certification. Due to strong, trusting relationships established with his customers, he does not feel like he needs a government issued certification to sell his products, however, he maintains the certification in order to maintain legitimacy when talking with government officials. This way, he can better voice his opinions when discussing policies such as incorporating locally grown organic produce in local school lunches. All of the lighthouse farmers helped establish and were leaders of their respective organic agriculture research groups.

External Allies

According to the assessment survey, this was the factor that most farmers seemed to struggle with the most, reflected in the lowest average score of 2.17. Of the nine farmers surveyed, most had regular interactions with other farmers, but collaborative

[1]In Japan, "eco-farmers" are defined as farmers who have successfully halved their synthetic input use.

partnerships with researchers or other specialists were limited. The four farmers who scored the highest and were interviewed, however, were extremely active and engaged regularly with researchers and extension agents. All of the farmer lighthouses hosted regular study groups. Farmer 5, for example, presents at academic conferences, maintains close relationships with local universities, hosts student visitors, and gives talks at local junior and senior high schools. Farmer 3 was an active member of JOAA and regularly attended IFOAM and URGENCI meetings as a delegate.

Benefit From Local/National Conducive Policies

While available subsidies to support organic agriculture have increased, they can also be considered a hassle, taking away valuable time that could be spent doing other things. Farmer 3 described how many Japanese organic farmers tend to also be anti-government, leading to an aversion to receiving any form of support from the government. While this may be associated with the older generation, it is still a noticeable factor for many farmers seeking a more autonomous lifestyle, away from the mainstream. For these reasons, the degree to which the surveyed farmers took advantage of available policy support varied greatly (with an average score at 3.00). Regardless, all the lighthouse farmers were very open to working with the government, and took advantage of the generous government subsidies available to new entry farmers, which many would struggle without (McGreevy et al., 2019). For example, when Farmer 9 was looking for farmland to initiate his agricultural career, he took advantage of information centers and the agricultural land bank scheme managed by the government to gain access to affordable land to rent. He chose to take advantage of this government mediated system, rather than purchasing his own, because it provides 10 year contracts to farmland, offering sufficient stability while saving on expenses. Farmer 5 applied for subsidies together with his own trainees who had set up their own organic farms nearby. Lighthouse farmers were all very open to collaborating with other farmers to obtain support from the government, as well as actively engaging with policy makers.

Favorable Markets

All lighthouse farmers had a strong network of customers to whom they could sell on their own terms, reflected in the second highest score of the ten indicators (3.6). As an organic farmer who cannot rely on conventional market mechanisms, establishing a reliable consumer base is a necessity. Those located closer to cities tended to have an easier time selling their produce. Farmer 9 who lives in northern Kyoto described their isolation as the largest limitation for those who become organic farmers in his region (which is located 2 to 3 h from the nearest urban center). To solve this challenge, he recently established a company as part of his farm to enable him to hire aspiring farmers in the community, as well as create a food processing center and a weekend cafe to make efficient use of and add value to produce that they cannot sell fresh.

Focus on Principles and Processes Rather Than Technologies and "Magic Bullets"

This indicator is closely reflective of the agroecology farm assessment tool conceived by Nicholls et al. (2020), which centered on the practices of each farmer based on agroecological principles including the recycling of nutrients and energy, enhancing soil organic matter and soil biological activity, diversifying plant species and genetic resources over time and space, integrating crops and livestock, and optimizing interactions of farm components. Most of the organic farmers scored relatively high on this indicator, as the development of organic agriculture in Japan, as previously described, is founded on a concern for ecologically sustainable farming methods based on the recycling of local resources, similar to the same set of agroecological principles. As organic produce is becoming more mainstream, however, there is concern around extensive reliance on technologies in the form of plastic mulch or minerally enhanced fertilizers. One farmer who scored low in this category was dogmatic in his focus on natural farming methods, and did not recycle or add any form of nutrients to his soil. In contrast, the farmer who scored the highest during this assessment used live mulch, instead of plastic mulch, to optimize biological interactions within his farm.

A compilation of amplification assessment scores and their averages is displayed in **Figure 1**.

Amplification and Territorialization Processes

The four farmers who scored highest in the assessment were interviewed to provide further detail and experience regarding amplification and territorialization processes in their rural communities.

Establishing Farms and Knowledge Networks

Each of the farmers had a unique story of how they established their farms and knowledge networks. Farmer 7 started farming as a part of his graduate studies, because of his collaboration with his advisor, did not choose where he started to farm. He relied on members in the community who were graduates of his university to get himself established in the community. Farmer 5 also decided to become a farmer as a university student. Once he decided, he visited around 100 farms to gain a deeper perspective on the state of the agricultural sector. Of those he visited, half were in the prefecture he ultimately chose to settle in, a quarter were suggested by those he visited, and the final quarter were conventional farmers he visited to understand what not to do. He chose to settle in a place with optimal climatic factors as well as the presence of traditional farmers in the community from whom he could actively learn. Farmer 3 started farming because he was interested in farming as part of a cooperative. He purposefully chose to settle in a rural community in which a group of thirty producers worked collectively to sell to an established consumer group of around 1,500 members. Joining this local farmer network proved to be a decisive factor in establishing his farm. Even though this cooperative has since decreased to only two producers and about 200 consumer members (primarily due to producer aging and changing consumer demographics), he

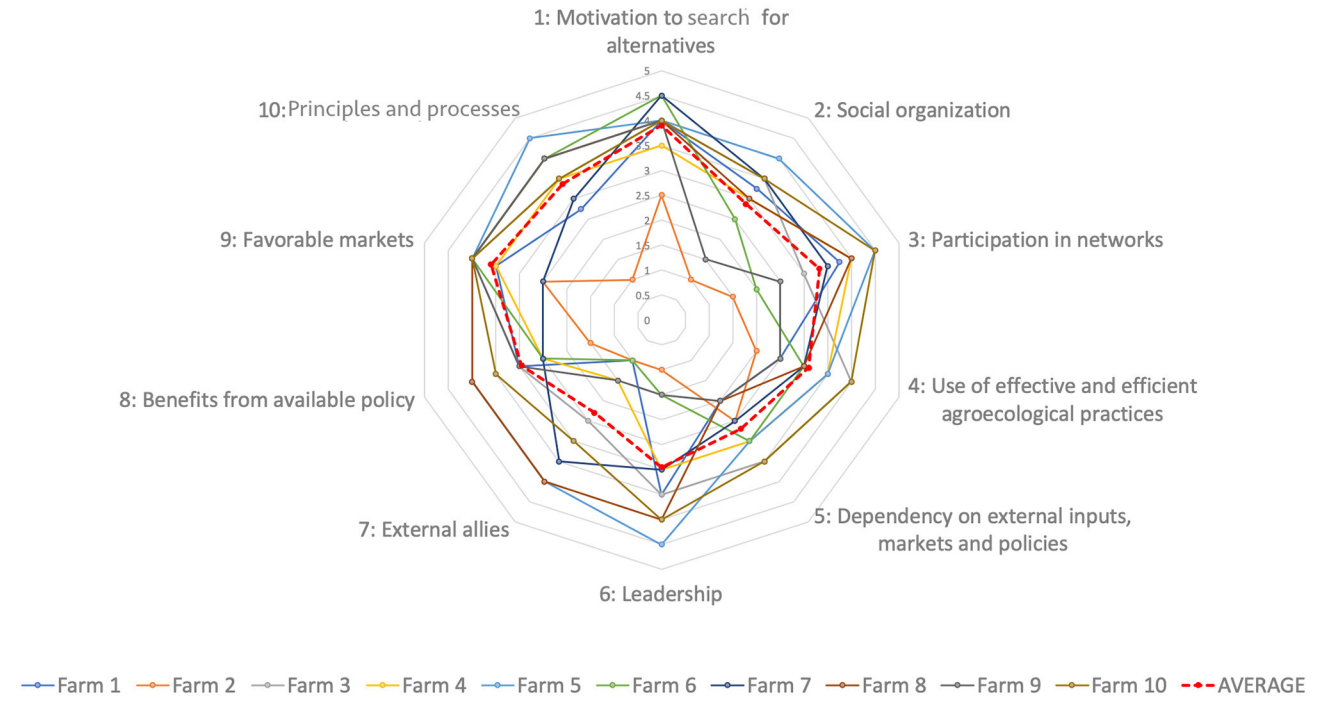


FIGURE 1 | Assessment of amplification potential for a sample of nine farmers and farms identified as farmer lighthouses (source: Authors).

maintains robust farmer networks at the regional scale. Farmer 9 started as a conventional farmer and chose to convert to organic after 6 years of farming. He describes the conversion as eliciting support from his neighbors:

> *"At that time, the conventional farmers in the community were supportive and agreed that I was trying to do something good, although they all expressed worry. To learn organic farming, I visited many farms around the region, but also learned a lot from the Natural Farming Research Center. They were researching the differences between till vs. no-till, live mulch vs. plastic mulch, etc. Also, there was a retired professor from Kyoto University who had a study group once a month. I learned a lot from him. The reason why I settled here was because of the opportunity to have a relatively large plot of land leased over a long period of time." [Farmer 9]*

Community Relationships and Clustering

None of the lighthouse farmers interviewed indicated that they had experienced social friction or pushback from the rural communities in which they live and farm. Cognizant of the economic and social hardships of previous generations of organic farmers, the lighthouse farmers were selective in choosing the location of their farms to maximize opportunities for direct sales channels and minimize contact with communities in which their form of production would be a target for friction. For example, Farmer 7 cites the fact that his village is not a major production area with a strong JA cooperative presence as a reason for enhanced social relations.

> *"Because of the proximity to an urban center and the existence of a direct sales market in our village, many new entry farmers have established themselves in my community who came after me. The fact that our village is not a major agricultural production area, made it easier for people like me, practicing something different, to be accepted. If it were a community with many full-time conventional vegetable farmers, it would probably be more difficult to emphasize organic practices. For this reason, I have not experienced any push back from the community. Rather, many in the community share the techniques they use in their kitchen gardens that do not rely on synthetic inputs." [Farmer 7]*

Many of the lighthouse farmers cited that, in fact, their farming neighbors were very interested in learning production techniques that don't utilize chemicals. The lighthouse farmers maintain are very open to interaction and learning opportunities with conventional vegetable farmers and anyone interested in their methods.

> *"I have very good relations with the people in the community. While some worried if I could make it as a full-time vegetable farmer, that came in the form of care, where many brought me a lot of food to eat. Once they realized that I was able to support myself, they became curious about my techniques." [Farmer 5]*

The ability of lighthouse farmers to form mutually beneficial social relationships with their farming neighbors also allowed them to establish fertile space for new entry farmers to settle and cluster in the area. This inclusivity and non-confrontational attitude were shared among all of the interviewed lighthouse

farmers and not only strengthened their knowledge networks, but allowed access to certain locally-held resources such as rentable land or equipment.

> *"Many people in the community visit me to ask how I am able to grow quality vegetables without the use of chemicals. Otherwise, all other farmers are a part of the same teikei groups, or a different organic cooperative. Other than that, we established an Organic Agriculture Research Association in our region, and we try to be open to anybody in the region who might be interested, no matter what kind of agriculture they practice." [Farmer 3]*

In addition, evidence of successful and productive farming helped to win the respect of local farmers and initiate the legitimation of agroecological farming principles in the community, making it easier for new entrants who share an interest in agroecological approaches to cluster in the area. Farmer 9, for example, has established himself in his community as a source of inspiration and expertise among conventional farmers.

> *"I think conventional farmers would rather not spray or at least minimize their use of pesticides. They are worried, however, about the impact that would have on the quality of their products. So, they often come by and ask why I am able to grow such beautiful vegetables without any pesticides. I haven't convinced anybody to become organic, but I try to understand the challenges they face and try to help wherever possible." [Farmer 9]*

Diverse Lighthouses as Amplifiers and Sources of Resilience

Each lighthouse farmer had a keen understanding and appreciation for diverse agricultural practices co-existing at the territorial level. This diversity was seen as a strength in creating an inclusive organic movement, amplifying territorialization, and as a source of resilience to continue production into the future. Appreciation of the rural communities that accepted many of them as an outsider in the first place may explain the unique position diverse-yet-co-aligned production practices hold for them, as these same communities accepted them and allowed them to thrive.

> *"Yes, I see certain people who practice a different management style than myself as sources of inspiration, or lighthouses. They all have different and unique wave lengths, and I want to find my own light, and my own brightness, within their light." [Farmer 7]*
> *"I don't have specific lighthouse farmers I go to. I try to learn whatever I need to from as many people as I can." [Farmer 5]*

Farmer 3 sees networks of lighthouse farms driving and supporting agroecological territorialization. He values diverse production practices as a way to survive and maintain resilience at the landscape level.

> *"It's not one lighthouse, but we try to maintain many small lighthouses to light the entire landscape. It's more sustainable that way. There are people who want to be left alone and I think that's fine, but if you are isolated, it becomes farming merely for self-gratification. I try to be active in a community because I don't want to get left behind with new technical innovations that come up. It's more stimulating that way, and we grow as a community. In our organic community, there are many kinds of farmers, ranging from farmers who add precise amounts of organic inputs to maximize their monocrop yields, to those who do no-till, no-input style natural farming. Overall, I think this kind of diversity improves our ability to survive collectively, and an effort to homogenize practices would be dangerous." [Farmer 3]*

Farmer 9 pointed out that certain species can also act as a form of biological lighthouse, amplifying agroecology at the agroecosystem level.

> *"A lighthouse is not limited to humans. To me, ladybugs are lighthouses. They embody functional biological diversity on the farm, and their presence guides me." [Farmer 9]*

DISCUSSION

Lighthouses Amplifying Community Ties and Clustering

An important aspect to consider when looking at barriers for the territorialization of agroecology is how agroecological farmers, including lighthouses, co-exist and interact with established farming systems and other territorial actors. In Japan, agroecological farmers are not only farming in a way that differs from mainstream conventional farming: they are also often outsiders to the local community, which underscores the importance of the characteristics of the locally dominant farming mode (e.g., part time vs. full time farming) and by extension of the socio-cultural aspects (mindset, values) of the local community (Zollet and Maharjan, 2021).

Zollet and Maharjan (2021, p. 19) found that farmer clusters–which often develop in part to the presence of lighthouse farmers–create "supportive 'communities (of practice) within the community' without at the same time distancing themselves from local society." There is further evidence of these aspects in the findings of this research: the lighthouse farmers interviewed experience little to no pushback from the communities where they settled because such communities had a high proportion of part-time farmers, many of which were still partially engaging in traditional farming practices compatible with agroecological farming. Furthermore, because many are new entrants into their communities to begin with, lighthouse farmers tend to have a non-confrontational attitude toward practices different or conflicting with theirs, which might have further contributed to the acceptance of their practices by the local community. The quote by Farmer 9 also emphasizes the importance of using effective agroecological practices (indicator 4) that can give good results even without pesticides, a factor that was important in convincing local conventional farmers that agroecological practices are legitimate. Supportive "communities of practice" within a diverse farming community, even though they may not all be practicing agroecology, provides stakeholder support for the agriculture and food system transition, a key component in the creation of agroecological-territories (Wezel et al., 2016).

In addition, the results highlight the importance of access to appropriate knowledge to facilitate learning and innovation, which has been recognized as essential in the successful territorialization of agroecology (Guzmán Luna et al., 2019). Among Japanese agroecological farmers, formal technical support and extension by mainstream agricultural organizations is generally deemed inadequate and restrictive in the type of knowledge and support offered (Zollet and Maharjan, 2021). Lighthouse farmers play an important role in this sense: all lighthouse farmers interviewed were actively engaged in learning and producing agroecological knowledge, as well as disseminating their practice through proximate networks (e.g., trainees, neighboring farmers within their community) but also with actors outside of their immediate circle (e.g., through online agricultural seminars, interaction with researchers, and consumers). The fact that many new farmers settle close to the lighthouse farmers where they completed their traineeship period further supports the process of agroecological territorialization, potentially leading to the creation, as auspicated by Farmer 3, of "many small lighthouses to light the entire landscape."

Beyond facilitating transformative learning, lighthouse farmers are also able to establish relationships with different local and extra local actors, thus displaying the ability to use bonding, bridging and linking social capital (Cofré-Bravo et al., 2019). A common example where bonding social capital is put to use is the establishment of common market channels or venues among agroecological farmers within a cluster, which in turn supports territorialization by making agroecological farmers' products more visible locally. Bridging social capital is more evident in the relationship with local community members, including conventional farmers, and in the ability of lighthouse farmers to create positive interactions with them. This might partly explain the capacity of lighthouse farmers to mitigate the effects of "dark social capital," such as closed attitudes to community outsiders and the rejection of agroecological practices by local conventional farmers and their organizations. For example, McGreevy found that new entry farmers in upland farming villages faced both social and knowledge-competency barriers to forming beneficial community relationships due to different knowledge cultures and notions of "good farming" (2012). New entrant organic farmers in particular are often unsuccessful in their farming operations, which can delegitimize agroecological practice in the eyes of locals. The results here show that successfully mitigating social friction might rest upon the intentional choice of more "open" communities or the demonstration of farming success. Finally, linking social capital can be seen in the role played by lighthouse farmers in interacting with institutional actors, such as local governments, a characteristic shared among all the interviewed lighthouse farmers.

Uniqueness of Territorialization in the Japanese Context

In the Japanese context, the discussion on territorialization and territorial resilience can be connected with culturally-specific concepts such as *satoyama*. The characteristics associated with *satoyama* landscapes mentioned by some of the farmers are the culturally significant agroecological territories of past agricultural regimes (Wezel et al., 2016). The idea of using and cycling resources within the community or region, including skills, money, and local employment in sustainable agriculture, and more money being spent locally is important for the maintenance of traditional *satoyama* landscapes and also a tenet of the Japanese organic farming movement. This echoes the importance of resource flows in agroecology (Rosset and Altieri, 2017; Nicholls et al., 2020) and can also be linked to the (re)use of traditional knowledge to enhance the effectiveness of farmers' practices and their independence from inputs provided by external actors. Some of the lighthouse farmers interviewed, most notably Farmers 5, 7, and 9, are explicitly connecting their farming philosophy and practice to a wider discourse of resource circulation that goes beyond agriculture and into broader principles of circular economy applied to the local context (Mori, 2020), which resonates with the idea of agroecological territories and with the principles of territorial resilience proposed by Guzmán Luna et al. (2019). The historical significance and modern-day vestiges of *satoyama* landscapes, as well as efforts to reintegrate agricultural practice into traditional circular resource flows also make them a unique form of territorial mediator (McCune et al., 2017). *Satoyama* is a highly resilient "cultural matrix" that can communicate across different groups and interests, and influence how community and farmer identity is formed and activated in agroecological territorialization (Guzmán Luna et al., 2019).

Second, the Japanese organic movement did not originate as a farmer-driven movement. Fears of food contamination and environmental pollution were acted upon by consumer groups and experts to form multi-stakeholder platforms, such as the JOAA, and promote safe and sustainable alternative agriculture. This is a very different experience from those described in the literature originating in Latin America, where vocal, farmer-led social movements drive agroecological territorialization in opposition to an industrial agricultural "empire" (van der Ploeg, 2009). This isn't to say that the farmers in this study didn't deal with opposition or resistance to their farming practices, as each was isolated from core rural institutions and marketing channels associated with the JA and were not provided a supportive policy environment to enhance their farms. However, the willingness of lighthouse farmers in this study to work alongside conventional farmers and create relationships to share knowledge and local resources points to the nuanced context rural Japan faces: the need to reduce de-agrarianization, but at the same time find economically and socially viable agroecological and repeasantized pathways (Hisano et al., 2018; McGreevy et al., 2019). We should also point out that *satoyama* landscapes were created and managed by traditional agricultural practices and that deagrarianization and the degradation of *satoyama* landscapes are intimately linked. Farmer-driven social movements are cited as a key element in successful agroecological upscaling (Khadse et al., 2018; Mier y Terán Giménez Cacho et al., 2018; Wezel et al., 2018), but Japan provides a counterexample where careful deployment of

social capital at the community level amplifies legitimacy and territorialization.

This appreciation of diverse yet cooperative communities is also seen in the successful historical cases of Kaneko and Sato's lighthouse farms. In both cases, the farmers labored diligently to create economically successful farms that attracted attention, after which they partnered with local actors to form new collaborations and further territorialize. The most successful lighthouse farmers in this study follow a similar trajectory, but are strategic to encourage the growth of cooperative networks and avoid "leading by conviction." Organic farmers in rural Japan can have a reputation for being overly dogmatic and unwilling to compromise personal dictates on how farming should be done (Knight, 2003), pointing to the importance of indicators 1 (motivation to search for alternatives) and 10 (principles and processes). The highest scoring lighthouse farmers in this study were able to build on the historical examples of success to prioritize community-level cooperation that leads to territorialization.

Limitations and Amplification Methodology

The research had a few limitations. More time could have been allocated for the evaluation, especially for assessing how the farm and farmer are able to create and maintain social relations and networks. The assessment was conducted by evaluators who had preexisting in-depth knowledge of the territory, but this may not be the case if replicating the methodology. Adequate time should be allocated to become familiar with the territory, as there is the risk of painting a partial or inaccurate picture of the farmers' role as an agroecological lighthouse. We addressed these limitations by conducting follow-up interviews with farmers to elucidate specific aspects of their social networks, practices, and experiences. Our sample was also dominated by male farmers, which no doubt led to missing some of the gendered nuisances associated with agroecological amplification driven by women farmer lighthouses (Mier y Terán Giménez Cacho et al., 2018).

In order to facilitate further research on farmer lighthouses, the amplification assessment rubric presented here is a first step. The assessment rubric could be further developed (e.g., through more detailed description of each indicators' levels) as a self-assessment tool for farmers interested in evaluating their role as lighthouses and their strengths and weaknesses regarding their potential to contribute to agroecological territorialization. More broadly, it could also support processes of farmer-to-farmer transformative learning as a tool for collective self-reflection or by farmers within a cluster to evaluate the possibility to improve their practices as a group.

CONCLUSION: COOPERATION ON-THE-GROUND VS. CONTESTED TERRITORIAL FUTURES

In their paper on *formación* and territorial mediators, McCune et al. (2017, p. 369) write: "territorial transformation is not a subject–object action carried out directly by a social movement; instead, it is a mediated process in which diverse subjects assume specific tasks in specific moments, creating social feedbacks and emergent principles." This insight is crucial in understanding agroecological amplification and territorialization in rural Japan now and into the future. Lighthouse farmers in this study detailed numerous moments in which they entered into cooperative relationships with diverse farmers, mediated farmer-to-farmer learning, and amplified agroecological principles in their communities via on-farm practices and knowledge exchange. Through these processes, new opportunities to maintain and expand agroecology were activated for the next generation of farmers, creating positive feedback in the community in the form of viable markets and access to local resources. Agroecological practice by lighthouse farmers revalorized culturally significant identities at the landscape level, such as *satoyama*, which further propelled territorialization. In these ways, lighthouse farmers led on-the-ground efforts of cooperation, in spite of the contested future for agriculture in Japan.

The prioritization of a neo-liberal, corporate agriculture is now beginning in earnest in Japan, as was evident in the lack of policy support for small-scale, environmentally friendly farming (Hisano et al., 2018). While this trend is more pronounced in the literature as a challenge for agroecological upscaling in Latin America (Giraldo and Rosset, 2017; Mier y Terán Giménez Cacho et al., 2018), the top-down encouragement of capital-intensive corporate agriculture (both conventional and organic) in the discourse at the national level has yet to have significant impact in the farming communities where this research took place. Instead, and without government support, interest in and experimentation with diverse forms of small-scale agroecological farming was flourishing and was able to coexist with conventional farmers because of high-quality produce and the ability of farmer lighthouses to integrate with rural communities. It remains to be seen whether or not farmer lighthouses will retain their "light" if and when the presence of corporate industrial farming expands its presence. Policy to support the amplification of agroecology in Japan could take the form of establishing guaranteed market opportunities for organic produce through public procurement schemes, recognizing, and subsidizing farmer-to-farmer networks as trainers and knowledge brokers for agroecological knowledge, expanding financial support for new and small-scale farmers in the form of direct payments, and more funding for research on how conventional agriculture can transition to agroecology.

"Diverse subjects assuming specific tasks in specific moments" also draws attention to the need for more research on socio-cultural, historical, and environmental contexts that influence agroecological amplification and territorialization processes (McCune et al., 2017, p. 369). This research highlights the unique situation in rural Japan, but comparative research with other countries experiencing de-agrarianization, de-peasantization, and rural aging might reveal new insights as to how amplification and territorialization are experienced or catalyzed by farmer lighthouses in diverse contexts. The agroecological movement, as well as other movements for sustainable agriculture, has developed to the point that the historical legacies and efforts of previous generations of farmer lighthouses is also a subject of

great interest. In this study, the current generation of farmer lighthouses, both heritage and new entrants were able to learn from the lessons of past lighthouses and make best use of the context in which they are able to farm, but this may not always be the case. There may also be fertile ground to explore the potential role of biological or ecosystem-embedded lighthouses as an amplifying presence.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Institute for Humanity and Nature, Ethics Committee. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SM, NT, MK, CN, and MA: conceptualization and methodology. SM, NT, MK, CN, MA, and SZ: formal analysis, writing—original draft preparation and subsequent draft writing—review and editing. NT, MK, CN, MA, KH, and SZ: fieldwork. MK, CN, MA, and SZ: data curation. SM: funding acquisition. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Food Sovereignty Indicators for Indigenous Community Capacity Building and Health

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Food insecurity, defined as a lack of stable access to sufficient and nutritious food, is a global public health priority due to its relationships with diminished mental and physical human health. Indigenous communities experience disproportionality high rates of food insecurity as a byproduct of settler-colonial activities, which included forced relocation to rural reservation lands and degradation of traditional subsistence patterns. Many Indigenous communities have worked to revitalize their local food systems by pursuing food sovereignty, regularly expressed as the right and responsibility of people to have access to healthy and culturally appropriate foods, while defining their own food systems. Food sovereignty is a promising approach for improving health. However, limited literature is available that identifies the diverse practices of food sovereignty or strategies communities can implement to strengthen their food sovereignty efforts. This article reviews the scientific literature and highlights key indicators that may support community capacity building for food sovereignty and health. The seven indicators are: (1) access to resources, (2) production, (3) trade, (4) food consumption, (5) policy, (6) community involvement, and (7) culture. A total of 25 sub-indicators are outlined to allow communities to understand how an indicator is operationalized as well as explore their own community's progress within each indicator. It is not expected that every indicator and their subcategories will apply fully to any given Indigenous community, and the application of these indicators must be adapted for each community's local context, however the indicators may provide support for building and assessing efforts to create more sustainable Indigenous food systems.

Keywords: food sovereignty, indigenous food sovereignty, food system, public health, health promotion

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INTRODUCTION

Indigenous communities are disproportionately impacted by food insecurity, defined by the US Department of Agriculture (USDA) as the lack of access to enough food to ensure a healthy and active life (Coleman-Jensen et al., 2020). Food insecurity is associated with a number of diet-related chronic diseases (Seligman et al., 2007, 2010; Laraia, 2013; Gundersen and Ziliak, 2015). Among Indigenous people surveyed in Oklahoma, nearly 60% were food insecure, and, compared to those who were food secure, the prevalence of obesity, diabetes, and hypertension was higher among

those who were food insecure, even after adjustment for age, gender, study site, education, and income (Jernigan et al., 2017).

Food assistance programs such as the Supplemental Nutrition Assistance Program (SNAP), the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), and Food Distribution Program on Indian Reservations, were developed to assist people with food insecurity by providing them additional resources to purchase fruits, vegetables, and other healthy foods. However, these programs were developed to augment household food supplies, not serve as the primary source of food for a household. Thus, households that experience more acute food insecurity, characterized by disrupted eating patterns and reduced food intake, are unlikely to receive enough food from these programs to become food secure (United States Department of Agriculture, 2006). In addition, these programs do not adequately address the root causes of food insecurity and may not be highly utilized in Indigenous communities (Jernigan et al., 2017). For example, one study found that WIC was used 16% less frequently by individuals living on reservations compared to individuals living off reservation (McLaury et al., 2016). This may, in part, be related to the limited food retail outlets on many reservations (O'Connell et al., 2011). Yet, these findings were consistent even among individuals who lived in communities where there was access to fresh foods, suggesting other additional barriers may hinder program usage (McLaury et al., 2016; Kelli et al., 2017).

Many Indigenous communities concerned about food insecurity, growing rates of diet-related disease, and inequities present in mainstream food systems, are actively working to restore their food systems through a food sovereignty approach. Food sovereignty is regularly expressed using the 1996 definition from La Via Campesina, a global activist group focused on the rights of Indigenous farmers, as "the right of people to have access to healthy and culturally appropriate foods, while defining their own food systems" (Global Small-Scale Farmers' Movement Developing New Trade Regimes, 2005). In 2007, at The World Forum for Food Sovereignty, over 80 countries signed a declaration stating:

"Food sovereignty is the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems. It puts those who produce, distribute and consume food at the heart of food systems and policies rather than the demands of markets and corporations. It defends the interests and inclusion of the next generation. It offers a strategy to resist and dismantle the current corporate trade and food regime, and directions for food, farming, pastoral and fisheries systems determined by local producers. Food sovereignty prioritizes local and national economies and markets and empowers peasant and family farmer-driven agriculture, artisanal fishing, pastoralist-led grazing, and food production, distribution and consumption based on environmental, social and economic sustainability" (Declaration of Nyéléni, 2007).

The 2007 definition was more expansive to account for the power structures and governance that shape local food systems (Delormier et al., 2017). This declaration provided a widely accepted definition used by the United Nations and the World Bank (Global Small-Scale Farmers' Movement Developing New Trade Regimes, 2005).

Similar to food sovereignty is the concept of Indigenous food sovereignty, which extends the focus of food sovereignty in a number of ways, including primarily by emphasizing not only a community's right but also their relational responsibilities to care for their food systems according to their traditional practices and beliefs (Morrison, 2011; Coté, 2016). The Indigenous food sovereignty movement, though based upon Indigenous knowledge developed over thousands of years, began to gain national and international recognition in the early 2000's, with the development of various groups such as the Working Group on Indigenous Food Sovereignty (WGIFS) in 2006. The WGIFS was developed based upon the need to recognize Indigenous voices in the various discussions taking place within the food security movement as well as within larger efforts of Indigenous peoples to exert their rights as sovereign peoples (Morrison, 2011), another key distinction between Indigenous food sovereignty and food sovereignty. The WGIFS was created to increase awareness of the underlying issues, concerns and strategies impacting food security in Indigenous communities and to apply culturally appropriate protocols and ways of knowing to issues regarding Indigenous food, land, culture, health, economics, and sustainability.

Food Sovereignty and Health Promotion

Indigenous food systems are considered a sacred gift from Creator to support the health and well-being of their communities (Coté, 2016). Indigenous food systems are ancestral, linking all people to their Creator, to each other, and other forms of life. Fishing, hunting, and foraging for Indigenous peoples are more than activities to fulfill nutritional needs; they help to promote health, emotional balance, mental clarity, and spiritual health. Exercising Indigenous food sovereignty supports communities taking greater control over their food systems by increasing traditional and healthy food access and reducing dependence on externally produced, packaged, and fast foods.

Indigenous food sovereignty mirrors many public health initiatives to address diet-related disparities through food system changes while also being a culturally-centered Indigenous model of health, making it an important area of focus for public health research (Story et al., 2009; Weiler et al., 2014). In recent years groups such as the Native American Food Sovereignty Alliance and the National Congress of American Indians Tribal Food Sovereignty Advancement Initiative have emerged to advocate for Indigenous communities seeking to achieve food sovereignty, building upon previous efforts, and strengthening the movement in the United States (National Congress of American Indians, 2021; US Food Sovereignty Alliance, 2021).

Indigenous food sovereignty can and does take on different meanings and approaches across different Indigenous communities. The First Nations Development Institute developed the Food Sovereignty Assessment Tool as a way to assess the food sovereignty of Indigenous communities (Bell-Shetter, 2004). This tool systematically examines community food assets in Indigenous communities including: access to healthy foods that are culturally appropriate; the ability to

produce food in a way that is sustainable; the ability to ensure that the food reaches all members of the community; provision of support for individuals providing the food; and policies in place that ensure control of the food systems and protect the resources needed to provide for the community. This tool is adaptive to different community settings, but does not produce quantified findings or provide methods to prioritize strategies to achieve specific goals. Other food sovereignty assessment tools provide checklist style assessments, but do not provide guidance for direct action or a way to evaluate progress (Woodley et al., 2006; Binimelis et al., 2014; Weiler et al., 2014).

This review aims to develop an improved understanding of the diversity of practices related to Indigenous food sovereignty and its potential to improve Indigenous community health. To accomplish this, we conducted a review of scientific literature, primarily in the area of public health, and identified publications where food sovereignty was used as part of a health-related initiative. We then reviewed and analyzed our findings to identify key indicators of food sovereignty that Indigenous communities can use to build their community food systems and improve health. Within each indicator we developed sub-indicators to allow communities to understand how an indicator is operationalized as well as assess their progress within that indicator.

METHODS

Author Positionality

This manuscript and described procedures were led by a Choctaw researcher and public health practitioner. In 2019, this researcher mentored two graduate students in the College of Public Health at the University of Oklahoma as they initiated the review of relevant literature. In 2020 and 2021 two additional graduate students in Oklahoma and California, both Indigenous, also assisted in conducting this review. The resulting Indigenous food sovereignty indicators were then reviewed and revised by a larger group of 7 Indigenous and 3 non-Indigenous scholars and practitioners working in the areas of Indigenous food sovereignty and health across the US and Canada. This diverse and inter-disciplinary collaboration provided value in considerations, utility, and implications of the produced indicators.

Narrative Review

This review took the form of a three-phase narrative review. A narrative review includes a comprehensive review of the previously published literature on a specific topic and narrative synthesis of this literature (Slavin, 1995). This format was chosen because it allows for presenting a broad overview of a topic, as well as varied perspectives on said topic. The review was conducted in 2019 and finalized in 2020. The findings were summarized and submitted for publication in 2021. The phases of the review are as follows: (1) article collection and exclusion; (2) content analysis; and (3) face and community validity review.

Phase One: Article Collection and Exclusion

Searches were conducted in English language using PubMed and ProQuest. Due to author language limitations this review was limited to English language publications in the geographic areas of the US and Canada. Urban, rural, and reservation communities were included in this search. The following search terms were used: Tribe OR First Nation OR Alaska Natives OR Indigenous OR Native American OR American Indian AND Food Sovereignty OR Food System OR Food Justice. These searches resulted in 1,126 sources. An additional 72 sources were then identified from a manual search of the identified article's references and cited reference searches.

The titles and abstracts of all of the articles were reviewed for relevance to food sovereignty, Indigenous communities, and health. Duplicate articles were removed ($n = 112$). Articles that described only food or agricultural growing practices, which comprised the vast majority of the publications, but were not related to Indigenous communities and health, wellness, or health promotion were excluded ($n = 832$). This left 182 articles, all of which were independently reviewed in full text by both students and the lead author.

Using Q-sorting methodology (Brown, 1996), each of the three reviewers sorted the 182 articles into "high," "medium," and "low" piles in terms of their (a) relevance to the search terms and (b) level of detail provided. The three reviewers then met in person and presented their articles and their rankings. Articles ranked as "low" by all three reviewers were excluded. These articles were those that, after full review by all authors, were determined to lack relevance to the study objective and/or sufficient detail. For example, articles that were heavily agriculture-focused and not related to health, and brief summaries that made only minimal reference to the concept of food sovereignty without describing its application or use within that particular publication or study, were assigned a "low" or "medium" ranking ($n = 103$). All articles that were rated "high" by at least two of the three reviewers were included in the next phase of the review. Articles ranked as "medium" were limited and their inclusion was determined on a case-by-case basis. This process resulted in 79 articles, all primary articles, that were included in the content analysis.

Phase Two: Content Analysis

A content analysis of the 79 included articles was conducted by the original three reviewers as well as two additional Indigenous graduate students and co-authors of this manuscript. The five reviewers assessed each article for descriptions of Indigenous food sovereignty and ways in which the concept was operationalized for health purposes within an Indigenous community. This phase, as well as the next phase, face validity, was guided by a community-based participatory research orientation used in previous research to build upon and identify new constructs and frameworks (Belone et al., 2016). Specifically, qualitative concepts within the articles were identified, sorted, and described by each reviewer independently and then discussed as a group. Concepts that were referenced repeatedly across most articles were deemed fundamental to operationalizing

Indigenous food sovereignty and identified as primary indicators. Reviewers then organized repeated related concepts as sub-indicators. Finally, the drafted indicators were compared to the four previously published food sovereignty assessment tools for general consistency (Bell-Shetter, 2004; Woodley et al., 2006; Binimelis et al., 2014; Weiler et al., 2014). A final list of indicators was then adapted to be comprehensive of all of concepts.

Phase Three: Face Validity

The key Indigenous food sovereignty indicators were then reviewed independently by a group of 7 Indigenous and 3 non-Indigenous scholars and practitioners. This group has expertise in nutrition, food security, cultural competence, traditional Indigenous foods, health disparities, food systems, and research design. These scholars hail from various communities across the U.S., providing diversity in lived experiences, cultural practices, and geographical considerations. Participants validated and expanded on the Indicators based on "real-world" praxis, resulting in the final Indigenous food sovereignty indicators.

RESULTS

Food Sovereignty Indicators

The synthesis of articles and participatory process resulted in a total of seven food sovereignty indicators: (1) access to resources; (2) production; (3) trade; (4) food consumption; (5) policy; (6) community involvement; and (7) culture (**Table 1**). The indicators include a total of 25 sub-indicators that operationalize the overall indicator and support communities to assess their efforts within each indicator. The indicators and sub-indicators are intended to be adapted to different Indigenous communities and circumstances, though applicability will vary based on a community's cultural values, history, traditions, geography, governance, beliefs, resources, capacity, and goals. Some of the indicators may not be relevant to a given community and should be disregarded if they are not applicable.

Indicator 1. Access to Resources

Access to resources encompasses resources that are not just physical, but also the knowledge of the individuals living in a community. The physical resources of the community should provide sufficient farm-able land, water sources, and natural resources to ensure availability of culturally appropriate foods for the entire community (Woodley et al., 2006; Patel, 2009; Alkon and Agyeman, 2011; Alkon, 2012, 2013; Bernstein, 2013; Binimelis et al., 2014; Vesely, 2014; Gupta, 2015; IAASTD, 2016; Parraguez-Vergara et al., 2018). The applicability of this indicator will change depending on each community's resources. For the Oneida people, the water sources are key, but for the Osage Nation, the tall grass prairie may hold a more significant place culturally than water sources. When looking at land, a community should have access to agriculturally viable and culturally significant land, and ensure that the land can be used for food production or to support traditional hunting, fishing, or gathering practices (Woodley et al., 2006; Creswell et al., 2011; Ehrhart, 2013; Meisner, 2013; Binimelis et al., 2014; Weiler et al., 2014; Carmen, 2016; Moreno-Calles et al., 2016; Peña, 2016). Thus, access to land and decision-making with regards to land is significant. While food production is not the only focus or outcome of Indigenous food sovereignty, if food production is of a high importance to a community, it is necessary to use food-producing land for that purpose.

An important aspect of Indigenous food sovereignty is a push against corporate and industrial farming, which can damage land and hurt smaller farming operations (Global Small-Scale Farmers' Movement Developing New Trade Regimes, 2005). Wildlife is another component of the resources that may be culturally significant. It is imperative that culturally significant wildlife be present on community lands and protected from overuse (Woodley et al., 2006; Patel, 2009; Creswell et al., 2011; Binimelis et al., 2014; Vesely, 2014; Weiler et al., 2014; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). Water sources should be kept pollution free and support long-term food production (Woodley et al., 2006; Creswell et al., 2011; Cherofsky, 2013; Binimelis et al., 2014; Vesely, 2014; Carmen, 2016; Moreno-Calles et al., 2016). This production is shaped by the individual Indigenous community; for example, a water-based community with cultural links to fishing may use water sources for fishing, being careful not to overfish, but another community may emphasize farming and use water sources to irrigate farmlands (Vesely, 2014). In order to plant and maintain food crops, it is necessary to have access to seeds for culturally significant crops accessible and available for exchange by local farmers and the community, not controlled by corporate agriculture (Woodley et al., 2006; Cherofsky, 2013; Binimelis et al., 2014; Breen, 2015; Carmen, 2016; Moreno-Calles et al., 2016; Peña, 2016; Daigle, 2019). An Indigenous community seeking to strengthen food sovereignty should also include individuals in the community that have agrobiodiversity knowledge and agroecological skills, including traditional Indigenous knowledge, to grow crops or tend to wildlife (Woodley et al., 2006; Patel, 2009; Altieri et al., 2012; Chappell et al., 2013; Cherofsky, 2013; Ehrhart, 2013; Binimelis et al., 2014; Vesely, 2014; Weiler et al., 2014; Jones et al., 2015; Moreno-Calles et al., 2016; Ellena and Nongkynrih, 2017). It is not enough to have access to the physical resources. Individuals must be present in the community that hold the knowledge and skills needed to use and maintain right relationships with those resources (Woodley et al., 2006).

Indicator 2. Production

Production looks at the steps in the process of the food supply chain from farm to table. It is necessary for the proportion of food producers in the community be high enough to ensure sufficient production (Woodley et al., 2006; Patel, 2009; Alkon and Agyeman, 2011; Binimelis et al., 2014). This often appears as localized production and consumption efforts, restoring sustainability to the community (Jones et al., 2015). Allowing for small farms to sustain production provides community members an opportunity to provide food for their communities without sacrificing their own financial well-being. It is not necessary for all food production to come from within the community, but it is key that the decisions to bring in outside food sources be made by the community

TABLE 1 | Food sovereignty indicators.

Indicator 1: Access to Resources
Sub-indicator question/statements used for discussion and to operationalize the indicator:
Our community has access to enough farmland, water sources, and natural resources to ensure the production of culturally appropriate foods for the entire community.
The costs allow for small farms to develop and sustain food production in our community.
Culturally significant wildlife is present in our community and protected from overuse.
In our community water sources are kept pollution free and used for long-term agricultural production.
In our community there is access to seeds for culturally significant crops that are easily accessible by local farmers.
Individuals in our community have the knowledge and skills to grow crops and tend to wildlife.
Indicator 2: Production
Sub-indicator question/statements used for discussion and to operationalize the indicator:
There are enough food producers within our community to maintain adequate production for the community.
Food production, from farm to table, is controlled and regulated by the community.
Indicator 3: Trade
Sub-indicator questions/statements used for discussion and to operationalize the indicator:
In our community food prices are fair and affordable for all community members.
Food markets are profitable enough to maintain long-term success.
There is a balance of food items that are coming into the community and going out of the community.
Indicator 4: Food Consumption
Sub-indicator questions/statements used for discussion and to operationalize the indicator:
In our community we maintain sufficient access to affordable healthy foods and minimize processed food and fast food consumption.
All community members have sufficient food access, and food distribution systems are in place to provide for low-income individuals.
In our community adequate food options are available to all community members to ensure the health needs of each individual are met.
Indicator 5: Policy
Sub-indicator questions/statements used for discussion and to operationalize the indicator:
In our community, policies are in place to ensure local farms are able to access the resources needed to maintain production, and the over-use of natural resources are regulated.
Policies are in place in the schools in our community to ensure school menus are nutritious; the schools are making efforts to provide healthy and traditional foods to children.
Our community has policies in place to ensure sustainability of food resources, wildlife, and natural resources that are culturally significant.
Food councils are in place within the towns in our community to investigate food production, food security, and health.
Indicator 6: Community Involvement
Sub-indicator questions/statements used for discussion and to operationalize the indicator:
Our community has many knowledge holders, such as elders, who are able and willing to pass on knowledge.
In our community we provide pathways to transfer food knowledge and restore traditional food practices.
Educational activities and programs are in place to pass on traditional knowledge, nutrition, and food practices to youth in our community.
Our community supports women's rights and equality to promote well-being and traditional agricultural practices among youth.
Indicator 7: Culture
Sub-indicator questions/statements used for discussion and to operationalize the indicator:
Culturally appropriate foods are prioritized in our community.
The crops and wildlife needed for cultural foods and traditions are available and affordable to all in our community.
There are adequate opportunities for traditional ecological knowledge to be shared amongst the community.

(Global Small-Scale Farmers' Movement Developing New Trade Regimes, 2005; Vesely, 2014). It is also important that farms have reasonable costs and high enough income to maintain production long-term and to adequately support food producers (Woodley et al., 2006; Holt-Giménez and Shattuck, 2011; Binimelis et al., 2014; Peña, 2016; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). In this context, long-term production is viewed as production that continues beyond the foreseeable future, providing sustainability for generations to come (Native American Food Sovereignty Alliance, 2018). The next piece in the supply chain is processing and distribution. Crops should be efficiently distributed to processing facilities or to vendors and community members (Woodley et al., 2006; Blain, 2010; Creswell et al., 2011; Meisner, 2013; Ruelle and Kassam, 2013; Binimelis et al., 2014). The underlying principle with processing and production is that the community is in control of the process and able to dictate the entirety of the food production process, whether this includes only internal resources or involves coordinating with external resources (Woodley et al., 2006; Creswell et al., 2011; Ehrhart, 2013; Meisner, 2013; Ruelle and Kassam, 2013; Binimelis et al., 2014; Peña, 2016; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018).

Indicator 3. Trade

The trading of food products is another key component of food sovereignty. Food prices should be fair and affordable for all community members; however, it is important that food markets are profitable enough to maintain long-term success (Woodley et al., 2006; Freedman and Bell, 2009; Patel, 2009; Alkon, 2012, 2013; Meisner, 2013; Binimelis et al., 2014; Peña, 2016; Grey and Newman, 2018). This balance is not easy to achieve, but high levels of food production can drive prices down while maintaining profits by externally selling surpluses (Freedman and Bell, 2009; Caspi et al., 2012). There should be a fair, transparent trading balance of food items that are coming into the community and leaving it (Woodley et al., 2006; Creswell et al., 2011; Holt-Giménez and Shattuck, 2011; Alkon, 2012; Ehrhart, 2013; Meisner, 2013; Peña, 2016). This balance can help lower consumer prices while allowing businesses to profit. Again, the community either controls or has access to decision-making to determine these aspects of the food trade.

Indicator 4. Food Consumption

Food consumption primarily focuses on food-related health of individuals within the community. Maintaining sufficient access to affordable healthy foods will minimize the consumption of processed food and fast foods (Woodley et al., 2006; Meisner, 2013; Binimelis et al., 2014; Goad, 2014). These processed and fast food items are prevalent in food deserts and food swamps (i.e., urban low-income areas), but can be replaced with fresh, local, healthy foods if production can sustain consumption and demand within the community (Blain, 2010; Ratcliffe et al., 2011; Leroy et al., 2015). It is also necessary to reduce and ultimately eliminate food insecurity amongst community members. All members should have access to sufficient food to maintain a healthy lifestyle, and food distribution processes should be in place to provide for low-income individuals (Woodley et al., 2006; Patel, 2009; Adamson, 2011; Alkon and Agyeman, 2011; Creswell et al., 2011; Holt-Giménez and Shattuck, 2011; Alkon, 2012; McMichael, 2013; Binimelis et al., 2014; Vesely, 2014; Weiler et al., 2014; Cidro et al., 2015; Leroy et al., 2015; Peña, 2016). In addition to having sufficient quantities of food, it is necessary that foods be nutritious to ensure healthy food consumption throughout the community (Woodley et al., 2006; Altieri, 2009; Patel, 2009; Adamson, 2011; Alkon, 2012; Bernstein, 2013; Kaufman et al., 2014; Weiler et al., 2014; Delormier et al., 2017; Food Sovereignty, 2018; Native American Food Sovereignty Alliance, 2018). Adequate healthy food options should be available to all community members to ensure individuals' health needs are met (Woodley et al., 2006; Adamson, 2011; Holt-Giménez and Shattuck, 2011; Leroy et al., 2015; Peña, 2016).

Indicator 5. Policy

In order to strengthen food sovereignty, Indigenous communities need self-governance or at a minimum the ability to influence policy to protect food resources and food producers (Jones et al., 2015). Land and resource regulations should be in place to provide fair resolutions over access to natural resources, ensuring local farms obtain the resources needed to maintain production (Woodley et al., 2006; Creswell et al., 2011; Ehrhart, 2013; Binimelis et al., 2014; Addressing household food insecurity in Canada - position statement recommendations - dietitians of Canada, 2016; Carmen, 2016; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). Sustainability is important for maintaining food sovereignty. Sustainability policies should be in place that provide legislative support, secure resources for the future, and maintain community control of said resources (Woodley et al., 2006; Creswell et al., 2011; Alkon, 2012; Bernstein, 2013; McMichael, 2013; Meisner, 2013; Binimelis et al., 2014; Vesely, 2014; Weiler et al., 2014; Cidro et al., 2015; Moreno-Calles et al., 2016; Peña, 2016; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). In order to maintain these policies and monitor the food system, community food councils comprised of community members, smallholder farmers, leadership, and other stakeholders should be in place within the community influencing the local system's food production, food security, and overall health (Woodley et al., 2006; Patel, 2009; Creswell et al., 2011; Binimelis et al., 2014; Cidro et al., 2015; Peña, 2016; Daigle, 2019). These councils should be responsible for adapting policies with changing political environments and the needs of the community (Woodley et al., 2006; Creswell et al., 2011; Binimelis et al., 2014). Many Indigenous communities are fearful of the long-term impacts of genetically modified organisms and toxic contamination, and call for local governance of research on genetically engineered food and genetically-modified natural resources flowing into their communities (McAfee, 2008; Blain, 2010; Ehrhart, 2013; Carmen, 2016; Peña, 2016; Raster and Christina, 2017; Daigle, 2019).

Indicator 6. Community Involvement

Community involvement is a necessity for food sovereignty, providing pathways to transfer knowledge and restore traditional food practices. Women's rights and equality should be ensured, as they are closely connected to the health of children and contribute positively to traditional agricultural practices (Patel, 2009; Rudolph, 2012; Cherofsky, 2013; Ehrhart, 2013; Weiler et al., 2014; Peña, 2016; Delormier et al., 2017; Ellena and Nongkynrih, 2017; Lemke and Delormier, 2017; Daigle, 2019). Youth are key to food sovereignty implementation and sustainability (Gliessman, 2018). Efforts should be put into place to pass traditional knowledge, nutrition, and food practices from knowledge-holders, such as elders, to children and youth (Blain, 2010; Rudolph, 2012; Cherofsky, 2013; Meyer, 2014; Weiler et al., 2014; Cidro et al., 2015; Carmen, 2016). General community education and activities to promote traditional food practices and nutrition is also prevalent in communities working to restore food sovereignty (Blain, 2010; Rudolph, 2012; Goad, 2014; Meyer, 2014; Weiler et al., 2014).

Indicator 7. Culture

The final indicator focuses on the culture of the community, as culture is a right of Indigenous peoples (Carmen, 2016). The policies that are in place should ensure reconnection to culturally significant natural resources, whether these are crops or wildlife

(Woodley et al., 2006; Blain, 2010; Creswell et al., 2011; Breen, 2015; Carmen, 2016; Grey and Newman, 2018; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). These resources should be sustained for long-term use (Woodley et al., 2006; Creswell et al., 2011; Peña, 2016; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). To maintain traditions, natural resources, ancestral food practices, and their spiritual significance needed for cultural foods and traditions should be available and accessible to all community members (Woodley et al., 2006; Alkon, 2012, 2013; Rudolph, 2012; Cherofsky, 2013; Binimelis et al., 2014; Goad, 2014; Vesely, 2014; Weiler et al., 2014; Cidro et al., 2015; Jones et al., 2015; Peña, 2016; Delormier et al., 2017; Lemke and Delormier, 2017). A community will develop a definition for restoring its relationship to the land and make efforts to provide the opportunity for spiritual and physical reconnection to the community members (Meisner, 2013; Meyer, 2014; Cidro et al., 2015; Peña, 2016; Delormier et al., 2017; Lemke and Delormier, 2017). Ultimately, the policies that a community has in place should allow for the maintenance of culture and traditions (Woodley et al., 2006; Patel, 2009; Creswell et al., 2011; Alkon, 2013; McMichael, 2013; Binimelis et al., 2014; Vesely, 2014; Weiler et al., 2014; Native American Food Sovereignty Alliance, 2018; The Six Pillars of Food Sovereignty, 2018). Many Indigenous people feel a responsibility to support environmental conservation and protection (Lane, 2018). Policies should be put into place to sustain the natural environment and agrobiodiversity, achieving both food sovereignty and sustainability efforts (McAfee, 2008; Meisner, 2013; Goad, 2014; Weiler et al., 2014; Breen, 2015; Carmen, 2016; Peña, 2016; Raster and Christina, 2017; Daigle, 2019).

DISCUSSION

This narrative review is one of the first to identify indicators to build community capacity for food sovereignty and health. The indicators aimed to capture a diversity of practices and be adapted for use across the unique geographic, cultural, and political contexts of Indigenous communities. Designed to be implemented in talking circle or focus group formats with different segments of a community, including health planners and community leaders, the discussion of the indicators can support a community in identifying priorities and strategies for achieving community-defined goals. The inclusion of food sovereignty as a public health issue can bring together previously siloed segments of a community (e.g., agriculture, land use, commerce, health departments), fostering broader community engagement and support for the local food system, a process that, in and of itself, builds capacity for health (Jernigan et al., 2018; Bird Jernigan et al., 2019).

This review has several limitations. First, food sovereignty is largely absent from the public health literature. We found few articles that included both a food sovereignty and a health focus. Virtually all of the articles in this review were found in the fields of agriculture, community development, and Indigenous culture and education. Thus, the review likely missed relevant articles due to the review's focus. Food sovereignty, as an Indigenous approach to food, food systems, and health, has not been included in the health literature to date. However, the potential of a food sovereignty approach to increase healthy food access and consumption and address long-term systemic problems related to food insecurity, poor diet quality, and poor health is significant (Jernigan et al., 2020a,b). Such an approach also responds to calls from Indigenous communities and researchers to support and promote Indigenous ways of knowing and models of health that are culturally-centered and thus more likely to be sustained over time (Jernigan et al., 2020a; Walters et al., 2020). Future research should identify ways that communities have applied a food sovereignty approach to improve health and how food sovereignty can be conceptualized within a larger model of community health promotion.

Secondly, while this review drew from a wide range of literature representing many Indigenous communities from urban, rural, and reservation contexts, these indicators are by no means applicable to all Indigenous communities and are intended to be adapted for each community as appropriate. It is expected that these indicators may lack feasibility or even relevance for some Indigenous communities and are intended only to add to the viritually non-existent literature on Indigenous models of health, within which we consider food sovereignty. Future work must assess the application and evaluation of these indicators and expound upon this effort.

Food sovereignty is of great interest to public health researchers and practitioners as it has the potential to reduce long-standing and pervasive diet-related disparities that have seen limited improvement from Western interventions aimed at improving individual dietary intake. Food sovereignty offers a culturally centered approach to improving a community's food system at the root causes of chronic disease, the inequitable food system, and does so in a way that may be more sustainable than external food security or health interventions. The proposed food sovereignty indicators can be used as a guide to foster discussion, community engagement, and capacity building toward a more sovereign Indigenous food system. The indicators can also provide framing for health promotion initiatives within Indigenous communities, supporting initiatives such as gardening, farming, harvesting, and cooking, all of which are important vehicles for traditional Indigenous knowledge. These efforts may aid in language and cultural revitalization and a much more holistic and integrated model for community health.

AUTHOR CONTRIBUTIONS

VB conceptualized and lead the study. VB, TM, CN, and TTa led the bulk of the writing. TTe and MM conducted early initial review and analysis. TB and SJ conducted a second review and analysis. TJ supervised and edited the manuscript. All authors contributed to writing, editing, and finalizing the manuscript.

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What Do Values Have to Do With It?: Resilience of Two Types of Farmers in Hawai'i to the COVID-19 Pandemic

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A history of agriculture and socio-cultural formation has led to a complex local food system in Hawai'i. Customary agricultural systems built by Kānaka 'Ōiwi (Indigenous Hawaiian) are now rested within a landscape filled with many different crops tended by farmers from a variety of ethnic backgrounds. Value systems dictating farming practices and crop selling decisions differ. In Hawai'i, values of food security or food sovereignty are of particular importance, especially as growing movements seek to increase local production and decrease the state's reliance on imported food in the wake of the COVID-19 pandemic. In this study, we systematically compare two different groups of farmers in Hawai'i and their values related to production and distribution. We then analyze the experiences of these two groups of farmers during the COVID-19 pandemic and their responses to them. The study is based on interviews with 22 Indigenous Kānaka 'Ōiwi (IF) and Non-Indigenous local farmers (LF) from the island of O'ahu. Ninety percent of IF say values associated with both food security and sovereignty drive their production and distribution decisions, while 75% of LF describe food security as the sole driver. Sixty percent of IF follow a non-profit economic model and emphasize cultural and educational values in their production decisions. LF follow profit-driven models and emphasize the influence the market has in their decisions. Prior to the COVID-19 pandemic, IF sold or donated the bulk of their crops to the local community through farm pickups, while restaurants were the primary buyers of LF crops. During the pandemic, the local community continues to be the primary recipient for IF, and due to the closure of many restaurants, LF have pivoted their sales to the community as well. Farmer interviews are augmented by three interviews with Hawai'i food system experts and relevant literature to suggest multiple pathways state agencies and local organizations could implement to support farmers from different backgrounds through COVID-19 and into the future.

Keywords: food sovereignty, food security, Kanaka Maoli, Hawai'i, COVID-19, food system, resilience, local food

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INTRODUCTION

The relationship between a farmer's values and the use of sustainable practices to foster environmental stewardship is well researched (Sullivan et al., 1996; Mccann et al., 1997; Schoon and Grotenhuis, 2000; Ryan et al., 2003; Lincoln and Ardoin, 2016). However, the role ethnic identity plays in this agricultural stewardship relationship, along with crop distribution decisions,

has not received as much attention (Alkon and Agyeman, 2011). This topic is especially relevant in Hawai'i, where the local food system is influenced by a complex history of land tenure, agriculture, and socio-cultural formation. This history has made values associated with food security and food sovereignty particularly prevalent (Loke and Leung, 2013a; Kent, 2016). The local food system has been stressed by the COVID-19 pandemic. In response to COVID-19 spreading across the United States and the globe, Hawai'i State Governor David Ige issued his first emergency proclamation on March 4th, 2020 (Young, 2021). The first COVID-19 case in Hawai'i was subsequently reported on March 6th. On March 23rd a stay-at-home order was issued by Honolulu mayor Kirk Caldwell closing all businesses, except for those deemed essential. On March 26th a 14-day quarantine for out of state travelers was implemented. Subsequent orders were implemented, expired, and reinstated as case numbers fluctuated throughout summer 2020. These orders allowed various businesses to open at limited capacity. In the face of this shifting political and economic landscape, farmers had to display resilience, shift their operations, and pivot their sales.

Drawing from 25 semi-structured interviews with farmers and food system leaders, this paper explores the values driving crop production and distribution for farmers belonging to two different ethnic groups on the island of O'ahu, Hawai'i: Kānaka 'Ōiwi (IF) and non-Kānaka 'Ōiwi local farmers (LF). In addition, we explore how these groups have responded to the COVID-19 pandemic. Specifically, we ask:

(1) How do sociocultural and economic values, including the desire to strive for community food security and food sovereignty, affect the decisions IF and LF make?
(2) To what extent has the response to the COVID-19 pandemic differed between IF and LF? Has one group shown more resiliency through the pandemic thus far?

Broadly defined resilience is the capacity to continue to achieve goals despite disturbances and shocks (Brown et al., 1987; Heller and Keoleian, 2003). In the context of the food system, define resilience as "ensuring sufficient, appropriate and accessible food to all. By sufficient, we understand sufficient quantity and nutritional quality of food; by appropriate, we include the notions of culturally, technically and nutritionally appropriate food; by accessible, we mean physically and economically accessible." To measure their resilience, we examine: the degree to which a farmer's pre-pandemic farming operations, consumer base, sales shifted; and how well positioned they are to continue operating through the pandemic and into the future.

This article proceeds in four parts. First, we outline the history of agriculture and movement building that has led to an agricultural landscape composed of farmers from many different backgrounds. Second, we present quantitative and qualitative findings demonstrating the ways in which IF and LF interact with subsets of consumers and seek out varied means by which to maintain their farming operations. Third, we argue that certain attributes of each value system provided unique opportunities and obstacles in trying to achieve resiliency through the COVID-19 pandemic. Last, we suggest multiple pathways state agencies and local organizations could implement to support farmers from different backgrounds through COVID and into the future.

STUDY SYSTEM BACKGROUND

Historical Foundations of Hawai'i's Food System

Beginning at their first arrival to the Hawaiian Islands, Kānaka 'Ōiwi established expansive systems of food production that ranged from offshore fisheries to mountainous agroforestry systems (Vaughan and Vitousek, 2013; Lincoln and Vitousek, 2017). These systems were embedded in socio-political institutions at the personal (religious, see Kame'eleihiwa, 1992), local (ahupua'a, see), and landscape scale (moku, see Winter et al., 2018). Kānaka 'Ōiwi socio-political institutions relied on cultural frameworks emphasizing familial and spiritual connections to land and crops and an understanding of overall community well-being and health (Goodyear-Ka'ōpua et al., 2014; Winter et al., 2020). The act of eating was spiritual, and great significance was attributed to the cultivation of crops (Kamakau and Barrère, 1992). The crop diversity, multi-tier structure, and use of altitudinal and seasonal shifts in these food production systems coupled with the socio-political institutions enabled high productivity and resiliency (Kagawa and Vitousek, 2012; Lincoln and Ladefoged, 2014; Kurashima et al., 2019). For example, Kurashima et al. (2019) concluded that terrestrial cropping systems could have sustained a population of 1.2 million people.

The actions of missionaries, their descendants, and the United States government have had a far-reaching impact on Kānaka 'Ōiwi society. With the first arrival of foreign traders in 1778 and missionaries in 1820, came disease and population decline. Along with a diminished population came shifts in socio-economic, cultural, and religious institutions. To further their religious agenda, missionaries pressured local chiefs to dismantle the customary Kānaka 'Ōiwi spiritual system. Soon many Kānaka 'Ōiwi were enveloped in an entirely new religious system, Christianity, that was not rooted in relationships with the community, land, ali'i and akua (gods). Missionaries exploited their new power and Kānaka 'Ōiwi were coerced into becoming the primary labor force, producing resources for growing settler colonialism on the island of O'ahu, which often came at the expense of their own daily food needs (Steele, 2015).

The 1848 Māhele, a property right and land redistribution act, further affected Kānaka 'Ōiwi land tenure and subsequently food production. Land that had been held in common by communities and produced abundant food was commodified and divided into parcels to be managed on an individual level. Not accustomed to Western land ownership practices, many Kānaka 'Ōiwi did not file claims to any parcel of land (Kame'eleihiwa, 1992). Western businessmen soon bought up and controlled large swaths of the island.

The illegal overthrow of the Kānaka 'Ōiwi Kingdom in 1893 by American businessmen backed by the United States Navy furthered the loss of Kānaka 'Ōiwi food production systems and

knowledge. The foreign businessmen established a government that suppressed Kānaka ʻŌiwi cultural practices, access to land, and the use of ʻolelo Hawaiʻi (Kānaka ʻŌiwi language) in public and at home (Warschauer et al., 1997). Kānaka ʻŌiwi food production systems and cultivation practices faded with the diminishment of cultural transmission and land access. Moreover, the Kānaka ʻŌiwi worldview and diet shifted under the pressures of colonialism (McMullin, 2016; Silva and Ngugiwa, 2017).

Eurocentric notions of environmental management took hold as well. Government regulation and bureaucracy has also limited the ability of Kānaka ʻŌiwi communities to regain formal management and oversight of traditional food producing regions (Vaughan et al., 2017). Finally, many famous historical native food producing landscapes have been paved over to make way for single family homes, shopping centers, and military bases, or are used for the seed corn industry (Gupta, 2015; Fujikane, 2021).

The result of this history of land and cultural loss has led to a sharp decline in self-sufficiency with Hawaiʻi importing almost 90% of its food. The Kānaka ʻŌiwi population in comparison to the rest of the Hawaiian state has a higher prevalence of hypertension, heart disease, diabetes, and obesity (McMullin, 2016). In addition, a disproportionate number of the Kānaka ʻŌiwi population is enrolled in the SNAP benefits program (U.S. Department of Agriculture, Food and Nutrition Service, Office of Policy Support, 2019) and experience a higher poverty rate (13.5) than the averages in the state (9.5).

Seeking to capitalize on a booming need for sugar in the US, and with ample land resources, foreign businessmen established sugarcane plantations in 1835 and imported workers as cheap labor from countries around the world: China, Japan, Philippines, Korea, Portugal, and Germany. These workers brought seeds of new crops as well as cultural traditions with them. While living on plantations, workers exchanged food, recipes, and traditions, ultimately giving rise to what is now known as local food and culture in Hawaiʻi (Yamashita, 2019). As the sugar industry shifted to South America and the Hawaiian plantations closed, these workers began farming their own plots across the state with polyculture cultivation including rice, taro, and pig (Takaki, 1984).

Movement Building and Food System Transformation in Hawaiʻi

The birth of the Kānaka ʻŌiwi sovereignty movement is built on the struggles of Kānaka ʻŌiwi farmers and community members who sought to maintain access to their lands and farming practices (Trask, 1987). A group of Kānaka ʻŌiwi farmers and community members facing eviction from their agricultural lands changed the narrative in 1969 by occupying Kalama Valley. Although the subdivision was ultimately built, the stand the Kalama Valley farmers took ushered in a wave of Kānaka ʻŌiwi activism and cultural resurgence that continues to this day. Therefore, the roots of the Kānaka ʻŌiwi sovereignty movement are firmly planted in land access and agriculture but evolved to include cultural revitalization in forms such as language, hula, and ocean wayfinding.

The movement has also evolved to center Kānaka ʻŌiwi conceptualizations of sovereignty and land-based relationships characterized by the terms "ea" and "aloha ʻāina." Like most Kānaka ʻŌiwi words ea holds multiple meanings including "life," "breath," and "sovereignty." Ea is described as "an active state of being . . . that requires constant action day after day, generation after generation . . . [It] is based on the experiences of people on the land, relationships forged through the process of remembering and caring for wahi pana, storied places" (Goodyear-Kaʻōpua et al., 2014). Ea is therefore an understanding that sovereignty and life itself is rooted in caring for and maintaining a relationship with the land. Aloha ʻāina encapsulates maintaining a righteous relationship between people and place. It has also become the name and rallying cry of the Kānaka ʻŌiwi sovereignty movement itself (Osorio, 2002).

Kānaka ʻŌiwi political scientist Noelani Goodyear-Kaʻōopua describes a plurality of sub movements in Hawaiʻi that contribute to the goals, mainly political and economic autonomy and self-determination, of the broader Kānaka ʻŌiwi sovereignty movement (Goodyear-Kaʻōpua et al., 2014). In this way, the Kānaka ʻŌiwi food sovereignty movement can be seen as a sub movement working towards Kānaka ʻŌiwi sovereignty at large. The first formal mention of this movement can be traced back to Maʻo Farm's "Hands Turned to the Soil" youth conference in 2003 (Meyer, 2014). From that conference came the proliferation of urban gardens and the rise of youth programs centered around cultural and agricultural education. A second food sovereignty conference on Hawaiʻi Island in 2007 began to define Kānaka ʻŌiwi food sovereignty as "a spiritual, physical and cognitive pathway toward greater wellbeing and self-sufficiency" (Gupta, 2015). A third conference took place in 2018 where a youth congress, comprised of Kānaka ʻŌiwi youth, crafted a future vision for Hawaiʻi's food system and expanded the definition of Kānaka ʻŌiwi food sovereignty to include the right and responsibility to ʻai pono (righteous food); co-design educational models outside of the classroom; the conscious care of resources for future generations; and uplifting of the community.[1]

The values associated with the Kānaka ʻŌiwi food sovereignty movement are aligned with food sovereignty and Indigenous food sovereignty struggles across the globe. The term food sovereignty was first coined by La Via Campesina in 1996. A commonly cited definition of food sovereignty comes from the Declaration of Nyeleni, where it is defined as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems" (Fairbairn, 2010).

A growing body of work from Indigenous scholars across North America have begun to define Indigenous food sovereignty (see Mihesuah et al., 2019; Settee et al., 2020). Moreover, Indigenous food sovereignty is seen as continuation of anti-colonial struggles and advancement of self-determination (Grey and Patel, 2015). In this study, we draw on Kānaka ʻŌiwi, Indigenous, and the Declaration of Nyeleni definitions of food sovereignty to define food sovereignty as the right of Kānaka ʻŌiwi to culturally significant foods produced through

[1]http://www.youthfoodsovereignty.com/saea-conference.html

ecologically sound methods; manage and access cultural food producing regions; and define their future outside of the purview of the State of Hawai'i and U.S. federal government.

The food landscape in Hawai'i is heavily influenced by a regional food movement started in 1991 by a group of local chefs wanting to utilize locally grown ingredients (Yamashita, 2019). The chefs pushed against a Euro-American food hierarchy stemming from plantation owning families and their descendants who looked down on local food (Laudan, 1996). Influenced by a burgeoning local food movement on the Continental United States and realization that comparable or even better food could be produced in Hawaiian Islands, these chefs began to procure food from local farmers and encouraged them to ramp up production. Since 1991, Hawai'i has seen an exponential rise in marketing schemes and labeling efforts for locally grown food, more farm to table restaurants, and a consumer base that demands locally grown food (Loke and Leung, 2013b).

The regional food movement is heavily aligned with the values of food security and subsequently self-sufficiency. At the heart is also a recognition that importing 90% of the island chain's food needs is unsustainable and provides little security should a natural disaster arrive. The State of Hawai'i government and other local entities utilize the United Nations Food and Agriculture Organization definition of food security, "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2001). This is the definition of food security utilized in this study as well.

Who are Hawai'i's farmers? Farmer demographic trends mirror the historical shifts discussed previously. The count of Kānaka 'Ōiwi or Pacific Islander farmers declined by half from 22% in 1900 to 11% in 1959. Conversely, in 1900, Hawai'i's principal farmers were of Asian (56%) and White decent (22%). In 2012, the number of Kānaka 'Ōiwi or Pacific Islander farmers declined even further to 9% while Asian and White farmers held large margins at 45 and 43% respectively (Hollyer and Loke, 2014). The number of farm operators in Hawai'i increased from 2,273 in 1900 to 7,013 in 2012. An overwhelming majority of farms on O'ahu are small scale tending to plots between 1–9 acres (76%) or 10–49 (15%)[2].

METHODS

Both authors are of Kānaka 'Ōiwi descent and a part of the food system community on the island of O'ahu. Leslie Hutchins first became involved in the local food system while interning with Paepae o He'eia, a local non-profit organization restoring He'eia fishpond. Mackenzie Feldman entered the food system through working with local organizations on food system related policy. The conceptualization of this work was born out of numerous informal conversations with farmers of many different backgrounds prior to and during the COVID-19 pandemic. Combined purposive and network sampling approaches to identify and contact potential farmers was implemented (Blaikie, 2000). In all, 22 interviews using a structured questionnaire approach with farmers across the island of O'ahu were conducted during the summer and fall of 2020 (see **Table 1**). The ethnic demographic of the farmers included 10 Indigenous Kānaka 'Ōiwi (IF) and 12 non-Indigenous local farmers (LF) comprised of 58% Asian and 42% White respondents. Three additional interviews were conducted with food experts and community leaders to help contextualize the interviews and relevant food movement(s). All interviews were conducted over the phone or through online video conference services and recorded for transcription. We used Nvivo 11 to identify common themes within responses. Interview text included in the article is left in its original format to allow the usage of Hawaiian Pidgin (creole langugage spoken in Hawai'i) spoken by several respondents. The "bipartite" package in R (version 3.6.2) was used to illustrate crop distribution between farmers and consumers. A review of popular, policy, and academic literature along with suggestions from farmers was utilized to write policy recommendations.

RESULTS

Reasons to Start and Continue Farming

Although similar reasons for farming were found in both groups, there were clear differences between the two groups in the value placed on Kānaka 'Ōiwi culture and people. When asked whether food security or food sovereignty influenced their decision to start and continue farming, 9 out of 12 LF selected food security while 9 out of 10 IF selected both (**Figure 1**). Farmers from both LF and IF groups described environmental considerations such as sustainability and climate change as important in their decision to farm. Each farmer had specific reasons for starting their respective farm. However, the reasoning given by LF and IF tended to cluster with their respective group. For example, 6 out of 10 interviewed IF are a part of, or lead, non-profit organizations with in-depth mission statements and goals that seek to increase the socio-economic outcomes for the communities they serve. For example, respondent 11 stated their mission is to provide "a gathering place for people in the community to connect with and care for the 'āina (land), perpetuate Kānaka 'Ōiwi culture through the cultivation and preparation of kalo (taro, *Colocasia esculenta*), and to be a place that would ultimately bring healing to people, especially at-risk youth."

The remainder of IF suggested similar socio-economic and cultural reasons for starting to farm. Respondent 1 noted how farming kalo became a way to heal from intergenerational trauma associated with growing up surrounded by drug, alcohol, and domestic abuse. They describe working with taro as therapy: "each time my feet step into the mud, it reconnects me to my culture and myself." IF take tremendous pride in growing culturally significant crops such as taro. Respondent 13 described this best saying "our ancestors took great pride in growing the best taro. They'd want to grow the best taro to feed their children and make their keiki [children] warriors. I grow with that same pride. I want my keiki to be strong." However, IF do not solely grow culturally significant crops,

[2]https://farmlandinfo.org/statistics/hawaii-statistics/

TABLE 1 | Demographic attributes of interviewed farmers (respondents).

Respondent #	For-profit? (Yes/No)	Ethnic identity	Years in operation (1–10 years, 10–20 years, 20+ years)	Location	Farm scale [Small (1–50 acres), medium (50–100 acres), and large (100+ acres)]
1	Yes	Hawaiian	1–10	East O'ahu	Small
2	Yes	Asian	1–10	East O'ahu	Small
3	Yes	Asian	1–10	East O'ahu	Small
4	Yes	White	20+	West O'ahu	Small
5	No	Hawaiian	20+	West O'ahu	Large
6	No	Hawaiian	20+	East O'ahu	Medium
7	Yes	Asian	10–20	Central O'ahu	Small
8	Yes	White	1–10	East O'ahu	Small
9	Yes	Asian	1–10	Central O'ahu	Small
10	Yes	White	1–10	Central O'ahu	Medium
11	No	Hawaiian	10–20	East O'ahu	Small
12	Yes	Hawaiian	1–10	West O'ahu	Small
13	No	Hawaiian	1–10	East O'ahu	Small
14	Yes	Asian	10–20	East O'ahu	Small
15	Yes	White	20+	East O'ahu	Large
16	Yes	Asian	1–10	East O'ahu	Small
17	No	Hawaiian	10–20	East O'ahu	Small
18	Yes	Hawaiian	1–10	East O'ahu	Small
19	Yes	White	1–10	East O'ahu	Small
20	No	Hawaiian	1–10	East O'ahu	Small
21	No	Hawaiian	10–20	East O'ahu	Small
22	Yes	Asian	10–20	Central O'ahu	Small

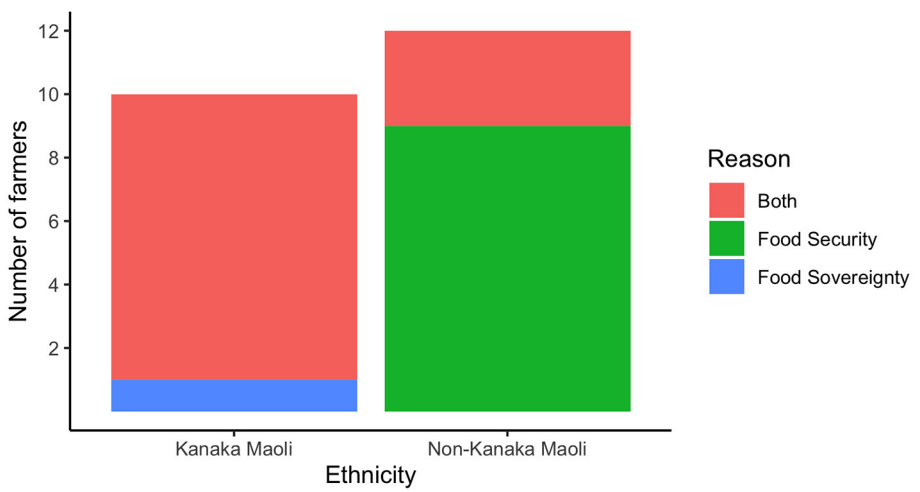


FIGURE 1 | Number of respondents who selected food secuirty, food sovereignty, or both as a reason they began and continue farming.

but also grow to fulfill market demands and cater to new preferences. Respondent 5 noted how they grow not only taro, turmeric (*Curcuma longa*), sweet potatoes (*Ipomea batatas*), and other Kānaka ʻŌiwi crops, but kale (*Brassica oleracea*), arugula (*Eruca vesicaria*), and many others because "if our Hawaiian ancestors knew about arugula, I'm pretty sure they'd grow it too."

The market is a huge factor in determining what 8 out of 10 IF and 9 out of 12 of LF decide to grow. Respondent 7 described how they grow different crops to cater specifically towards different community demographics represented in the farmers markets they serve: "the Waipahu market has lots of Filipino people, so I'll grow bitter melon and bring it to them. I cater towards Americans at the Kapiʻolani Community College and Mililani

markets, so I grow stuff for salad like kale and lettuce." Other farmers discuss tracking what sells best at their markets and shifting their growing practices accordingly. The 2 out of 10 IF and 5 out of 12 LF with grocery stores discussed the need to focus on high demand and specialty crops. Moreover, they emphasized the need to produce a consistent ample supply to provide to produce managers to keep those accounts open. Respondent 5 explained the crops provided in general are seen as an addition to the supply shipped in from outside the state as opposed to a direct substitution.

Food Sovereignty

IF see food production as a medium through which larger visions of social and political change can be achieved. Respondent 20 highlighted this saying "what we're doing—it's not only about food; it's not only about kale. We're trying to connect people to place. The food is just a byproduct of trying to get people to connect to 'āina (land)."

Access and Kaiāulu (Community)

Cultivating food provides a way for IF and community members to get their feet in the soil again and an opportunity for Kānaka ʻŌiwi crops to spread their roots once more. Eight out of ten interviewed IF host community workdays and cultural activities on their farms, where participants can harvest kalo, learn how to prepare traditional foods, and engage in various ceremonies. Their farms become key gathering places where Kānaka ʻŌiwi community members get to connect and reconnect with others. Moreover, 3 out of 10 IF highlighted how community members often interact with and eat Kānaka ʻŌiwi crops for the first time while visiting.

Many of these organizations are nested within landscapes dominated by other uses—urban, large scale agribusiness, private access—not conducive for many cultural practices. Therefore, their farms can be considered cultural kipuka (safe, regenerative places to be Kānaka ʻŌiwi). Many of their farms feed the community both spiritually and physically by growing and distributing Kānaka ʻŌiwi culturally significant, nutritious crops and engaging in cultural practices they might not be able to access otherwise. Respondent 17 solely started offering educational programs to the community because they noticed a lack of resources about how to grow and prepare Kānaka ʻŌiwi culturally significant crops. In addition, they sell culturally significant crops at a discounted price. They noted that many individuals can only gain access to their ancestral foods because of their programs.

Identity and Place

Food and the landscape it's grown in are intertwined into the identity of the people belonging to that place. Respondent 5 captured this relationship well: "there's a story behind all food and a lot of indigenous people are tied to that. It's embedded in our culture and our DNA. Food is not only something that gives you life. Food is the resilience of our people, our knowledge, and our ancestor's actions."

Community members participating in workdays are often reminded of the rich history of the landscape and its identity. For example, respondent 11 teaches community volunteers that their ahupuaʻa (socioeconomic subdivision of land) was once a famous "taro breadbasket" that provided abundance for the entire region. Respondent 6 said they share similar sentiments with volunteers about the fish grown in their fishpond: "Pauahi [a revered Kānaka ʻŌiwi aliʻi] called the mullet of our fishpond the sweetest mullet she ever tasted, and I would take her word for it more than mine, 'cause she's probably ate way more mullet than me in her lifetime than how much I've eaten. . . . the water quality and limu [seaweed] specific to our pond is probably behind the sweetness." Therefore, reclaiming Kānaka ʻŌiwi cultural identity is rooted in revitalizing the cultural landscapes across Oʻahu and ensuring their health and abundance. As Respondent 12 puts it "if we have a healthy ahupuaʻa, we have a healthy community. It takes conscious everyday actions by us and those in the community to restore the abundance of our island home."

Education

The non-profit model of IF makes education a cornerstone of their operations. By providing hands-on education with a focus on community and culture, IF hope to inspire youth to learn more about themselves and how they can uplift others. Respondent 6 described the goal of their efforts:

"The fishpond feeds us spiritually and educationally. Our job is to try to spark interest in the kids that visit. And, we do. Sometimes those kids that come here and just don't wanna step in the mud, by the end of the day, they do catch on to something. Maybe they're gonna see a fishpond in their community, and they'll be like, "we can do this. We can start somewhere. We can start building this pond." Soon enough, that pond will be feeding people. And then another pond, and then another pond, and that's how we're gonna change communities."

Education is vital to ensuring that the next generation is prepared for a successful future. Using Kānaka ʻŌiwi crops and farming practices as a model, IF offer a robust set of internship programs and funding pathways for personal and professional development. For example, respondent 11's organization offers programs for youth between ages 12 and 23. Their entry level program focuses on improving social functioning and cultural connection for at-risk youth through taro farming and mentorship from life coaches. Their advanced programs offer paid internships and apprenticeships for those in high school and college to gain value-based job preparedness.

Self Determination

Kānaka ʻŌiwi food sovereignty leads to overall Kānaka ʻŌiwi self-determination and sovereignty. Respondent 20 noted how their individual actions contribute to the greater community, "it's all about aloha 'āina. If we can do our own part for our community and teach people about our stories, about haloa as our older brother, and build connection, then hopefully the end result is self-determination." Respondent 13 described food sovereignty and self- determination being achieved through daily actions to grow, gather, and eat traditional Kānaka ʻŌiwi foods: "you can't fight for sovereignty by waving a hae Hawaiʻi [Kānaka ʻŌiwi flag] just 1 day. You have to take action all 7 days. True sovereignty is gained each time a kanaka plants taro. Each time they plant taro, they're planting a hae Hawaiʻi."

LF on Food Sovereignty: From Allyship to "Sounds Nice"

Three out of tweleve LF respondents mentioned food sovereignty inspired their farming operations. Two out of the three see themselves as allys to Kānaka ʻŌiwi food sovereignty. For e.g., respondent 4 leads an innovative extension program from their farm that buys excess harvested fruit (e.g., mangoes and breadfruit) from primarily low-income Kānaka ʻŌiwi households in the surrounding community and sells it at a discounted rate to those in the community. The program provides a secondary source of income for these Kānaka ʻŌiwi households while providing access to crops others across the island could not afford. In this way, although the farm is not operated by nor solely focused on Kānaka ʻŌiwi, respondent 4 described the programs work specifically as being rooted in some Kānaka ʻŌiwi values: "we're creating great abundance, abundance was always here. And I think it's rooted in culture. And I think it's also cultural that people don't want to waste food and that's partially why they want to share food. So our program wanted to become an extension of sharing."

When LF were asked to expand on their reasoning for not engaging in food sovereingty, their responses clustered around having no general knowledge or interest to not wanting to engage in politics. For example, respondent 15 described their lack of knowledge of food sovereignty saying "it sounds nice. Never heard of it. I grow Polynesian crops but I ain't Hawaiian or participate in the sovereignty movement." In terms of the political aspect of food sovereignty, respondent 19 explained "[I'm] just looking to do the farming, not trying to get involved in any politics. I think digging my hands in the soil is an escape for me. It's like an escape from the headlines and what not.

Food Security and Its Interaction With Food Sovereignty

A majority of LF picked food security as being a primary inspiration for farming. They see their work as a means to provide consistent access to healthy foods to the local community at all times. Respondent 14 encapsulated these sentiments: "I want everyone to have access to healthy food. If the container ships stop coming in, I'll be here to provide."

Community

Supporting local communities by feeding them is important to LF. Their focus on community is not primarily on Kānaka ʻŌiwi, but those on the island in general and in their specific town. Respondent 2 expressed their joy in feeding the community: "I love going to the farmers markets and seeing community members come by my stall. I'm doing what I am doing for them." 9 out of 12 interviewed LF do not host community workdays or conduct cultural activities on their farms. Respondent 22 gave one possible reason why this might be the case: "hosting requires a lot of organizing and coordinating that I don't have time for. I don't know how the liability and insurance works either. Maybe I'd do it in the future though."

Respondent 4 explained the main driver behind their work with the community is the realization that the food security model emphasized by many in Hawaiʻi does not seek out justice for all: "with food security, we're actually not even looking at that injustice of who is excluded from the marketplace. . . some food security advocates say we should bring food over here as cheaply as possible so that people can afford it and have it but then you're ignoring a lot of people's diets."

In terms of IF, respondent 18 highlighted food security is a matter of empowering a community where many do not have access to healthy food: "a lot of people in the community are stuck going to McDonalds and other fast-food places because that's what they can afford. People in my ʻohana [family] like most families here have a history with diabetes and other stuff like heart disease. I want to give them fresh and healthy food. The homeless kanaka on the beach, they need food now. They need that security.

Past, Present and Future Disaster

Both LF and IF brought up the importance of being prepared for disastrous situations citing past instances of hurricanes, tsunamis, and the current pandemic as key indicators of why Hawaiʻi should increase its self-sufficiency and grow more of its own food. Respondent 15 (LF) recalled past and present anxieties to localize the food system: "after the tsunami in 2011, everyone started realizing we need to grow more food here. Everyone was worried about the ports getting destroyed. This pandemic is another good example to show how we need to grow more local. The grocery shelves are getting emptied out. Where are people supposed to turn when Costco no more supplies?"

Ensuring the island is prepared for the future disasters was discussed by 45% of IF and LF. Respondent 6 (IF) described the virtues of farming in ensuring food security: "The great disaster of Hawai'i is its 7 days of food supply. If the disaster comes, we get 7 days of food. If you can farm, those 7 days don't apply to you. That's out the window. You've got a lifetime supply of food to feed you and your community."

The Taste and Feel of Local Food

A common sentiment shared by LF revolved around valuing the taste of locally grown food and the pride emmitnating from growing local food. Respondent 8 explained how they favor the taste of local food over imported food: "I always try to eat my own vegetables or the stuff my friends grow. The climate and soil here just makes everything taste better. When I need to eat stuff shipped over from California, I ain't happy. It tastes old." Respondent 19 described how growing and eating local food makes them feel like a better citizen: "I'm doing part to help the island. Feels good. My customers tell me they feel good buying my products too. They like support too."

The sentiments that local food tastes better and makes you feel better are used by LF to attract customers and potential vendors. These sentiments are shared through in-person conversations, the labeling of products, and advertisement. Respondent 9 explained an interaction they had with a new potential restaurant customer: "We market ourselves as fresh, never frozen. Most people eat frozen chicken imported from the mainland. But fresh chicken is so much better. We made a connection with a restaurant. Told them we had local chicken. They seemed skeptical at first, but then we sent a sample chicken, and they were

hooked. At first they ordered infrequently, but now they ask for chickens every week."

Two Different Solutions to the Same Problem?

Food security and food sovereignty are different food system models that LF and IF find themselves participating in. However, there are instances where these two disparate approaches intersect with each other, but only to a certain extent before widely diverging. Although 9 out of 12 LF did not see their work inspired by food sovereignty, their responses nonetheless mirror food sovereignty discourse: LF want to control local food production by increasing production, and do not want to rely so heavily on importing food, which is a main tenet of food sovereignty. Their desire to control the food system, however, is less political than IF and their focus is generally not on culturally significant crops. In addition, LF see working with the State of Hawai'i, whose food security model relates to economics and individual buying power, to create incremental change, as the primary pathway towards a more localized food system.

IF are part of a community in which many members experience food insecurity, not even gaining daily access to basic nutritious foods. Therefore, they selected food security as a model that would serve them. They focus on both short and long-term ways to feed their communities. In the short-term, IF want to guarantee continued access to healthy food to community members. However, in the long-term, IF seek to dismantle the current food system. In its place, IF want to have the power to create a new system that centers on their cultural values and teachings to determine the future of their community and food system outside the purview of the state.

Adaptations and Pivots During COVID-19

Pre-COVID-19 Production and Marketing Strategies

Prior to the COVID-19 pandemic, LF and IF experienced a broad range of economic realities. 4 out of 12 LF and 3 out of 10 IF experienced a plateau in sales due to their inability to increase production due to labor or land shortages, while 5 out of 12 LF and 2 out of 10 IF experienced exponential growth with an expansion into hotels and supermarkets. LF and IF often pursued different economic avenues to make ends meet. Due to the non-profit nature of a majority of IF, they commonly seek out external grant funding from local and federal agencies/organizations. Respondent 20, who leads a non-profit, described how they feel like a "subsidized farmer" because their organization does not rely on crop production revenue but grant sources to stay afloat. IF nonprofits rely heavily on a funding model rooted in providing educational services to the community by hosting school groups and/or local companies. Therefore, the non-profit model allows for a suite of outcomes that transcend crop production, including community upliftment. The non-profit business model also allows IF to conduct the business practices most suitable to their cultural values and community-oriented goals. Respondent 13 expressed this sentiment best: "if I were to run a business, I'd be charging $7.50 a pound for taro. Who can afford taro at $7.50 a pound? Nobody in my community." On the other hand, grant funding sources in most instances need to be reapplied to every year and provides uncertainty. This uncertainty can make long range planning and staffing difficult. In addition, when applying for funding, IF are faced with rehashing the same precarious solemn narrative about their community. Respondent 17 explained their uneasiness with this narrative: "We're trying to uplift our community. And we've made great strides in doing that, but each grant cycle, I need to talk about the poverty, the diabetes, and the dissarray. I want to start telling new stories."

Taro and poi, the primary staple food of Kānaka 'Ōiwi culture made of steamed and mashed taro, are at the center of 6 out of 10 IF operations. Therefore, the price of these products heavily influences the stability and longevity of IF. For-profit IF may have trouble when selling to the same consumers targeted by non-profit IF. Respondent 1 described their personal struggle: "the non-profits [are] doing great work, but it can be hard to sell my poi with so many competitors, especially since they have all these big grants and volunteers. I'm only here supporting myself with the money in my pocket." Respondents 11 and 13 provided more insight into the forces determining the price of taro and poi explaining that large scale commercial producers from other islands, such as the Hanalei region of Kaua'i, use highly intensive practices and cheap labor to produce a surplus that they then sell at an extremely discounted rate (∼70 cents/lb as opposed to the $3–5/lb sought by the respondents).

LF expressed similar issues with large scale commercial production as well. Respondent 7 has seen their fellow vendors at the farmers markets they serve selling produce shipped from the US and abroad instead of locally grown food. They further explained that these vendors can sell their produce at a cheaper price point. 10 out of 12 are for-profit and sell their produce at various markets.

Three out of 10 IF and 6 out of 12 LF pursue secondary sources of income by gaining employment in establishments such as restaurants and engaging in ecotourism by leading farm tours. Engagement in these activities mainly contributes to household income and not necessarily maintaining farming operations. Those engaged in these secondary income activities emphasized the importance of these activities in allowing them to continue farming. Although 59% of IF and LF expressed good economic health trends, profitability and paying down debt were issues brought up. Farmers expressed that although their sales were increasing, they were still only breaking even due to farm costs and paying down existing debt taken on to purchase equipment or land.

Adapting to COVID-19

Prior to COVID-19, the crops produced by LF went to a wide assortment of consumers (**Figure 2**), with farmers markets, restaurants, and high-end restaurants being the primary recipients. However, during COVID, LF experienced a contraction in their consumer base and a pivot in where most crops went, with community-based pick-ups and CSA (Community Supported Agriculture) programs becoming a major recipient. Farmers with restaurant accounts experienced a 70–90% drop in orders. For example, respondent 3 (LF) experienced a retraction of all their restaurant accounts: "All my sales were going to a handful of restaurants in Waikiki. I lost all

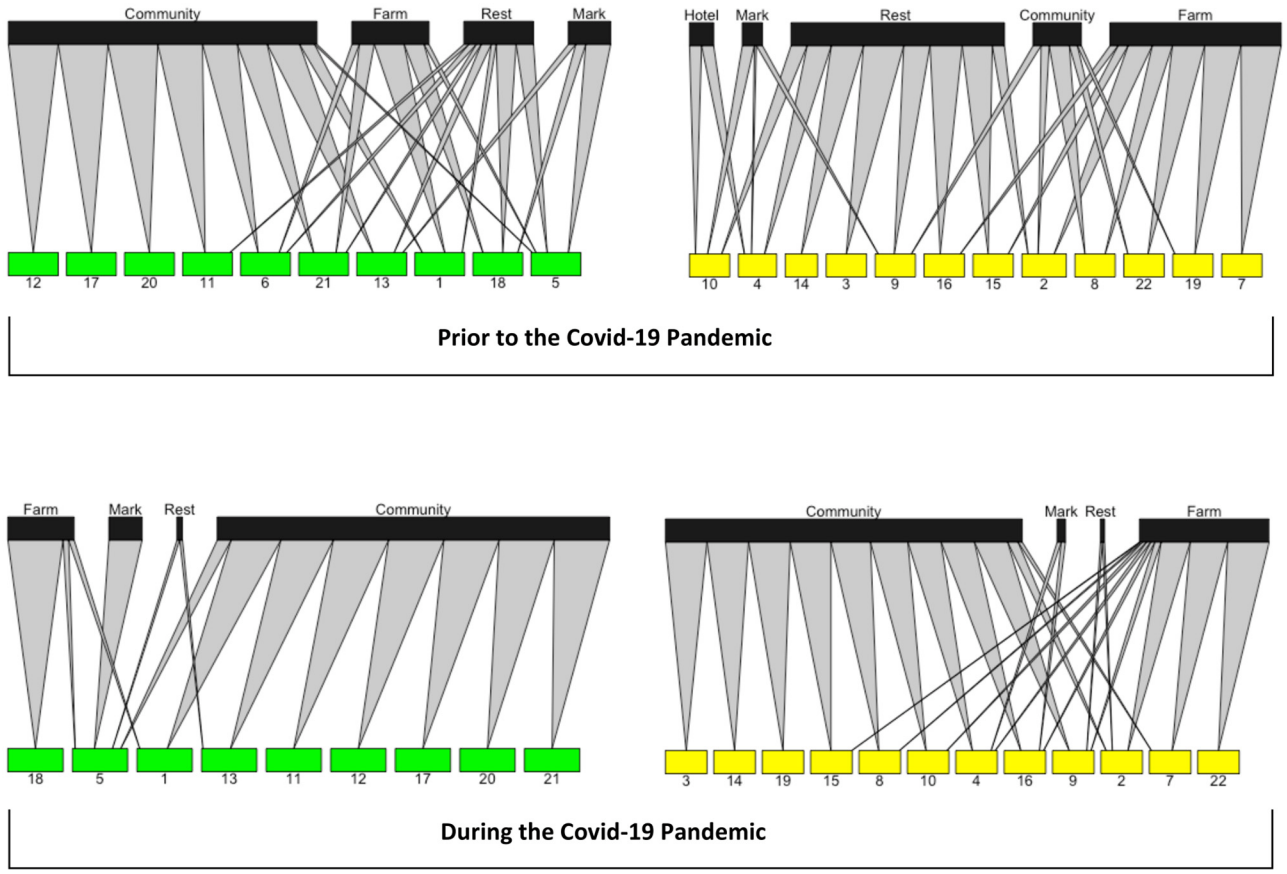


FIGURE 2 | The distribution of crop sales between each respondent [lower boxes; green = Kānaka ʻŌiwi Farmers (KF) and yellow = Non-Indigenous Local Farmers (LF)] and different consumer base types [community (e.g. CSA boxes, farm pick ups, and donations), supermarkets (Mark), farmers markets (Farm), restaurants (Rest), and hotels] prior to and during the COVID-19 pandemic. The links between the two represent the proportion of pounds distributed to that consumer base relative to the overall pounds harvested by each respondent.

of those accounts. A couple of CSA services approached me and now I got a bump in sales. I don't know how long it'll last."

Crops produced by IF went overwhelmingly to community-based pick-ups, with farmers markets and restaurants also being significant recipients (**Figure 2**). During COVID, community-based pick-ups and CSA programs became an even more overwhelming recipient of crops receiving the excess associated with the retraction of farmers markets and restaurants. Recipient 22 (LF) described farmers markets remained an important source but many of them temporarily closed: "I go to two farmers markets weekly. The busier market I rely on is temporarily closed. Hope it opens back up soon. I'm harvesting and selling less in the meantime. One market is keeping me afloat for now—barely."

The impacts of the COVID-19 pandemic required almost all farmers to innovate and change their business model. As the local population began to seek out opportunities to avoid in person contact in grocery stores and honor the idea of buying more local, farmers set up online sales platforms, "drive- thru" pick up options, and joined or created their own direct to consumer CSA programs. LF and IF both benefited from the uptick in community sales, seeing a 2–5-fold increase in CSA based subscriptions. However, the drastic increase in demand for CSA services has not been a golden opportunity seized by all. Farmers that do not already have the infrastructure in place or the resources to acquire it may be at a disadvantage. For example, respondent 7 primarily relies on a two-to-four-person work crew and could not keep up with the demand from CSA services. Since they did not have the capital to pay more workers, they had to stop production for CSA accounts all together.

Respondent 4 (LF) and respondent 17 (IF), both of whom focus on food security and food sovereignty, did not need to change their business model, they instead ramped up their pre-pandemic strategies. In addition to growing their own crops, they procure crops from other small-scale farms and act as a hub of distribution. Respondent 17 explained how their work has enabled many small-scale farmers to continue operations throughout the pandemic:

"Prior to the pandemic, we were buying from maybe eight farmers, but now we are up to around 15 every week. That has increased our distribution from 500 pounds to 2,000 per week. The farmers are from all over the island. A couple of them

have said we are solely contributing to their persistence. It feels good to help out but its heavy knowing we are their lifeline at the moment."

The pandemic proved to be troublesome for IF non-profits that rely on volunteer help and received income from education programs as well. As schools and summer programs moved to online platforms and the State of Hawai'i implemented restrictions on group gathering, income revenue from education sources declined. Moreover, the volunteer help often needed to complete laborious tasks disappeared. IF expressed anxiety in terms of grant money drying up due to the economic crisis, thus either eliminating significant sources of funding or making them even more competitive to receive. Respondent 12 and 21 have started to consider implementing new production-oriented funding models, such as increasing crop acreage and acquiring more land.

Four out of 12 LF and 8 out of 10 IF mentioned inter-farm relationships became especially important to gain advice on how to adapt to and sell their crops during the pandemic. For IF, this involved relying on relationships that have been forged and tended to over many years. Prior to the pandemic, inter-farm visits between IF commonly occurred. During these visits, farmers from two or more farms would come together to complete a large task or learn how to care for a unfamilar crop. During the pandemic, these visits shifted towards picking up the extra slack from a lack of volunteer help and perpetuating a sense of community between farmers. For LF, the pandemic provided inspiration to reach out to fellow farmers they had not spoken to years or ever. Their discussions centered on discussing what markets are open, what crops are popular, and how to operate with CSAs in mind. Both IF and LF found avenues within their respective communities or between their communities to make joint value-added products or incorporate each other's products in CSA boxes.

Food Security and Food Sovereignty Resiliency

Throughout the pandemic, three IF have led large initiatives to give out free taro and sweet potato cuttings to the community. They have done so by organizing drive thru events and community pickups. Each person that shows up receives a handful of cuttings they can take home and grow in their own garden. Respondent 1 discussed the importance of providing cuttings: "This is to create more resilience for our Kānaka 'Ōiwi families out there. They can take the huli [taro cutting] plant them and it'll grow a corm they can eat and keiki [off shoots] they can plant. They can even give the keiki to more 'ohanas so they can grow too. It's like that old saying: Give a man and fish and they can eat for the day. Teach him how to fish and he'll eat forever."

IF have experienced less of a pivot in crop distribution in comparison to LF. The focal recipient of their crops was community both before and during the pandemic. Moreover, the strong value placed on forging relationships with others in the community has proven to be an invaluable source of work aid and crop sales. However, IF with a non-profit funding model are facing some form of financial instability now and into the future. LF experienced a greater pivot in distribution in comparison to IF, as the restaurant accounts they relied greatly on closed abruptly. However, CSA programs have improved their stability through the pandemic. Three LF discussed forming a relationship with food bank programs in the State of Hawai'i during the pandemic. Respondent 23 pointed out the complexities in such a relationship: "The Hawai'i Foodbank is doing great work to get food to people. Lots of farmers I work with have been delivering crops to the foodbank. And we all want to continue to help but they want to buy their crops at a pretty discounted rate. I don't know how long they could sustainably give a bulk of produce to them at that price."

The relationships formed between the farmers and food banks, and the formation of the food banks themselves, are centered on food security and localization. Food security on O'ahu has and is currently keeping farmers afloat, but has not exactly enabled them to be resilient and thrive economically. Food security initiatives are essential in providing food to the community, especially during rough times, but it is more of a response to a dysfunctional system than a pathway for long term resilience. IF have deployed food sovereignty strategies and from a standpoint of crop distribution pivoting and relationship strength have shown greater resiliency through the pandemic. As the pandemic continues and as the island moves forward into the future, both IF and LF can work together to overcome challenges, become more resilient, and feed the local and Kānaka 'Ōiwi community at different time scales. Many of the aspirations of IF, and the food sovereignty movement in general, are a long-term undertaking that cannot easily be met in the short term. Food security provides a short-term solution to address some food system problems but does not meet the overall goals of LF and IF in the long term.

Future studies might include a larger respondent size and an inclusion of more for-profit Kānaka 'Ōiwi farmers. As the study went on, we found it increasingly relevant to interview non-profit IF, partially due to the sheer number of them, but also because we found it to be the model most conducive to their values and mission. However, keying in on the struggles of the for-profit IF may illuminate additional or contrasting values to the non-profit IF. In addition, since this study was conducted during the summer of 2020, future work might capture the later impacts of the pandemic on farmers and their recovery.

CONCLUSION: INTEGRATING FINDINGS INTO POLICY

We conclude with suggestions that state and federal agencies and local organizations could implement to support farmers from different backgrounds through COVID-19 and into the future. During discussions with farmers, sentiments of wanting to see change happen through a

shift in policy was brought up frequently. These policy pathways are centered on increasing food supply chain access; and mitigating financial and bureaucratic barriers. It should be recognized that these policy and broader food system shifts will require a sustained effort by all parties to be realized.

IF are currently seen as essential sources of place-based education for the local community as a whole. However, these sites should also be seen as key producers and suppliers of culturally significant foods. Legislation intended to expand the Hawai'i farm to school program (Act 218, Session Laws of Hawai'i 2015) and meet current goals to source 15% by 2025 and 30% by 2030 of public-school meals locally should require a portion of each percentage to be acquired from IF. This would be especially helpful for IF non-profit organizations seeking to diversify their financial portfolio to focus on education and production due to pandemic related hardship. This will allow Kānaka ʻŌiwi children, who represent the single largest ethnic group in Hawai'i public elementary and secondary school student population, to gain access to culturally significant foods they might not otherwise encounter at home (Goodyear-Kaʻōpua, 2013). In addition, the expansion of the program will further uplift the numerous LF that already participate.

Loans and microloans are valuable to farmers looking to invest in new infrastructure, acquire land, implement innovate crop plans, and meet food safety and processing standards. However, eligibility and high interest rates have long been a barrier. Legislation to expand loan programs with increased eligibility and lower interest rates for farmers could prove pivotal to many pivoting and rethinking business plans through and after the pandemic. Likewise, partnerships between State of Hawai'i, federal, and private partners to expand grant programs and their scope could be especially beneficial (Croix and Mak, 2021). In addition to expanding loan and grant programs, dedicated support and education should be provided to farmers to help them understand what they qualify for and how to complete successful loan and grant applications. Respondent 9 discussed their interest in expanding their business but felt held back because of the grant application process: "I want to venture into the realm of making value added products. The opportunity is there, but I am limited by money and time. I see grants pop up here and there that could be helpful. I don't even know how to go about applying for one—what do I write?"

For IF and the Kānaka ʻŌiwi community, gaining access to ancestral lands to restore cultural food producing regions and increase the abundance of culturally significant foods is a priority. Efforts to restore abundance and gain access to sites have long faced bureaucratic barriers erected by the State. Many cultural food producing regions are zoned for conservation or exhibit a need for more formal community oversight and cultural values to ensure persistence of abundance. Therefore, communities often go through community-based subsistence fishing areas (CBSFAs), Memorandum of Understanding (MOU), or seek administrative rule changes to gain access to an area and engage in co-management. These processes often involve unequal power relations and a disregard for different world views and data types (Ayers et al., 2018). While there have been legislative wins (see Hobart, 2017; McMillen et al., 2017; Vaughan et al., 2017), the time, effort and adherence to bureaucratic red tape required to achieve those wins has often minimized their scale and efficacy (Vaughan and Caldwell, 2015). Legislation to streamline bureaucratic barriers and designate additional CBSFAs and carry out more MOU sought out by communities should be considered. In addition, amendments to conservation zoning should be done to encourage the efficient use of conservation lands for Kānaka ʻŌiwi food production now and into the future. This recommendation, however, represents incremental change within the existing governing structure of the state. The sovereignty movement that many IF and those in the broader Kānaka ʻŌiwi community engage in seeks land restitution and greater political autonomy. Therefore, for the goals of Kānaka ʻŌiwi food sovereignty to be fully realized, state and federal officals must engage in meaningful dialogue with Kānaka ʻŌiwi communities to initate pathways towards land restitution and political sovereignty. Until these actions take place Kānaka ʻŌiwi community members will find themselves in a contentious position in trying to realize feed and empower their communities.

These policy suggestions and the main findings of this study provide academics, policy makers and public servants, community leaders, and food system practioners with an up-to-date analysis of a diverse local food system comprised of Indigenous and non-Indigenous community members impacted by COVID-19, along with actionable strategies for achieving resilience and equity for all members of the community. We specifically focused on farmers values associated with food sovereignty and food security, and the degree of resiliency each provides through the COVID-19 pandemic. Both groups of farmers shared similar values when it came their reasoning to begin farming and providing food to the community, but they diverged on their specific focus, intentions, and envisioned futures. IF values are associated with food sovereignty. They are focused on revitalizing their cultural practices and crops while uplifting Kānaka ʻŌiwi communities. IF are utilizing food as pathway towards greater political sovereignty. LF values are associated with food security. They are focused on feeding local communities and are not focused on growing culturally significant crops. LF seek to work with the State to achieve greater food security. LF and IF interacted with different subsets of consumers prior to the COVID-19 pandemic, with the community being the primary recipient of IF crops, and restaurants the main recipient of LF crops. As the impacts of the pandemic took hold, both LF and IF had to adapt and show resilience. IF pivoted less of their crop distribution and relied on established relationships with other IF to adapt. LF pivoted a lot of their crop distrubution from restaurants to community based programs. Both LF and IF face barriers in continuing to operate during the pandemic and into the future. However, both groups have a vision for a better agricultural future that will require consistent participation between themseleves, political representatives, and other related programs and officials. Policies that uplift both groups and their associated values through the pandemic and into the future should be considered. These policies should be centered on food supply chain and land access,

financial and bureaucratic barriers, and fostering relationships among farmers.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by UC Berkeley Committee for Protection of Human Subjects Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

LH conceptualized the study, analyzed the data, and wrote the first draft. Both LH and MF conducted interviews and edited manuscript drafts. All authors contributed to the article and approved the submitted version.

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Achieving Food System Resilience Requires Challenging Dominant Land Property Regimes

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Although evidence continues to indicate an urgent need to transition food systems away from industrialized monocultures and toward agroecological production, there is little sign of significant policy commitment toward food system transformation in global North geographies. The authors, a consortium of researchers studying the land-food nexus in global North geographies, argue that a key lock-in explaining the lack of reform arises from how most food system interventions work through dominant logics of property to achieve their goals of agroecological production. Doing so fails to recognize how land tenure systems, codified by law and performed by society, construct agricultural land use outcomes. In this perspective, the authors argue that achieving food system "resilience" requires urgent attention to the underlying property norms that drive land access regimes, especially where norms of property appear hegemonic. This paper first reviews research from political ecology, critical property law, and human geography to show how entrenched property relations in the global North frustrate the advancement of alternative models like food sovereignty and agroecology, and work to mediate acceptable forms of "sustainable agriculture." Drawing on emerging cases of land tenure reform from the authors' collective experience working in Scotland, France, Australia, Canada, and Japan, we next observe how contesting dominant logics of property creates space to forge deep and equitable food system transformation. Equally, these cases demonstrate how powerful actors in the food system attempt to leverage legal and cultural norms of property to legitimize their control over the resources that drive agricultural production. Our formulation suggests that visions for food system "resilience" must embrace the reform of property relations as much as it does diversified farming practices. This work calls for a joint cultural and legal reimagination of our relation to land in places where property functions as an epistemic and apex entitlement.

Keywords: food system transformation, food sovereignty, agroecology, resilience, property regimes, land tenure, land reform

INTRODUCTION

Although evidence continues to indicate an urgent need to transition food systems away from industrialized monocultures and toward agroecological[1] production (IPES Food, 2016; Clapp and Moseley, 2020), there are only few signs of significant policy commitment toward food system transformation in global North geographies (Lang et al., 2018; Pe'er et al., 2019). We, a consortium of scholars studying the land-food nexus, argue that reticence to directly confront the logics of global North[2] property regimes is a key lock-in that waters down food system reform ambitions. In a lock-in scenario, a dominant technology or socio-technological system creates a pattern of path dependence, excluding alternative technologies (like agroecology) even if the alternatives are superior, demanded by citizens or other actors, or indicated by scientific evidence (Vanloqueren and Baret, 2009). Private property norms in many global North contexts presents a structural challenge to the emergence of an equitable and resilient food system.

In such geographies, private property regimes take the form of a strong "ownership" or "castle-and-moat" style (Sax, 1993; Sax, 1451), distributing authority of decision making to rights holders, dispensing capacity to adapt to current owners of property and their heirs, and entrenching incentive structures aligned with forms of exploitative and exclusionary resource use (Shoemaker, 2021). These regimes present an intractable tension between individual liberties guaranteed by the state and the urgent structural changes required of a food systems transition. For the food systems of the global North, a landscape of competing private farmland businesses makes systematic behavior change counter intuitive (van der Ploeg et al., 2019) while simultaneously encouraging trends of farmland consolidation, market articulation (Thorsøe et al., 2020), asset financialization (Howard, 2016; Fairbairn, 2020), and narrowing rural succession patterns (Calo, 2020a).

The allocation and maintenance of property rights is a core function of Westernized liberal state-making (Sikor and Lund, 2009), which may explain the reticence for direct reform of property relations even if changes in land use is a consensus policy choice (Trauger, 2014). Fundamentally, agroecology operates through ecological and social interdependencies at the farm, field, landscape, and governance levels. The forms of collaborative land and resource access regimes like commons, collectives, and solidarity markets that tend to be associated with emblematic models of agroecology (Miery Terán Giménez Cacho et al., 2018) contrast with the atomized and competitive logics of land divided into parcels with strongly guaranteed individual rights. Proposing new access regimes that encourage land use consistent with agroecology therefore challenges the legitimacy of the state, rendering such policy ideation unattractive.

While the connection between land governance and food systems has long been an important area of research (Wittman et al., 2017), research on agricultural land reform policies or land tenure innovations has largely been relegated to the global South, whereas states in the global North rarely challenge the socio-legal commitments to property (Borras and Franco, 2012). Instead, food system reform efforts often choose (implicitly or explicitly) to operate *through* dominant logics of property to achieve their objectives, like the use of easements to protect farmland from development (Morris, 2008), the use of certification schemes (Guthman, 2009) and the policy dominance of ecosystem service frameworks that aim to incentivize change amongst existing agricultural land owners (Büscher and Fletcher, 2019). It is within this property context that application of resilience thinking to food systems tend to unfold, in which the relative power of human actors to adapt to change is subsumed by technical analysis, the goal of community self-reliance abdicates state action (Cretney, 2014) and the singular scales suitable for analysis elides the cross-scale forces that may prefigure adaptability and present lock-ins (Olsson et al., 2014).

We argue that agroecology has failed to scale up when linked with dominant property models because of two key reasons. First, agroecology's alignment to collective use rights stands in direct contrast to the primacy of private property relations in late-stage capitalist economies. Second, concentration of ownership and/or access, and rising farmland prices restrict access for small scale farmers who seek land for diversified farming operations (van der Ploeg et al., 2015). These contradictions between agroecological transition and property relations endemic to developed economies have not been adequately highlighted.

Research on agrarian transition in the global South shows how formalization of land tenure to global investment capital changes the social, environmental and economic dynamics of local food systems (Akram-Lodhi and Kay, 2010). Research shows how land access is negotiated through informal power relations (Ribot and Peluso, 2009), how logics of "under-utilized" land enroll the state in large-scale contract farming (Li, 2011), and how movements of dispossessed peoples deploy counter logics to secure new land rights (Desmarais, 2002; Anthias, 2018). This work focuses on the penetration of capitalist farming relations into non-capitalist land tenure relations like common lands, Indigenous territories, and areas of shifting cultivation (Hall et al., 2011). In the global North, however, the centrality of agricultural land tenure has faced less scholarly scrutiny establishing a pattern where: "understandings of land were largely neglected in agrarian studies, unless land was 'othered'" (Sippel and Visser, 2021, 272). The aim of remaking land tenure to foster food sovereignty and agroecology amidst a seemingly settled system of property rights (Bromley and Hodge, 1990) poses numerous unanswered questions.

[1]Agroecology is a process to meeting food production needs through complex working landscapes that encourages the maintenance of biodiversity as a tool to reduce the need of off-farm inputs. While agroecology began as a study of the agronomic ways certain food systems could produce nutrient dense, culturally relevant diets with low external inputs, it has expanded to include the types of social relations and governance regimes that support and expand these forms of food production, indicating new emancipatory labor and market relations brought forth via social movements and policy change.

[2]We recognize the term global North may be unhelpfully homogenizing, but is an improvement on terms such as developing and developed. We take the term global North to generally indicate geographies with Western-liberal political ideologies, higher comparative per capita gross domestic product, and service-oriented economies. For the purposes of our paper, we aim for the term to conjure locales where the strong ownership model of property is expressed in the law in the social mind.

Instead of working through the logic of property, we argue that visions for food system resilience must embrace the reform of property relations as much as it does diversified farming practices. Direct engagement with property relations will help to advance resilience thinking to engage with the more transformational domains of power, agency, and politics (Olsson et al., 2014). At the same time, we recognize that there may be some "non-reformist reforms" that create spaces for alternatives to emerge (Gorz, 1964). Squarely addressing the socially constructed rules of property relations that distribute the assets forming the basis of the food system is central to understanding and then providing the "how" of food system transformation.

TOWARD A LAND LOGICS FRAMEWORK

Our perspective complements recent work that similarly centers the role of land in differing dimensions of food system reform. Kepkiewicz and Dale (2018) demonstrate how goals of food sovereignty are incongruent with the legal underpinning of settler colonies like Canada, and that land must be decolonized and repatriated before food justice objectives can be realized. Borras and Franco (2012) put forth the concept of "land sovereignty" as an underdeveloped aspect of food justice literature, although their focus is more the global South. Sippel and Visser's (2021) concept of "land imaginaries" demonstrates how narratives and imaginaries of what land is, can, and should be, are central to reworking land use arrangements, whether into new, financialized or more equitable, non-capitalist/non-property-based forms. Shoemaker (2021) analyzes the relationship between the way property is legally constructed and how this leads to racial injustice in the US rural sector. Importantly, Horst et al. (2021) attempt to advance a "land justice" research agenda through the mechanisms of international comparison and dialogue.

We aim to add to this percolating attention toward the logics of land and property as an upstream element of meaningful systems transition through a brief exploration of emerging international cases where the "ownership" model of property is usually entrenched. We show how a focus on the logics through which land is used, accessed, valued, and controlled provides insights into how food system transformation visions hinge on the ways property regimes are expressed or contested. This method of examining the "land logics" that may prefigure pathways of agrarian transitions emerged from series of international collaborations between the authors who found that their central concern of advancing food system transformation in a global North context was repeatedly confounded by entrenched land property regimes—and the associated need to put this much more prominently on the research agenda. We thus set out to develop an initial comparative case analysis—based on our respective geographical foci—from the standpoint of identifying how property regimes condition food systems change potential.

In the first two cases, contestations over large-scale and/or foreign agricultural land acquisitions have led to a reinvigoration of the national significance of land with states altering their legal frameworks for the acquisition of land by foreigners or by corporate actors (e.g., Fairbairn, 2015; Desmarais et al., 2017; Sippel and Weldon, 2020). Cases from Australia and Japan demonstrate how the state, facing pressure from civil society groups to address increased land acquisitions and concerns over food security, may leverage legal, and cultural norms of property to legitimize their control over the resources that drive agricultural production. The effect is the deployment of property norms to shut down alternative land governance and food system reform pathways.

Land struggles have also triggered political mobilizations and resistance. Cases from Canada, France, and Scotland are indicative of "counter movements" against increasing farmland financialization, restricted access, and consolidation through a diversity of land reimaginations and provide a unique opportunity for novel thinking on the relationship between property and agroecology. These cases demonstrate the power of a joint cultural and legal reimagination of our relation to land in places where property functions as an apex entitlement.

INTERNATIONAL VIGNETTES—CENTERING PROPERTY REGIMES IN LAND FOOD NEXUS ANALYSIS

Australia—A Reinforced Neo-Nationalization and Financialization of Farmland

Between 2010 and 2015, the Australian government revised its legal regime with regards to foreign investment in Australian farmland (Sippel and Weldon, 2020). This revision was both part and result of a broader public debate surrounding what some considered to be the "selling out" of Australian farmland to foreigners. This highly politicized debate emerged against the backdrop of the financial, food price, and energy crises in 2007/08, and the subsequent increase of foreign interests in acquiring Australian farmland. While the geographical origins of investors played an important role—investors from the Middle East and China were especially scrutinized—the debate also addressed the (assumed) motives behind investments, their market orientation, the loss of control over resources to foreign sovereign powers, as well as nationalistic sentiments. In essence, the revision has allowed the state to expand its control over the process of foreign land acquisitions, together with an increased support for Australian ownership of land. This specific combination of national control over the land-buying process, coupled with an emphasis on Australian national interests and land ownership within a neoliberal governance structure, can be interpreted as a "neo-nationalization" of Australian resources. The prominent and contested sale of S Kidman—Australia's largest agricultural business in terms of the size of its property—in 2016 to Australia's richest person (as majority owner) was emblematic of this neo-national land governance and its distributive mechanisms, which give preference over ownership to wealthy nationals' and national interests. What is more, given the problematic character of (some) foreign investments, new substantial sources of capital are needed, which

blend flawlessly with the "moral economy" of the neoliberal regime while responding to the urge for "nationalization" (Sippel, 2018). Australian superannuation capital, similar to a corporate pension plan in a US context, was identified as such a "perfect match." In an interesting twist, the neo-national land governance is thus going hand in hand with a reinforced financialization of farmland, where the investment of domestic superannuation capital has emerged as a moral imperative to keep farmland in "national hands."

Japan—Fading Farmers and the Entry of Corporate Agriculture

As a super-aging society experiencing massive depopulation, Japan faces multiple challenges to maintain rural infrastructure and agricultural lands. About 40% of farmland occurs in mountainous areas, characterized by poor soils, and small, fragmented tenant farms. The result is that 33% of Japanese hamlets are extremely aged (average age 65 or older) and agricultural land is abandoned or left fallow. To ease this trend, the Japanese government has developed mechanisms and strategies to attract and support new farmers and reform the sector (McGreevy et al., 2019). However, regulatory measures that govern land ownership and distribution embrace a logic that seeks to erode long-held protections for local governance, and promote corporatization and large-scale, industrial agriculture (Jentzsch, 2017).

The national government encourages corporate investment in the agricultural sector via the 2009 Agricultural Land Law amendment. With the amendment, agricultural land leasing was no longer limited to agricultural cooperatives and individual farmers, but open to corporate leasing, provided that the farmland is used for production. This jump-started corporate entry into the agricultural sector. Notably EON, Seven and I Holdings, and Sumitomo Chemical Co. Ltd. have opened their own agricultural farms, all claiming, in their own way, commitment to environmentally friendly and safe food production (Hisano et al., 2018). The amendment increased the role of direct investment and management of agricultural land by these corporations, expanding vertical integration in the sector. In addition, prefectures are encouraged to centralize the leasing of agricultural land through the use of "land banks," a measure enabled by the Agricultural Land Bank Act in 2014. This initiative was designed to make it easier for landowners to lease their farmland, and for newcomers to find farmland. Most of all, it was intended to support further consolidation of farmland into larger, contiguous parcels. While such consolidation trends are contributing to the improved use of underused farmland, there are growing concerns and lack of research on enclosures of the most productive land, exploitation of rural farm labor, and other predatory practices deepening the corporatization of Japanese agriculture.

Canada—Attempts to Maintain Collectivity and Multifunctionality of Grazing Land

Canada's agri-food system is highly industrialized and export-oriented. While key links in the agri-food chain are controlled by large corporations, the vast majority of agricultural land is privately owned and 97% of farms are family owned (Statistics Canada, 2016). In recent decades, average farm sizes have increased significantly, and land ownership is now markedly more concentrated (Qualman et al., 2020). Facing tight profit margins, many farmers maximize production by tilling native grasslands, filling in wetlands, and deforesting their land. Economic pressures coupled with the private property model impede a more multi-functional and ecological approach to agricultural land use.

An important exception exists in the legacy of the federal community pasture system. Established in 1935, it managed over 2.3 million acres of sensitive public land in the prairie provinces with the aim of providing livelihoods to ranchers, preserving the soil, protecting threatened species, and providing access for recreation. In 2012, the federal Conservative government ended the program, creating a risk the land would be privatized. However, ranchers, hunters, conservationists, and others united to resist privatization and, ultimately, provincial governments kept the land publicly owned, leasing it to private and non-profit grazing collectives. These collectives have partnered with conservation organizations that provide funding to help ensure stability of tenure, public access, and wildlife habitat. In short, the collectives seek to preserve a multifunctional understanding of prairie grasslands as a public good. This civil society driven model, while encouraging, faces challenges including unstable funding and changing priorities of partners. We suggest that the community pastures model provides an avenue for reimagining agricultural land in the public interest and for facilitating land access and ownership changes that foster agroecology.

France—A Renewed National Debate About Farmland Management and Property Relations

In France, a parliamentary taskforce was established in 2018 to prepare legal reforms on farmland management. It has discussed the capacity of farmers and current agricultural land management tools to deal with the issues of land concentration and financialization, farmers' generational renewal, and land conversion to development (Petel and Potier, 2018). It has proposed legal innovations and invited local stakeholders to experiment with them before the potential law reform, recently postponed until after the 2022 general elections. Another parliamentary taskforce reported in 2020 on possible updates of the *fermage* lease, which guarantees strong protection to the tenant (i.e., including long term lease, automatically renewed and transferred to children, and a right of pre-emptive purchase), but which is increasingly questioned.

Indeed, France has an established history of the state mediating property relations concerning agricultural land use, dating from the 1960s. As a result, existing farmers benefit from secure land tenure without the need to buy expensive farmland (Baysse-Lain and Perrin, 2018). The sub-national committees which control land transactions (i.e., sales and rents), such as the *Société d'aménagement foncier et d'établissement rural* (SAFER), involve mainly local authorities and farmers representatives. Even though SAFER committees engaged more diverse stakeholders in 2005, their decisions and representativeness are often debated by farmers and their

representative bodies, NGOs, or community groups seeking to maintain or gain land property-rights and ownership. Recent criticisms concern the inability of such sub-national committees to avoid land asset financialization and to support more agroecological farming practices. Protagonists of the agroecological transition create, manage, and call for a range of alternative land tenure arrangements. For instance, since 2009, the civil society organization *Terre de Liens* has deployed unique financial instruments (e.g., civic investments, donations, etc.) to hold over 6,400 ha of land (225 farms) in a quasi-common trust for ecologically sustainable agricultural use. Urban local authorities also rent public land to new-entrant farmers willing to develop agroecology and short food supply chains in peri-urban areas, where access to land is otherwise very difficult for those with non-farming backgrounds (Perrin and Baysse-Lainé, 2020). Such alternative land-tenure systems contribute to debates surrounding the pending land law reformulation and the possible impacts of property relations and land governance mechanisms on food system transition (Baysse-Lain and Perrin, 2018).

Scotland—New Rights for Community-Driven Compulsory Purchase

The Scottish First Minister, Nicola Sturgeon, has stated that: "*Scotland's land must be an asset that benefits the many, not the few*" (see also Scottish Government, 2014; Black, 2016). A suite of far-reaching land reform Acts is now law in Scotland following a wave of legislation between 2003 and 2016. These Acts and policies aim to promote fairness, social justice and economic revitalization of rural areas *via* the creation of new entitlements to land (Scottish Government, 2020). The key power of the Acts revolves around a "community right-to-buy," affording a community body the first right of refusal over rural and urban property (Lovett, 2010). In the case of crofting[3] communities and sustainable development, these rights become absolute (Ross, 2020). These powers support a goal of the current devolved administration to transfer land from public and private ownership to ownership by local community bodies, due in part to the highly concentrated pattern of private landownership in Scotland[4].

The latest phase of the Land Reform Act (Scotland) 2016 ("Part 5") facilitates compulsory land sales to community bodies where it is considered that the transfer of ownership will further the achievement of "sustainable development" in relation to land, and where maintaining the status quo is considered "harmful" to the local community and the public interest. Land reform legislation, the resulting community activism (Combe, 2020), and the Scottish Government's official discourse toward the "right" use of land has provoked fresh debate about the virtues of property entitlements, and how to decide who benefits from the land (McKee, 2015; McCarthy, 2020).

The limitation of the new legislative landscape arguably remains the lack of integration with other national policy goals, with regard to climate change, rural renewal (e.g., focusing on depopulation, rural housing, and employment), and crucially, food policy. The opportunity arises, albeit untested, for the "Part 5" legal powers to imagine transfers of land for the purposes of small-scale new entrant land access and agroecological production.

DISCUSSION AND CONCLUSION

The international cases above demonstrate the way norms of property act as an upstream driver of agricultural land use. In some cases, like in Australia and Japan, a virtuous logic of private property is deployed to shore up farmland for investment and consolidation, closing down pathways for new land governance regimes inclusive of demands for agroecological transformation, such as those made by the Australian Food Sovereignty Alliance (http://afsa.org.au/). The vignettes from Canada, France, and Scotland, show how attention to identifying new socio-legal logics of property open up cracks in the capitalist agrarian system and offer a chance for agroecology to flourish within.

The cases demonstrate a diversity of approaches to contesting dominant land relations that reflect a creative use of both existing and novel legal maneuvers (i.e., legislative reform, preservation of the common form, regulation of land use, preemptive, and absolute rights). These contestations occur amidst a socio-political context marked either by inherited strong inequities (Scotland) or by accelerating corporate dynamics leading to "contemporary" inequities (Canada, France), with distinct narratives and rationales motivating change. Where a challenge to entrenched property regimes appears, the role of the state is crucial, deploying an intervention in land relations to achieve potential agrarian reforms, rather than relying on market-based interventions (Holt Giménez and Shattuck, 2011).

Even though the conditions and scale of production differ widely, the Australia and Japan cases show how entrenched property regimes can inhibit more equitable pathways to food system reform. These regimes may be able to respond to increasing environmental demands for narrowly defined resilient agriculture, but may reproduce land access inequities that prevent meaningful agroecological transition (Holt-Giménez et al., 2021). Here the role of the state is also central, but instead of citizen- led reform, a path toward an entrenched ownership model of property regimes is favored.

We argue that these cases show how technical interventions to promote food system resilience must be coupled with land tenure counter movements, else be stymied by the socio-legal power of property entitlements (Blomley, 2005). Without such attention to challenging the dominant property imaginations of the global North, the resilience concept fails, as it's critics suggest, to support processes critical to transformation, such as rejecting stable yet unequal socio-ecological systems, clarifying the role of state politics in generating adaptability for some, and analyzing how agency is formed in terms of capacity to adapt to harmful change (Olsson et al., 2014). Instead of purely technocratic calls

[3]Crofting is a form of small-scale land tenure that is specific to the North, West and island regions of Scotland. Crofters are guaranteed pre-emptive rights to the land as long as the land is use for productive use, usually for food or fiber production, although this was recently expanded to other rural economic activities. Crofting lands are usually co-located small parcels of secure tenancies in lower terrain, with the upland habitat being managed as a common grazing area amongst the community of crofters.

[4]It is reported that 50% of rural private land in Scotland is held by only 438 owners (Wightman, 2013).

for resilience in the agricultural sector (Walsh-Dilley et al., 2016), a focus on land tenure and property relations helps to bring the largely apolitical "resilience" framework squarely back into the realm of questions of power relations and the distribution of benefits (Calo, 2020b; Holt-Giménez et al., 2021).

Our perspective aligns with a rising awareness that the maintenance of Westernized liberal property regime waters down well-intentioned interventions in the overlapping agricultural (Shoemaker, 2021), climate (Baker et al., 2017), global public health (del Castillo, 2021) and affordable housing (Desmond and Gershenson, 2017) crises. The institution of property has long been critiqued from academic sectors for relying on settler colonial imaginaries of liberty and dominion in ways that prevent pathways to egalitarianism. The epistemic character of Westernized property regimes may be at an inflection point where a diverse transdisciplinary constituency can mobilize the emergence of new emancipatory land logics. We argue that a creative 21st century land reform is a mandatory project that must co-inform questions of equitable and transformative food systems resilience in the global North.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

AC conceived of the paper and authored drafts of the introduction, literature review, and discussion. Each author contributed equally to developing the international vignettes (AMc, AC, and KS: Scotland, SRS: Australia, CP, AB-L, and PG: France, NB, AMa, and AD: Canada, MK and SM: Japan) All authors contributed equally to feedback and copyediting of all sections.

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Food Sovereignty and Rights-Based Approaches Strengthen Food Security and Nutrition Across the Globe: A Systematic Review

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This systematic review assembles evidence for rights-based approaches–the right to food and food sovereignty–for achieving food security and adequate nutrition (FSN). We evaluated peer-reviewed and gray literature produced between 1992 and 2018 that documents empirical relationships between the right to food or food sovereignty and FSN. We classified studies by literature type, study region, policy approach (food sovereignty or right to food) and impact (positive, negative, neutral, and reverse-positive) on FSN. To operationalize the concepts of food sovereignty and the right to food and connect them to the tangible interventions and practices observed in each reviewed study, we also classified studies according to 11 action types theorized to have an impact on FSN; these included "Addressing inequities in land access and confronting the process of land concentration" and "Promoting gender equity," among others. We found strong evidence from across the globe indicating that food sovereignty and the right to food positively influence FSN outcomes. A small number of documented cases suggest that narrow rights-based policies or interventions are insufficient to overcome larger structural barriers to realizing FSN, such as inequitable land policy or discrimination based on race, gender or class.

Keywords: food security and nutrition, food sovereignty, right to food, agroecology, sustainability, equity, food systems, Millennium development goals

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INTRODUCTION

Progress toward ending hunger on a global scale has stalled. Reductions in global malnutrition and hunger rates have slowed after decades of decline, while the absolute number of people suffering from hunger and malnutrition is increasing (FAO, 2019). These trends were evident even before the emergence of COVID-19 and its impact on economies and global food security (FAO, 2020). Such challenges require an examination of approaches to strengthen food security and nutrition (FSN)—-in particular, evidence-based assessments of underutilized or typically overlooked approaches that may be able to overcome barriers to progress where more established approaches have not.

Approaches to meeting FSN goals can be broadly classified by their focus: increasing agricultural productivity, the supplementation of foods and other means of delivering specific micronutrients to undernourished populations, and realizing the human rights of populations vulnerable to hunger and malnutrition. Of these approaches, *increasing agricultural production* is the most long-standing, and remains dominant at major institutions tasked with ensuring FSN as well as coordinating agricultural policies, such as the United Nations Food and Agriculture Organization (FAO) and the United States Department of Agriculture (USDA). The theory of change or processual explanation behind this approach is that increasing productivity will meet the growing population's food needs by making food more available and accessible to the poor; it could also increase profitability on farms and stimulate rural economies where poverty and food insecurity is prevalent. However, greater food availability or capacity to purchase food does not ensure sufficient nutrition. Consumption of cheap, calorically-dense but non-nutritious starches has increased over the years, resulting in epidemics of obesity and diet-related diseases (Khoury et al., 2014). This coexists with the "hidden hunger" of micronutrient deficiencies estimated for two billion people (FAO, 2014; Bailey et al., 2015). A second approach, the nutritional supplementation for FSN, seeks to provide specific nutrients to large populations via staple foods. Since the 1920s, supplementation has mainly taken the form of staple foods fortified with nutrients like iodine and vitamins A, B, and D that have virtually eliminated diseases like goiter and rickets that were caused by single-nutrient deficiencies (Bishai and Nalubola, 2002). More recently, *biofortification* has involved developing crop varieties high in micronutrients commonly absent from diets (Bouis and Welch, 2010), such as a sweet potato rich in vitamin-A (Low et al., 2017).

An alternative, and more recent approach to the production-focused FSN approaches described above is rights-based. The theory of change behind rights-based approaches is to guarantee the human rights required to achieve food security and healthy nutrition. This may involve addressing political conflict, the denial of basic human rights, and other forms of oppression that are root causes of hunger and malnutrition.

Sen (1981) influentially argued that famines are not caused by a lack of food, but by a lack of "entitlements and capabilities," or the social, economic, and political means to produce or acquire sufficient food. His approach represented a departure from dominant thinking, and opened investigations into the political and economic conditions that shape access to food beyond agricultural productivity and innovations in agricultural technology (e.g., Watts and Bohle, 1993; Blaikie et al., 1994). If hunger has political causes, it follows that FSN can be strengthened or even guaranteed by policy and political actions. In this paper, we focus on two rights-based approaches: food sovereignty and the right to food[1]. Building on a systematic review of peer-reviewed and gray literature, we aim to answer the question: What are the contributions of food sovereignty and right to food approaches to food security and nutrition?

Rights-based approaches—ranging from policies of governments or other institutions, to grassroots advocacy, to interventions by non-governmental organizations (NGOs)—touch people's lives and livelihoods in diverse ways and are implemented at varying scales. Food sovereignty, an approach originating with social movements, informs grassroots advocacy and demands, as well as policies of local institutions such as farmers' cooperatives. Additionally, food sovereignty increasingly informs interventions by some international NGOs and has recently appeared in some national policies (Knuth and Vidar, 2011; Wittman, 2015). The right to food, originating with an intergovernmental treaty that mandates national policies (United Nations, 1966), tends to be implemented as such—but also informs the policies of many non-governmental institutions.

In the next sections, we outline the emergence of food sovereignty and the right to food as rights-based approaches to FSN. Then, we outline our methodology to define theories of change associated with food sovereignty and the right to food, and action types associated with each theory of change. We subsequently characterize and evaluate the breadth of empirical evidence associated with the implementation of rights-based approaches. Finally, we highlight opportunities for further research on rights-based approaches and their impact on FSN.

Food Sovereignty

The concept of food sovereignty originated with small-scale producers organized as the transnational social movement La Vía Campesina (LVC), and was launched globally at the 1996 United Nations World Food Summit. Food sovereignty is a broad concept focused on the rights of people—rather than corporations and market institutions, the actors that LVC believes have come to dominate the global food system—to control how and what kind of food is produced. LVC's seven principles of food sovereignty include: Food as a basic human right, the need for agrarian reform, protection of natural resources, reorganization of food trade to support local food production, reducing multinational concentration of power, fostering peace, and increasing democratic control of the food system (Claeys, 2013).

While mainly led by grassroots communities, food sovereignty has reached other spheres and has been enshrined in the

[1]We recognize that the strengths of food sovereignty and right to food approaches may extend far beyond FSN, enabling, for example, improved ecosystem services and cultural diversity, and counteracting biodiversity loss (Perfecto et al., 2009; Iles and Montenegro, 2014; Pimbert, 2017).

constitutions and policies of several national, regional and municipal governments. In Latin America, Bolivia and Ecuador have included food sovereignty as a way to secure food needs of the local population (McKay et al., 2014). Also, food sovereignty has been mobilized in a range of NGO and grassroots community organizations to guide interventions at different geographical and institutional scales (Claeys, 2013; Chappell, 2018).

Right to Food

States have an obligation to realize human rights, including the right to food, under international law. The International Covenant on Economic, Social and Cultural Rights (United Nations, 1966) established this obligation. Article 11 establishes the right to an adequate standard of living, including food, and the right to be free from hunger. Article 12 establishes the right of everyone to the enjoyment of the highest attainable standard of physical and mental health. States are obliged to respect the right to food by not taking any measures that prevent access to food, by ensuring that individuals are not deprived of access to adequate food, and by proactively carrying out activities that strengthen people's access to resources and means to ensure food security. In cases where people are unable to realize the right to food, states are obliged to provide that right directly through food aid but should facilitate future self-reliance and food security (UNCESCR, 1999). The Committee on World Food Security (CFS) at the UN-FAO adopted the Voluntary Guidelines for the Progressive Realization of the Right to Adequate Food in the Context of National Food Security (Right to Food Guidelines) in 2004, providing a precedent for the inclusive and participatory approach to governance of FSN. Spurred by successive global food, financial and economic crises caused by the 2007–2008 food price spike, the CFS underwent a reform in 2009. The mandate to contribute to the progressive realization of the Right to Adequate Food was included in the vision statement of the reformed CFS (CFS, 2009) and has since been reaffirmed in most substantive CFS policy decisions.

The right to food has been implemented in specific policy instruments in many jurisdictions (Knuth and Vidar, 2011). For example, in India, the constitution guarantees the protection of life and requires the state to raise the level of nutrition of all citizens. In 2001, civil society groups went to court to demand that the right to food for all citizens was recognized, and their case was upheld by the Supreme Court. As a result, the various food, social security and livelihood programs enacted by the state in India have become a legal entitlement rather than a benefit program (Mander, 2012). In Brazil, the right to food was enshrined in the 1988 constitution and the re-democratization of the country created new channels of participation to define public policies in order to guarantee social, civil and political rights.

Food Security and Nutrition

Food security "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Conceptually, food security and nutrition overlap, with food security being a necessary but not sufficient condition for nutrition security (Jones et al., 2014). The four pillars of food security and nutrition are articulated by FAO (1996) and other organizations to include the following:

1. Availability: Sufficient food supply of appropriate quality.
2. Access: Adequate resources (including infrastructure and economic resources) to actually acquire appropriate and nutritious foods (i.e., the presence and functioning of appropriate entitlements).
3. Utilization: The ability to actually consume and benefit from an adequate diet, which is strongly affected by overall health status, clean water, appropriate sanitation, and health care (i.e., nonfood inputs in food security).
4. Stability: Consistency in access to adequate, nutritious food and nonfood resources—in other words, the avoidance of or resilience to natural, financial, or social shocks as well as stability in food security throughout seasonal or gradual changes.

Access to food is understood by a number of scholars (Sen, 1981; Watts, 1983; Blaikie et al., 1994; Holt-Giménez, 2002; Chambers, 2016) to have two critical dimensions: asset-based agency, currently emphasized under access as the second FSN pillar above; and institution-based agency, essentially concerned with where powers reside, and their transfer when necessary to increase empowerment (Chomba et al., 2015).

Institution-based agency is central to debates around the democratization of food systems. Since the four pillars were first articulated, increasing evidence indicates a need for more explicit ways of addressing critical aspects of human empowerment, recognition of rights, and reinforcement of community capacities (in particular with respect to water and sanitation, infant and young child nutrition, and women's education) to make progress in achieving FSN outcomes (Smith and Haddad, 2015). The methodological framework of this study incorporates a fifth FSN pillar on "agency," in keeping with its emergence as a critical dimension, defined as:

5. Agency: The empowerment of citizens in defining and securing their own food and nutritional security, requiring sociopolitical systems wherein policies and practices may be brought forth by the will of citizens and be reflected in governance structures to enable the achievement of overall food and nutrition security. This includes access to accurate information, the right to such information and to other aspects of food security, and the ability to secure such rights (adapted from Rocha, 2009; Chappell, 2018, p. 57).

Overlapping and Dynamic Rights-Based Approaches

One challenge to synthesizing evidence for these rights-based approaches is that they often involve overlapping concepts. Food sovereignty, in particular, has evolved to articulate the rights of countries to determine food policies as well as the broader rights of communities and movements to influence the formal and informal institutions that govern food systems (Claeys, 2013; Lambek et al., 2014; Chappell, 2018). Popular movements continue to expand and refine the conceptualization of rights included in food sovereignty frameworks, guided, for example,

by multiple feminisms and Indigenous approaches to knowledge making (Bezner Kerr, 2020; Morales, 2021). While the right to food has more formal definitions recorded in laws and policies, the concept continues to evolve and diverge in practice from place to place, particularly with regard to the importance of people's agency in defining food policy (Chomba et al., 2015).

The food sovereignty and right to food concepts inform each other, and the conversations that define and re-define them play out in interacting arenas. While the definition and scope of food sovereignty is generally driven "from below" by social movements and their collaborations with researchers and NGOs, and the right to food is largely driven by governments and intergovernmental processes, neither happens in isolation. In practice, both concepts advocate supporting local food systems, protecting the social and economic rights of producers and consumers, protecting communities' rights to land and water, and promoting gender equity in policy. Both approaches address the actions of states and formal institutions. In very broad strokes, food sovereignty differs from the right to food in that it centers social movements in its analysis and addresses the dynamics of power and agency within communities and movements, and between social movements and formal institutions, while the right to food has a more state-focused, legal approach. However, in practice, many of the policies, projects, and case studies reviewed here are informed by both rights-based approaches.

In this review, we treated food sovereignty and the right to food as independent concepts, and conducted independent literature searches, screening processes and quantitative analysis for each. This approach allowed us to assess the evidence for each on its own terms. After presenting the results for each review, we discuss the similarities and differences between them, and the evidence for rights-based approaches to FSN as a whole.

Research Approach

To assess the contributions of food sovereignty and right to food approaches to FSN, we conducted systematic reviews of peer-reviewed and gray literature from 1992 to 2018. We focused on empirical studies that provide quantitative or qualitative evidence of a causal relationship between the right to food or food sovereignty and FSN, and assessed factors influencing the diverse contributions of rights-based approaches to FSN.

Evidence for the contributions of food sovereignty and right to food approaches to FSN has been broadly documented and is heterogeneous. Peer-reviewed literature, published over decades, documents associations between the social and ecological aspects of food systems dynamics and their effects on producer and consumer communities. However, much of the evidence for the contribution of rights-based approaches to FSN may lie outside of peer-reviewed literature, given how these concepts have been mobilized by social movements and inter- and non-governmental organizations. There is an increasing recognition of the importance of including diverse sources of knowledge, such as the knowledge and experience of local communities, which have historically been ignored or not validated in research or western-science approaches. Where many earlier global assessments of ecological sustainability, such as the Millennium Ecosystem Assessment, had clear guidelines to limit consideration of knowledge to peer reviewed data, the IAASTD (International Assessment of Agricultural Science and Technology for Development) and the IPBES (Intergovernmental Platform for Biodiversity and Ecosystem Services) both explicitly included traditional knowledge as sources of information. Many global platforms increasingly feature case studies as valuable sources of context-specific knowledge (for example, FAO's Agroecology in Action Profiles).

Evaluating heterogeneous sources documenting the impact of rights-based approaches for FSN requires novel approaches. New methods enable in-depth understanding of causal relationships based on qualitative and case study data, and build on these to infer broader patterns in a form of meta-analysis (Magliocca et al., 2018). In this review, we have adapted the methods in Magliocca et al. (2018) to enable us to assess these varied and valuable sources of data. We sought to identify research or case studies that (1) describe the experience of a clearly delineated community affected by interventions or policies (either their own or external) related to food sovereignty or the right to food, and (2) report the effects of these interventions or policies on food security and nutrition at the household and/or community level. We aimed to include both quantitative and qualitative assessments, and to include reports published as peer-reviewed and as gray literature.

METHODS

Identification of Studies

We conducted two independent searches: one for food sovereignty and the other for the right to food. We obtained studies on each through a search in academic databases, a manual search of key organization's websites, and consultation with key experts. Search terms were based on literature and consultation with key experts (see **Supplementary Material 1**), and identified and tested in collaboration with librarians from Cornell University. Searches on academic databases were focused on PubMed, Web of Science, CAB Abstracts, and Agricola. To identify gray literature, a review team assembled a list of key organizations involved in food sovereignty research (**Supplementary Material 2**) and searched their websites for case studies related to FSN. Additionally, we assembled a list of key experts on both the right to food and food sovereignty, and requested any unpublished case studies from them by email. The search included references from 1992 (1 year prior to the formation of the most relevant global movement for food sovereignty, La Via Campesina) and September 26, 2018 (2 years after which the right to food sovereignty was explicitly demanded by the NGO forum during the UN Food Systems Summit).

Screening

First, we de-duplicated search results using Zotero (www.zotero.org). Then, we used Rayyan (www.rayyan.qrci.org) for initial inclusion/exclusion screening of titles and abstracts to exclude the following types of studies: (1) Opinion pieces that did not report empirical data; (2) Reviews that did not report primary data; (3) Studies without human subjects; (4) Studies that did not address food sovereignty, the right to

food or an indicator of these approaches; (5) Studies that did not report food security or nutrition outcomes (either quantitative or qualitative); (6) Articles in languages other than English, Spanish, French, Portuguese, Italian, and German. Two reviewers screened each study for inclusion/exclusion, and in the event the reviewers disagreed about a citation meeting the inclusion/exclusion criteria, a third reviewer broke the tie.

Eligibility

We accessed full texts for all studies included after the first screen. After reading the full text, we excluded several additional studies based on the above-mentioned exclusion criteria. Most of the studies dismissed at this stage were excluded because they did not report empirical data. We accepted studies reporting either quantitative or qualitative data, but to be included, studies had to report both an indicator of at least one aspect of the right to food or food sovereignty, and evidence of a change in FSN status. Initially, we intended to assess study quality using questions based on the Critical Skills Appraisal Program's checklists (CASP, 2018), by applying the case-control studies checklist to quantitative studies, and the qualitative checklist to qualitative studies. However, these quality assessments would exclude virtually all of the gray literature and case studies, which generally either do not explicitly report methods in enough detail to pass the bias assessment, or report experiences in forms other than systematically collected data. Because the data contained in gray literature and case studies had significant value for addressing our key research question, we opted not to exclude any studies using these checklists.

"Action Types" for Food Sovereignty and the Right to Food

Food sovereignty and the right to food are high-level concepts rather than specific practices. To operationalize these concepts, we first identified a core "theory of change" (Magliocca et al., 2018) that underlies each concept, specifying the main ways that rights based approaches are theorized to influence FSN. We then drew from relevant literature (e.g., Pimbert, 2006; Lemke and Bellows, 2015; Anderson et al., 2019) and our collective experience in academic, intergovernmental, and social movement engagements with these approaches to define a set of "action types" expected to affect FSN (**Table 1**). The action types can be thought of as categories of calls to action and policy proposals widely discussed within food sovereignty and right to food discourse. The action types are necessarily a reduced and simplified typology that doesn't fully encompass the holistic, dynamic, and contested concepts of food sovereignty or the right to food. Distinguishing these action types, however, allowed us to delineate search terms based on actions, so that studies that documented evidence relevant to the action types could be included in the sample whether or not they used the words "food sovereignty" or "right to food." The two concepts overlap in their theory of change, and as a result, they share several action types and accordingly some studies appear in both reviews.

We searched, reviewed and classified studies by the principal action type investigated. Although many studies addressed more than one action type, reviewers assigned a single principal action type to each study, based on which action type was most directly measured or assessed in the study's methods. As a result, we included studies that reported a causal relationship between a kind of action widely promoted by either food sovereignty or the right to food, and FSN outcomes, even in cases where the publication did not explicitly use the term food sovereignty or right to food (see **Supplementary Material 1**).

Coding and Analysis

We coded right to food and food sovereignty studies according to several categories that identify the context and methodological

TABLE 1 | Food sovereignty and the right to food: theories of change and action types evaluated in this review.

Rights-based approach	Theory of change	Action types
Food sovereignty	Policy instruments, grassroots efforts, and NGO interventions that seek to build food sovereignty of peoples and communities had significant impacts on the food security and/or nutrition of those peoples or communities	A. Supporting local producers and/or protecting local markets B. Addressing inequities in land access and confronting the process of land concentration C. Recognizing, valuing, and supporting the dissemination of local and traditional knowledge D. Increasing autonomy over the production process through agroecological production practices E. Asserting/expanding the social and economic rights of producer and consumer communities F. Promoting gender equity
Right to food	Policy instruments, grassroots efforts, and NGO interventions that address the right to food have significant impacts on the food security and/or nutrition of peoples or communities	A. Advancing physical availability and economic access to adequate food through appropriate actions by governments and non-state actors B. Fulfilling human rights that affect food access, availability, and utilization C. Creating and supporting local and regional markets to make food accessible D. Advancing the rights and capabilities of marginalized groups to produce and access food E. Protecting the right to access land, water, and genetic resources for food and agriculture, or redistributing these rights F. Promoting gender equity

approach of each study, including: (1) type (Quantitative, Qualitative, or mixed-methods; corresponding to an intervention or observation; cross sectional, case control, or longitudinal); (2) date, location and region; and (3) sample size. In assessing the impact of each study, we sought to identify associations between rights-based approaches and FSN outcomes; therefore, we also characterized (4) the measure of food sovereignty or right to food or an indicator of these approaches"; (5) action types (**Table 1**), and (6) measure of food security/nutrition outcome. For each study, the effect of a food sovereignty or right to food approach on FSN outcomes was recorded as positive (+), negative (–), neutral (0), or reverse positive (reverse+). Reverse positive scores referred to cases in which a reduction in food sovereignty or a lack of right to food policies leads to a reduction in FSN. Reverse positive results still indicated a positive relationship between rights-based approaches and FSN, but were tallied separately. We coded action types according to what we identified as the dominant action type in each study. Some studies involved more than one action type, yet we only assigned one principal action type to each study to avoid double counting studies. Data and code used for analysis and visualization are available at https://github.com/devonds/rights_and_food_security.

We analyzed results applying a synthesis method, following Magliocca et al. (2018). Synthesizing or integrating knowledge about a heterogeneous topic that draws upon multiple sources of data, explanation, and analytical techniques, risks losing the potential depth of each methodological approach. Magliocca et al. (2018) suggest an alternative to conducting syntheses to conserve the richness contained in multiple study approaches; they advocate for explicitly identifying the "theory of change," "causality" or causal relationships that the researchers examine as well as the "conditionality" of the findings, in order to identify the bounded range of conditions under which a generalization is expected to be true. The types of studies included in this review are heterogeneous in terms of the processes to account for validity of the results; the value studies hold for their corresponding creators and audiences; and their potential publication bias, which typically favors studies reporting positive or significant results between drivers and effects—in this case, the association between rights-based approaches and FSN. To avoid flattening this heterogeneity, in this paper we focused on the theory of change (associated with the action types defined for each rights-based approach; see **Table 1**), on quantifying the evidence, and on qualitatively analyzing the state of the evidence for rights-based approaches with an emphasis on where and under what conditions they result in significant changes in FSN.

This review is not focused on quantifying the number of positive vs. negative results in the compiled evidence for two reasons. First, publication bias almost certainly favors documentation of studies with positive results. Second, much of the experiential knowledge of rights-based approaches, and particularly about the impacts of food sovereignty, are reported in case studies. Of these, some rely on systematically collected data while others are based on personal or institutional experience and reflection. We consider these experience-based reports to be valuable sources of evidence, because they often contribute underrepresented points of view (e.g., that of farmers or fishers) and often include a depth of experience that most formal studies are unable to capture. However, pooling and counting the results of less formal, experiential reports along with those of systematic research would be misleading.

RESULTS

Review Process and Literature Overview

We identified a total of 4,873 books and articles on food sovereignty and 733 books and articles on the right to food through structured database searches. We found an additional 152 articles and reports on food sovereignty through other sources, including website searches of key food sovereignty organizations and consultations with key experts. Using similar methods, we found no additional literature on the right to food that was not also included in the article database search. Based on titles and abstracts, screeners excluded all but 497 studies on food sovereignty and 198 on the right to food. After excluding additional studies that were inaccessible or did not explicitly report a quantitative or qualitative assessment of FSN outcomes, we included and coded 162 studies on food sovereignty and 54 studies on the right to food (**Figure 1**). Most studies on food sovereignty were qualitative ($n = 100$), followed by mixed-methods studies (27) and 15 quantitative studies; more than half reported observations ($n = 118$) with 27% reporting interventions ($n = 44$), and most studies included cross-sectional approaches ($n = 135$). Studies on the right to food included 22 qualitative, 17 quantitative and 15 with mixed-methods approaches. More than 90% of the right to food studies reported observations ($n = 50$) with few studies reporting the results of interventions ($n = 4$); and 85% of the right-to-food studies were cross-sectional ($n = 46$).

Studies addressing the impacts of rights-based approaches on FSN have increased through time, were conducted in broad geographic locations, and mainly showed positive relationships. Most of the studies were published after 2010, especially those concerning the impact of food sovereignty for FSN (**Figure 2**). Most studies were peer-reviewed for both rights-based approaches (food sovereignty $n = 55$; right to food $n = 44$). There were more studies evaluating relationships between food sovereignty and FSN in the gray literature ($n = 55$), compared to studies evaluating impacts of the right to food ($n = 6$). In terms of the spatial distribution of the studies, relations between food sovereignty and FSN have been documented in all geographic regions, with the greatest representation in Central and South America and the Caribbean ($n = 60$), followed by sub-Saharan Africa ($n = 44$). Studies evaluating the implications of the right to food have been conducted in Africa ($n = 17$) and in the Americas ($n = 25$), and to a lesser extent, in Asia and the Pacific ($n = 9$). We found no studies on the influence of the right to food on FSN from the West Asia/North Africa region (**Figure 3**). Studies addressing impacts of food sovereignty for FSN most frequently reported positive ($n = 121$) or reverse positive impacts ($n = 29$), and studies on the impacts of the right to food for FSN reported overwhelmingly positive ($n = 24$) or reverse-positive results ($n =$

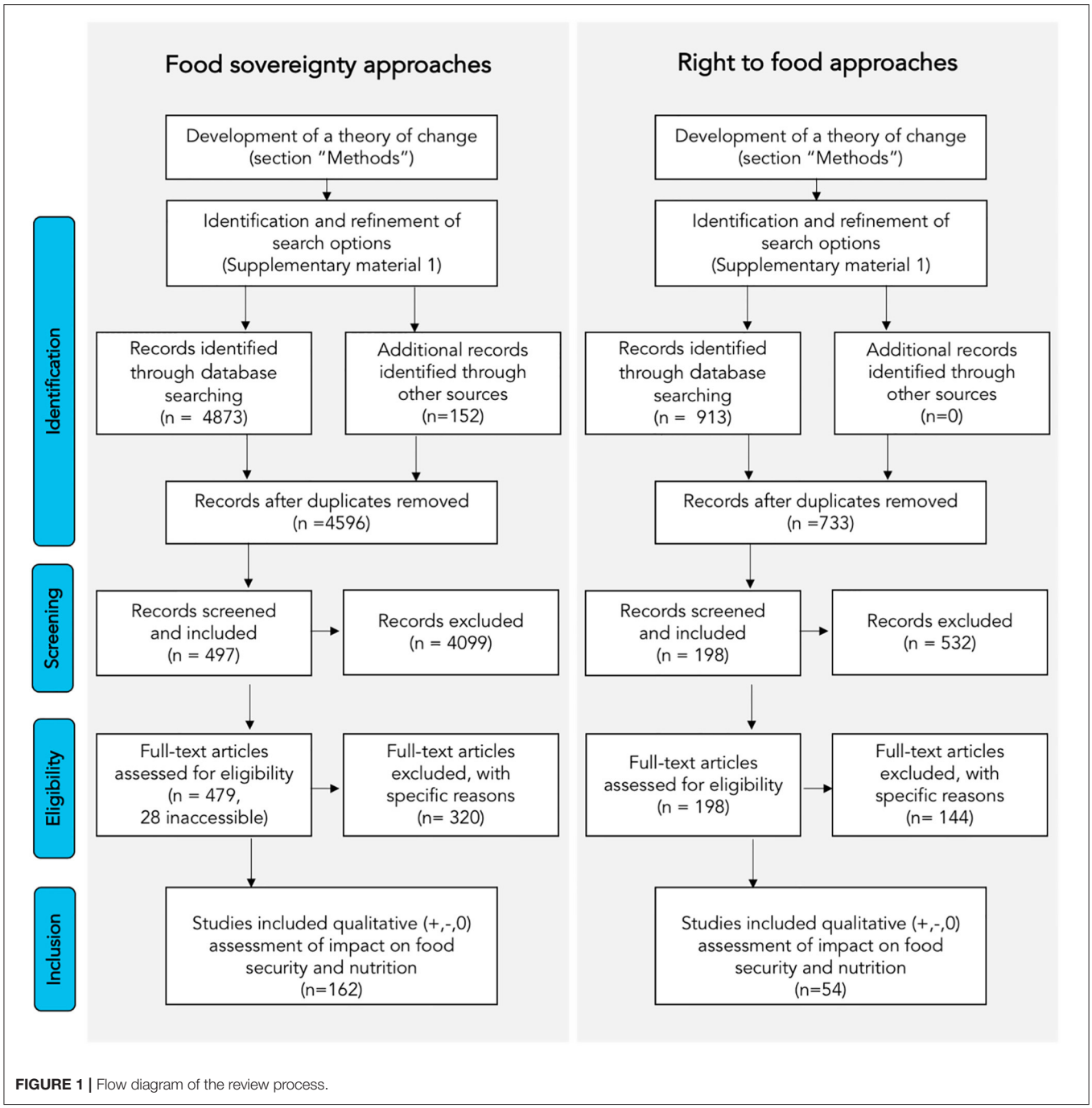


FIGURE 1 | Flow diagram of the review process.

23), with only five studies reporting negative impacts. This was true across literature types (**Figure 4**) and regions.

Along with quantifying the number of positive vs. negative studies, we also examined the evidence for each "action type" that we identified under the high-level concepts of food sovereignty and the right to food. At the end of the results section, and later in the discussion, we look at the relatively few cases in which rights-based approaches had a negative or neutral impact on FSN, and discuss the barriers and limits to such approaches for realizing FSN.

Impacts of Food Sovereignty Actions

The reviewed literature represented all of the food sovereignty "action types" we identified (see methods). More than half of the studies examined the effect of either action type D, increasing autonomy over the production process through the adoption of agroecological practices (54 studies), or action type E, protecting the right of communities to access land, water, and genetic resources for food and agriculture, or redistributing these rights (40 studies; **Figure 5**). The impact on FSN was not equally positive across food sovereignty

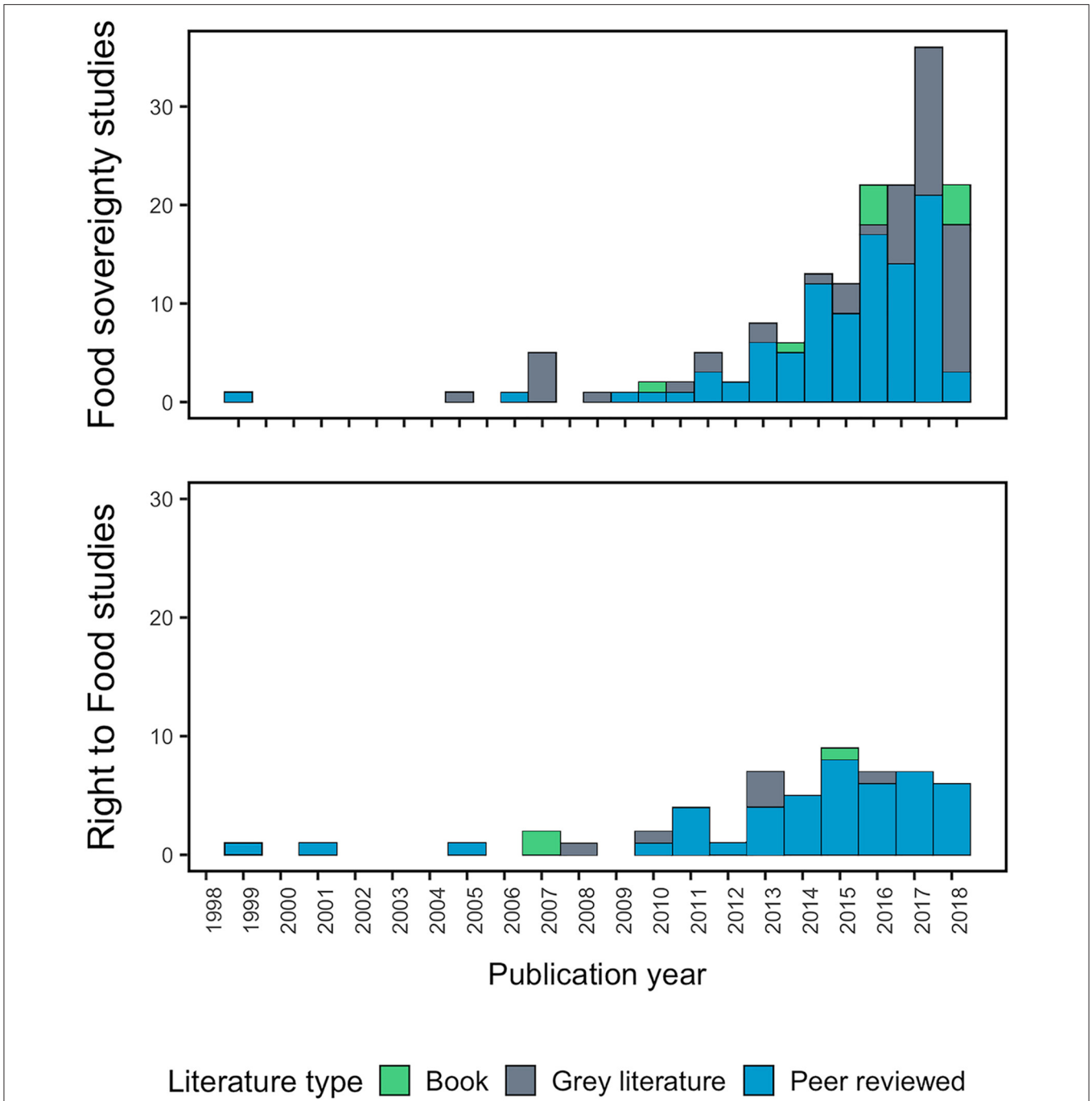


FIGURE 2 | Publication year of studies on the impact of food sovereignty and the right to food on FSN. Included studies were published between January 1992 and September 2018 (2018 is a partial year).

action types. Positive impacts dominated in action types D, E, C, and F. Most studies of action types A and B reported either positive or reverse positive results as well, but there was a greater representation of studies reporting neutral impacts in those two action types. The sole study reporting a negative impact for FSN was in action type A (Supporting local producers and/or protecting local markets; **Figure 6**). In the research on food sovereignty, literature types concentrated on different action types. The majority of gray literature (62% of studies) concentrated on increasing autonomy over the production process through agroecological production practices (action type D). Meanwhile, the majority of peer-reviewed literature (34% of studies) focused on asserting/expanding the social and economic rights of producer and consumer communities (action type E).

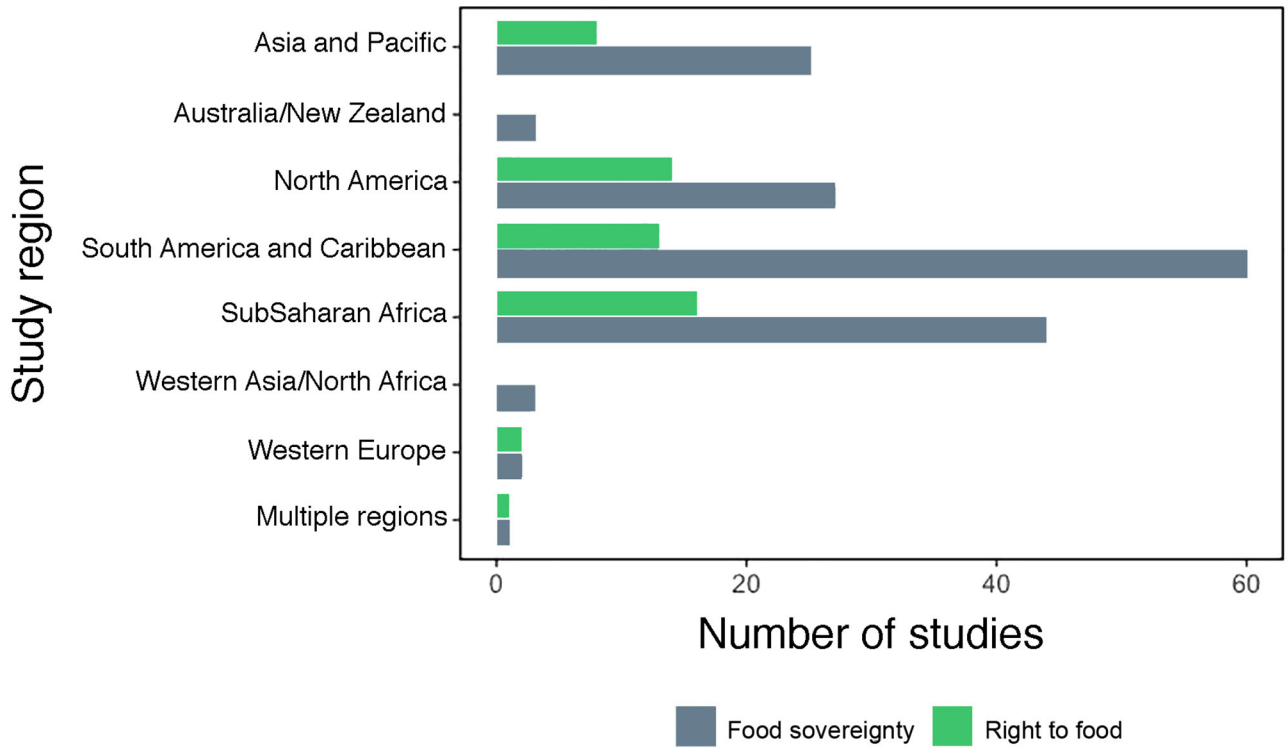


FIGURE 3 | Studies on food sovereignty and the right to food by region.

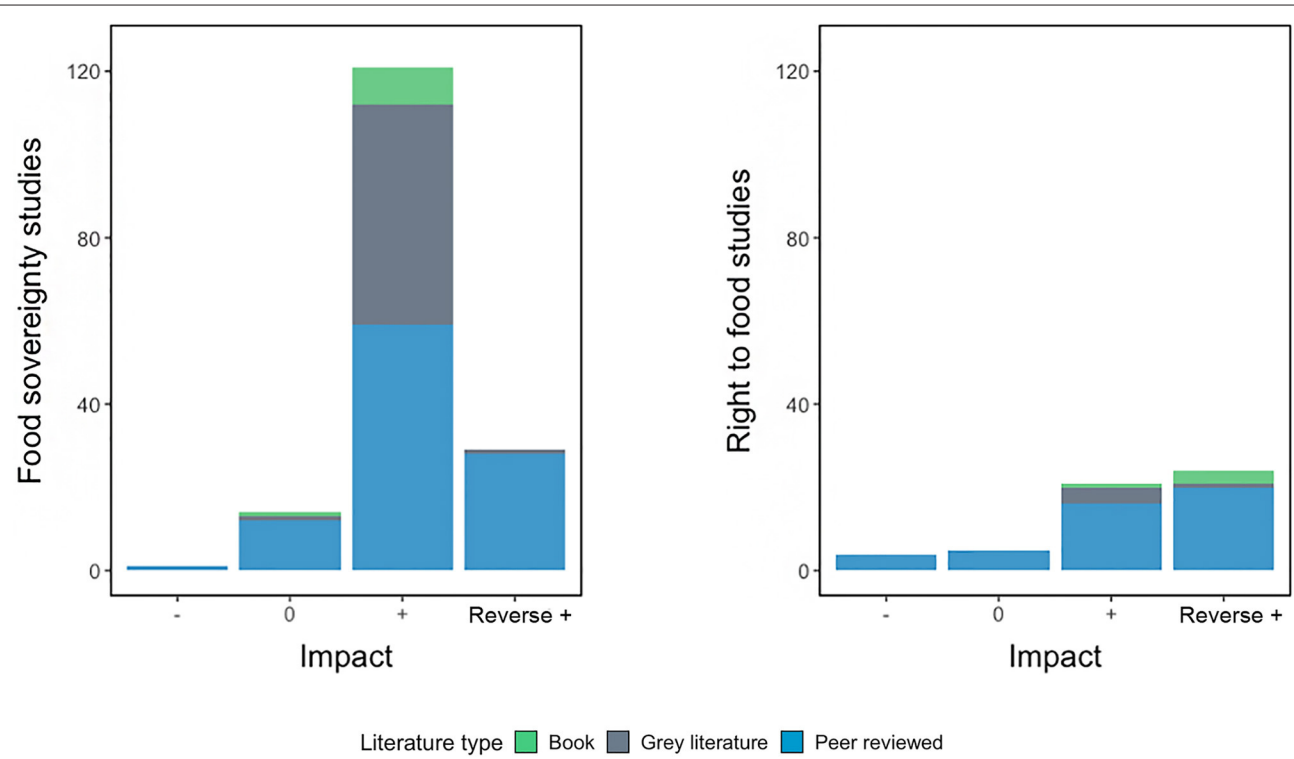


FIGURE 4 | Impact of food sovereignty and the right to food on FSN outcomes, and type of literature reporting the relationship.

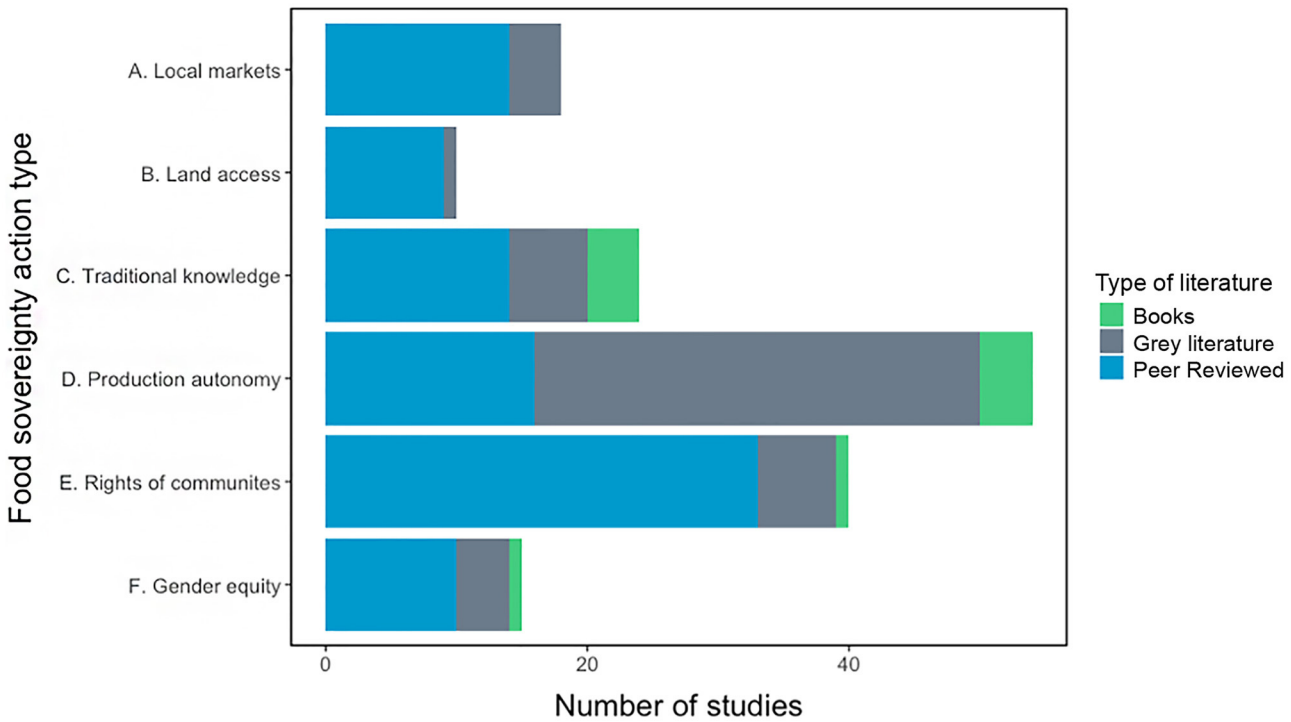


FIGURE 5 | Studies reporting each type of food sovereignty action type. Descriptions of action types are detailed in **Table 1**.

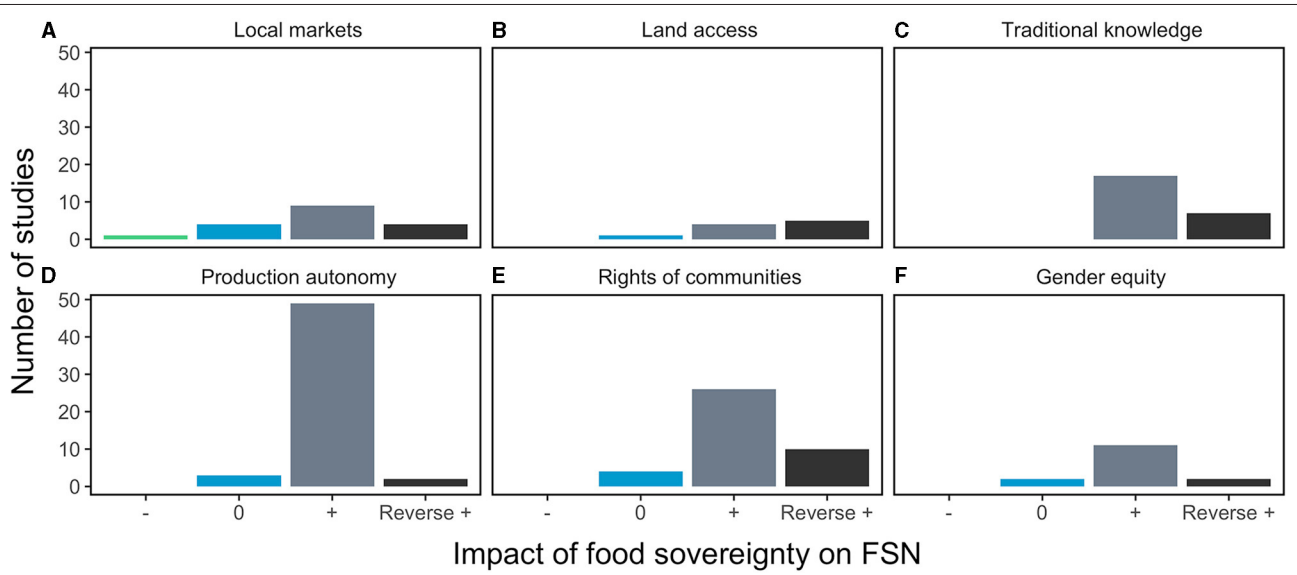


FIGURE 6 | Impact of each type of food sovereignty action on FSN. Local markets stands for "Supporting local producers and/or protecting local markets" **(A)**. Land access stands for "Addressing inequities in land access and confronting the process of land concentration" **(B)**. Traditional knowledge stands for "Recognizing, valuing, and supporting the dissemination of local and traditional knowledge" **(C)**. Production autonomy stands for "Increasing autonomy over the production process through agroecological production practices" **(D)**. Rights of communities stands for "Asserting/expanding the social and economic rights of producer and consumer communities" **(E)**. Gender equity stands for "Promoting gender equity" **(F)**.

Supporting Local Producers and/or Protecting Local Markets (A)

A central tenet of food sovereignty is the right to local and community control of food and agricultural markets, particularly in response to forces of globalization (LVC, 2007). Our review included 18 studies that assessed the impact of this type of action on FSN. Of those, 13 reported either a positive or reverse positive impact, one reported a negative impact, and 4 reported no impact; it was the only action type for which positive results did not overwhelmingly dominate. Still, positive results were most common. Cases of positive impacts include, among others, a study of the perceived impacts of a public purchasing program in Mato Grosso, Brazil, implemented by food sovereignty proponents. In this case, small- and medium-scale farmers reported that the public purchasing program granted them autonomy from commodity markets where they were unable to compete with larger agribusinesses (Wittman and Blesh, 2017). Another study in Guatemala found that farmers strengthened their food security by combining traditional *milpa* farming practices and off-farm employment opportunities within rural areas, giving them more flexibility to invest in their local food systems (Isakson, 2009).

Addressing Inequities in Land Access and Confronting the Process of Land Concentration (B)

Five studies on the impact of land tenure report reverse positive impacts, where a loss of tenure resulted in a decrease of FSN, while four studies reported the positive effects of increasing land access for FSN, and one study reported no impact associated with this action type. Encroaching shrimp production in Khluna, Bangladesh decreased access to land and labor opportunities for landless workers, resulting in reduced food access (Paprocki and Cons, 2014). For Maasai pastoralists in Olgos, Kenya, a policy shift from community land tenure to individual land titles resulted in fragmentation of grazing lands, which undermined food security along with social structures and ecosystem resilience; work is now underway to restore community land tenure (Tiampati, 2018). Conservation policies can also restrict access to land for agriculture, hunting and gathering with negative impacts on FSN, as documented in Oaxaca, Mexico (Ibarra et al., 2011) and Sulawesi, Indonesia (Siebert and Belsky, 2002). This last case reported a positive impact on FSN, documenting how farmers organized to take back the right to practice shifting cultivation in an Indonesian national park, increasing their food supply and security.

Other studies document cases in which communities have gained or strengthened land tenure, with positive impacts on FSN. Members of two Indigenous groups in the state of Minas Gerais, Brazil, joined forces to purchase land, which opened opportunities to produce food and restore ecocultural traditions (Rocha and Liberato, 2013). Across British Columbia, Canada, farmers are using multiple legal structures for community land tenure initiatives, enabling them to access land that they would be unable to afford individually; this has helped increase supplies of fresh fruits and vegetables in both rural and urban communities (Wittman et al., 2017).

Recognizing, Valuing, and Supporting the Dissemination of Local and Traditional Knowledge (C)

Diversified farming practices informed by traditional ecological knowledge, such as incorporating livestock and wild plant harvesting, are associated with greater nutritional diversity. The 24 studies in this action type reported either positive ($n = 17$) or reverse positive impacts ($n = 7$) in multiple locations, from northwestern India (Bisht et al., 2018) to Pohnpei, Micronesia (Englberger et al., 2013), to an Indigenous community in South Dakota, United States (Ruelle et al., 2011). In some cases, formal education programs designed around traditional ecological knowledge provided students with both actionable farming techniques and a sense of broader possibilities for meeting FSN needs (Chollett, 2014; Seminar et al., 2017; Mier et al., 2018). Although in this section we only count studies involving valuing local and traditional knowledge as main action type, this can also imply promoting gender equity, as documented in several villages in South Asia (Mazhar et al., 2007) (and described in action type F, below), and increasing autonomy over the production process through agroecological production processes (action type D, below).

Increasing Autonomy Over the Production Process Through Agroecological Production Practices (D)

Agroecological practices include a wide array of methods and technologies that decrease farmers' reliance on external inputs by instead taking advantage of ecological functions (Wezel et al., 2014). Examples of practices include increasing on-farm nutrient cycling with compost and cover crops, or controlling pest populations with crop diversity. A total of 49 studies were found with positive impacts on FSN, whereas three studies reported no impact and two studies reported reverse positive impacts. Many studies in this category document farmer-researcher collaborations to develop or apply agroecological methods in a particular context. For example, Indigenous gardeners in northern Ontario, Canada found ways to grow potatoes and bush beans without the use of greenhouses, achieving comparable yields to high-input agriculture (Barbeau et al., 2015). In Cuba, facing a shortage of synthetic fertilizers, farmers, and researchers have developed a suite of ecological soil management practices that significantly improved both yields and farmer autonomy; the success of this approach is documented in both rural (McCune et al., 2011) and urban (Leitgeb et al., 2016) parts of Cuba. An in-depth case study of several families dedicated to agroecological production in the Sierra Sur of Ecuador found that agroecological practices decreased input costs while increasing produce quality, with positive FSN impacts for the families and their communities (Ochoa Minga and Caballeros, 2016).

For many Indigenous communities, adopting agroecological production practices is inseparable from the work of valuing and reviving traditional knowledge and practices (although counted only in this action type for consistency). Researchers working in Yucatan, Mexico saw promising preliminary results in their project that coupled agroecological practices with participatory action research to address seemingly intractable food insecurity (Putnam et al., 2014). In case studies of agroecology projects in four communities in Guatemala, researchers documented not

only improved FSN outcomes, but a greater sense of autonomy and self-esteem among many participating families, and an increased capacity for collective action among participating communities (Salazar and Caballeros, 2016).

Within this action type, several studies documented cases in which one key agroecological practice– cultivating diverse crops–positively impacted FSN. There is evidence for a positive impact of diversification or conservation of Indigenous crops on FSN in places ranging from the Patagonian steppe in Argentina (Eyssartier et al., 2015), the Tolon-Kumbungu district of Ghana (Quaye et al., 2009), and multiple locations in Bolivia (Jacobi et al., 2017) and Guatemala (Salazar and Caballeros, 2016).

Asserting/Expanding the Social and Economic Rights of Producer and Consumer Communities (E)

This action type concerns the democratic processes and popular movements that aim to expand rights for both producers and consumers. Twenty six studies reported positive impacts involving communities who effectively increased access to fresh fruits and vegetables by campaigning for city ordinances in several North American urban areas (Minkler et al., 2018), collectively advocated for changes in existing food aid systems (Miewald and McCann, 2014), or created innovative produce distribution mechanisms (Block et al., 2012; Kato and McKinney, 2015; Lagisetty et al., 2017).

Ten studies investigated cases in which a lack of social and economic rights constrains people's ability to achieve food and nutrition security, coded as reverse positive impacts. In Haiti, one study reported that poor people's food preferences were shifting toward more processed and less nutritious foods, and that social inequities, especially race and class, underpinned a cultural devaluation of more nutritious peasant foods (Steckley, 2016). Similar observations on the role of marginalization based on race, indigeneity, or class in nutrition transitions were made in Ecuador (Vallejo-Rojas et al., 2016) and Sri Lanka (Townsend et al., 2017). Other studies reported that a lack of social or economic rights directly undermined FSN in other ways. Debt and patronage relations undermined food security and sovereignty among rubber plantation workers in the Bolivian Amazon (Romanoff, 1992). In northern Malawi, a lack of access to locally adapted seeds limited people's ability to achieve food and nutrition security, which was exacerbated by power asymmetries and anticompetitive actions by agri-food companies posed as interventions to promote food security (Bezner Kerr, 2013).

Promoting Gender Equity (F)

Out of 15 studies in this action type, 12 reported evidence of the positive impact that women's empowerment had on FSN across many geographic and economic contexts. In Uruguay, technical assistance grounded in feminist and agroecological perspectives proved effective at improving FSN, in part because women favored diversification of crops and household livelihood activities (Oliver, 2016). Interventions designed to promote maternal autonomy and decision making resulted in better child health outcomes in Indonesia (Agustina et al., 2015) and Nepal (Cunningham et al., 2015). Two studies reported negative outcomes for FSN due to lack of women's empowerment. Among Ugandan women dairy farmers, the introduction of a forage chopping tool eased labor demands, but women were generally unable to translate gains in efficiency into gains in FSN because they had to spend saved time in activities as defined by their husbands (Kiyimba, 2009). Another set of case studies in Georgia and South Africa documented ways in which violence against women impeded FSN (Bellows et al., 2015). A report from the NGO ActionAid Brazil detailed how agroecology projects often encounter limits in the form of strict gender roles and other cultural limitations imposed by men, and documented some successes in overcoming those limitations (Lopes and Jomalinis, 2011).

Impacts of Right to Food Actions

We found 52 studies documenting the impacts of the right to food for FSN and they involved all action types. The greatest number of studies ($n = 16$) documented action type A, advancing physical and economic access to adequate food through appropriate actions by governments and non-state actors (**Figure 7**), with the impacts of Creating and supporting local and regional markets to make food accessible (action type C) for FSN having the fewest reports ($n = 4$ studies). The impact for FSN was not equally positive across right to food action types. Reports were entirely positive (or reverse positive) in action types C, D, E, and F, whereas neutral results were only found in action type A and negative results were found in action types A,B, D, E, and F (**Figure 8**). Gray and peer-reviewed literature in the right to food focused on different action types. Gray literature was entirely concentrated on three action types: B (fulfilling human rights that affect food access, availability, and utilization), C (creating and supporting local and regional markets to make food accessible), and D (advancing the rights and capabilities of marginalized groups to produce and access food. Much of the peer reviewed literature concentrated on action types A (advancing physical availability and economic access to adequate food through appropriate actions by governments and non-state actors) and B (fulfilling human rights that affect food access, availability, and utilization).

Advancing Physical and Economic Access to Adequate Food Through Appropriate Actions by Governments and Non-state Actors (A)

This action directly focuses on the outcomes of projects and programs by governments or other actors to increase access to food. In this sense, the action could be seen as not substantially different than the "access" pillar of food security, yet the studies reviewed reveal the strong equity dimension that the right to food contributes to the attainment of food security and nutrition. The majority of studies reviewed under this action are, as is to be expected, from those countries and regions that have already implemented government policies on the right to food or on food access through government intervention, including Brazil, India, the United States, South Africa, and Australia.

Studies reported mainly reverse-positive and negative effects, with few positive effects of this action type for FSN. Six studies reported on the reverse-positive effects of this action type.

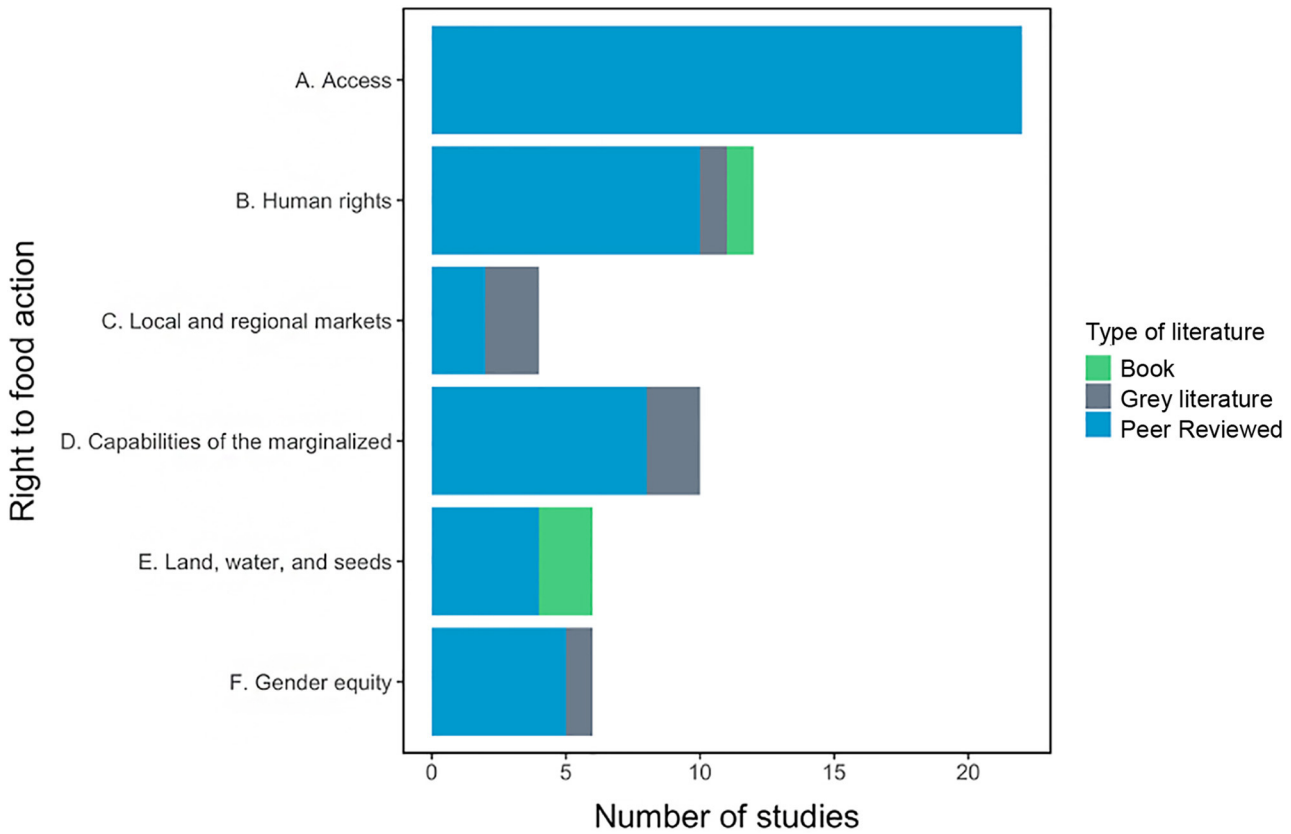


FIGURE 7 | Studies reporting each type of right to food action. Descriptions of action types are detailed in **Table 1**.

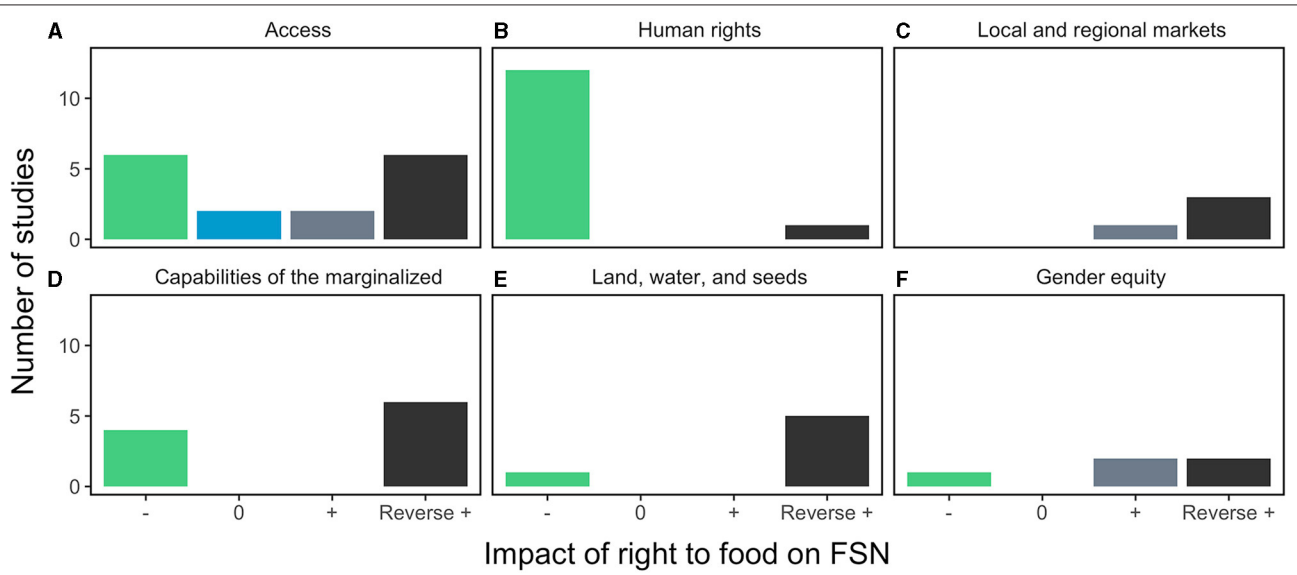


FIGURE 8 | Impact of each type of right to food action on FSN. Access stands for "Advancing physical availability and economic access to adequate food through appropriate actions by governments and non-state actor" **(A)**. Human rights stands for "Fulfilling human rights that affect food access, availability, and utilization" **(B)**. Local and regional markets stands for "Creating and supporting local and regional markets to make food accessible" **(C)**. Capabilities or the marginalized stands for "Advancing the rights and capabilities of marginalized groups to produce and access food" **(D)**. Land, water and seeds stands for "Protecting the right to access land, water, and genetic resources for food and agriculture, or redistributing these rights" **(E)**. Gender equity stands for "Promoting gender equity" **(F)**.

In Uganda, there were negative outcomes for children's food security in privately operated and unregulated children's homes where the right to food was not respected (Olafsen et al., 2018). A study in India found awareness of the right to food as a basic right and key factor for FSN is often missing, due to a lack of its inclusion in public programs (Mathur and Mathur, 2015). Also, not guaranteeing the right to food through policies or state programs had serious health consequences for *quilombola* communities (settlements established by former slave communities of African descent) in Brazil (Ferreira et al., 2011). Strikingly, six studies reported negative impacts of this action type on FSN. In India, programs to address food security served to displace previous food habits, with negative effects on FSN (Murty, 2018). Another study highlighted how the potential for private-sector subsidized programs intended to provide resources for food security could be subverted for commercial gains (Moran et al., 2017).

Frequently, studies reported positive impacts of school feeding programs for child food security and nutrition. In the United States, subsidized school meal programs that featured healthier meal options for food insecure children succeeded in maintaining student participation (Vaudrin et al., 2018), and instituting standards for the nutritional quality of meals changed the types of foods selected by students (Schwartz et al., 2015; Brewer et al., 2016). In San Diego, US, strikingly high levels of food insecurity could have been addressed by government programs, but only through recognizing the challenges of underserved populations (Smith et al., 2017). In other countries such as Colombia, managerial weaknesses in school feeding programs were related to a weak commitment to recognizing the right to food (Diaz et al., 2011).

Fulfilling Human Rights That Affect Food Access, Availability, and Utilization (B)

Respecting human rights as a prevailing condition for FSN was evident in 12 studies indicating food insecurity among those populations denied their fundamental human rights, accompanied by one study reporting a reverse-positive effect of this action type on FSN. In Canada, the occurrence of food insecurity among economically marginalized populations including women, Indigenous people, and children was nearly five times higher than in the general Canadian population, suggesting that intersecting axes of oppression negatively affect FSN (Normen et al., 2005). In three countries in sub-Saharan Africa, HIV/AIDS prevalence and access to treatment has been shown to influence human capital and the agency to achieve food security, with a strong disadvantage for female-headed households aiming to access key labor inputs for growing food (Curry et al., 2007).

Food deprivation is not merely a biological condition, but has psychological and social elements, including fears, learning deficiencies and difficulties in performing daily activities (Hamelin et al., 1999). The high prevalence of food insecurity in the Sergipe community of Grande Aracaju, Brazil was associated with precarious living conditions including poor sanitation and access to health services (Andrade et al., 2017). Along similar lines, high food insecurity in Mexico was characterized by lower well-being, lower education levels, disability of household members, and lack of support from social welfare programs (Mundo-Rosas et al., 2014), and in India, caste-based discrimination in several districts impeded access to food and nutrition security (Thorat and Lee, 2008). These observations underscore how the success of right to food programs is tied to the realization (or lack thereof) of other basic rights, and mediated by power relations and participation in decision-making, with specific implications for marginalized populations (Kravva, 2014).

Creating and Supporting Local and Regional Markets to Make Food Accessible (C)

Our review included four studies of this action type, with three reporting reverse-positive effects and one reporting positive effects. An example of the capacity of local markets to ensure food security was evidenced in a study of the San Lorenzo village in the Bolivian lowlands (Hospes et al., 2010) where Chiquitane people have secured access to food, land and resources through reciprocity and other social relations and practices that provide labor for different activities. In other cases, governments have undertaken innovative measures to implement the right to food by mandating that state-run schools purchase food produced on family farms through regionally-based public procurement programs. Across Brazil, this policy has improved food availability for children as well as the livelihoods of family farmers (Schwartzman et al., 2017). Also, informal markets are increasingly being shown to be critical to food security—an important insight given that in many countries these markets are not legally allowed or encouraged. In Dar es Salaam, egg sales in informal markets generated income for local communities while allowing community consumers to access more affordable and higher quality eggs compared to those found in supermarkets (Wegerif, 2014).

Advancing the Rights and Capabilities of Marginalized Groups to Produce and Access Food (D)

This group of studies documents cases in which an expansion of human rights among marginalized groups leads to increased access to food or the means to produce it, and cases in which a lack of human rights prevents marginalized groups from producing or accessing sufficient food ($n = 6$ studies). In India, information technologies used in a public program promoted better access to food aid, as it gave people more freedom to choose how and what to use (Rajan et al., 2016). Also in India, positive food security and health benefits among poor, rural communities were attained through efforts to revitalize traditional Dalit foods, including through media campaigns on the value of millet-based foods, promotion of recipes and cooking classes, development of a millet processor, and mobile biodiversity festivals (Salomeyesudas et al., 2013). A similar project in Peru helped Indigenous people revitalize their knowledge, crop diversity, and food related practices, leading to some improvements in nutrition and food security (Damman et al., 2013). Reverse-positive effects of this action type on FSN were reported in Ghana, where dumping of commodity rice from countries that can produce it more cheaply, combined with

decreased governmental support for smallholders growing rice, has decreased the profitability of local farms and thus increased the food insecurity of local farming families (Suárez, 2013).

Studies of the success of food relief initiatives after emergencies may show outcomes that do not sufficiently implement a right to food approach, rendering a negative impact on FSN reported in four studies in this review. After a major landslide disaster in 2010 in the Bududa district of Eastern Uganda, some affected households resettled in the Kiryandongo district in Western Uganda. Food security was not uniform, and those with access to land were most able to access food and income (Nahalomo et al., 2018). Another study demonstrates that factors such as HIV/AIDS status may be a determinant of marginality, aggravating not only the capacity to work and receive income, but also the ability to participate in solidarity networks, enhancing the negative outcomes of marginality for people's food security (Kalofonos, 2010). Lastly, protected area policies that limit Indigenous peoples' access to their traditional territories may serve to increase their vulnerability, resulting in negative outcomes for food security, as was shown in a study of the Bribri people in La Amistad, Costa Rica (Sylvester et al., 2016).

Protecting the Right to Access Land, Water, and Genetic Resources for Food and Agriculture, or Redistributing These Rights (E)

Most studies in this action type ($n = 5$) involved cases where reduced rights to the means to grow, raise and harvest food negatively impacted FSN. In central Uganda, rampant land evictions due to increased land sales between 2006 and 2014 resulted in widespread insufficient access to food (Nahalomo et al., 2018). In Cameroon, increasingly resource-constrained populations had less access to wild foods that had formerly been important components of their diets; instead, they were increasingly resorting to cheaper (more refined, less nutritious) imported food, or to eating less frequently (Sneyd, 2013). In South Africa, commercial fishing vessels could disrupt key fisheries providing protein for local people and the poor, whereby governance systems addressing conflicts between large vessels and small fisherfolk have the potential to significantly improve food access (Isaacs, 2015). In contrast, smallholder farmers in El Salvador provide testimony as to how reinforcing their intimate expertise in managing specific agricultural environments improves FSN and enhances traditional knowledge about growing food (Millner, 2017).

There may be highly variable outcomes associated with agricultural development projects if disparities in power and access to resources are not directly addressed. Within the Southern Agricultural Growth Corridor of Tanzania, those farmers actively participating in and benefiting from the transfer of technologies to increase yields were those that were relatively well-endowed with land, access to water, investment capital, and some level of social organization (Tumusiime and Matotay, 2014). Researchers in Kenya identified differential access to resources as a human rights failure, where the limited access to decision-making power on the part of women-headed farming households was the main constraint to addressing food security (Julliet et al., 2007).

Promoting Gender Equity (F)

We found five studies assessing how equity and rights for women impact FSN, with two positive and two reverse-positive reports. In an oral history study from Honduras, women recounted that they occupied land in order to feed themselves and their families. This had far-reaching effects on the food security of the community and other aspects of their empowerment, including political participation (Suárez, 2013). In the Indigenous communities of the Gwich'in nation, Northwest Territories, Canada, the consumption of traditional foods was important for the food security of women, although their availability is perceived as threatened by climate change (Kuhnlein et al., 2006). In Nepal, most women-led households perceived themselves to be food insecure at different levels and had no property rights. However, they accessed land for farming and used various adaptation mechanisms to contribute to food security (Bhawan, 2015). In terms of reverse-positive effects, in three out of five children's homes for girls in Uganda, the realization of the right to adequate food for the girls was not met (Vogt et al., 2016). In India, caste, clan, and socioeconomic status were found to affect the ability of women to access public food distribution systems and thus their right to food; this was aggravated by gendered relations, resulting in negative outcomes for women's food security (Pradhan and Rao, 2018).

Negative and Neutral Impacts on FSN

While the overwhelming majority of studies reported a positive relationship between rights-based approaches and FSN outcomes, studies that report neutral or negative impacts on FSN also provide valuable insight into the efficacy of these approaches, and the barriers to their effective implementation.

In many of the 14 studies reporting neutral impacts of food sovereignty on FSN, the intervention of choice was insufficient for overcoming larger structural barriers to realizing FSN. In northern Nicaragua, for example, many farmers participating in a coffee cooperative's initiative to establish home gardens saw the potential benefits to their household food security, but expressed doubt about their ability to maintain gardens in the long-term given the expense and labor required (Boone and Taylor, 2016). Two studies, in the United States and Canada, pointed to the mixed effects of urban gardening and farming projects that provide healthy food but also contribute to rising costs of living and gentrification that excluded the most food-insecure people (Miewald and McCann, 2014; Vitiello et al., 2015). The sole study reporting negative results similarly cites constraints on farmer decisions and livelihoods that could not be overcome by food sovereignty interventions. For impoverished farmers in the Telengana region near Hyderabad, India, local and agroecological modes of farming promoted by an NGO were often insufficient to meet household needs. Farmers were often constrained by small land holdings and low social status, and in many cases, growing market-oriented monocultures of cotton or corn presented a better option to provide cash income (Louis, 2015).

In the right to food review, the nine studies reporting negative or neutral impacts of the right to food on FSN describe ineffective policies and insufficient government interventions. Studies in two locations in India reported that household food subsidies were insufficient and exacerbated local state corruption (Garg, 2006; Jha et al., 2013). In South Africa, schools provided an important point of food access for girls, but also accelerated unhealthy transitions in body image and eating behaviors (Stupar et al., 2012). One study in Greece documented the ways emergency food assistance programs conflict with political efforts to address the underlying causes of poverty and hunger (Kravva, 2014). The studies reporting negative and neutral outcomes point to the possibility that poorly implemented right to food programs can have unintended consequences, and are in some cases simply insufficient to impact FSN.

DISCUSSION

This review compiles a broad set of cases in which food sovereignty and right to food approaches have strengthened food security and nutrition outcomes, demonstrating a general positive impact of food sovereignty and the right to food on FSN. It also includes several studies in which a loss of rights, or a failure to ensure rights, resulted in negative FSN outcomes. These studies are widespread, based on data from all continents except Antarctica, and documented in both peer-reviewed and gray literature. Publication bias typically favors positive results, so it would be misleading to judge the efficacy of rights-based approaches by the ratio of positive or reverse positive to negative or neutral impacts. However, the fact that reports of food sovereignty and the right to food supporting FSN are widespread across geographic regions in both the gray and peer-reviewed literature indicates that these approaches hold the potential to strengthen FSN in a wide range of contexts. Taken together, these studies indicate that rights-based approaches can be used to solve urgent problems of food insecurity and malnutrition.

Future research should focus on how, and under what circumstances, these rights-based approaches positively impact FSN, or fail to do so. The few observed neutral effects, and even fewer negative effects, of rights-based approaches on FSN are informative. In the food sovereignty literature these were largely cases in which a food sovereignty-oriented intervention was insufficient to overcome larger structural barriers to realizing FSN. Thus, neutral and negative outcomes of case studies should not be seen as an indication that the approach does not work. It is not the case, for example, that urban gardens and local food projects exhibiting mixed results (such as the gentrification documented in Miewald and McCann, 2014) cannot have positive impacts on FSN. Rather, their results may be limited because there are structures and forces in place that prevent them from reaching their full potential. Pre-existing forms of discrimination that fall along categories of difference such as race, indigeneity or ethnicity, class, gender, and ability, among others, can be so entrenched that a policy or intervention focused rights closely tied to FSN is not broad enough to overcome these oppressions. For those whose social locations are placed at the intersection of multiple oppressions, the structural barriers to realizing FSN are even higher (Crenshaw, 1991; Nyantakyi-Frimpong, 2017). This indicates a need for intersectional analyses and attention to human rights and entitlements beyond those most directly linked to food (i.e., the right to housing, health and healthcare, education, and so forth), and to power relationships at multiple scales.

Similarly, the lack of studies on land access and tenure (food sovereignty action type B) and gender equity (food sovereignty action type F) should not be taken as an indication that these aspects of food sovereignty matter less for FSN outcomes. Instead, this review shows that there is an assessment gap in both research and policy with respect to these two action types. The same is true for the relatively few studies on access to markets (right to food action type B), which indicates market engagement is understudied in regards to realizing the right to food. The low number of studies in these action types indicates a particular need for research linking human rights-based FSN interventions to land access, gender equity, and engagement with markets.

Rights-based approaches to FSN, including food sovereignty and the right to food, hold the potential to advance the slow and seemingly intractable progress toward eliminating hunger and malnutrition. Current approaches to food security and nutrition are highly unlikely to meet intergovernmental targets by 2030, including the FAO's Zero Hunger target, and the food security and nutrition targets in the Sustainable Development Goals (FAO, 2019). Rights-based approaches like food sovereignty and the right to food differ from other approaches in that they work on the underlying set of human rights and entitlements that allow people and communities to achieve adequate food security and nutrition, in contrast to policies and approaches that, for example, focus solely on food availability and affordability (e.g., increasing food production or lowering food prices) or consumption (e.g., nutrient supplementation). This review includes ample evidence from across the globe that rights-based approaches can and do positively impact FSN in a wide range of contexts, and can potentially contribute to progress on intergovernmental targets in ways that increasing production and expanding supplementation cannot.

The collective scope and diversity of case studies in this review–documenting positive impacts of rights-based approaches, negative impacts of the loss of rights, and the limitations of some actions that that addressed one kind of right but were unable to overcome lack of rights of another kind–suggest a course of action for rights-based approaches. Realizing FSN requires multiple efforts to address the different ways in which communities are made vulnerable, their agency to respond to changing conditions is constrained, and structural forces may limit their ability to secure adequate and culturally appropriate food and livelihoods.

CONCLUSIONS

This review searched for evidence of the contribution of rights-based approaches–food sovereignty and the right to food–to FSN. Overall, we conclude that the majority of reviewed studies found that food sovereignty directly improves FSN, that processes impairing food sovereignty and the right to food negatively impact FSN, that efforts to improve FSN through rights based

approaches can be limited by structural barriers difficult to overcome, and that impacts of the right to food on FSN are context-dependent. Most studies regarding food sovereignty examined the effect of increasing autonomy over the production process through the adoption of agroecological practices, with a positive effect on FSN. Comparatively, few studies focused on the role of land access, local markets, and gender equity to advance FSN. Literature in the right to food concentrated on advancing physical availability and economic access to adequate food through appropriate actions by governments and non-state actors, with mixed effects on FSN; and on fulfilling human rights that affect food access, availability, and utilization, with some negative impacts on FSN. Studies reporting negative or neutral effects of rights-based approaches involved unintended consequences regarding enhancement of structural barriers or displacement of former food habits and cultural norms that further impaired FSN. These constitute important cautionary examples for planners of rights-based interventions in land and food systems. There is a need for research that assesses the factors that increase or decrease the efficacy of rights-based approaches to FSN, and that describe the conditions for the changes. This study provides clear indications on different action types articulated by rights-based approaches that result in positive outcomes for FSN. However, more studies are needed to address dynamics determinants to equal access to productive resources such as water and land for men and women, intersectional approaches to FSN; and that detail how, and under what circumstances food sovereignty and the right to food positively impact FSN—or fail to do so. This is the first review to assess whether rights-based approaches have positive impacts on FSN, and adds weight to recent global calls for further research investment in rights-based approaches and their importance for FSN, and other benefits beyond direct human well-being (HLPE, 2019).

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://github.com/devonds/rights_and_food_security.

AUTHOR CONTRIBUTIONS

DS coordinated the review process and prepared the final draft. MC-S led the coding process, contributed to concepts and analysis, assisted in preparing the final draft, designed charts, and revised the manuscript based on feedback from anonymous reviewers. BG-H developed the concepts and methods for the review, prepared the first draft of the manuscript, and contributed to screening and keying the literature. NB contributed to screening and coding and provided feedback on the final draft. AB contributed to coding, provided feedback on the final draft, and revised the manuscript based on feedback from anonymous reviewers. RB contributed to coding, provided guidance on methods and concepts, and provided feedback on the final draft. JB contributed to coding and provided feedback on the final draft. EB contributed to coding, provided input on methods, and provided feedback on the final draft. MF contributed to screening and coding. DJ contributed to coding, provided input on methods, and provided feedback on the final draft. TK contributed to coding. SK contributed to coding, provided input on analysis, and contributed to the final draft. AG contributed text from the HLPE report. AW contributed text from the HLPE report. HW contributed initial concepts and methods and provided feedback on the final draft. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.686492/full#supplementary-material

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Biocultural Diversity for Food System Transformation Under Global Environmental Change

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Biocultural diversity is central to the nutrition, resilience, and adaptive capacity of Indigenous and traditional peoples, who collectively maintain the longest ongoing human experiences with the provision of food under environmental change. In the form of crops and livestock and associated knowledge on their cultivation and use, food-related biocultural diversity likewise underpins global food security. As food system transformation is increasingly recognized as an urgent priority, we argue that food security, sustainability, resilience, and adaptive capacity can be furthered through greater emphasis on conservation, use, and celebration of food-related biocultural diversity. We provide examples from the Parque de la Papa, Peru, a "food biocultural diversity neighborhood" which through advocacy and partnerships based around its diversity, has both enhanced local communities and contributed to food security at a much larger scale. We outline collaborative actions which we believe are important to up- and out-scale food biocultural diversity neighborhood successes. Further research and knowledge sharing are critical to better document, understand, track, and communicate the value, functions, and state of biocultural diversity in food systems. Expanded training and capacity development opportunities are important to enable the interchange of experiences and visions on food, health, sustainability and resilience, climate adaptation, equity and justice, and livelihood generation with others facing similar challenges. Finally, strengthened networking across food biocultural diversity neighborhoods is essential to their persistence and growth as they increasingly engage with local, national, and international organizations, based on shared interests and on their own terms, across five continents.

Keywords: sustainable food systems, farmers' rights, crop wild relatives, crop diversity, climate change adaptation, agrobiodiversity

BIOCULTURAL DIVERSITY AND NEEDED TRANSFORMATION OF THE GLOBAL FOOD SYSTEM

The food we eat connects us to those who cultivated it, to the seeds they planted, and, ultimately, to the diverse peoples and places around this planet where the crops and livestock that nourish us originated (Khoury et al., 2016). All of us are the beneficiaries of processes that began for the most part 4,000–12,000 years ago, when many different cultures around the world became increasingly interdependent with the plants and animals they interacted with, through the biocultural processes of domestication (Larson et al., 2014).

These co-evolutionary processes have continued through to the present day in geographic centers of origin of agriculture, now commonly called "primary regions of (crop and livestock) diversity," resulting in tremendous variation in cultivated species, varieties and breeds, and underlying genetic and phenotypic diversity, as well as myriad cultural uses and customs around them (Bellon et al., 2005, 2017; Baltazar et al., 2015). This biocultural diversity—defined here as "dynamic, place-based aspects of nature arising from links and feedbacks between human cultural diversity and biological diversity" (Bridgewater and Rotherham, 2019)—provides the foundation for Indigenous and traditional peoples' nutrition, as well as the resilience and adaptive capacity of their food systems (Kuhnlein et al., 2009).

Cultivation and use practices both maintain and further evolve this diversity, with exchange and gene flow among domesticated (and occasionally also with wild progenitor) forms encouraging the development of new variation, and continued cultivation and selection leading to local adaptation (Bellon, 1996; Louette et al., 1997; Jarvis and Hodgkin, 2002; Allinne et al., 2007; Mercer and Perales, 2010; Rojas-Barrera et al., 2019). These traditions embody the longest ongoing human experiences with the provision of food under environmental change, including, due to commonly being in mountainous and other areas of great ecological diversity, significant stresses, shocks, and extremes (Arce et al., 2018; Argumedo et al., 2020; FAO Alliance of Bioversity International CIAT, 2021).

Food-related biocultural diversity—in the form of crops and livestock and associated knowledge on their cultivation and use—has dispersed from its primary regions of diversity to the far reaches of the planet, as humanity itself has spread around the world and become more interconnected (Khoury et al., 2016). Virtually all cultures now produce, trade, and eat a highly varied assortment of plants and animals, most of which were originally domesticated and diversified in distant lands. In their new homes, these foods have further evolved to meet local needs, conditions, and tastes, contributing to food security and nutrition, agricultural livelihoods, and cultural identities. Yet these food systems also remain connected to and dependent on primary and other regions of diversity, including for the genetic resources used in crop and livestock breeding to address productivity, pests and diseases, new markets and products, and other challenges and opportunities (Hoisington et al., 1999; Gepts, 2006).

Modern economic and agricultural development, globalization, urbanization, and other forces have led to the dominance of certain foods in the global food system, especially high starch, sugar, protein, and fatty foods, and have driven increasing homogeneity in food supplies worldwide (Khoury et al., 2014). This has contributed to reduced rates of undernutrition, but, in combination with widespread changes in lifestyle, has also led to increasing overweight and obesity as well as diet-related non-communicable diseases globally, and has not resolved persisting micronutrient deficiencies (Popkin, 2006; Pingali, 2007; Kearney, 2010). The industrialized production, transport, and marketing systems organized around these foods create daunting sustainability and equity challenges, with agriculture now being the world's largest terrestrial ecosystem and among the most significant contributors to environmental degradation, climate change, and biodiversity loss globally, and with health and ecological impacts disproportionately affecting marginalized populations (Béné et al., 2019; Rockström et al., 2020). These forces have likewise led to widespread and ongoing losses in food-related biocultural diversity, including crop landraces and traditional livestock breeds as well as their wild relatives (Khoury et al., 2021).

A key pathway to greater food security and nutrition, sustainability, resilience, and adaptation outcomes in food systems is therefore through diversification, including of food products as well as processes and actors (IPES-Food, 2016; Bioversity International, 2017; HLPE, 2017, 2019; FAO, 2018a,b, 2019a; Hunter et al., 2020a; Vermeulen et al., 2020). While consultations and dialogues on food system transformation are ongoing, including currently as part of the processes of the United Nations Food Systems Summit (UNFSS), the Convention on Biological Diversity (CBD)'s post-2020 Global Biodiversity Framework, and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), there is concern that Indigenous and traditional peoples' food systems, knowledge, and biocultural processes are not receiving the acknowledgment and attention they deserve (Argumedo et al., 2020; FAO, 2021; Nature Editorial Board, 2021). This must change.

In this Perspective piece, we—a group of Indigenous and non-Indigenous researchers and activists with longstanding collaborations around biocultural diversity—argue that food system transformation can be furthered through greater emphasis on conservation, use, and celebration of food-related biocultural diversity. We provide examples from the Parque de la Papa, Peru, a "food biocultural diversity neighborhood" which through community action, advocacy, and partnerships based around its diversity, has both enhanced local communities and contributed to food security at a larger scale. Finally, we outline collaborative actions which we believe are important to up- and out-scale food biocultural diversity neighborhood successes. These include further research and knowledge sharing, expanded training and capacity development, and strengthened networking.

SAFEGUARDING, USING, AND CELEBRATING FOOD-RELATED BIOCULTURAL DIVERSITY

To achieve greater food security and nutrition, sustainability, resilience, and adaptation in this era of global environmental change, we suggest that further attention must be paid to safeguarding, creatively using, and celebrating the food-related biocultural diversity that sustains humanity.

Safeguarding: Conserving and Accessing Food-Related Biocultural Diversity

International recognition of the importance of safeguarding the world's food-related biocultural diversity has increased over recent decades (FAO, 2002, 2010, 2015, 2019b; Convention on Biological Diversity (CBD), 2010; UN, 2015; Díaz et al., 2020). Despite the wider awareness in high level policy and technical fora, much of the variation which persists in farmers' fields and in wild and semi-wild places remains vulnerable to erosion and even extinction, including traditional and local knowledge (FAO, 2019b; Khoury et al., 2021). While *in situ* diversity is constantly changing due to environmental pressures and human preferences, significant declines over many decades are cause for alarm (Khoury et al., 2021). This diversity is only partially safeguarded in *ex situ* conservation repositories, such as national, regional, and international genebanks, and is therefore not fully conserved for long-term preservation, nor readily accessible to crop and livestock breeders (Gepts, 2006; FAO, 2010; Castañeda-Álvarez et al., 2016).

To continue to meet unique local needs, bolster the resilience and adaptive capacity of agricultural communities, and to evolve alongside biotic and abiotic pressures, crops and livestock must be acquired, cultivated, selected on, and exchanged by local peoples (Berthaud, 1997; Fenzi and Bonneuil, 2016; Bellon et al., 2018). To support these processes, further strengthening of locally managed *in situ* conservation methods is needed. Emphasis on the conditions and processes that foster diversity is essential—including informal trade and exchange systems—particularly through Indigenous and traditional farmer-led efforts (Brush, 2004; Thomas et al., 2012; Stenner et al., 2016; Bellon et al., 2017; Halewood et al., 2021). These can be further supported through a wide range of external approaches, for example diversity inventories and fairs, agrobiodiversity zoning and crop diversity park systems, community seedbanks, specialized markets, participatory evolutionary breeding, and payments for agrobiodiversity conservation services (Tapia, 2000; Narloch et al., 2011; Graddy, 2014; Vernooy et al., 2017; Fadda et al., 2020). Tools and approaches appropriate to location and culture should be identified based on inclusive processes (de Haan, 2021).

To be better safeguarded against climate change and other human-caused as well as natural disasters, to be available for the innovation of crop and livestock species around the world, and to provide a historical record of biocultural diversity under global environmental change, this diversity also needs to be maintained in *ex situ* conservation repositories with the capacity to openly distribute it to breeders, researchers, educators, and farmers (Hoisington et al., 1999; Gepts, 2006; Khoury et al., 2021). To provide the necessary protections for these resources, safety backups of this diversity should also be made (Westengen et al., 2013). As with *in situ* food-related biocultural conservation efforts, these *ex situ* systems can be bolstered, in this case through the development and dissemination of improved methods and practices, and through more reliable support for essential activities and infrastructure.

It is also critical that *in situ* and *ex situ* approaches are better integrated such that resources usefully flow in both directions (Westengen et al., 2018; Ceccarelli and Grando, 2020; Fadda et al., 2020). Genebanks maintain many varieties and breeds that are no longer found on farms in regions where producers are facing increasing climate-related and other challenges, and where formal seed/breed systems are scarce or non-existent. *Ex situ* facilities should serve much more than is currently the case as providers to communities, to restore diversity lost in the past, and to distribute novel diversity, as requested. Likewise, *in situ* conservation initiatives could serve as sources for the periodic collection of germplasm. In all cases, conservation and distribution of diversity should proceed as inclusive processes, based on mutual trust and benefit, and following community agreements as well as national and international frameworks on equitable access and benefit sharing (FAO, 2002; Convention on Biological Diversity (CBD), 2014; Halewood et al., 2020).

Creative Use: Enhancing Livelihood Opportunities Based on Food-Related Biocultural Diversity

Indigenous and traditional agricultural communities in primary and other regions of food-related biocultural diversity have persisted to the present day despite loss of access to land and other natural resources, and numerous other intentional and unintentional actions which have disrupted their traditional ways of life (Garnett et al., 2018; FAO, 2019b). These communities have been impacted by economic and agricultural development and associated policies, including the industrialization of production and subsidized cultivation of staple crops in developed regions, combined with trade agreements which undermine local competitiveness. Often located in mountainous and other environments with extreme topography, such communities are also some of the most directly impacted by shifts in temperature and precipitation patterns resulting from climate change. While there is increasing awareness in global fora of equity issues related to Indigenous and traditional peoples (IFAD, 2009; UN, 2014; FAO, 2019b), and in some countries legislation has been enacted that acknowledges the rights of Indigenous peoples to their traditional livelihoods, in practice there remains much to be done to redress historical injustices, secure access to land and other resources, and open a greater range of opportunities for such communities in the food and agriculture sectors.

In this context, Indigenous and traditional agricultural communities adapt to changing livelihood challenges and opportunities through innovative use of food-related biocultural diversity. This is accomplished through ongoing introduction,

management, exchange, selection and improvement of crops and livestock, adjustments to agricultural practices and systems, and the development of new markets (FAO, 2021). External support for livelihood opportunities based on the use of food-related biocultural diversity can be accomplished through a wide range of existing and experimental tools and processes, such as through diversity-sensitive food procurement initiatives (De Schutter, 2014, 2015; Valencia et al., 2019; Swensson et al., 2021) and community-based development and marketing of value-added products, including those promoted with biocultural branding (Swiderska et al., 2019; AGUAPAN, 2020; FAO Alliance of Bioversity International CIAT, 2021).

Celebration: Awareness-Raising Around Food-Related Biocultural Diversity

Redressing the historical imbalances that have disadvantaged Indigenous and traditional agricultural communities and undervalued the food-related biocultural diversity they have generated and continue to maintain also necessitates reframing this diversity as a central community asset.

Indigenous and traditional agricultural communities are increasingly raising local and regional awareness about their biocultural diversity with practices such as community inventorying and traditional monitoring (**Figure 1**), food biodiversity fairs and seed exchange events, and school garden programs (Cocks et al., 2012; Centro Internacional de la Papa (CIP) et al., 2015; Ministerio de Agricultura y Riego (MINAGRI) et al., 2017). The development of locally appropriate dietary and nutrition guidelines and formal education programs have also demonstrated success as supportive processes (Hunter et al., 2020a,b). To expand these efforts, we see substantial potential in media, product development, festivals, and other initiatives aimed at better connecting communities to consumers, with focus on championing the links between delicious food and biocultural traditions (Chefs' Manifesto, 2018; Crop Trust, 2019; Hunter et al., 2020a). National examples of these include the agrobiodiversity and gastronomy linkages promoted by Peruanos Unidos por la Cocina y la Alimentación (PUKA) in Peru, and Movimiento de Integración Gastronómica (MIGA) in Bolivia (Biocultural Diversity and Territories Platform for Sustainable Inclusive Development, 2021).



FIGURE 1 | An example of a published community landrace diversity inventory for the district of Chugay, Sánchez Carrión province, La Libertad department Peru (Centro Internacional de la Papa (CIP) et al., 2015). Baseline-level documentation of crop diversity and associated knowledge is intended to facilitate agrobiodiversity monitoring, geographical indication, biodiscovery, and local education. Image by Asociación Pataz.

Parque de la Papa—A FOOD BIOCULTURAL DIVERSITY NEIGHBORHOOD INITIATIVE

The Parque de la Papa (or Potato Park) (https://parquedelapapa.org/), located in the primary region of diversity of that crop in the Andes mountains of Peru, is an initiative that is demonstrating the potential of community action, advocacy, and partnerships around food-related biocultural diversity. The Parque, encompassing more than 10,000 hectares, was established in 2000 by six Quechua communities around Cusco as a Biocultural Heritage Landscape (Argumedo, 2008, 2012; Argumedo and Stenner, 2008; Asociación ANDES, 2016; Swiderska et al., 2020). More recently, the Parque is being envisioned as a "food biocultural diversity neighborhood"—a defined geographic region where community members work together to conserve, use, and celebrate their food-related biocultural diversity.

While the Parque was organized around, and celebrates, potato diversity, it's communities also maintain diverse maize, quinoa, bean, and various Andean root and tuber crop varieties, as well as alpaca and other livestock, through locally developed holistic management approaches (Asociación ANDES and the Potato Park, 2015; Agroecology Fund, 2020). The communities advocate for practices that conserve natural resources, as alternatives to extractive mining and other industries.

An enormous amount of potato diversity—more than 1,365 cultivated and wild types—is conserved by farmers in and around their fields in the Parque, some of which has been acquired over the past decade through a collaboration with the International Potato Center (CIP). This diversity is also conserved and supported locally through a community seed bank, seed multiplication center, and greenhouse facilities. True seeds have been deposited by the communities of the Parque in the Svalbard Global Seed Vault as an additional safety backup. This deposit directly by Indigenous communities/organizations was a first for the Svalbard initiative. These collaborative, inclusive, integrated efforts represent promising models for conservation, continued evolution, and access to potato diversity both for local communities and for plant breeders and farmers around the world (Agroecology Fund, 2020).

The Parque has worked to enhance livelihood opportunities around its food-related biocultural diversity by developing local technological, market, and policy innovations based on traditional knowledge and biocultural heritage (Asociación ANDES and the Potato Park, 2015). These innovations—ranging from changing the areas and timing of potato cultivation, establishing a community seed bank, improving plowing and water retention methods, creating biocultural descriptors for potato varieties, developing microenterprises based on cultivated and wild plant products, establishing horizontal partnerships with scientists, and working with the Peruvian government to declare a National Day of the Potato—have significantly improved the food security and livelihoods of community members. Celebration of this diversity at local to national scales has resulted in the Parque being recognized as an Agrobiodiversity Zone by the Peruvian government (INIA, 2020) (**Figure 2**). Awareness of the value of local diversity and empowerment around its use has been such that the Parque has also become a provider of food to others in times of need. For example, communities donated one ton of potatoes to Cusco during the COVID-19 crisis in 2020, to support food-insecure migrants and other vulnerable groups (Local Futures, 2020).

ACHIEVING GREATER FOOD SYSTEM RESILIENCE AND EQUITY THROUGH SUPPORT FOR FOOD-RELATED BIOCULTURAL DIVERSITY

To achieve greater food security and nutrition, sustainability, resilience, and adaptation in this era of global environmental change through conservation, use, and celebration of food-related biocultural diversity, we outline below what we consider to be important, interrelated actions in collaborative research and knowledge sharing, training and capacity development, and networking.



FIGURE 2 | Parque de la Papa community members celebrate the annual festival of "Papa Tinkay," a ritual offering to the flowering potato plants to bring a fruitful harvest (Agroecology Fund, 2020). Image by Asociación ANDES.

Collaborative Research and Knowledge Sharing

Despite awareness of the importance of, and threats to, food-related biocultural diversity in high level policy and technical fora, and the increasing variety of research, action, and advocacy tools designed to conserve, increase use, and celebrate this diversity employed at community levels, major gaps in understanding the significance of change in this diversity over time, and the best approaches to mitigate or reverse further losses, remain (Khoury et al., 2021).

A worldwide effort to take stock of the state of food-related biocultural diversity is urgently needed to provide a cross-cultural knowledge base to guide current and future initiatives. This knowledge base can only be adequately established through inclusive, multi-disciplinary and participatory processes, engaging Indigenous and traditional agricultural communities in and beyond primary regions of diversity. Strategies to bring together traditional as well as scientific knowledge and methodologies need further development to create a network of research sites/observatories, enabling collaborators to address complex questions related to food and nutrition, sustainability, resilience, adaptation, and livelihoods (Díaz et al., 2015, 2018). Importantly, food biocultural diversity neighborhoods and other such communities must have a stronger voice than in the past in communicating their perspectives to the global scientific and development communities (Nature Editorial Board, 2021). Such a knowledge base should inform conservation and development actions globally for decades to come.

Training and Capacity Development

Food biocultural diversity neighborhoods and other agricultural communities in regions of diversity are innovating stewardship models that explicitly maintain the biocultural processes which conserve and use diversity and provide livelihood opportunities. The Parque de la Papa has both slowed the loss of crop diversity *in situ* in its communities, and added new diversity obtained from *ex situ* repositories to the point where the communities now maintain arguably the most potato diversity per unit cultivated area in the world. Key to this success are the methods, tools, and processes collaboratively developed to implement and manage the diversity within a holistic landscape, based on a combination of Indigenous cosmologies, local use traditions, and scientific research.

Up- and out- scaling such models requires the advancement of systems of learning in creative environments in which different forms of knowledge can coexist. The Yachaykuychi (Rainbow of knowledge) Pluriversity, an outgrowth of experiences gained in the Parque de la Papa, is an incipient international, intercultural educational institution aimed at these goals (Asociación ANDES, 2021). Dedicated to the conservation, innovative use, and celebration of biocultural diversity, its vision is that all Indigenous peoples and smallholder farmers benefit from state-of-the-art research, tools, and training that embody multiple ways of knowing. To realize this vision, the Pluriversity is promoting and enabling partnership-driven, Indigenous-led research in interwoven food and agriculture topics, including the integration

of *in situ* and *ex situ* conservation, farming under climate change, Indigenous governance and agrobiodiversity management, and sustainable livelihood innovation.

To advance the aims of these training and capacity development initiatives, currently scattered research efforts and resources relevant to food-related biocultural diversity need to be compiled, with focus on the pressing priorities of Indigenous and traditional communities. Second, the perspectives of Indigenous and non-Indigenous experts need to be combined to help transform the way the public see and understand these communities and the diversity they safeguard. Further, existing investments in community-based biocultural diversity conservation research need to be bolstered by collaboratively designing and building core infrastructure for monitoring and data management. Finally, innovative training methods for Indigenous peoples, farmers, students, and scientists need to be created to prepare a new generation of researchers, leaders and activists able to bridge cultures, collaboratively address environmental challenges, and raise awareness of food-related biocultural diversity opportunities.

Training and capacity development through structures such as the Yachaykuychi Pluriversity, supported by local, national, and international organizations, will provide critical transformative processes through which biocultural knowledge systems surrounding food can be better recognized as the foundations of conservation and innovative use initiatives. Such activities will also provide a major medium by which communities can learn from the successes and challenges of others regarding safeguarding diversity and creating livelihood opportunities.

A Network of Food Biocultural Diversity Neighborhoods

Communities in the primary and other regions of diversity of crops and livestock typically maintain a varied range of domesticated species, and in addition collect wild foods to supplement their nutrition and livelihoods. This said, their food systems generally center on a few iconic foods, e.g., potatoes and quinoa in parts of the Andean mountains, maize and beans in Mesoamerica, and bananas and starchy roots and tubers such as yams and taro in the highlands of Papua New Guinea. A promising pillar around which to organize a network of food biocultural diversity neighborhoods, building on the many existing networks and initiatives of Indigenous, rural, and small-scale farmers, is therefore the conservation, use, and celebration of such emblematic crops and livestock.

A network based on the emblematic crop and livestock concept has recently emerged, inspired by the Parque de la Papa and hosted by the International Network for Mountain Indigenous Peoples (INMIP) (https://inmip.net/). This currently includes interested communities in China, Ethiopia, Guatemala, India, Kenya, Mexico, Papua New Guinea, Peru, and Tajikistan. Such a network, aligning with wider efforts, offers opportunities for substantive positive change in the primary regions of diversity, by providing focus for initial integrated conservation and use efforts, connecting communities based on shared needs and diverse experiences, and embracing local, national, and international collaborations.

The initial focus on integrated conservation and use, innovative livelihood, and celebration actions for emblematic crops and livestock can be leveraged in and beyond communities to benefit other, less well-known species and their stewards. In the spirit of the generosity of sharing of biocultural diversity that has characterized these communities for countless generations, the network can also play a key role in instigating dietary, sustainability, resilience, and adaptation innovations through interchange among and beyond communities, preferably with support from nutritionists, chefs, researchers, and others.

In emphasizing conservation, use, and celebration around food-related biocultural diversity, and in recognition of the rights and the roles of Indigenous and traditional communities, progress on the actions outlined here will substantially contribute to the Sustainable Development Goals, the CBD, and the ITPGRFA, among others. This focus on biocultural diversity and on the neighborhoods that nurture it is certainly not the only set of actions needed to create more secure, nutritious, sustainable, resilient, climate-adapted, and equitable food systems. However, it is a critical element of such systems and one where progress is being made.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

AA, CK, and HD wrote the first draft of the article. All authors edited, contributed to the article, and approved the submitted version.

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Identifying Critical Thresholds for Resilient Regional Food Flows: A Case Study From the U.S. Upper Midwest

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Improving the regional organization of food flow requires an understanding of system constraints. System transformation is necessary if the system is to include regional, independent wholesale food suppliers and to distribute food in an equitable and sustainable manner. Regional suppliers play a pivotal role in overall food system resilience, an emerging issue in wake of the numerous failures in conventional food supply chains exacerbated by COVID-19-related disruptions. Yet alternative supply chains that link local producers with towns and urban centers regionally, represent a small fraction of our nation's food suppliers. They struggle to compete with larger distribution networks that can supply products in-and out-of-season by global procurement. The upper Midwest harbors numerous local and regional food supply chains consisting of farms, processors, trucking companies, wholesalers and other firms that share a commitment to sustainability and local economic development. A constellation of challenges hamper their emergence, however, even as larger scale food supply chains flounder or fail to effectively serve communities. Informed by Donella Meadows's work on leverage points for systemic change, a collaborative, transdisciplinary and systems research effort examined conventional food supply networks and identified key opportunities for shifting food supply chain relationships. System concepts such as stock and flow, leverage points, and critical thresholds helped us to frame and identify challenges and opportunities in the current system. The second and third phase of our collaborative research effort occurred over 4 years (2013–2016) and involved twenty-six people in co-generation of knowledge as a loose-knit team. The team included farmers, supply chain practitioners, students, academic staff and faculty from multiple departments and colleges. Our primary method was to host public workshops with practitioner speakers and participants to identify dominant narratives and key concepts within discourses of different participants in distribution networks. The literature review was iterative, based on challenges, ideas and specific questions discussed at workshops. Our research exposed two meta-narratives shaping the supply chain: diversity and efficiency. In addition to these high-leverage narratives, we identified and examined five key operational thresholds in the Upper Midwest regional food system that could be leveraged to improve food flow in the region. Attention to these areas makes it possible for businesses to operate within environmental limits and develop social structures that can meet scale efficiencies

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necessary for economic success. We iteratively shared this co-produced knowledge with decision-makers via local food policy councils, local government, and national policy circles with the goal of supplying actionable information. This phased action research project created the environment necessary for a group of food system entrepreneurs to emerge and collaborate, poised to improve system resilience in anticipation of food system disruptions. It forms the basis for on-going research on food flow, regional resilience, and supply chain policy.

Keywords: supply chain, agricultural resilience, market access, food distribution, leverage points, midwest

INTRODUCTION

Over the last half century, smaller scale, regionally focused wholesale regional food supply networks have faced seemingly insurmountable barriers in gaining market share as they compete with national and global food supply chains (Day-Farnsworth and Miller, 2014). While large-scale food supply networks efficiently move food at a low cost, their configuration burdens society in critical ways. This paper discusses current system limitations and ways that regional food systems can support innovation and competition in the marketplace, improve food access in both rural and urban areas, and increase resilience through redundancy that is critical to rapid and flexible responses in crises such as the COVID-19 pandemic and shocks due to extreme weather associated with climate change. Using the Upper Midwest as a case study to understand national and regional food system interactions, this transdisciplinary system diagnosis points to ways to meet multiple societal goals through system redesign.

Costs to society from large-scale agriculture and supply chains are well-documented and largely born by vulnerable populations or left to governments to address. Water quality and quantity concerns are foremost among these: Dead Zones in the Gulf of Mexico and Lake Michigan due to fertilizer and manure runoff from farms that pollute surface waters, groundwater and private wells polluted with fertilizers and pesticides, and rivers diverted for irrigation purposes that leave indigenous communities without water. Other concerns are soil erosion, depletion and salinization; labor abuses; systemic waste; and the financialization of land. Tello and de Molina (2017) term this the "dis-ecology of scale." Instead of the current heavily extractive systems, their case for re-localizing the food system is to close nutrient cycles, improve biodiversity at a landscape scale, improve overall systems energy efficiency, build on local, expert knowledge that farmers and practitioners possess, and make the urban-rural relationship fairer and more democratic.

Local food and farming movements in metropolitan regions demonstrate the potential of symbiotic enterprises in food supply chains to restructure relationships between urban and rural communities in ways that enhance the well-being of both (Jennings et al., 2015). In research to understand economic sustainability using network flow analysis, Goerner et al. (2009) found that small and mid-scale enterprises can balance both diversity and efficiency in ways that sustain regional economic flows in the face of disturbances, Infrastructure to support regional and local wholesale markets are good public investments. Research has shown that they tend to operate with a civic commitment to local economies, including the retail sector (Croushorn, 1990; Tangires, 1997), improve rural and urban food access (Beilock et al., 1990; Tangires, 1997; King et al., 2010; Walker et al., 2010; Pomponi et al., 2013) and meet culturally specific food needs for diverse communities (Walker et al., 2010; Day-Farnsworth, in Preparation[1]). Smaller-scale supply chains have also been shown to be more flexible and responsive to system shocks such as regional weather disruptions, rapid urbanization, political crises, and market shocks (Tendall et al., 2015). In addition, by operating at mid-to-high volumes but over short distances, regionally-organized supply chains can optimize transportation efficiencies reducing emissions (Roeth, 2016; Mihelic and Roeth, 2019) and provide affordable, regionally sourced foods (Croushorn, 1990; Tangires, 1997; Day-Farnsworth, in Preparation[1]).

Regional distribution is linked with diversity in urban food enterprise scale as well. In their study of New York's "last mile" food system, the city's Economic Development Corporation (EDC) documented the importance of the multi-tenant terminal market at Hunts Point. Its tenants supply independent corner stores and restaurants, especially those under 5,000 square feet (Economic Development Corporation, 2016). Significantly, regional distributors at Hunts Point were important suppliers to schools and other institutional kitchens and commissaries. In total, regional companies distributed 53% of the goods in the city, while national grocery and food service distributors moved half that volume (Economic Development Corporation, 2016). Croushorn (1990) identified food distribution as a high-leverage point to counteract market concentration, strengthen independent wholesalers, and improve food access.

The Center for Integrated Agricultural Systems, a sustainable agriculture research center at the University of Wisconsin's College of Agricultural and Life Sciences, has engaged with farmers since 1989 to identify system-based solutions to food system challenges through participatory action research. Early in the Center's history, farmers voiced concern over market access, especially for food produced using sustainable agriculture methods. These entrepreneurial farmers had to create separate, smaller, wholesale supply chains to move their produce. They found it difficult to link their smaller chains with wholesale

[1]Day-Farnsworth, L. (in Preparation). "Wholesale terminal markets as regional food system assets."

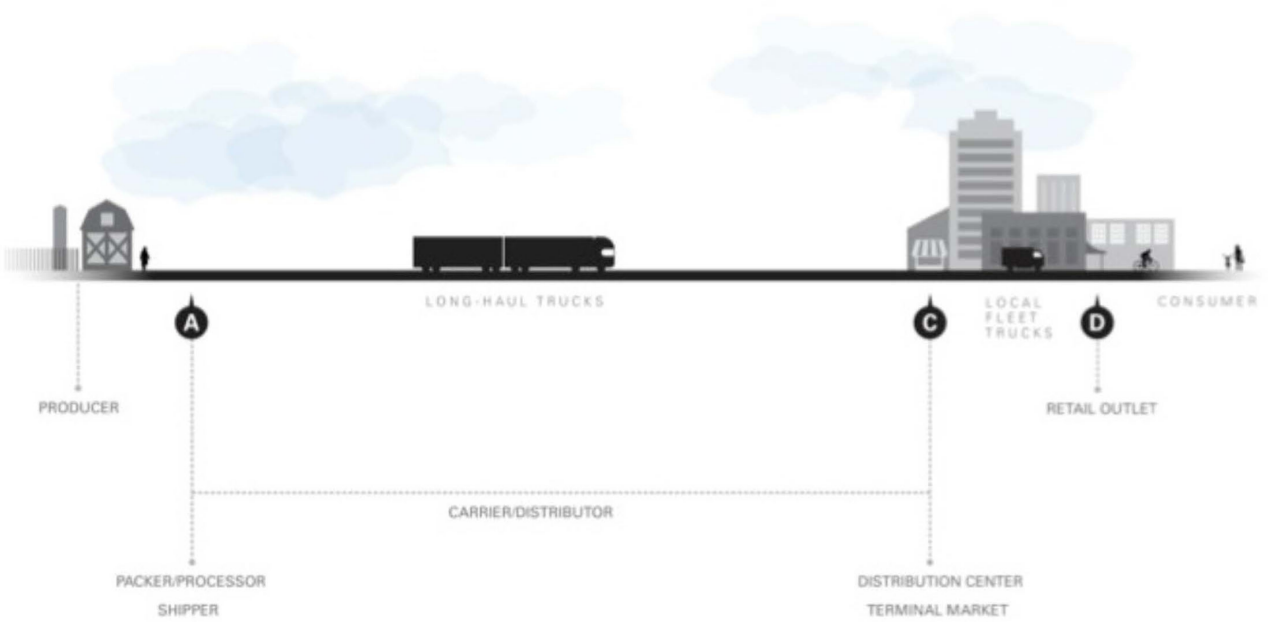


FIGURE 1 | This figure illustrates how food flows from farm to retail market. First mile movements are those from farm to packer or processor for aggregation, who then is responsible for shipping costs to market. Over-the-road trucks haul product from point **(A)** to point **(C)**, the private distribution center or public terminal market. Here product is disaggregated and moves to retail markets, point **(D)**. What is missing is point **(B)** - the infrastructure necessary to improve the organization of food movements from **(A)** to **(C)** at the regional level.

markets in major urban regions, especially Chicago, where national and global suppliers dominate, as documented by trade consultants (MWPVL, 2010), freight flow analysis [Chicago Metropolitan Agency for Planning (CMAP), 2012] and network food flow analysis (Lin et al., 2014). This is discussed in more detail in section Food Flow in the Upper Midwest of this paper.

The driving objective of this work is to understand why Wisconsin farmers are unable to access the nearby Chicago market with perishable products at a reasonable distribution cost, and identify ways to rectify the situation. This objective emerged from a regional needs assessment the Center conducted in 2011–2012, The Center conducted a series of workshops on local food and sustainable agriculture in the Four-state Drift less region. Local speakers shared their perspectives and insights and participants formed working groups on topics of interest and concern. One of those working groups identified transportation and distribution challenges as a key roadblock to rural economic development in the region.

To follow up on farmer interest in distribution challenges, the Center partnered with the USDA Agricultural Market Service's Transportation Services Division to convene a 2-day workshop entitled "Networking Across the Supply Chain." We organized this event as a pre-conference workshop at the Drift-less region's premier farming conference, the Organic Farming Conference in February 2013. More than 100 representatives from food and farming businesses in the region participated. Speaker panels discussed challenges from the perspective of farmers, distributors, processors and retailers, and participants discussed their take-away in small groups. For more detail on the process and findings see Day-Farnsworth and Miller (2014).

We then embarked on a third phase in 2014 to further explore issues that surfaced at the 2013 conference. **Figure 1** illustrates the food supply chain and was used early in the third phase to explain how food freight moves so that all participants could get quickly up-to-speed. A full report on the third phase details methods and findings (Miller et al., 2016). This article summarizes findings from this series of projects and continues the iterative research process by linking our past project findings with additional proof of concepts and current literature in preparation for new projects. Five new projects that further investigate regional food systems are in process. They are (1) a multi-university collaborative led by economist Hikaru Peterson at the University of Minnesota looking at three distinct megaregions to assess lessons that can be learned about resilient food systems from an analysis of the COVID-19 pandemic; (2) a closer look at cold chain food flows led by the author in collaboration with the Konar lab at the University of Illinois Urbana at Champaign; (3) a comparative study of rural and urban food access in a transportation context, led by the author in collaboration with the New Jersey Institute of Technology; (4) a project on dairy supply management policy led by the author to provide dairy farmers with policy research; and 5) a multi-university collaboration to explore ways to democratize analytics, using "smart foodsheds" as a use case, led by Dhabaleswar Panda & Casey Hoy at Ohio State University, Thomas Tomich,

University of California-Davis, and Alfonso Morales, University of Wisconsin-Madison.

THEORY

Food systems are non-linear. This means that they hinge on critical thresholds that can be leverage points for change. System concepts such as stock and flow (in our case, defined as sustainably produced food grown within the Upper Midwest region and the movement of food between point of shipment and wholesale market), as well as the concepts of leverage points helped us frame our work. There are multiple critical thresholds in the food system, both naturally occurring and human-constructed. We identified narratives and critical operational thresholds at the heart of challenges and opportunities that farmers face (Meadows, 2008).

Meadows defines leverage points as "places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything." Narratives and critical thresholds are types of leverage points. Meadows identifies twelve types of leverage points within a system and ranks them from most to least effective. The most powerful points of leverage are those that shape how people think about their world, the narrative(s) that drive our everyday actions. Narratives have a logic of their own, so narrative differences are based on different logics, or understanding of how a system works (Frankova et al., 2017). The least powerful leverage points are those that "rearrange the deck chairs on the Titanic," the smallest changes that may seem easiest to make but that may make little difference in the overall system structure.

Ecological systems theory applied to human—natural systems helped our team to understand narrative bias. Emerging from quantitative work in South Florida's Cypress wetland ecological system, researchers engaged in ecological network analysis and found that the most efficient food network supported the most life (i.e., largest carbon flows), but was not resilient (Ulanowicz et al., 1996). Simply maximizing diversity in the system reduced carbon transfer and efficiency. Optimizing both efficiency and diversity resulted in slightly more carbon transfer (i.e., organisms in the system) and a more stable system overall. Resilience is quantified as the balance between the efficiency and redundancy of resource flow through the network (Fath, 2015). System level indices such as these highlight the relationship between internal processes and whole system performance. They identify a sweet spot between diversity and efficiency.

Most supply chain literature emphasizes negative feedback, such as regulation and top-down intervention to control a system and slow growth, but others observe that emergent patterns in complex adaptive supply networks can be better managed with positive feedback through reward systems that allow for autonomy of supply chain businesses (Choi et al., 2001). Rather than focusing on what we do not want and controlling it, the focus shifts to articulating a shared vision, such as sustainability, and articulating the steps necessary to create it. This is the purpose of crafting compelling narratives.

Critical thresholds are the parameters around how material, information, and capital flows through a system. Critical thresholds are further down on Meadow's list of effective tools for systems change than are narratives. Nonetheless, they provide other avenues for change. While Meadows' notions of systems change have been widely applied, less has been done with these ideas in the context of food systems and agricultural transformation. Recently, Tendall et al. (2015) and Rosenzweig et al. (2020) have addressed the opportunity by articulating key leverage points in the food system as a whole. They argue, as do we, that it is necessary to examine the larger system in order to improve system resilience and proactively prepare for disruption. This is done by listing opportunities at various functional and scaler point to broaden the narrative around agriculture, food systems, resilience and climate change, from field level change to systems transformation.

We found European literature on food systems especially useful. In 2015, the first Mediterranean Conference on Food Supply and Distribution Systems in Urban Environments convened scholars and decision makers in the fields of complex systems and system dynamics to find practical tools to improve food systems (Armendariz et al., 2015). Their use of stock and flow diagrams show how urbanization drives the need for food systems reorganization. System archetypes are common feedback or interaction patterns that arise from the structure of the system. The relationship between urbanization and the food system indicate a system archetype of "eroding goals," where long-term goals are not met because the underlying causes of failure are not addressed. The current food system also shows signs of "shifting the burden" and "fixes that fail."

The United Nations Food and Agriculture Organization (FAO, 2017) identified four trends that are stressing our food systems, and we found evidence of these trends in the Upper Midwest, as well. The trends are: (1) patterns of urbanization and related traffic congestion and patterns of food production, (2) business sector concentration as a result of weak and outdated market rules and lack of anti-trust enforcement, (3) pressures to increase labor and fuel efficiencies, and (4) climate change and other major social disruptions, such as COVID19. Climate change is thought to have the highest impact on trends because of its long-term nature and global scale (Calicioglu et al., 2019).

METHODS

The targeted objective for the project's third phase was to investigate how we can make our food system more resilient by undergirding national and global supply chains with robust regional food supply chains. We began with collecting feedback on findings from the second phase. Presentations on these findings at transportation conferences, particularly the leverage points identified in the second phase of the project, were tested (Day-Farnsworth and Miller, 2014). Examples of conferences include a paper presentation at the National Logistics, Trade and Transportation Symposium, Gulfport, MS, February 2014, a local food panel convened at Northwestern University, Chicago,

IL, November 2013, and a panel at the American Planning Association, Chicago, IL April 2013.

Understanding how food flows through our food system requires a transdisciplinary approach, most easily accomplished through a targeted case study. We chose the Upper Midwest, with Chicago as the primary market. Akin to Maani's Learning Lab 2013, over the project's third phase, we engaged a research and advisory team of twenty-six, including farmers, supply chain actors, students, academic staff and faculty from multiple departments and colleges to collaboratively explore food flow in the Upper Midwest. We started the project with a core group from phase two. As the project progressed we added other interested practitioners, students and faculty in a snowball fashion. We relied heavily on practitioner involvement to identify intersections between supply chain functions and incentives for innovation (Ruben et al., 2018). The formal project culminated in a workshop hosted by the Chicago Metropolitan Agency for Planning in Chicago's Willis Tower. The project produced a final report with detailed descriptions of methods and findings with many of the core team participating as co-authors (Miller et al., 2016).

To identify and explore leverage points in the food system, we hosted three 1-day meetings with regional food supply chain businesses and stakeholders. The first meeting was a write shop that resulted in an early concept paper. The second meeting used scenario-building methods to discuss four groups of trends that shape food systems: public health and food access; climate change and population growth; fuel and labor costs; traffic congestion and public infrastructure. We then grouped potential solutions into four approaches: policy and regulation, data and information technology, private and public sector engagement/opportunity; and infrastructure and other innovations. Our final workshop highlighted the experience of people working in food distribution, and equal time for participants to discuss what they heard in small groups. We had the good fortune to engage two teams of professionals in phase three as part of their degree programs on the University of Wisconsin-Madison campus. The team from the Department of Landscape Architecture worked on land use challenges. A team from the Grainger Center for Supply Chain Management worked on supply chain challenges and transportation logistics.

This process supported the co-generation of knowledge. Our collective understanding of the system evolved over the course of this phased project, based on feedback from within and outside the team. The large and diverse team, public meeting presenters, and practitioners involved created the system diagnosis. The literature review is iterative as this fast-evolving field of study expands. Every meeting and discussion built on the work done before. Our work necessitated that we piece together divergent narratives from a number of professional "languages" to build trust and a common language among team members. This process helped us to identify powerful narratives that both limit and support food system improvement.

As a group, we synthesized findings from multiple perspectives and disciplines such as history, ecology, geography, regional and transportation planning, engineering, business, economics, law and food production in order to gain insight into continental and regional food systems. We diagnosed the challenges and obstacles to improvement, and how long-term food shipment trends impact current and future food production and markets. We explored the history of food supply chains through the lens of business development, using academic and professional writing as well as oral histories from research partners and meeting participants. We looked for proof of concept throughout the process. We also shared co-produced knowledge with decision makers.

One of the approaches that was particularly helpful was path dependency analysis, a historical, sociological method (Mahoney, 2000). In this approach, we looked at the beginnings of food distribution to understand the impact of early technology adoption—the diesel truck—and how it shaped market development. The CR England proof of concept (Section Identifying Critical Thresholds in the Context of Efficiency and Diversity below) arose from practitioner knowledge shared during the course of the project and illustrates the arc of food system development from pre-diesel distribution to the current lock-in, to distribution reorganization during climate change and the Anthropocene.

Ultimately, this led to the creation of a local team linked to a food policy council, city and state governments, local businesses, and private firms, all of which are now acting on findings in an effort to reorganize our regional food system in the Upper Midwest. Our approach helped us to clarify "nested" system complexities identified by Meadows (2008) as critical "places to intervene in a system." Our historical analysis pointed to some potential leverage points for improving the current food system infrastructure that are less effective at changing the system than addressing narratives may be, but nonetheless have the potential to improve system design at the regional level. We identified specific types of businesses that are systemically alleviating transportation barriers to regional food supply chains for mid-scale businesses. Our inclusive analysis also identified elements like traffic safety, congestion, and inadequate public resources for infrastructure and logistics planning. Thus, our analysis of regional food networks speaks to challenges faced by transportation and city planners, especially in a region critically important to national food flow like Chicago and the Upper Midwest.

REGIONAL FOOD SYSTEM REVIEW AND DIAGNOSIS

Over the last 75 years, the US food system has evolved from a system of regional food flows between arable land proximate to cities, to a food system wholly reliant on national and global food flows. While direct marketing through farmers markets and other means is highly popular with consumers, from a farmer perspective these direct markets are a mixed blessing. They give farmers, especially beginning farmers, a chance to interact directly with their customers and build a business, although inefficiencies cut into profit margins. In a review of USDA data, Bauman et al. indicate that until a farm is of sufficient scale to sell into wholesale markets, their farm business is unlikely

to succeed without off-farm income (Bauman et al., 2018). Some research indicates that driving produce to farmers markets further than about fifty miles is simply cost-prohibitive (Grigsby and Hellwinckel, 2016).

Historically, wholesale food distribution capacity and urban development go hand-in-hand (Baics, 2016) because it improves how the system organizes food distribution to fulfill basic human needs. Public (as opposed to private) wholesale markets have played a significant role in food supply distribution, as documented in Maryland (Croushorn, 1990; Tangires, 1997). Privately held multi-tenant terminal markets are less common in North America but are found in other parts of the world. The World Union of Wholesale Markets has 217 members, in over 40 countries worldwide, and covering 5 continents. Some of these markets are privately owned and operate within government guidelines to serve public needs. Public-private partnerships are the most common governance arrangement and they share the primary objective of organizing the movement of fresh produce to market to reduce waste and realize energy savings by organizing truck movements (Escoffier, 2021).

For instance, Rungis Market, outside Paris, France, is operated by SEMMARIS, a self-described "semi-public company which includes public and private partners." Rungis is a member of the French Federation of Wholesale Markets. This Federation is made up of "all national interest markets and certain Wholesale markets in France." These markets place a high priority on local commerce and regional food production (Rungis International Market, 2017). Another example is the Central de Abasto, serving Mexico City and is the largest wholesale market in the world. A 99-year government trust initiated in 1981 oversees operations managed privately. The trust also provides financing to farmers so that they may access principle Mexican and global markets (Open Source, 2021).

Over the last 60 years in the United States public participation in wholesale food terminals has gradually decreased, deferring to private interests. Vertically integrated private distribution centers are made possible by the interstate road network and refrigeration technology. Beilock et al. (1990) documented the fading of multitenant wholesale produce markets as the food sector was consolidating, and how suburbanization contributed to the trend, from the 1950s onward. Tangires (1997) documents municipal and federal leadership in wholesale market development as early as 1913. The ability to meet the public goal to feed urban populations at the neighborhood level eroded as private sector efforts to maximize distribution efficiency took precedence (Tangires, 1997). Concentration in the grocery industry pushed independent community-based grocers out and replaced them with big box grocery stores that served a regional customer base (Pinard et al., 2016). Now, in a second wave, rural areas are experiencing another retreat of groceries, as rural population density falls below the critical mass necessary to be connected in with the increasingly dominant mega-supply chains (Parker, 2020).

Section Regional Food System Review and Diagnosis reflects insights and experiences shared in the presentations and discussions held at the meetings given throughout the project. We found that moving food from rural areas into large metropolitan regions is an expensive proposition. Regional shippers are looking for ways to reduce labor costs and improve fuel efficiency. Distribution centers are interested in securing more regionally-produced food to meet consumer demand and differentiate their stores. Planners are looking for ways to reduce traffic congestion and improve air quality. Food activists want to see food businesses owned by community members bloom in their neighborhoods. For more detail on meeting agendas, presenter topics, participants, and comments, see Day-Farnsworth and Miller (2014) and Miller et al. (2016).

Food Flow in the Upper Midwest

The Upper Midwest includes a constellation of cities in relationship with different farm production eco-regions and a unique food flow, one that supports regional food production while also serving as a hub for national and global food flows. The Upper Midwest food economy is built on innumerable food system interactions between Chicago, Milwaukee, Madison and the Twin Cities in Minnesota, and all the people and communities in-between. Overall, this region is home to more than 21 million people—and growing. Regional food production in the Upper Midwest is relatively diverse, with commodity dairy, meat and grain production, as well as remnants of a once-vigorous specialty crop economy around fruits and vegetables. This production pattern is shared by other states in USDA's "Northern Crescent region," loosely defined by the Great Lakes states. Regional crop diversity has contributed to the development of thriving direct marketing networks, centered around urban areas like Minneapolis/St. Paul and Madison, involving farmers markets, CSAs, and grocery cooperatives.

Meanwhile, fruit and vegetable production regions have shifted from city-proximate regional production to the "Fruitful Rim"—coastal states where production is unhampered by severe winter conditions, supported by irrigation and transportation subsidies (Aguilar et al., 2015). The ability to efficiently transport refrigerated produce also contributed to this shift from fruit and vegetable production near northern cities to the Fruitful Rim regions.

In Chicago, however, the story is different from the rest of the Upper Midwest. As more farmer-centric regional food systems emerged in and between the Twin Cities and Madison, the urban corridor of Chicago developed as a gateway for national and global food freight. Even though Chicago hosts O'Hare airport and is a rail and barge nexus, an insignificant portion of perishable food moves via air, rail and barge. Over a quarter of all US freight originates, terminates or passes through the Chicago region (CMAP Chicago Metropolitan Agency for Planning, 2021). Two hundred and sixty-nine million tons of freight worth over $564 billion moved through metropolitan Chicago in 2017 [Chicago Metropolitan Agency for Planning (CMAP), 2017]. The Chicago urban corridor now serves as a hub for the transportation of food produced in Western states moving east, and Milwaukee functions as a spur of Chicago. Urban sprawl whittles away at food production opportunities near this great city, further driving land prices up and subsequent urban development in a positive feedback loop. Federal farm policy supported commodity production (i.e., large scale corn,

soybean, and meat) and did little to support more diversified regional food production to serve nearby cities.

Over 95% of cooled produce moving through North America travels by truck and refrigerated trailer (Pullman and Wu, 2012). Lin et al. (2014) work on national food flow found that the Chicago region is central to the national food network, as evidenced by findings that it has the largest square footage of food warehousing—pre-dominantly privately owned (MWPVL, 2010). Freight moves vary by trip type, and "through traffic"—which initiates and terminates elsewhere—is the largest component of truck freight in Chicagoland. In-bound truck freight that serves the city constitutes only 17% of freight traffic, indicating that much of Chicago's freight traffic is simply "passing through" [Chicago Metropolitan Agency for Planning (CMAP), 2012]. A 2017 Texas Transportation Institute analysis of the cost of congestion in Chicago estimated that over 15 million annual hours of truck delay, more than 30,737 gallons of wasted fuel from trucks, and congestion costs to shippers of over $753 million (Eisele et al., 2013; TTI, 2017), the price paid by the region for freight through-traffic.

Driving goods into cities thus involves surmounting several challenges. Historically, traffic congestion has pushed many multitenant produce terminals to relocate from the inner city to the outskirts. In Chicago, Haymarket, South Water Market, and now the International Produce Terminal located near I-55, are examples of this progression (Block and Rosing, 2015). By 1940, Chicago's centrally located public wholesale market was overwhelmed with traffic congestion, so the city replaced the downtown market with the South Water Market, and eventually in 2003 with the International Produce Market, geared for larger scale shippers and buyers, especially those selling global produce, as its name signifies. In turn, large, vertically integrated, and privately held supply businesses emerged, able to take advantage of efficiencies of scale and logistics analytics. Smaller distributors and farmers struggled to compete, and last-mile efficiencies associated with central city locations were lost.

This context exposes how the Midwest's *regional* wholesale food flow is profoundly depressed by the national and global flow of food and capital into Chicago, leading to both rural and urban areas experiencing insufficient access to farmland, markets and food (Miller et al., 2016). As described by Block and Rosing (2015), Chicago became a national and global food distribution center at the expense of serving regional farmers.

Our research identified seventeen companies that do business from Chicago's International Produce Market; currently only three produce houses list locally sourced product (potatoes, onions, and beets) at the height of the local growing season. This is despite its accessibility to the I-55 corridor, one of the major interstate corridors in the US, connecting the Great Lakes to the Gulf of Mexico [Merchant Directory (n.d.)]. Mandal et al. (1993) documented the underutilization of Chicago wholesale markets by Illinois fruit and vegetable farmers in their 1993 report, produced at the time planners began to advocate for the creation of the International Produce Market. They highlighted the efficiencies that could accrue to mid-size farms, as well as the high transportation costs to move product the last mile into the city by improving the market (Mandal et al., 1993).

Many crops once grown in the Northern Crescent for wholesale fresh market fell below critical production levels (or thresholds) necessary for efficient transportation to regional markets. Farmers we interviewed indicated that predatory pricing strategies from grower/shipper alliances in the Fruitful Rim states and Mexico undercut their ability to participate as regional producers. Chicago's central role in the development of national distribution and resultant evolution in market structure contributes to the atrophy of the Upper Midwest's regional distribution sector.

Key Global Trends That Influence Regional Food Systems

Our analysis of the Upper Midwest regional food system resonates with the four dominant global trends currently shaping the North American food distribution system, as well as food access world-wide. These trends point to opportunities for changes beneficial to local and regional business networks. The current Pandemic has proven to be a good testing ground for food system resilience, or lack of it. Because the Pandemic is also a global disruption, and because it came on quickly with little warning, it illuminates systemic weaknesses in the structure of our food system and opportunities for systemic change.

Urbanization is a primary driver of market concentration and has slowly warped the structure of the food system. Market dynamics related to urbanization have the potential to devolve into colonial, extractive relationships with farmers and rural areas. In these market relationships, urbanites give little thought to outlying regions, except as tourist and supply sources, assuming they lack autonomy or cultural significance. The sheer scale of urban markets, and accompanying transportation challenges may disrupt regional distribution that then stunts small, independent, entrepreneurial, and community-responsive business development, from farm to retail.

Considering *concentration across the food system* as a whole, market concentration is only one aspect of supply chain concentration prevalent today (Pullman and Wu, 2012; Howard, 2016). From seed companies to retail stores, the system favors large, vertically integrated businesses that can manage risk by controlling for costs across multiple supply chain sectors, (Howard, 2016). The entire food supply chain has undergone concentration and as a result, is less competitive and barriers to small business are high. Howard (2016) notes that of the top five hundred firms in the world according to market capitalization, forty were engaged in food and agriculture. Of these, eighteen focused on packaged goods, eleven in retail, and nine in agricultural inputs. Distributors and commodity firms were represented by one company each, and there are no farms at this scale. This creates a system in which a dwindling farming population produces the dietary ingredients of an increasing population of consumers with just a few firms controlling the flow from farm to plate (William et al., 1999).

Anti-trust enforcement began with a wide focus and over time has devolved into looking at only one measure: price paid by consumers (Baker, 2019). Current US anti-trust laws also assume that markets are sufficiently competitive, so that the courts can

manage the edges in such a way that competition is protected. Unfortunately, this has not been the case. Independent businesses such as locally owned grocery stores, mid-size farms that produce fresh produce, meat, and dairy, small processors developing new products such as organic salsas or grass-based specialty cheeses struggle to enter markets dominated by vertically integrated companies, including cooperatives. Market rules are needed to assure opportunities for price discovery (where sellers can see what prices are being paid in the market for their goods), technology and information access, and protection from market power abuse (Carstensen, 2008). Updating market rules to reflect 21st century supply chain operations is a necessary next step to ensure small business success and an "economy-of-the-middle." It is possible to restore a competitive economy, as was done in the US in 1946 with the creation of programs such as USDA's Agricultural Marketing Service to set market rules (Baker, 2019), or even earlier in 1913 with the USDA Office of Markets (Tangires, 1997). In contrast, the European Union and Canada take an administrative rather than an adversarial approach to regulate mergers and acquisitions effectively, (Baker, 2019).

Pressure to increase *fuel and labor efficiencies* contribute to sector concentration, although the need for innovation can also open up opportunities for more local and regional producers and distributors. Roughly 6% of energy used in the food system is used to move food, mostly its transport by truck. That figure is low, as it does not include delivery from farm to processor, diesel truck trailer refrigeration (Heller and Keoleian, 2000) or transport from store to home or restaurant, also referred to as the "last mile" (Wakeland et al., 2012). These studies neglected to investigate how changes in distribution could potentially change energy use downstream, such as with home refrigeration and wasted food (Verma et al., 2019) or fuel and labor waste from traffic congestion (TTI, 2017). These are examples of unintended systemic outcomes of how food is distributed. As Rosenzweig et al. (2020) point out supply chain opportunities for reducing Green House Gas (GHG) emissions are linked to overall systems design, and the consumption and distribution end of the system can drive improvements at the farm and processing end.

In response to pressures to increase fuel and labor efficiencies, and more recently to *reduce carbon emissions*, engineers are innovating truck design so that they are specialized for the type of use or "duty cycle." The trend is away from "jack-of-all-trade" trucks, toward specialization that correlates to trip segments (Roeth, 2016, 2020). Many innovations optimize truck design for specific segments illustrated in **Figure 1**—first mile, Over-The-Road (OTR), regional, and last-mile trips. First mile is the distance from field to packing house or processor; OTR is 400+ miles; regional is loosely defined as <400 miles but >50 miles; and last mile is the distance from retail (or its warehouse) to consumer. There is also a move away from diesel-driven trailer refrigeration to battery dependent systems as a carbon reduction measure, and now a move to all-electric regional freight systems (see Roeth, 2021 for a call for industry participants to participate in a study on the topic).

In addition, newly implemented Hours of Service (HoS) regulations (FMCSA-USDOT, 2020) rely on geographic positioning systems (GPS) asset tracking technologies and require drivers to follow strict driving schedules that also push the system to regionalize. For these reasons, many larger logistics and distribution companies are adding regional warehouses with state-of-the-art material handling and traceability technologies to improve system performance. Regional distribution logistics are replacing OTR, making it easier to adopt alternative fueling infrastructure, improve driver working conditions, and improve road safety and congestion (Mihelic and Roeth, 2019).

Optimizing for Efficiency and Diversity-Merging Two Powerful Narratives

Bringing together innovative farmers with innovative transportation planners and practitioners was eye-opening. Farmers tended to discuss how diversity at the farm and landscape level was critical to the biological health of their systems and expressed frustration that they were unable to attain necessary transportation efficiencies to economically thrive. The transportation sector is steeped in narratives about efficiencies and struggles with diversity issues, such as the size of businesses, their ownership and access to capital; labor relations; supply chain concentration; and the fallout from overefficiency, such as-insufficient food access, as well as urban congestion, poor driver retention, and unnecessary GHG emissions. The acceleration of on-line food purchasing and delivery exacerbates systemic inequity when rural people, poor people, and their community businesses lack access to the internet, and don't have capital assets to support it.

As people interested in making the food system more fair, resilient and sustainable, our ability to recognize this either-or tendency that system actors take toward efficiency or diversity creates an opportunity for change. As Meadows articulated, the stories we tell ourselves frame what we do, so changing the narrative is one of the most powerful leverage points available to us as change agents. Transcending a single narrative or mindset is tantamount to expanding one's toolbox—realizing that we no longer need to see a nail, since we have more than a hammer to respond. When we encourage and support system actors to successfully optimize for both efficiency and diversity throughout the supply chain, we realize a more resilient food system that has the potential to elegantly address multiple business and public sector goals. Network analysis reinforces this conclusion. Solutions that tackle food systems efficiency and diversity, address governance and ownership challenges, and build resilience to crises have an indirect and systemic effect on all aspects of food security and need to be prioritized (Calicioglu et al., 2019). Multiple narratives allow us to think more broadly about food system design and open the discussion for improving the regional organization of food flow.

Improving the regional organization of food flow, based on an understanding of the non-linear constraints in regional food movements, may allow private sector entrepreneurs to seize opportunities to optimize fuel use without sacrificing food access and other measures of diversity. Transportation is a non-linear system of human design; certain minimums must be reached for the system to operate efficiently. Sustainable agricultural production is both of human and ecological design

and is also non-linear. It involves understanding system limits and optimizing diversity for specific environmental conditions. Attaining transportation efficiencies requires that individual crop production minimums be met for markets of varying sizes. Our discussions clarified how optimizing both diversity and efficiency is in the public interest, whether from the perspective of supply chain infrastructure or food production.

A growing body of research suggests that undergirding national and global supply chains by relinking cities with proximate production regions shows promise for realizing system efficiencies while promoting socioeconomic and agro-ecological resilience (Lengnick et al., 2015; Frankova et al., 2017; Clancy and Ruhf, 2018). A European study found that "urban consolidation centers" achieve an overall reduction in costs (5%), reduction in carbon emissions (7%), reduction in vehicles used (10%), reduction in total distance traveled (19%), and an increase in total number of delivery points visited per trip (11%), (UTURN, 2018). Such efficiencies save the public and private sectors money and improve service to those in need. To know where collaborative logistics are best placed to realize these and other benefits, planners need to know the network structure for food flow.

If regional food systems are optimized for logistics and fuel-efficiency, shorter distance food movements have the potential to successfully "compete on proximity" with large-scale growers at great distance to markets. This could allow farmers using sustainable agriculture practices to fine-tune their production in agro-ecosystems so that they may optimize crop diversity on-farm as well as within growing regions. It is unclear if seasonal advantages for producers in warmer climates will outcompete the advantages of proximity. Setting explicit market rules that support regional food production may be necessary in order to balance production advantages between regions. For instance, federal market orders for dairy production are explicit federal rules developed in the 1930s to encourage regional fluid milk production, but similar measures were not enacted for other perishable products. These dimensions of regional food distribution have significant ecological, economic, and governance implications that remain underexplored.

Supply chain and market governance, whether it is formal or informal, is developed from our mental models of the system. Our narratives must be explicit and ultimately, they must be shared. Innovative supply chain governance may expand regional producers' access to markets and access to affordable, regionally sourced products (King et al., 2010). A public commitment to once again support regionally based wholesale food supply chains could offset food system consolidation in the private sector and stimulate entrepreneurial business development (Beilock et al., 1990; Croushorn, 1990). Lengnick et al. (2015) suggest that enhancing the modularity and diversity of regional food production and distribution in tandem with optimizing system efficiencies is crucial to fostering sustainable and climate resilient food systems nation-wide.

Farms that aggregate products for shipment use multi-firm collaboration. Smaller and larger farms commonly work together to aggregate products for market. Forward-thinking businesses and the public sector could organize and support similar efforts within food supply chains to improve collaboration between shippers, trucking firms and wholesale buyers. Public terminal food markets are one way to aggregate product and are realizing a renaissance in major cities such as San Francisco, Toronto, Syracuse, NY, Jessup, Maryland, and Atlanta, and new ventures are emerging in San Jose, CA and Madison, WI (BAE Urban Economics, 2016; Karst, 2018; Wholesale Market Stakeholder Meeting—NAPMM, 2018; Gottwals, 2019). Business investment in multi-firm collaboration puts innovative entrepreneurs in the lead as investors who develop societal assets (Miles et al., 2005). Collaboration is possible when a core group of firms have a shared vision, common set of values, competence in teamwork, and interest in continuous innovation, as we see with farms committed to sustainable agriculture. For continuous innovation and collaboration to emerge, supply chains need redesigned reward and control systems. Choi et al. (2001) support the idea that positive interaction through rewards is more effective at managing complex adaptive systems than is regulation or other controls. Governing multi-tenant cold storage is another area for future research and development. Determining when and how decisions are made and how disputes are resolved is important for timely supply chain management and building trusted working relationships.

Factoring in social equity, more broadly than simply through food access measures, is important as we attempt to optimize efficiency and diversity, if we intend to make lasting food system improvements (HLPE, 2019). Other characteristics of the human component of system relationships, such as predation, competition, collaboration and cooperation, deserve a closer look, especially from a governance perspective.

Identifying Critical Thresholds in the Context of Efficiency and Diversity

Even as the system is currently structured, practitioners identified leverage points where supply chain collaborations can create regional efficiencies that support bioregional diversity. Our diagnosis indicates how simple, targeted public and private investments in regional logistics can improve regional food distribution now and in the future. As Armendariz et al. (2015, 2016) conclude, food distribution is often insufficiently organized to meet current and future urban and rural needs. Transportation and distribution infrastructure that supports small and medium supply chains could encourage entrepreneurial responses to rapidly changing circumstances and extend food access to underserved urban neighborhoods and rural communities.

A team member alerted us to the story of CR England, North America's largest wholesale cold chain trucking company (Miller et al., 2016). It's story, as told on their web site, follows the food system's trajectory. Founded in 1920, the company began as a regional food carrier in Utah. They bought their first refrigerated trailer ("reefer") in 1950 and by 1960 the company was operating regular cross-country runs from Western producers to a public terminal market on the East Coast. In 1978, the company opened its first private distribution center in New Jersey, and now operates three more terminals in California, Indiana, and Texas (CR England, 2015). As the largest cold

chain company, CR England is at the forefront of logistics innovation. EPA's Smart Way program has honored CR England for its high environmental performance multiple times and most recently in 2015 (U.S. Environmental Protection Agency, 2015). The company serves as a beacon for innovation in food supply chain logistics. Its business trajectory demonstrates the importance of public food terminals to smaller businesses in realizing efficiencies and increasing regional resilience.

In 2015, CR England reorganized their business in Southern California. They built drop yard infrastructure just 56 miles outside of Los Angeles. As a dedicated contract carrier—that is, a trucking company that contracts with a specific shipper to move product along regular routes—it is relatively straightforward to swap a truck tractor designed for long-distance hauling with another tractor for the urban segment of a trip. This practice has allowed the company to power some of its urban trucks with more efficient alternative fuels, adopt technologies to improve long-haul efficiency on other tractors, and improve overall fleet efficiency.

The Southern California facility includes a maintenance shop, Driver Resource Center, and parking for more than 250 tractors and 350 trailers. The new facility made it possible to expand their local fleet with Liquefied Natural Gas (LNG) tractors. The company credits collaboration with vendors and shippers–positive freight market dynamics-as critical to the success of converting to LNG tractors (CR England, 2014). A contracted rate structure allowed for greater efficiencies between the urban and rural segments of the trip. Now, the OTR fleet moving product from the shipper to the drop yard can move continuously, while the local fleet can drive the shorter distance inside the urban area with LNG vehicles. This reduces fuel costs, and reduces air pollution that is released while trucks wait in queues at congested delivery points, such as the Port of Los Angeles. It also allows the company to make better use of drivers, where newer drivers can take OTR routes and more experienced drivers can handle urban routes.

A more granular look at the food system that took place in meetings with practitioners helped us to identify quantifiable critical thresholds that can leverage change for this improved food system organization, as discussed in Ruben et al. (2018). These thresholds are a function of human-designed systems that operate within environmental limits *and* scale efficiencies. Some thresholds are common knowledge within freight transportation and sustainable agriculture circles, while others may require additional research, especially region-specific research with analytics. Many studies detailing these practices and research into public logistics for regional food supply chains are reviewed in Mittal and Krejci (2018), and they reinforce findings from our Chicagoland case. Additional cases from other regions also reflect these thresholds (Martinez et al., 2009; Miller et al., 2016; Wellborn and Lamie, 2017; Mittal and Krejci, 2018).

Cropping Diversification

There is a need for greater farming diversification, especially near urban mega regions, to hit the sweet spot between efficiency and diversity. The Chicago mega region is a case in point, where Illinois farmers are less diverse than farmers in Wisconsin and Michigan. Restoring agricultural diversification throughout the US Corn Belt is important to regional resiliency, especially within the 400-mile regional radius of large urban wholesale markets, and within a 200-mile radius for smaller cities and rural regions. Cities that protect farmland in this zone and improve the flow of capital and information to support food supply chains (as opposed to commodity production) are investing in food resilience, as we found in an Ontario proof of concept.

Producer and Distributor Collaboration

Sustainable agriculture practitioners are identifying bio-physical critical thresholds for food production at the farm level that are specific to the agricultural production region (Lengnick, 2014). In turn, they seek supply chain partners in transportation and markets that share their commitment to sustainability. In order for regional food production to feed into wholesale markets, there must be sufficient availability of products, both seasonal and year-round. This can be accomplished through producer collaboration. Offering a mix of products that require refrigeration–fruits, vegetables, meat, dairy, beverages–can improve the efficient use of trucks, warehousing, and service contracts, and maintain consumer loyalty for "local." Regionally produced, in-season food must have market access and consumer demand to successfully compete with the national flow of the same products. As an example, California carrots may be available for 12 months, while carrots grown in the more northern states are likely available for 9 months or less. Creating a marketplace where smaller growers may develop new relationships with wholesale buyers may soften long-term relationships between larger national supply chains and add regional resilience. Protecting smaller producers from predatory markets is a role for governments to create and enforce market rules. Historic proof of concept from the 1930s US could be applied.

Contracts

Regular contracts along the supply chain are more efficient than erratic, irregular relationships that carry high transactional costs. Seasonal farming constraints in the Upper Midwest, and extreme weather impacts on food production mean that shippers and trucking companies must find creative ways to overcome volatile conditions and associated uncertainty. Regular professional meetings and relationships at point of purchase between small supply chain businesses may improve communication and build trust. Another approach may be to encourage north-south collaborative intra-regional supply chains mid-continent, such as those on the East and West Coasts.

Transportation Efficiencies

Based on efficiency research, farmers may want to handle their own first mile distribution when located within a 50-mile radius to market. Farmers interested in pooling product for regional wholesale markets could limit their regional markets to about 200 miles. Markets between regions (from one region to another) could stretch to 400 miles, especially in the more rural center of the continent. To boost access to significant local wholesale markets, shippers might partner with mid-size cities

in developing combination facilities that both aggregate products for more distant markets and weave together multiple smaller supply chains so that they may sell to wholesale buyers, especially independent businesses within about fifty miles to the terminal.

- In terms of **vehicle efficiency**, 53' trucks must be fully loaded (30 pallets or weight limit) for shippers to realize efficiency and must meet a financial threshold for product value. Farmers must have sufficient production and/or aggregate their products for shipment at this scale to efficiently reach regional markets.
- Trucks designed to be used for shorter hauls save fuel. If city deliveries and deliveries navigating extensive traffic congestion are made with trucks designed for that purpose, companies can invest in more efficient engineering for longer hauls. Considerable research on engine efficiencies is underway and can shape how we invest in food infrastructure to create positive incentives to adopt these engineering innovations. For instance, we know that longer haul vehicles operate best at constant, higher speeds. We know that public investment in alternative fuel vehicles and infrastructure, such as charging stations, will support private sector investments and help us meet GHG emissions targets. Advances in hybrid technology may alter existing critical thresholds, as may other engineering innovations. Engineers are setting the pace for change so there is opportunity in anticipating and matching this pace. Hosting design sessions with supply chain practitioners-farmer to wholesale buyers-may yield unexpected innovation.

Public Support for Infrastructure

Large cities that invest in distribution infrastructure could prioritize service to smaller, community-owned supply chains that are unable to invest in their own private warehouses, and work with shippers doing business no further than 400 miles outside metro limits. Numerous proofs of concept exist outside the US. An important public role may be to convene and assist with business collaboration and to serve as a champion. Capital investment may pose a significant hurdle for large infrastructure projects with public interest at their core. Public facilities ownership, low-or no-interest loans, or on-going investment in operations may accelerate change. Distribution infrastructure can ease logistical challenges near large cities where congestion is an issue or where natural features such as the Great Lakes or mountains complicate direct routes. For regional wholesale food shippers to gain efficiency, they need one point to transfer ownership of the product. Combining regional hauling with last mile deliveries is inefficient. Terminals that operate with an explicit goal to serve small wholesale supply chains are increasingly necessary as private national supply chains continue to consolidate even while extreme weather threatens those supply chains. Terminal redundancy can also improve logistical efficiency for drivers adhering to HoS regulations and allow smaller businesses to access new technologies such as automated warehousing, block chain ledgers, and digital twins software. If they collaborate, software technology to match loads is affordable for wholesale businesses in small supply chains.

CONCLUSIONS

The U.S. Upper Midwest has fostered numerous local and regional food supply chains made up of farms, processors, trucking companies, wholesalers and other firms that invest in sustainability and local economic development. These businesses are committed to operating within environmental limits and at a scale where economic efficiencies can be realized. At the same time, they have struggled to gain economic access to markets dominated by larger scale, concentrated food distribution systems. Transportation congestion around cities creates significant barriers to freight efficiency and drives associated costs that are shouldered by trucking companies and shippers. Big box stores outside the city center act as small distribution centers, where consumers incur the transportation costs when driving the last mile. This unchecked tendency of the system as currently designed leads to limited food access in poorer regions of cities and further contributes to congestion. Rural and remote regions lack food access when there is a lack of regional food production diversity and where supply chains are too large to efficiently serve them.

Improving the regional organization of food flow requires an understanding of the relationships that create system constraints. It is in the public interest to create an ecosystem where private sector entrepreneurs may respond to opportunities in their communities to concurrently optimize fuel use, food access and sustainable farming practices. First mile, regional, and last-mile transportation businesses; product aggregation intended for regional wholesale markets; and regional supply chain aggregation in mega-regions are just a few opportunities for small business development in the food processing, distribution and retailing sectors.

Additional research to better understand the ebb and flow of food through the seasons, in different regions, as it moves through the food system would be of use to supply chain managers and logistics professionals and could improve market rules. Developing measures of food enterprise diversity could provide regional planners with a tool to gage the strength of food flow into urban and rural communities. Other characteristics of business relationships along supply chains deserve a closer look so that we may understand how supply chain actors may better collaborate to meet their business and public goals, and how truly competitive markets can thrive and innovate.

Public and private investment in multi-firm collaboration supports innovation at the community level, so that entrepreneurs may take the lead as primary investors in developing societal assets. Midsize farms that aggregate products for shipment currently practice multi-firm collaboration. Forward-thinking businesses, with encouragement from the public sector, could also organize and support similar efforts within regional food supply chains to improve collaboration between shippers, trucking firms and wholesale buyers. Given the unique importance of food in a healthy society, it is our civic responsibility to improve food supply chain organization so that the food sector may meet increasingly urgent public goals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MM developed and managed the study.

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Politics of Seed in Ethiopia's Agricultural Transformation: Pathways to Seed System Development

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Seed system development in the developing world, especially in Africa, has become a political space. This article analyzes current Ethiopian seed politics in light of the historical dynamics of national and international seed system politics and developments. Drawing on multiple power analysis approaches and employing the lens of "international seed regimes," the article characterizes the historical pattern of seed regimes in Ethiopia. While colonial territories underwent three historical seed regime patterns—the first colonial seed regime, the second post-WWII public seed regime, and the third post-1980s corporate-based neoliberal seed regime, Ethiopia has only experienced one of these. Until the 1950s, when the first US government's development assistance program—the Point 4 Program—enabled the second government-led seed regime to emerge, the farmers' seed systems remained the only seed innovation and supply system. The first colonial seed regime never took hold as the country remained uncolonized, and the government has hitherto resisted the third corporate-based neoliberal seed regime. In the current conjuncture in the contemporary Ethiopian seed regime, four different approaches to pluralistic seed system development are competing: (1) government-led formalization, (2) private-led formalization, (3) farmer-based localization, and (4) community-based integrative seed system developments. The Pluralistic Seed System Development Strategy (PSSDS) from 2013 is a uniquely diverse approach to seed system development internationally; however, it has yet to realize its equity and sustainability potential. This study shows that the agricultural modernization dependency and government-led formal seed systems development have sidelined opportunities to tap into the strength of other alternatives identified in the PSSDS. In conclusion, an integrative and inclusive seed sector is possible if the government takes leadership and removes the current political, organizational, and economic barriers for developing a truly pluralistic seed system.

Keywords: seed politics, seed regime, power analysis, pluralistic seed systems, 4D pathways approach, Ethiopia

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INTRODUCTION

Calls for zero hunger, poverty eradication, and adaptation to climate change have increased the focus on seeds and seed system development in sub-Saharan Africa. The focus has been explicitly geared toward developing and supplying good quality seeds of improved varieties among smallholder farmers aiming at agricultural production and productivity increase, nutritional enhancement, system resilience, and income generation (Otieno et al., 2017; Ariga et al., 2019). To contribute to these goals, donor countries, multilateral institutions, foundations, and non-governmental organizations (NGOs) have supported several policies and programs[1] (Odame and Muange, 2011; Joughin, 2014; Borman et al., 2020; FAO, 2020). However, while most actors' policy and program interventions share the goal of increasing seed security among smallholder farmers, the strategies differ substantially and sometimes conflict (Scoones and Thompson, 2011; Westengen, 2017). These policy and program interventions also come with pressure from diverse actors who want their interests to be met with appropriate measures. Simultaneously, a country's political regime's governance and economic system want policies to align with its interests and priorities, making it difficult for policymakers and legislatures (Tansey, 2011; Mockshell and Birner, 2015). Moreover, actors' diverse interests and strategies contribute to the lack of coherent policies, programs, and practices to create a robust seed system development and enhance seed security (de Boef et al., 2010; Amanor, 2011).

This article is about seed system politics and development in Ethiopia. It aims to describe and analyze Ethiopia's seed system development trajectories under three different governance regimes and focuses on its current pluralistic seed system development strategy (PSSDS). It examines why and how the formal seed system has been prioritized over other alternatives (farmers' and community-based seed systems) by government policies and programs since the beginning of Ethiopia's agricultural modernization in the 1950s. It shows how the agricultural modernization agenda (Geels, 2004) ignores opportunities to tap into the strength of the farmers' seed systems (Mulesa et al., 2021), even after its official recognition by government policy in 2013 (MoA and ATA, 2017), and the experience of decades of an ineffective formal seed system (Ariga et al., 2019). The article further illustrates how developing countries' growing seed systems development debate generates challenges for policymakers and governments using the Ethiopian case. The discussions have put policymakers under financial and donor pressure to develop coherent national seed policies while at the same time serving the national governance regime's overall agricultural development plans.

[1]Some of the recent programs and policies related to seed sector development in Africa include: African Seed and Biotechnology Program (ASBP), Integrated Seed Sector Development (ISSD) program in Africa, Alliance for a Green Revolution (GR) in Africa's Program for Africa's Seed Systems (AGRA/PASS), World Bank's Seed Sector Development projects, COMESA Seed Harmonization Implementation Program (COMSHIP), ASARECA's Seed Policies and Regulations harmonization in East African Community, SADC Seed Laws harmonization program and ECOWAS's Harmonization of Seed Trade Laws in West Africa.

A seed system refers to physical, organizational, and institutional components, their actions and interactions that determine seed conservation, improvement, supply, and use (Cromwell, 1992; Scoones and Thompson, 2011), and includes formal, informal, and emerging "intermediate" seed systems (Mulesa et al., 2021). Farmers' seed systems involve farmers' seed selection, production, storage, and dissemination (Almekinders and Louwaars, 2002). The formal seed system comprises public and private sector institutions and a linear series of activities along the seed value chain, including germplasm conservation in genebanks, plant variety development, variety release and registration, quality seed production, and distribution (Louwaars et al., 2013). The intermediate seed system has recently emerged from market-oriented farmer groups that produce and market non-certified seeds of improved varieties and farmer-preferred local varieties. These are community-based seed producer groups, including community seed banks that produce good quality uncertified seeds (MoA and ATA, 2017) and seed producer cooperatives (SPCs), who produce quality declared seeds of improved varieties (Kansiime and Mastenbroek, 2016; Sisay et al., 2017). Quality declared seed is a simplified certification scheme in which seed-producing farmers are responsible for seed quality while the government plays a monitoring role (FAO, 2006).

Until the advent of the first Green Revolution (GR), the age-old practice of seed saving, selection and exchange, and farmers' knowledge associated with seed use and seed sourcing were the single most important seed systems farmers used in Ethiopia. The 1960s and 1970s transfer of the technology paradigm during the first GR in Africa promoted formal seed systems to boost agricultural production and productivity (Groosman et al., 1991; Tansey, 2011; Byerlee, 2020). Since then, developing countries, including Ethiopia, have used the linear model of formal seed systems as a blueprint solution for seed sector development. This approach assumed that the farmers' seed systems would be replaced by the government-led formal seed system, gradually moving toward privatization and liberalizing the seed market with the public sector's withdrawal (Louwaars and de Boef, 2012; Louwaars et al., 2013). Despite these assumptions, the farmers' seed systems remain the leading supplier of large quantities of seeds of diverse crops and varieties in developing countries (Coomes et al., 2015; McGuire and Sperling, 2016). Over the years, critical voices have risen in response to the linear formal seed system's poor performance. Its perceived and actual consequences for seed security and seed governance issues are today a debated topic. Emanating from these debates are alternative development visions and pathways suggested by different actors. These alternative development visions include formalization vs. localization of seed systems, high-yielding improved varieties vs. locally adapted farmers' varieties, private-led vs. government-led certified seed supply, community-based vs. private-led seed production and marketing, and farmers' rights vs. plant breeders' rights.

This article's point of departure is that the seed is political. All areas of contestation (environmental, social, economic, political, and system resilience) around seeds involve asymmetric power (Tansey, 2011; Sumberg et al., 2019). For instance, studies

show that intellectual property rights (IPRs) over seeds and seed regulations have resulted in seed market concentration in the hands of few multinational seed companies. Consequently, the socio-cultural connections between people and plants have mobilized resistance against IPRs and seed market concentration (Lyon et al., 2021; Tschersich, 2021). In this case, power asymmetry relates to access to and control over seeds. Moreover, studies suggest that particular historical factors shape national seed policies within each country (Westengen et al., 2019; Mulesa and Westengen, 2020). Therefore, contestation of seed system development pathways is ongoing in Africa as the production and regulation of seeds limit farmers' political and economic participation and weaken state political interests under the current "New Green Revolution" (Scoones and Thompson, 2011; Mayet, 2015).

Analyzing Ethiopia's historical seed sector development brings valuable knowledge to the seed systems literature. European countries never colonized Ethiopia, unlike many other countries in Africa. For this reason, its institutional foundation is independent of colonial influences. Ethiopia's long history of independence means that national autonomy is practiced in policy formulation (Keller, 1991). It has also undergone different governance regimes with different agricultural modernization approaches since the establishment of its Ministry of Agriculture (MoA) in 1907 (Diriba, 2018) and especially after its re-establishment following the second Italo-Ethiopian war (1936–41) in 1943 (Belay, 2003). Ethiopia's governance and economic systems changed from authoritarian monarchy rule/dominant feudal society (Cohen, 1974a) to military government/dominant socialist enterprises (Cohen and Isaksson, 1988) to an authoritarian developmental state/"free market" economy (Clapham, 2018). These governance regimes had different political effects on agricultural development that have affected the seed sector development pathways. Moreover, Ethiopia experienced extreme disasters such as drought, war, and consequent famine during the socialist regime, which created debate among technocrats about the role of formal and farmers' seed systems since the 1980s. Exploring seed sector development by considering these political and economic regime changes and environmental shocks provides unique perspectives to better understand how historical settings impact the dynamics of current seed system policy processes and practices.

In recent years, Ethiopia has gone "against the grain," deviating from the linear approach to formal seed system development by favoring a PSSDS as the country's overarching seed policy (MoA and ATA, 2017; Mulesa et al., 2021). The government of Ethiopia was the first country to officially adopt a PSSDS in 2017 as an alternative to the dominant linear formal seed system development to comprehensively transform its seed sector. The PSSDS proposes support for three major seed systems operating in the country (informal, formal, and intermediate) and promotes complementarity between the value chain components of each seed system. It assumes that the public, private, community, and NGO stakeholders take particular roles in dissimilar seed value chains and integrate activities along the seed value chain between the three seed systems. This article is a follow-up of an in-depth study that examined farmers' seed security as functions of seed systems in two districts of Central Ethiopia characterized by subsistence-oriented teff cultivation and commercially oriented wheat production and relates this to the country's PSSDS (Mulesa et al., 2021). Mulesa et al. (2021) find that the interventions prioritized in the PSSDS can address the widespread seed insecurity and seed system dysfunctions identified in the study districts. However, the implementation lags, particularly for the informal seed system, which is neglected by government programs despite its role in supplying large quantities of seeds and most of the crops and varieties farmers use. The study suggested further research that examines the complex interplay of factors to understand why the Ethiopian government has not fully implemented the PSSDS. Therefore, this article analyzes the effects of actors' seed politics on the opportunities and challenges in creating more equitable and sustainable seed systems in the new PSSDS—as a unique contribution to seed system literature. I draw on Leach et al.'s (2020) power analysis which combines plural approaches for studying food politics and development. The power analysis is used to understand the dynamics of Ethiopia's seed sector development process over the past seven decades, starting from the emergence of formal seed systems in the mid-1950s. The approach is used to analyze a continuous and dynamic process of institutional transformation co-shaped by a complex interaction of the regime's political and economic orientation, global seed-related frames and funding, and local environmental risks and explores how different pathways have emerged. To do this, I examine the history of the seed sector's evolution under agricultural policies of three different governance regimes: imperial, socialist military, and authoritarian developmentalist. The analysis helps to understand how the government prioritized some seed sector policies while excluding other policies under these political regimes and the policy directions, benefits, costs, and risks involved in these processes. Specifically, the article addresses the following research questions: (1) How have seed sector development policies been formulated and implemented, (2) How have different actors' interests influenced seed policy formulation and implementation, and (3) What are the socio-political and ecological outcomes of the current seed system policies and practices in the country?

ANALYTICAL FRAMEWORK

To understand seed system politics and development in Ethiopia, I draw on the analytical approach of Leach et al. (2020), combining plural approaches/concepts underpinned by broader theoretical traditions in power analysis. From Leach et al.'s (2020) list of approaches to power analysis in food politics and development, my analysis of Ethiopia's seed sector policy development and implementation is informed by approaches of food regimes (Harriet and Philip, 1989), food institutions (Clapp, 2012), food contentions and movements (Borras et al., 2008; Patel, 2009), food innovation systems (Scoones and Thompson, 2009; IPES-Food, 2016) and food discourses (Sumberg et al., 2012). I treat these approaches as nested or use their possible

pairwise combinations to study seed system politics and development in Ethiopia.

First, I identify the *seed regime* pattern linked to historical and political changes over the past seven decades of agricultural modernization in Ethiopia. The seed regime typology proposed by Lyon et al. (2021) is an adaptation of the food regime framework (Harriet and Philip, 1989; Jakobsen, 2021). In Leach et al.'s (2020) power analysis, the strength of an actor, and consequently its capacity to control exists in historically shaped political, social, and value regimes, including relations between states and capital and their supporting ideologies. In Ethiopia, the seed system development has changed from a farmer-managed seed system to a government-led formal seed system to a pluralistic approach. The seed regime approach can reveal how these changes occurred, who has gained and who has lost, implicating various power relations between diverse actors. As part of this analysis, historicizing institutional development allows to examine how the prior history of conflict or cooperation, the incentives for actors to participate, power and resource imbalances, governance and institutional design, shared narratives, interests, and politics have shaped the Ethiopian seed system development (McCann, 2005; Mulesa and Westengen, 2020).

Lyon et al. (2021) identify three seed regimes based on Kuyek's (2007) adaptation of Harriet and Philip's (1989) food regimes. The chronicles of these different seed regimes can vary from country to country, and not all countries have gone through the three seed regimes. The first seed regime is a relatively stable set of relationships, norms, and regulations that organized the increasing commodification and enclosure of seed during the early colonial period. Lyon et al. (2021) exemplify the first seed regime by describing the disruption of agricultural practices and foodways during the early colonial period when European settlers introduced few cash and commodity crops for the export market in North America. This regime constitutes colonial dispossession and displacement of indigenous people and their crop diversity. Post-WWII, the breeding, delivery, and adoption of new plant varieties by public institutions were the key features of the second seed regime. The third corporate-based neoliberal seed regime is related to the advent of transgenics in the 1980s (James and Krattiger, 1996) that enabled agrochemical firms to research and develop transgenic plants (Lyon et al., 2021) and prevent other actors from commercial production and marketing of their product using technological and legal control means (Tansey, 2011). Such technical and legal control of seeds was not new as this has been the practice since the 1930s in North America when hybrid cultivars emerged. However, IPRs protection[2] of new cultivars became a global phenomenon with the advent of biotechnology applications to agriculture during the past five decades (Kloppenburg, 2004; Lyon et al., 2021). The IPR protection has given more power to the private sector in the seed industry to make independent decisions on what to invest in and the type of technology they can promote (Kuyek, 2007; Clapp, 2021). Government intervention is limited to facilitation, i.e., providing incentives and removing impediments for private sector investment. The overview of the history of seed sector development in Ethiopia shows a unique national pattern of seed regimes. As mentioned, Ethiopia never became a colony in the classical sense. Therefore, the first colonial seed regime never really took hold in Ethiopia. But post-WWII, we see a distinct patterning of seed regimes that follow other essential patterns in Ethiopian history. My analysis operates with three regimes at both levels, i.e., three governance regimes (imperial, socialist, and developmental government regimes), and uses three seed regime patterns (the first, second, and third seed regimes). However, the seed regimes do not follow the political regimes in a one-to-one fashion.

I use the *food institution* approach to Leach et al.'s (2020) power analysis, which conceptualizes the actor's strength and capacity to control events as embedded in and to operate through multilevel formal and informal institutional arrangements, or the "rules of the game" (North, 1990). This kind of power contributes to the change in the food/seed system *via* norm and rule changes. Such norm and rule changes can occur in particular institutions or shifts in different institutions' relative power and influence (Tansey, 2011; Leach et al., 2020). The food institution approach provides a more nuanced picture of seed system development linked to smallholder agricultural commercialization. For instance, the food institution concept helps analyze Ethiopia's seed system development policy related to seed sector liberalization and privatization, funding requirements, and the government's political and economic orientation or national interests. In addition to incentives for the private sector, such liberalization can include the actual implementation of IPR laws and regional seed trade regulations. The food institution is associated with the *food/seed contentions* and movements approach, which involve power and agency that resist institutional changes through grassroots social mobilization and collective action, countering dominant force and interests (Demeulenaere and Piersante, 2020). This article applies the seed contention and movements approach to reveal how several years of joint project implementation and documentation work among NGOs (local and international) and a national institution influenced the government to recognize farmers' seed systems in Ethiopia.

While not restricting specific themes and contexts, I use the approaches of *food innovation* systems to analyze actors'

[2]IPR protection of new cultivars started when the government of the United States (US) introduced Plant Patent Act in 1930, which allowed patenting of asexually reproducing plant cultivars (except tubers). In 1970, the US introduced the Plant Variety Protection (PVP) Act to protect new varieties of sexually reproducing crops. In Europe, the Netherlands (1942) and Germany (1953) were the first countries to introduce the PVP Act. The harmonization of the PVP Act started in 1957 through the facilitation of the Government of France. Later the European governments adopted the international system of protection of new plant varieties under the auspices of the International Union for the Protection of New Varieties of Plants (UPOV) Convention in 1961 (Correa, 2015). Since 1961, the UPOV Act was amended a couple of times (1972, 1978, and 1991). National PVP Acts have been primarily developed based on the UPOV system to support the 1995 Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement of the World Trade Organization (WTO). Patents on plant traits (not varieties) emerged together with transgenics. In the Global South, stringent IPR protection (UPOV 1991 and plant patents) on seeds expanded since the adoption of TRIPS (Tripp et al., 2007).

narratives, beliefs, values, practices, and rules for analyzing multiple trajectories of seed system development. Specifically, food/seed innovation systems emphasize socio-technical and ecological systems and their dynamic and complex interactions that involve different actors or institutions that challenge path dependencies or "lock-ins." The food innovation system approach can also explain the path dependency of promoting the dominant seed system development model as an intertwining political interest of the state. Finally, power and agency are located more firmly in ideas, rather than people, institutions, or systems in *food discourses* that can help understand the narratives, interests, politics, and actions of actors or narrative coalitions in seed system development. Overall, Leach et al. (2020) argue that the combination of different conceptualizations and power sites helps understand change and transformation owing to their relevance to a diversity of actors and relationships and various scales—at the local, national, and global level.

Concluding the historical pathway analysis, I engage the "4D pathways approach" questions proposed by Leach et al. (2020) as an integrative analytical lens for assessing agri-food system political outcomes. Critical questions about the overall *direction* and *diversity* of technical and institutional innovation pathways, their *distributional* consequences, and the extent of *democratic* inclusion in decisions about the turning point in Ethiopia's seed policy reveal that the agricultural modernization dependency ignores opportunities to tap into the strength of the farmers' seed systems, even after their official recognition by the PSSDS in 2013 and after decades of an ineffective formal seed system.

METHODS

This study is a follow-up to a thorough investigation of the performances of different seed systems in two districts in the central highlands of Ethiopia, as mentioned in the introduction section. In order to address the above analytical questions and the main research questions, I gathered additional data using qualitative interviews with key actors in the seed sector during fieldwork in Ethiopia from December 2017 to March 2018. I interviewed 26 representative experts and researchers from various public and private institutions in agricultural and environmental governance. The actors include individual representatives from public seed enterprises ($N = 5$), private seed companies ($N = 2$), decision making and regulatory bodies ($N = 6$), NGOs ($N = 5$), agro-dealers ($N = 4$), and extension service providers ($N = 4$). The interview with each interviewee lasted between one and a half hours to 2 h. Issues related to the genetic resource governance of plants and the supply and use of commercial seeds in Ethiopia are filled with asymmetric power relations, contestation, and seed struggle (Alemu, 2011; Mulesa and Westengen, 2020). With this in mind, I purposively selected the interviewees from actors with different politics and values, framings, and perspectives regarding agro-ecological, social, cultural, and economic factors. In addition to key informant interviews, the qualitative analysis utilizes participant observations in two national seed policy meetings. The first meeting was a 1-day "Workshop on Assessment and Identification of Constraints to Private Seed Sector Development in Ethiopia" in February 2018. It gathered 40 representatives of key private and public seed sector actors. The second meeting was a 1-day "National Seed Policy Consultation Workshop" that gathered 63 representatives of seed sector actors from federal and regional institutions, farmers, NGOs, and the private sector in March 2018. I produced minutes from both meetings that documented actors' interests, politics, vision, activities in the seed system development from the presentations and discussions. I used this information to examine actors' approaches to Ethiopia's seed system development. In addition, the qualitative analysis of literature and documents uses a large volume of peer-reviewed articles, research reports, policy and strategy documents in Amharic and English, and gray literature such as minutes from a high-level policy meeting. Information gathered from key informant interviews was triangulated with the document analysis to validate and supplement evidence to increase the validity of the findings.

EARLY POLICY CHANGES: FROM FARMERS' CUSTOMARY SEED SYSTEMS TO GOVERNMENT-LED FORMAL SEED SYSTEM (THE EARLY 1900s TO 1974)

Bypassed Colonial Seed Regime

The current diversity of seed systems in Ethiopia is the result of five to seven millennia of wild plant species domestication by indigenous people (Vavilov, 1992), selection and diversification of the domesticated species (Harlan, 1969), and seed exchange over a wide geographical range (Murdock, 1960; Harlan and de Wet, 1976). This age-old practice of seed selection, saving and exchange, and farmers' knowledge associated with seed use and seed sourcing (McGuire, 2007) are the foundations of the farmers' seed systems in Ethiopia (Thijssen et al., 2008). However, the diversification of farmers' seed source and management started to change in colonial countries of the developing world in the early 1900s. Europeans introduced new agricultural technologies (e.g., improved seeds) and technical agronomic practices to promote cash and commodity crops (Bonneuil, 2000; Austin, 2009). The colonial promotion of cash and commodity crops (e.g., coffee, cotton, and tea) brought a new set of relationships, norms, and control, which pushed out most indigenous crops such as sorghum and millet through agricultural extension and marketing (Tansey, 2011; Bezner Kerr, 2013). Scholars have seen the contours of a distinct colonial food/seed regime within this historical context (Kuyek, 2007; Lyon et al., 2021). For instance, the radical dispossession of indigenous crops in colonial Africa marks the first seed regime. Until their independence, imported crops displaced over 2000 native grains, fruits, vegetables, and root crop species in colonial Africa (National Research Council, 1996). National and international agricultural initiatives have also neglected these crop species, and these countries have been unable to repossess most of their food culture (Highfield, 2017, p. 3).

Unlike colonial African countries, Ethiopia did not go through the first seed regime. The imperial governments

and Ethiopian people resisted Italian occupation and stayed uncolonized (Rubenson, 1961), and farmers continued to depend on their indigenous seeds and Neolithic agricultural innovations (Westphal, 1975; Diriba, 2018). The only exception was the introduction of agricultural technologies during their first Italian colonization attempt in the late nineteenth century and WWII, which discontinued owing to the first (1893–1896) and second (1935–41) Italo-Ethiopian war (McCann, 1995, 2011). Thus, farmers' seed systems remained the only supplier of seeds in Ethiopia until post-WWII. Ethiopia's seed regime change started with the second public seed research and development when the Imperial Ethiopian Government (IEG) introduced modern agricultural technologies. These included a mix of cash and commodity crops such as cotton and tobacco and the GR food crops (e.g., wheat and maize) discussed below.

The Beginning of the Second Seed Regime During the Imperial Period in the 1950s

Post-WWII, the advance in plant breeding in developed countries brought different technologies (e.g., new varieties) and seed management practices and created formal institutions to govern breeding, delivery, and adoption of new plant varieties (Timothy et al., 1988; Fernandez-Cornejo, 2004). These new technologies and seed regulation practices through formal institutions were transferred to colonial countries in Africa in the 1920s except in Ethiopia (Rusike, 1995; Rusike and Donovan, 1996). In Ethiopia, this was delayed until the mid-1950s (Simane, 2008), when the IEG established physical, organizational, and institutional infrastructure for agricultural research and extension. The IEG received financial support from the first United States (US) government development cooperation in the Global South and other multilateral donors for building institutional and physical infrastructure to achieve its ambition of a monetized economy (Elliott, 1957; McVety, 2012). In his inaugural speech in 1949, the incumbent President of the US, Harry S. Truman, announced his government's readiness to support agricultural modernization to fight hunger and poverty in developing countries (Truman, 1949). Scholars argue that Truman's speech marks the origin of modernization theory in development studies (Westengen and Banik, 2016). Following Truman's announcement, the US government established a development assistance program, widely known as the Point 4 Program[3], referring to President Truman's fourth point in his list of foreign policy objectives. At the time, Ethiopia was in a deep agricultural and food crisis after the second Italo-Ethiopian war (Diriba, 2018), and Emperor Haile Selassie sought US support while subscribing to their anti-communist stand (Velissariou, 1954; McVety, 2008). The US development partners used this as a reason to select Ethiopia in Africa's horn as a testing ground for Point 4 Program implementation (1952–1957) and to induce social and economic change through technology and capital transfer, assuming that this would eventually steer Ethiopia away from communism (McVety, 2012). The US government provided an average of USD 2,466,700 per year for economic and military assistance to the IEG between 1952 and 1957 (Elliott, 1957; McVety, 2012).

The Point 4 Program supported extensive infrastructure development, including establishing higher learning agricultural institutions, public and agriculture schools, community/agricultural clubs, and creating agriculture extension groups and training professionals. Besides, the IEG received financial and technical assistance from the United Nations Development Program and the Food and Agriculture Organization of the United Nations (FAO) to build the technical and institutional capacity for its agricultural research, extension, and technology dissemination. With this assistance, the IEG established the Ethiopian Institute of Agricultural Research (EIAR) and a seed unit at the MoA in 1966 (Stommes and Sisaye, 1979a; Bishaw and Louwaars, 2012). The physical and institutional infrastructure building laid a foundation for the IEG's agricultural modernization projects through public agricultural research and GR technology extension, which marks the main features of the second seed regime in Ethiopia. Ethiopia attempted to implement the first GR projects with this institutional base as part of the IEG's three successive five-year agricultural development plans from 1957 to 1973 (Cohen, 1975; Stommes and Sisaye, 1979a,b). Considering the seed regime pattern in Ethiopia, the second public seed regime found fertile ground owing to the emperor's shared anti-communism platform with the US administration. Ethiopia's seed policy moved from almost non-participation in the first colonial seed regime to becoming the "pioneer" of the second public seed regime in the horn of Africa. In addition to the 15 years of agricultural development plans, the IEG also prioritized commercialization concession contracts for foreign companies and established state commercial farms to produce export crops such as coffee, sugarcane, cotton, tobacco, fruits, and vegetables. For this purpose, the government appropriated land for investors, which displaced pastoralists, agro-pastoralists, and peasants from their grazing- and farmlands and their indigenous seeds. By examining the situation using the food institutions approach, we see the institutional and political factors were the leading causes of social exclusion and increased vulnerabilities. For instance, pastoralists and peasants became laborers and survived on a "contribution" rather than a wage payment. At the expense of this exploitation, the companies who exported agricultural products and the industrialists in Europe who exported machinery and technology were winners. In contrast, the IEG, whose benefit from taxes and dividends was lower than commodity import expenses, and laborers who squandered their local livelihoods, were losers (Bondestam, 1974).

[3]President Harry Truman announced four major courses of action for achieving global peace and freedom post-WWII. Truman said, we will continue to (1) support the United Nations and related agencies, (2) American programs for world economic recovery, including reducing the barriers to world trade and increasing its volume, (3) strengthen freedom-loving nations against the dangers of aggression, i.e., in the form of collective defense arrangement within the terms of the United Nations Charter, and (4) embark on a bold new program for making the benefits of American scientific advances and industrial progress available for the improvement and growth of underdeveloped areas because more than half the people of the world are living in conditions approaching misery, their food is inadequate, and their economic life is primitive and stagnant.

Later during the 1960s and early 1970s, the IEG's agricultural development plan emphasized the implementation of big GR projects. The biggest of all was the Chillalo Agricultural Development Unit in Ethiopia's southeastern highland supported by the Swedish International Development Cooperation Agency, which aimed to replicate a "successful" GR experience from the Comilla district of Bangladesh in 1957 (Karim, 1985). The agency's support focused on increasing bread wheat production and productivity using improved seeds, chemical fertilizer, and pesticides. The IEG later scaled out the GR projects to other regions in Ethiopia and crops (e.g., maize) with the financial and technical support from other donors such as the World Bank, United States Agency for International Development (USAID), and France's government (Cohen, 1974b; Stommes and Sisaye, 1979a). The IEG's first GR projects prompted seed system formalization. However, with its emphasis on donor-supported government agricultural research and extension for higher yields and productivity, the IEG's second seed regime of the GR projects created winners and losers among participants. Specifically, the political economy of the donor-supported and IEG-centered GR projects created inequality between landlords and tenants through its exploitative land tenure system, especially in the southern provinces of Ethiopia.

In the nineteenth and twentieth centuries, the "land hunger" of the imperial regime led to the expansion and consolidation of the southern regions by confiscating land from southerners and granting it to the regime's supporters from the north and center (Brietzke, 1976; Clapham, 2019). The imperial regime created solid political bondage with the few landlords and absentee landlords[4], who acquired large tracts of fertile land. When they lost their land, most local tillers and pastoralists became peasants and tenant sharecroppers for the landlords. They paid one-third or one-half of their annual produce, depending on the fertility/productivity of the land they plowed. With the donor-supported GR projects, peasant sharecroppers became more vulnerable instead of benefiting from commercial wheat and maize production. For instance, corrupt local and provincial government officials and their associates neglected donor policy provisions to only supply subsidized inputs to peasants holding <20 hectares of land. Instead, they took advantage of their position and purchased the subsidized inputs under favorable credit terms (Cohen, 1975; Brietzke, 1976). In the rare cases where tenants had access to limited GR technologies, they benefited from yield increase as sharecroppers. Still, their landlords, who owned the land, benefited the most from the tenants' payment. Landlords also evicted their tenants when they saw the benefits of using GR packages compared to sharecropping. For each new machine these landlords acquired to expand their commercial farms, they evicted about 20 sharecropper tenant families (Bondestam, 1974; Cohen, 1975). According to Cohen (1975), GR seeds' arrival led to the eviction of about 20–25% of 60,000 tenant households between 1968 and 1971. Here, the agricultural modernization discourse of Truman and other donors which adhered to the preconceived belief in technological solutions to hunger and poverty failed to recognize the underlying structural problems, primarily the exploitative land tenure system of the IEG and poor physical and institutional infrastructure (e.g., roads, irrigation), diversity of crops and agro-ecology in Ethiopia.

Moreover, the adoption of high-yielding bread wheat and hybrid maize varieties resulted in local genetic erosion of farmers' seeds (e.g., barley, durum wheat, and local maize). Loss of local seeds and positive yield advantage created a dependency on commercial seed producers for new seeds and varieties, which were not always readily available (Teklu and Hammer, 2006). Overall, the IEG's GR projects contributed to inequality, creating elite winner landlords and hungry loser tenants and consumers (Ståhl, 1973), triggering the early 1970s riots among students, teachers, and the working middle class. When examined closely by drawing on approaches to food contentions and movements, these riots articulated frustration about hunger and famine created by the exploitative land tenure system and modern agricultural input supply of the IEG that favored the regime's loyalists. The riots amplified into a revolution popularly known with the slogan "Land to the Tiller," leading to Emperor Haile Selassie's overthrow by the socialist government in 1974 (Crewett et al., 2008; Yemane-ab, 2016).

FOOD AND AGRICULTURAL CRISIS-INDUCED ALTERNATIVE SEED SYSTEM AND LOCK-INS IN THE GOVERNMENT-LED FORMAL SEED SYSTEM (1975 TO MID-2000s)

The Beginning of Seed Contestations and Movements in the Socialist Era in the Mid-1980s

The mid-1970s witnessed landmark reforms to eliminate the feudal order in Ethiopia. The Military Administrative Council (PMAC)—also called Derg—announced that it would eradicate the imperial regime's traditions of autocracy, inequality, and subjugation as soon as it assumed power in 1974 (Harbeson, 1977). Not knowing what political ideology and economic system the PMAC would follow, the US government, World Bank, United Nations Development Program, and several bilateral and multilateral development cooperations continued to provide financial assistance to keep the GR project going. The donors also wanted to keep the new government from getting too friendly with the Soviet Union. The US government supplied about USD 250 million in economic and military aid to the PMAC until it halted following the PMAC's inauguration of a National Democratic Revolutionary Program in April 1976. With this program, the PMAC declared a return to civilian democratic government, but it announced its firm position to fight feudalism, imperialism,

[4]The landlords were members of the royal family, church, and high ranking clergymen, and absentee landlords were war returnees, senior military, and civil servants.

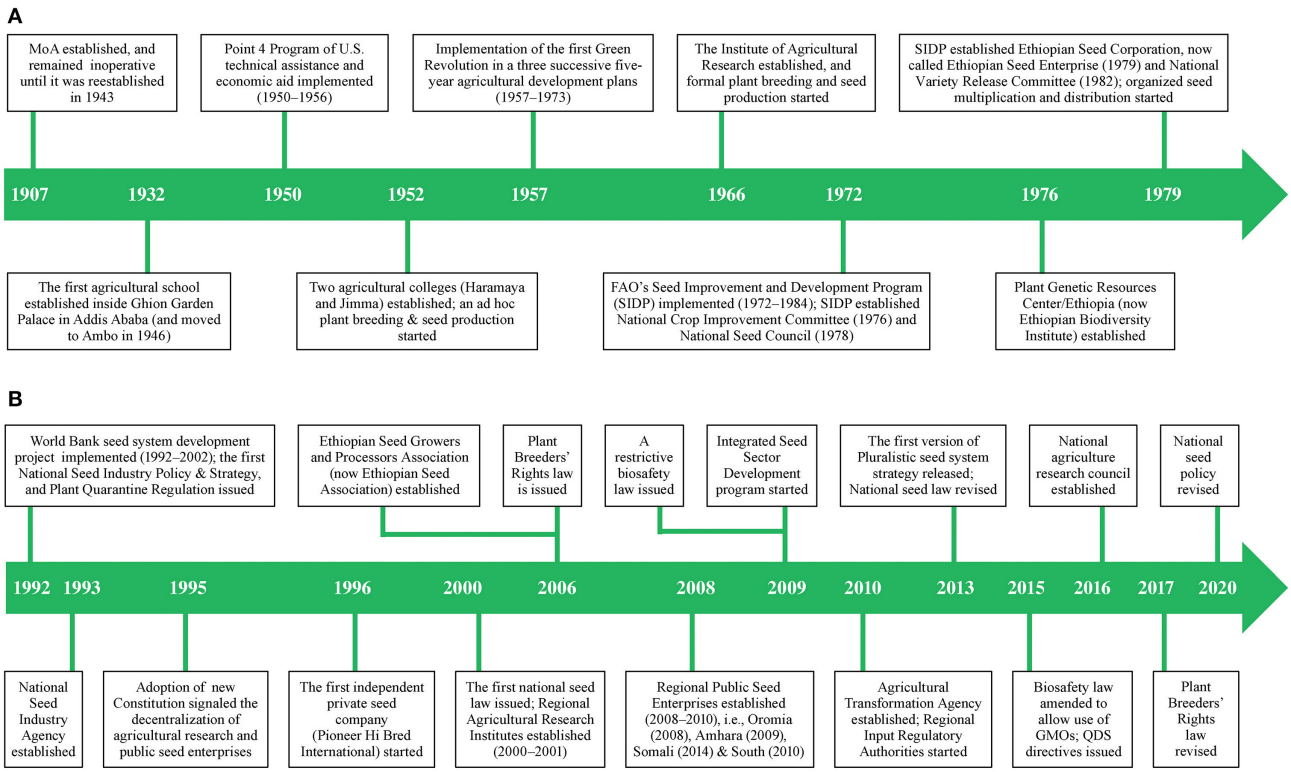


FIGURE 1 | Timeline of major historical landmarks of the Ethiopian seed system policy and institutional developments during **(A)** the imperial (1889–1974) and socialist (1974–1991) governments, and **(B)** the developmental state government regime after 1991.

and capitalism and Ethiopia's transition to socialism (McVety, 2012).

The World Bank and other donors continued to support FAO's Seed Improvement and Development Program (SIDP), which started in 1972 in Ethiopia since the agriculture crisis was evident and hunger was looming at the time (Ker, 1979). The SIDP was implemented in many developing countries and aimed to develop the national capacity to multiply good quality seeds of high-yielding improved varieties, distribute them to farmers, increase production and productivity, and contribute to national and global food security (World Bank, 1980; FAO, 1984). In Ethiopia, the SIDP was probably the most notable second seed regime activity or public investment in crop improvement research and extension during the socialist government, mainly because of the limited funding from western development partners and political crises. The SIDP helped to establish Ethiopia's central institutions for the formal seed system between 1972 and 1984 (**Figure 1A**). Besides, it strengthened the EIAR's capacity in plant breeding and quality seed production by training plant breeders and agronomists. The EIAR conducted a plant breeding and adaptation trial of improved varieties introduced from Kenya, Mexico, Ecuador, and the US in partnership with the International Maize and Wheat Improvement Center and released 22 improved wheat varieties: 18 bread wheat and four durum wheat (Ker, 1979; Woldemariam, 1990). Although the SIDP contributed to the organizational development of the formal seed system, it did not develop a seed policy and regulatory framework in Ethiopia, unlike in other developing countries. Like in many developing countries, where it was implemented, SIDP also failed to create financial sustainability for the maintenance of the infrastructure and technical activities (e.g., seed laboratories, field inspection capabilities) in Ethiopia, which weakened the formal seed sector in the years that followed (Woldemariam, 1990; Cromwell et al., 1992).

That said, the socialist government introduced a radical land policy reform that abolished the feudalistic land tenure system by declaring all rural lands the collective property of the Ethiopian people and redistributed land to peasants previously held by landlords (PMAC, 1975). Moreover, the regime introduced an agricultural socialization policy that emphasized expanding state farms and cooperative farming through villagization, allegedly intending to increase crop production and productivity and eradicate famine in Ethiopia. However, although the land redistribution and cooperative expansion had increased the demand for improved seeds and chemical fertilizer, the government-led agricultural socialization, and subsidy on GR inputs failed to increase agricultural production and productivity. Both state and cooperative farms recorded the lowest yield (only 6% of the national output) between 1975/76 and 1985/86, resulting in an estimated grain deficit between 350,000 and 500,000 metric

tons despite the government's highest investment in these farms (Ghose, 1985; Cohen and Isaksson, 1988). The failure was due to a range of interlinked factors such as bureaucrats' lack of experience in mechanized farming, poor planning, inadequate input supply, mismanagement, discrimination of private peasants for input supply, and discouraging abusive peasant labor deployment (Ghose, 1985; Clapham, 1988). The overall consequence was low agricultural growth and a food crisis (Belete et al., 1991). Ultimately, the food and agriculture crises signaled the failure of modernization driven by agricultural socialization.

The combination of poor governance, civil war, and droughts of the mid-1980s and the resulting food and agriculture crisis (Keller, 1992) led to a new wave of seed contestation and movements (Cromwell et al., 1993). A coalition of environmentalists and local NGOs from Ethiopia joined an international movement advocating for on-farm management, facilitated access, and fair and equitable sharing of benefits from the use of plant genetic resources for food and agriculture (PGRFA)—hereafter referred to as the PGRFA movement (Pistorius, 1997). This coalition also advocated for strong farmer' seed systems in developing countries (Cooper et al., 1992). In Ethiopia, the major actor in the PGRFA movement was the Plant Genetic Resource Center/Ethiopia, now called the Ethiopian Biodiversity Institute (EBI). While actively participating in the international PGRFA movement that advocated for farmers' rights as a countermeasure to stringent IPRs (Pistorius, 1997), EBI worked to link farmers with genebanks through farmer-based PGRFA management projects since 1989 (Worede, 1992; Cromwell et al., 1993). As the PGRFA movement gained momentum in the 1980s and 90s, environmental sustainability discourses gradually pervaded science and technology. The Ethiopian PGRFA movement's discourse was that GR crops could not substitute Ethiopia's biodiversity treasure trove and did not consider the socio-cultural and agro-ecological diversity of the country linked to these resources. Proponents of the PGRFA movement argued that ensuring national food security and sustaining Ethiopian food culture requires promoting locally adapted diverse seeds and protecting valuable crop diversity (Worede, 1992). Their discourse attempted to frame locally adapted seeds as an alternative to GR varieties for Ethiopia's food and agricultural crisis. The discourse builds on the idea that local crop diversity is vital in providing yield stability and harvest security in the face of pests, diseases, and unfavorable environments (Clawson, 1985; Brush, 1992). Although this seed discourse did not yield a significant seed policy shift until 2013, it received recognition from the government and donors. Besides, it attracted several donors who supported projects for on-farm management of PGRFA and strengthened farmers' seed systems (Brink, 2013; Mulesa and Westengen, 2020). EBI and its collaborating local partners implemented several projects with the recognition of the MoA despite government emphasis on the use of GR technologies for agricultural development. From the late 1980s, EBI deployed local crop varieties from the national genebank to farmers' fields through a network of farmers and community seed banks in drought- and famine-affected areas and in the productive regions where GR modern varieties replaced local ones (Westengen et al., 2018).

The Developmental State's Resistance to Seed Sector Liberalization Since the Early 1990s

In 1991, Ethiopia entered another sphere of political reforms in a social and economic development system. The Ethiopian People's Revolutionary Democratic Front (EPRDF), an ethnic federalist political coalition, came to power after a decade and a half civil war, a war between the socialist government and oppositions. Clapham (2018) characterizes the EPRDF government as the clearest example of a 'developmental state' in Africa, which effectively captured "rents" from state monopoly of companies and forced loans accumulated from the private sector's deposits in government bonds to fund massive development projects. During the transitional period (1991–1995), the EPRDF government announced an agricultural development-led industrialization strategy as its overarching strategic framework for guiding Ethiopia's economic development and poverty reduction in 1993. They developed and promoted this strategy based on the 1960s and 70s development theories that commercialization of smallholder agriculture can ensure the availability of raw material for industrialization and drives economic growth (Ellis and Biggs, 2001; Alemu et al., 2002). The strategy aimed to intensify the use of GR technologies to boost smallholder farmers' agricultural production and productivity, increase food security, and achieve sustainable exports and import substitution. To implement it, the EPRDF government needed institutional reform for agricultural research, extension, and effective delivery of GR technologies, for which it requested financial assistance from donors (Spielman et al., 2010). At the time, the World Bank and International Monetary Fund (IMF) structural adjustment program had already begun to weaken public seed research and extension in developing countries (Bernstein, 1990; Bishaw and Louwaars, 2012).

Moreover, debates over the meaning and consequences of GR gave rise to a global environmental agenda affecting the development aid priorities of international donors (Sumberg et al., 2012). Amid these changes in international development politics, the EPRDF resisted the structural adjustment program and received substantial international assistance for agricultural research and development in Ethiopia. EPRDF got this privilege mainly because it dissociated Ethiopia from the alliance with socialist countries and new connections with western countries, and its commitment to democratic values and western economic policies (Clapham, 2019).

In 1992, the transitional government received USD 657.4 million from the World Bank, bilateral and multilateral donors to implement an emergency recovery and reconstruction program. The government allocated about 45% (USD 296 million) of this funding to agricultural intensification (World Bank, 1998), of which USD 22 million went to seed system development projects between 1992 and 2002 (World Bank, 2003). The government used USD 50 million for agricultural extension services per annum, emphasizing the promotion of high-yielding

varieties, chemical fertilizer, and pesticides among smallholder farmers (Spielman et al., 2012). In addition to the World Bank, the Sasakawa Africa Association and Global 2000 of the Carter Center (SG-2000)[5] also made considerable investments in agricultural extension services, focusing on adopting the GR technologies since 1993 (Berhane et al., 2020). These investments helped revive the crop improvement research and development activities after a long period of low activity during the socialist regime. Although there has not been a time since the 1950s when public research and development was not a priority in government-led agricultural modernization, the investment in the second seed regime was very significant during the EPRDF government. At the time, the EPRDF transitional government issued a new constitution (FDRE, 1995) based on liberal and democratic principles to challenge the dominance of one political force in Ethiopia, effectively and ostensibly decentralizing power to regional and local authorities (Vaughan and Tronvoll, 2003). With the decentralization signal, the new constitution granted agricultural and rural development programs implementation responsibilities to newly formed autonomous regional states. Nine (currently eleven) regional states are "delimited based on the settlement patterns, language, identity, and consent of the peoples concerned" (FDRE, 1995, Article 46.2) under the federal government policy framework in Ethiopia. The corresponding sub-regional administrations, zones, and districts are responsible for agriculture and rural development at the local level (Gebre-Egziabher, 2014). With donor support, the EPRDF government implemented its decentralization policy of agriculture and rural development, including physical and institutional infrastructure development in the regions (Bechere, 2007). In the seed sector, it established Regional Agricultural Research Institutes, Regional Extension of the Bureaus of Agriculture, Regional Input Regulatory Authorities, and Regional Seed Enterprises in addition to preexisting national institutions in the formal seed system such as the EIAR, ESE, and EBI. Explaining the then needed decentralization of agricultural research and extension—which the government implemented in earnest during the 1990s with the financial support from donors—a high government official said:

> "We [technocrats/experts/organizational leaders] were happy with the SG-2000 extension program and World Bank support. However, at the time, we noted a sharp increase in demand for improved seeds. Yet, we only had one public seed enterprise [the ESE] to produce and distribute certified seeds. Therefore, it was impossible to meet even half of the seed demand, especially for hybrid maize. So, the government decided to decentralize seed production and distribution by creating regional research institutes, parastatals[6]."

In the 1990s, donor support was the key driver for the development of formal seed systems. In addition to the decentralization and capacity-building of public institutions for research and extension, the government developed and implemented a national seed policy framework throughout the 1990s (**Figure 1B**). The outcome was seed production and distribution increase, although it was impossible to fully meet the growing demand due to increased government extension programs' coverage after the decentralization (Gebreselassie, 2006). Arising from GR's realization, which began in earnest in the mid-1990s (Rohne Till, 2020) and continued agricultural growth (Berhanu and Poulton, 2014; Bachewe et al., 2015), the government embarked on a further formalization of the seed system, including the implementation of seed regulations. For instance, the government prioritized strengthening the formal supply of quality seeds of high-yielding plant varieties in almost all government policy documents[7] on poverty reduction, food security, and agricultural growth and transformation until recently (Simane, 2008; Bishaw and Atilaw, 2016). One informant explained the 1990s government's seed system formalization and its constraints as follows:

> "The 1990s green revolution was the main triggering effect toward genuine seed system formalization in Ethiopia. As a result, the use of improved varieties and certified seeds would have increased significantly. But the lack of investment incentives for private seed companies and government-pricing of seeds affected the supply of quality seeds based on real competition[8]."

The statements from the above informants corroborate my analysis showing EPRDF resistance to seed sector liberalization and privatization and emphasis on government-led formal seed system development conforming to the developmental state model. The statements are also consistent with an explanation by one informant who described the failure of the World Bank support seed system project, especially the community-based seed production and distribution, which is one of the growing seed systems during the last decade, as discussed below. My informant said:

> "EPRDF refused to privatize the ESE and preferred to use the community-based seed production scheme supported by the World Bank as out-growers for the ESE instead of helping them to become viable seed entrepreneurs. The current expanding seed producer cooperative approach in the intermediate seed system is not new. It is the same World Bank type of project, but the

[5]SG-2000 was established in Geneva in 1987 with the initiatives of Philanthropist Ryoichi Sasakawa (founder and former Chairman of The Nippon Foundation) who contacted Dr Norman Borlaug (the only Nobel Peace prize winner in food and agriculture until 2020), and President Jimmy Carter (who was involved in peace negotiation in Ethiopia in the late 1980s) following the 1970s and 1980s conflict and famine in the horn of Africa to solve food security problems.

[6]Personal interview with a government official of the Ethiopian Seed Enterprise (Addis Ababa, February 5, 2018).

[7]The 1990s Agricultural Development Led Industrialization framework, National Five-Year Development Plan (2000–2004), Sustainable Development and Poverty Reduction Program (2002–2005), Plan for Accelerated and Sustained Development to End Poverty (2005–2010), The First Growth and Transformation Plan/GTP-I (2010–2015) and Second Growth and Transformation Plan/GTP-II (2015–2020).

[8]Personal interview with a senior researcher of the CGIAR (Addis Ababa, February 1, 2018).

current one integrates business model and technical skill training of farmers in seed production and marketing[9]."

In agreement with Chinigò (2014), who examined the case of land administration in Ethiopia, my analysis shows that the decentralization of agricultural research and development is mainly an institutional expansion for strengthening the already hierarchical system of local administration and thereby extending the federal government's power to regions. In the seed sector, stringent federal regulations and centralized planning and control continued even after the decentralization of plant breeding, seed production, certification, and marketing in favor of the public seed sector. The EPRDF government resisted privatizing nearly all economic sectors, including land (Crewett et al., 2008), finance, and agriculture, for example, parastatal seed companies (Ojo and Ramtoolah, 2000; World Bank, 2003). Despite ideological differences between EPRDF and its donors[10] about the role of the private sector in economic development, Ethiopia has been a significant recipient (about USD 26 billion during the first two decades) of international development aid (Feyissa, 2011). Examined through Leach et al.'s (2020) food institution approach, we see the developmental state model overriding donors' neoliberal conditionalities to implement a competitive free market economy. According to Feyissa (2011) and Clapham (2018), EPRDF shielded Ethiopia from "neoliberal pressure" by playing a "sovereignty card" and placing itself diplomatically as a force for regional stability in an "unstable" region and as a leading partner in the Global War on Terror, for example as the largest contributor of troops (over 8,000) to UN peacekeeping. With the sovereignty narrative, which embodies power (Leach et al., 2020), and skillful negotiating strategy, Feyissa (2011) and Clapham (2018) argue that EPRDF buffered neoliberal influences. Seen through the food institution lens, donors' willingness to continue supporting Ethiopia is all about Cold War geopolitics and state alliances. Similarly, the EPRDF government's need for financial assistance did not mean that its political and economic development interests were the same as Western countries. As Feyissa's (2011) study shows, national sovereignty on policymaking and implementation was a priority for EPRDF.

Because the new constitution and EPRDF's agriculture and rural development policy also allowed non-state actors—including community-based organizations, local and international NGOs—to engage in development work and service delivery at the local level (Cerritelli et al., 2008), the PGRFA–movement coalitions (the EBI, local NGOs, and their partner western NGOs) continued to promote farmer-based seed system development. They promoted farmers' seed systems as an alternative to the dominant government-led formal seed system and resistance to privatization. At the international level, the rise of the environmental agenda favored the proponents of the global PGRFA movement to intensify the seed contestation and movements through project implementation and policy advocacy (Cromwell et al., 1993, pp. 71–75). This movement contributed to Ethiopia adopting international agreements such as the United Nations Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and corresponding funding mechanisms for supporting projects for their implementation. In Ethiopia, donor-funded projects strengthened the on-farm PGRFA management (e.g., participatory variety selection, community seed banking) during the 1990s (Mulesa and Westengen, 2020). There are two main reasons for reinforced support to implement community-based PGRFA management and farmers' seed systems. First, the Ethiopian delegates played a prominent role in international negotiations related to biodiversity agreements (Gebre Egziabher et al., 2011), which earned the country an international reputation as a progressive country in environmental governance. Second, Ethiopia's community-based PGRFA management work since the late 1980s (Worede, 1997) attracted international development actors for exchange and experience sharing with other developing countries (Dalle and Walsh, 2015). That said, the state's financial and institutional support primarily went to conventional GR seed research and development. The financial support provided for community-based PGRFA management projects was much less (about USD 5 million) than the funding that formal seed system development received (over USD 22 million) over 10 years period (Worede, 1991; IBC, 2007). Although implementation was incomplete, the government issued several policies and legislation to favor the farmers' seed systems. Recent studies provide an overview of these policy frameworks, which the EPRDF government issued in favor of farmers' seed systems in Ethiopia, and of the status of their implementations (Beko, 2017; Mulesa and Westengen, 2020; Mulesa et al., 2021).

Despite seed contestation and movements promoting farmers' seed systems since the mid-1980s, its role in supplying the most considerable quantities of crop varieties and seeds, and the approval of supportive policy frameworks, the EPRDF government continued prioritizing government-led formal seed system development. Viewed from a food innovation systems perspective (Thompson and Scoones, 2009; IPES-Food, 2016), we see agricultural modernization and the continuation of the historical legacies of the Ethiopian government's political interests and incumbent powers for top-down control of farmers by ignoring alternative development pathways to the formal seed system. Studies link the regime's predominant focus on supplying agricultural input through public institutions, including certified seeds, as an instrument for securing political control of rural constituencies throughout Ethiopia. These studies also show how wealthier model farmers benefit from government input supply at the expense of poor farmers (Lefort, 2012; Berhanu and Poulton, 2014; Hailemichael and Haug, 2020). The modernization path dependencies or "lock-ins" to agricultural development and government-led formal seed

[9]Personal interview with a senior technical staffer of an NGO, Bilateral Ethiopian-Netherlands Effort for Food, Income and Trade Partnership (Addis Ababa, February 14, 2018).

[10]USAID, the World Bank, IMF, the European Union, Britain's Department for International Development (DFID), German Technical Cooperation (GTZ), Canadian International Development Agency (CIDA) and many other bilateral donors.

TABLE 1 | Dominant and alternative pathways to policy practices in Ethiopia's pluralistic seed system development.

Dimensions of policy practice	Government-led seed system formalization	Private-led seed system formalization	Farmer-based seed system localization	Community-based seed system integration
Dominant approach and underlying narratives for seed policy-making and actors' actions	*Agricultural growth and transformation*—Government institutions and farmer cooperatives/unions collaborate with public seed research and development institutions to provide reliable Green Revolution (GR) technologies[a] to increase agricultural production and productivity. On this account, national food and nutrition security can improve, and agriculture-led industrialization can accelerate.	*Renewed GR*—Commercially viable agro-dealers network linked to private seed research and development companies can effectively deliver GR technologies for all commercial farmers. Access to new GR technologies increases agricultural production and productivity and, consequently, can eradicate hunger and malnutrition and accelerate Ethiopia's transition to agro-industry.	*Biodiversity-based sustainable agriculture*—Government policies and investments that prioritize market-led GR technology supply have been ineffective to meet the diverse agro-ecological, socio-cultural, and economic needs, and people's livelihoods. The approach has jeopardized smallholder farming. Therefore, strengthening farmers' knowledge, practices, and institutions for supplying locally adapted crop varieties can have the potential to satisfy these diverse needs and sustain stable crop production.	*Sustainable agricultural productivity*—Trained and empowered farmer cooperatives and other local commercial groups linked to public seed conservation, research, and development institutions can deliver quality seeds of high-yielding GR crops for farmers in potential areas. They can also supply locally adapted diverse crops and varieties to increase agricultural production and productivity in marginal regions. Consequently, they can contribute to food security, entrepreneurship, and job creation.
Actors' coalitions articulating the dominant narratives	Federal, regional, and international agricultural research institutions; public seed enterprises; Ministry of Agriculture; the Ethiopian Agricultural Transformation Agency; extension and input supply authorities; input regulatory authorities; multipurpose farmers cooperatives and unions; the ruling party	Private seed companies (national and multinational); Ethiopian Seed Association; bilateral and multilateral donors; philanthropic foundations; Alliance for a Green Revolution in Africa; the Ethiopian Agricultural Transformation Agency; International agricultural research institutions	Ethiopian Biodiversity Institute, Local and western NGOs; Bioversity International; FAO's ITPGRFA Secretariat; Community Seed Bank groups; Dutch-government-supported ISSD program	ISSD program; Agricultural Faculties of Higher Learning Institutions; the Ethiopian Agricultural Transformation Agency; federal, regional, and international research institutions; seed producer cooperatives
Main critiques and actors' coalitions enunciating it	*Proponents of private-led formalization*: Centrally planned ineffective seed production and marketing cause untimely supply and poor-quality certified seeds. Consequently, seed carryover arises, and farmers' demand is unmated; the private sector should replace the public seed research and development institutions. *Proponents of localization:* The top-down seed research and development distribute poor-quality seeds that are less adapted to farmers' diverse agro-ecological and socio-economic needs and poses production risky, especially for poor farmers and farmers in marginal areas. *Proponents of integration*: Centralized, bureaucratic, and lengthy planning, production, and distribution of certified seed makes timely access to seeds difficult, which requires complementary local seed businesses.	*Proponents of localization*: Access to certified seeds is difficult for poor farmers due to high seed prices. Privatization creates a dependency on few improved varieties, drives genetic erosion, and creates seed enclosure and food control by a few powerful seed companies. *Proponents of government-led formalization*: Relying on the private sector is inadequate. They cannot meet national seed security needs due to their focus on commercially successful crops and profit; therefore, government intervention is necessary. *Proponents of integration*: Seeds from private companies are expensive for some commercial farmers, and seed producer cooperatives can offer affordable quality seeds.	*Proponents of formalization (private)*: Farmers have limited knowledge and skill in quality seed production, and they supply low-quality seeds of variable quantities. *Proponents of formalization (public)*: Promotion of local varieties should not be at the expense of the government agricultural transformation plan (i.e., use of a complete package of improved varieties, chemical fertilizer, pesticides, and improved agronomic practices) to increase crop production and productivity. The national genebank is responsible for guaranteeing the conservation of crop diversity. *Proponents of integration*: Skill training and provision of agricultural infrastructure (e.g., seed cleaning and storage facilities) for collective seed production and marketing can improve farmer-based seed production, storage, and marketing. Therefore, market orientation is necessary for sustainable local seed supply.	*Proponents of private-led formalization*: Commercial seed production and marketing by farmers bring unnecessary competition in the national seed industry, especially for economically critical commercial crops. Farmers have limited technological know-how in commercial seed production and marketing, and their seed business must be limited to local crops to avoid productivity loss.

(Continued)

TABLE 1 | Continued

Dimensions of policy practice	Government-led seed system formalization	Private-led seed system formalization	Farmer-based seed system localization	Community-based seed system integration
Dominant rules, practices, and relationships governing seed research and development	Seed research and development through public institutions are entrenched in state laws—the constitution, proclamations that establish the Ethiopian Institute of Agricultural Research, and membership. It also amended seed (FDRE, 2013b, 2016) to align with the COMESA Seed Trade Regulation and biosafety law (FDRE, 2015b) to allow the use of GMOs. However, the implementation lags. In addition, the institutional barriers (e.g., lack of access to land, seed import, and export restrictions) discourage private sector investment. Ethiopian Agricultural Businesses Corporation that includes seed parastatal (FDRE, 1995, 1997, 2015a). In addition, developmental state policy (Clapham, 2018) allows EPRDF government structures to maintain state control over agricultural research, inputs supply, and agricultural extension—the government-led seed system formalization.	EPRDF government developed a *sui generis* plant breeders' rights law (FDRE, 2017) to qualify for World Trade Organization developmental state administrative and	Sovereign rights on plant genetic resources articulated in the constitution and biodiversity policy (FDRE, 1995; EPA, 1997), farmers' rights provisions included in breeders' rights law (FDRE, 2017), access to plant genetic resources, and benefit-sharing rules issued (FDRE, 2006, 2009) and institutional arrangements established (FDRE, 2013a) to encourage biodiversity-based agriculture. However, implementation mandates of these laws and institutional arrangements are misplaced. i.e., under the ministry of environment, diverting the attention of the government investment through the MoA in farmers' seed systems.	EPRDF agricultural cooperatives sector development policy (FDRE, 2012), Quality Declared Seeds certification directives (MoA and ATA, 2015), and investment in local seed business model (Thijssen et al., 2015; Sisay et al., 2017) encourage seed production and marketing of local and improved varieties—an integrative approach to seed system development (Mulesa et al., 2021).

Green Revolution technologies in the seed sector often refers to certified seeds of high-yielding plant varieties.

system development have continued even after the launch of the PSSDS, as I discuss below.

AGAINST THE GRAIN: THE EMERGENCE OF PSSDS AND ITS IMPLEMENTATION PATHWAYS

Since the mid-1980s, diverse coalitions of actors have promoted alternative pathways to seed system development following the food and agricultural crisis. These alternatives (**Table 1**) were debated intensely for about 8 years, beginning in 2006 until the Ethiopian Agricultural Transformation Agency (ATA)[11] and MoA released the first version of the PSSDS in 2013 (MoA and ATA, 2017). The PSSDS in Ethiopia was the result of an externally funded intensive 1-year tailor-made training program[12] based on a multi-stakeholder process approach (Thijssen et al., 2008; ICARDA, 2009) and the Integrated Seed Sector Development (ISSD) program[13] that emerged from this process (CDI, 2009) and played a catalytic role by bringing diverse seed sector actors together. These actors debated policy and governance issues related to the different seed system development alternatives at different levels during the training. The debate continued during the first phase of the ISSD program implementation (2009–2011) and the PSSDS process under the auspices of the Ethiopian ATA (2011–2013). Overall, the impact of the externally funded 1-year training program and the ISSD program was significant in facilitating the PSSDS development (ICARDA, 2009; Borman et al., 2020). There are three major discourses in the contestation surrounding the current Ethiopian seed regime (privatization, localization, and integration) proposed by different actors while

[11]The establishment of Ethiopian ATA was initiated by the late Prime Minister Meles Zenawi after he approached Melinda Gates, Co-Chair of the Bill and Melinda Gates Foundation (BMG Foundation), and asked for the Foundation's support in identifying an innovative way to catalyze agricultural growth and transformation in his country. Following this request, the BMG Foundation financed a study that identified the lack of intersectoral coordination and integration within the agriculture sector, and implementation capacity as the main hindrances. Addressing this would require an organ to streamline coordination and transformation activities. In 2010, the Council of Ministers established ATA (Regulation No. 198/2010) as an autonomous federal organ to: (i) provide leadership in identifying, designing and effectively implementing solutions to basic hurdles in agricultural development; and (ii) provide policy directions and leadership in order to ensure that effective coordination is realized by different actors involved in agricultural development (FDRE, 2010).

[12]The training program was supported by the Dutch Government through Wageningen Centre for Development Innovation of the Wageningen University and Research under a project titled "the improvement of farmer-based seed production scheme and revitalizing farmers' seed supply of local crops and varieties in Ethiopia." The project was implemented in partnership with International Center for Agricultural Research in the Dry Area's Seed Unit and the Ethiopian Seed Enterprise in 2006 (Thijssen et al., 2008; ICARDA, 2009).

[13]The ISSD program is part of the "Bilateral Ethiopia–Netherlands Effort for Food, Income and Trade Partnership supported by the Dutch Government through the Embassy of the Kingdom of the Netherlands in Addis Ababa since 2009. The Centre for Development Innovation of Wageningen University and Research Centre and the Royal Tropical Institute, the Netherlands, is operationalizing the ISSD program. It implements the program to support the African Seed and Biotechnology Program of the African Union Commission (African Union, 2008) through its local partners in Ethiopia, Mozambique, Nigeria, and Uganda.

formulating the PSSDS in addition to the government-led formal seed system (**Table 1**).

Proponents of private-led seed system formalization have been working to increase the roles of private actors in plant breeding and commercial seed production and marketing in Ethiopia, which has not yet been anchored in the country's formal seed system. For instance, they supported policy and regulatory reform, e.g., the development of plant breeders' rights and seed laws, seed quality control by seed companies, and capacity-building of government agencies for effective seed certification. They also provide financial and technical support for start-ups and small seed companies (O'Connor Funk, 2009; Holtzman et al., 2020). The donor and philanthropic support that goes to private-led seed system formalization is mainly a renewed commitment from the international community to invest in African agriculture following the food crisis that struck the world in 2008 (Scoones and Thompson, 2011). But it can also be piggy-backing on the influence of other actors' protests against the dominance of government-led seed research and development, as discussed below.

Most of the coalition of the second group of actors subscribing to the localization discourse has supported the seed contestation and movements (the PGRFA movement) at different times to strengthen farmer-based seed system localization since the mid-1980s (Cromwell et al., 1993). As a protest against privatization or seed enclosure through IPRs, and ineffective government-led seed supply systems, they have promoted participatory plant breeding, community seed banks, farmers' rights, and less stringent seed certification processes for seed producer groups' local seed marketing (Feyissa et al., 2013; Gotor et al., 2014). The third pragmatic coalition group of actors is proponents of the seed system modernization. They endorse the integration of formal and farmers' seed systems that are neither government-led nor private-led formalization but are instead a pragmatic approach to seed sector development. Building on experiences of the World Bank seed system project that partly supported community-based seed production and distribution in the 1990s, the coalition of these actors has supported the integration of formal and informal seed systems through SPCs. At the SPCs level, they support infrastructure development, skill training in planning, production, processing, packaging quality seeds, organizational governance, marketing strategy, and business management. For this purpose, they support the supply of early generation seeds of improved varieties to SPCs from agricultural research and quality declared seed certification schemes for seed marketing (Sisay et al., 2017; Borman et al., 2020). For example, the participation of some actors such as the ISSD program, ATA, and research institutions in the formal and local seed system while promoting the integrative community-based approach demonstrates their pragmatic approach to seed innovation.

These three alternatives in the PSSDS are competing with one another and the dominant government-led formal seed supply system. The seed sector privatization alternative seeks market-based seed supply of profitable crops, which increases commodification and seed enclosure through IPRs protection. It aims to access basic agricultural inputs (e.g., land) to have its breeding program, developed its crop varieties, and access improved varieties bred through public research for seed multiplication and marketing. Moreover, it aims to exclude other actors (e.g., public seed enterprises and SPCs) from certified seed production and marketing of target crops (e.g., hybrid maize). The localization alternative resists IPRs and privatization in favor of farmers' rights and aims to build local capacity to produce and distribute locally adapted seeds using non-market channels. Proponents of localization blame the government-led formal system for seed insecurity owing to ineffectiveness, despite the investment priorities it received from the government over the past decades. In return, the actors supporting government-led formal seed supply believe that an investment that promotes local varieties could impair the government's agricultural transformation. The integrative alternative seeks to increase local availability and access to quality declared seeds of diverse improved and local varieties with farmer-preferred traits. The alternative prioritizes the marketing of open-pollinated crops that the government-led formal seed supply has ignored for decades. **Table 1** shows how different actors' coalitions framed seed system development through particular discourses to promote specific policies and interventions to remedy their problem definitions. It also shows that the government-led formal seed system remains the dominant alternative despite critiques from opponents.

The actors' coalition narratives, values and goals, and priorities based on knowledge politics and dynamics of power led to adopting a pluralistic seed system. However, the direction, diversity, distributional effects, and democratic participation in PSSDS implementation show challenges, as I discuss below.

Moreover, there is growing optimism about possible liberalization and privatization of Ethiopia's agri-food system, including the seed sector, following a leadership change and reforming the developmental state's political and economic policies since 2018 (Geleti, 2020; Woolfrey et al., 2021). A widespread youth protest was an everyday experience between 2015 and 2018 due to two-and-a-half decades of growing inequality and multiple forms of youth exclusions from the developmental state's development future that unequally distributed the fruits of economic growth. Contestations around violent forms of government land-grabbing, farmer dispossession, youth unemployment, lack of political freedom, and human rights violations were at the core of the youth protest. This protest brought the "reformist" Prime Minister Abiy Ahmed to power in April 2018 (Abebe, 2020). The seed sector privatization optimism links to Prime Minister Abiy Ahmed's recent Homegrown Economic Reform Program of making Ethiopia the African icon of prosperity by 2030. The program received USD 5 billion from the IMF and the World Bank in 2019 and USD 3 billion from the United Arab Emirates in 2018, owing to its prioritization of the private sector (Collier, 2019; Kibsgaard, 2020). With this recent economic reform, the MoA has already issued a new strategy in 2019 to strengthen the private seed sector (MoA, 2019). However, when writing this paper, Ethiopia faces a political rift that has led to civil war, making the future uncertain (Walsh and Dahir, 2021; Ylönen, 2021). As a result, some western donor countries are undertaking evidence-based analysis of the country's fragility to

make informed bilateral relations and investment policies for the future (Rameshshanker et al., 2020).

THE "4Ds" OF ETHIOPIA'S CURRENT SEED POLICY AND PRACTICE

Following Leach et al.'s (2020) 4D approach to the study of food politics and development, I assess the outcomes of the PSSDS through four questions: What has been the direction of the seed system development; What diversity of technical and institutional innovations have resulted, to what extent has the development been democratic and inclusive and; what have been the distributional outcomes for marginalized people.

The direction of seed system development under Ethiopia's PSSDS framework is still the dominant government-led formal seed system emphasizing the development and use of GR technologies, including improved varieties as a response to food and nutrition insecurity, climate change, and rural poverty. This dominance is also unexpected given that Ethiopia is the most significant international aid recipient and has approved policies and strategies on paper in favor of a free-market economy, including privatization. It shows the marginal effect of donor influence compared to other developing countries where power asymmetry between governments and donors is at play in setting seed sector development policies (Scoones and Thompson, 2011). One respondent explained how the dominance of the public seed sector (e.g., in major food crops) had been maintained by the Ethiopian government as follows:

> "Our developmental state fears that there could be a risk of food insecurity if competent private seed companies overtake the public enterprises and cannot supply affordable seeds, especially for food crops like hybrid maize. They do not say it, but we know they also fear a loss of political support and income if the private sector overtakes the public enterprise and extension services for the key food security crops. However, the government is for competent private seed companies in horticulture to increase foreign currency gain from seed and food exports. Still, institutional capabilities are too poor to appropriately implement existing policies and laws, such as the revised plant breeders' rights protection law in 2017, which discourages companies from entering the sector[14]."

The state's power as entrenched in developmental state policy and skillful negotiation with donors that continue to support the GR approach to agricultural development is the driving force for this dominant path. Describing state power and development practices in government institutions, one informant with intimate knowledge of Ethiopian seed policy said:

> "Ethiopia's developmental state economic policy goes beyond directing, supporting, and guiding executive bodies of public institutions because the government wants to implement everything related to agricultural development by itself. The organizational leaders that I have interacted with told me that they must deliver inputs, including certified seeds, to farmers. The agriculture bureaus at the regional, zonal, and district levels think that seed distribution is their primary responsibility, and others cannot play a central role except helping them. They believed that public parastatals should be the leading seed producer, and the extension at the bureau of agriculture is responsible for its distribution to farmers through cooperatives. I see a symbiotic relationship between government staff unwilling to give up the seed distribution job to agro-dealers and government use of seed as a political commodity, i.e., maintaining strong links with and controlling farmers[15]."

Explaining the continued donor supports, despite the government's unwillingness to sign up to neoliberal institutions and encourage seed sector liberalization and privatization, one informant said:

> "Several donors such as BMG Foundation, USAID, the World Bank, and the Dutch government have provided aid for agricultural research and development during the past decade in Ethiopia. Simultaneously, they have been pushing for policies for seed sector privatization. For example, they provided technical and financial assistance through AGRA, ATA, ESA, and the ISSD program to develop seed and PVP laws[16]. The government approved these laws, but they are not enforcing them, making it difficult for the private sector to operate. For example, the DUS test and issuing of PVP certificate is almost nil as there are no directives issued, making variety import and export very difficult for the private companies. On top of this, regulatory services at the federal level are centralized and bureaucratic. Besides, Ethiopia has not acceded to the WTO and is unwilling to join UPOV. Unfortunately, the government continues to discourage privatization, and it is not easy to change the government's [politicians/executive leaders] negative attitude toward the private sector[17]."

In addition to community seed banks that EBI and NGOs promoted since the 1990s in Ethiopia, community-based seed production and marketing (through SPCs) emerged as an additional alternative during PSSDS formation and its implementation. As a result, the SPCs and community seed banks have contributed to the diversification of the country's seed systems regarding farmers' choice of crops, varieties, and seed sources (Sisay et al., 2017; Alemu et al., 2019; Andersen, 2019).

The distributional effect of dominant government-led seed research and development that marginalized the private sector in the formal system and farmers' seed systems is evident from a recent field study conducted on farmers' seed security in the central highlands in Ethiopia (Mulesa et al., 2021). The study identified seed insecurity in a commercially oriented wheat farming district and a subsistence-oriented tef (*Eragrostis tef*) growing community. The study links the limited availability

[14] Personal interview with a senior technical staffer working for donor funded seed system development program (Addis Ababa, January 18, 2018).

[15] Personal interview with a senior technical staffer working for donor funded seed system development program (Addis Ababa, January 18, 2018).

[16] Acronyms: Alliance for a Green Revolution in Africa (AGRA), Ethiopian Agricultural Transformation Agency (ATA), Ethiopian Seed Association (ESA), Integrated Seed Sector Development (ISSD) and Plant Variety Protection (PVP).

[17] Personal interview with a senior manager working for donor funded seed system development program (Addis Ababa, February 1, 2018).

of improved varieties and specially certified seeds of these to the ineffectiveness of the public institutions and the availability of few commercial actors. The PSSDS acknowledges the importance of diversity on paper, but the bias of supporting the dominant modernization approach is pulling in another direction. However, it is important to note that Ethiopia's seed system is mainly farmer-based, and agriculture is—in comparison to most of the world—highly diverse in terms of crops, varieties, and seed sources. We also observe a lack of locally adapted varieties linked to a lack of democratic participation in priority setting, technical and institutional innovation, for example, with priority crops for breeding, participatory variety development of such crops, and involvement in policy processes (Beko, 2017). For instance, farmers in wheat and maize growing agro-ecologies benefited from the formal seed system more than those growing other indigenous crops due to the concentration of the public breeding, dissemination, and adaptation work in the two crops since the first GR. Moreover, farmers' differentiated access to preferred seed and information (including wheat and maize commercial areas) according to sex, age, and wealth, links to gender inequality and political allegiance that the developmental state extension institutions use to select model farmers, favoring the wealthier ones for seed access.

CONCLUSIONS

This article analyzed the historical evolution and current policy practices in the Ethiopian seed sector development, focusing on actors' interests and actions and political and economic priorities of three different governance regimes (imperial, socialist, and developmental) since the 1950s. Despite agricultural policy changes from commercial farming of the feudal system to state enterprises and cooperativization of the socialist government to the developmental state's commercialization of smallholder farmers, all governance regimes have retained public seed research and development in Ethiopia. Moreover, these governance regimes also held public seed research and development as a priority despite awareness, recognition, and policies on paper about how diverse seed systems can increase access to enough good quality seeds of suitable plant varieties by farmers.

The power analysis allowed me to identify some insights concerning this specific Ethiopian seed policy and practice. Of historical significance is Ethiopia's idiosyncratic historical patterning of the seed regimes compared to most colonial territories and industrial countries. The first colonial seed regime never took hold, and the third corporate seed regime has never been anchored in the formal seed system. Consequently, Ethiopia's seed system development remains government-led. Related to this, we see two paradoxical aspects of Ethiopian government policy practices. First, the Ethiopian governments have received financial assistance from western donors, including neoliberal financial institutions, while disagreeing with them and establishing the distinct seed sector development policies in line with the agricultural development ideology of the governance regimes. For example, the EPRDF government has received funding from the IMF and the World Bank to finance public agricultural research and development, including during the structural adjustment program in the 1990s. Still, Ethiopia is not a member of WTO and UPOV[18], which are the key neoliberal seed institutions. Second, Ethiopia's positions in environmental governance, climate change, and UN development goals are perceived as "progressive" on the international scene. At home, the government has sidelined alternative development pathways in support of these positions. For example, support for the farmers' seed systems mainly comes from multilateral institutions, local and international NGOs.

Ethiopia has a very centralized and top-down state-led seed sector development policy. Practically, the government has sidelined both its development partners' democratic values and neoliberal economic policies as well as measures to implement its policies on alternatives to the dominant public seed research and development. That said, the two perspectives have common ground in notions of independence, sovereignty, skepticism against foreign forces, liberalization, and free-market ideology. In the end, the government investment emphasizes state-led seed sector development, leaving other alternatives to NGOs and smaller overseas development assistance projects. While heavily dependent on external funding, the Ethiopian example of paradoxical state-led policy development and action exemplifies variations specific to countries in international politics and development work.

In line with other studies (Alemu, 2011; Beko, 2017), we see a link between the nature of the Ethiopian state and the marginalization of alternative seed sector development in the country. Decades of centralized planning and execution of agricultural development, state control of rural constituencies, elite interests, and agricultural modernization path dependency have contributed to the lack of inclusive and equitable seed sector development. In addition, the historical events and processes are vital elements that have shaped the practices of the Ethiopian state in the governance of seed sector development. For instance, the limited participation of the private sector in the formal seed system links to the first colonial seed regime that never took hold in Ethiopia compared to other African countries such as neighboring Kenya, which has signed over to the neoliberal institutions. In agreement with McCann (2011), we see that policymaking and implementation in Ethiopia treat external influences and the international seed market as of lesser importance. Again, resonating with McCann's (1990) observation, we find that the state and elite's vested interest in maintaining the status quo of the agricultural cycle for resource extraction from the farming community is the major hindrance to breaking the cycle and bringing an inclusive and equitable seed sector development to Ethiopia.

For inclusive and equitable seed sector development to happen in Ethiopia, there needs to be a political will to establish effective institutional arrangements and allocate an adequate budget for the recent PSSDS. One motivating factor or source of inspiration in this direction is the growth of

[18]WTO is the acronym for World Trade Organization and UPOV is the acronym for Union Internationale pour la Protection des Obtentions Végétales (French) or International Union for the Protection of New Varieties of Plants (English), which is also the name of the organization that established the International Convention (called the UPOV Convention).

community-based seed production and marketing. However, other matters deserving attention are the biased attitudes and bad governance, including legal hurdles in the seed sector that marginalize other alternatives and actors, for instance, farmer-based seed system innovation and participation of the private sector in seed research and development.

Finally, when applying Leach et al.'s (2020) plural approaches to power analysis in developing countries, it is vital to carry out a historical analysis of the policies and institutions involved in seed system governance, as this study has done in the case of Ethiopia. Analyzing seed regime patterns allows one to examine how historical conflicts or cooperation between donors and governance regimes have shaped distinct seed policies and practices in developing countries. In considering the particular historical, political, and institutional factors within each country, a more nuanced picture is created by going beyond existing institutional, infrastructure, and financial limitations that donors often focus on for their intervention.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available upon request to the author.

ETHICS STATEMENT

The study was conducted according to the guidelines for research ethics of the Norwegian University of Life Sciences and Norway's guidelines for research ethics in the social sciences, humanities, law, and theology. A notification form was submitted to the Norwegian Center for Research Data (NSD) before data collection based on these guidelines, and approval was received from NSD (Harald Hårfagres gate 29, N-5007 Bergen, Norway) on 18.09.2017. The guidelines did not require explicit ethics approval in Ethiopia. However, I informed the authorities, which gave a letter of permission to carry out the interviews and discussions. Voluntary informed consent was obtained from all research participants after explaining the research project's objectives, the implication of their participation, and how their information is used.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Who Gets to Adopt? Contested Values Constrain Just Transitions to Agroforestry

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Agroforestry is often promoted as a multi-benefit solution to increasing the resilience of agricultural landscapes. Yet, there are many obstacles to transitioning agricultural production systems to agroforestry. Research on agroforestry transitions often focuses on why farmers and land managers chose to adopt this type of stewardship, with less focus on the political context of practitioner decisions. We use the case study of agroforestry in Hawai'i to explore how agroforestry transitions occur with particular attention to politics and power dynamics. Specifically, we ask, what factors drive and/or restrain transitions to agroforestry and who is able to participate. We interviewed 38 agroforestry practitioners in Hawai'i and analyzed the data using constructivist grounded theory. We then held a focus group discussion with interview participants to share results and discuss solutions. Practitioners primarily chose agroforestry intentionally for non-economic and values-based reasons, rather than as a means to production or economic goals. Agroforestry practitioners face a similar suite of structural obstacles as other agricultural producers, including access to land, labor, and capital and ecological obstacles like invasive species and climate change. However, the conflict in values between practitioners and dominant institutions manifests as four additional dimensions of obstacles constraining agroforestry transitions: systems for accessing land, capital, and markets favor short-term production and economic value; Indigenous and local knowledge is not adequately valued; regulatory, funding, and other support institutions are siloed; and not enough appropriate information is accessible. Who is able to practice despite these obstacles is tightly linked with people's ability to access off-site resources that are inequitably distributed. Our case study highlights three key points with important implications for realizing just agroforestry transitions: (1) practitioners transition to agroforestry to restore ecosystems and reclaim sovereignty, not just for the direct benefits; (2) a major constraint to agroforestry transitions is that the term agroforestry is both unifying and exclusionary; (3) structural change is needed for agroforestry transitions to be just. We discuss potential solutions in the context of Hawai'i and provide transferrable principles and actionable strategies for achieving equity in agroforestry transitions. We also demonstrate a transferrable approach for action-oriented, interdisciplinary research in support of just agroforestry transitions.

Keywords: agroecology, political ecology, food system, transformation, Hawai'i, equity, food sovereignty

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INTRODUCTION

The triple threat of climate change, biodiversity loss, and food insecurity is a major challenge to food system resilience. Re-localization of food systems, shortening supply chains, and adding redundancy to markets can enhance resilience of distribution and market channels (Tendall et al., 2015). At the same time, calls for changes in agricultural production to be regenerative and climate smart abound (Newton et al., 2020; Petersen-Rockney et al., 2021). How we produce food matters for food system resilience.

Agroforestry is widely promoted as a resilience strategy. The term agroforestry was coined in the late 1970's by researchers and development professionals, primarily from high income countries, to describe land management systems that simultaneously increase the productivity of landscapes while also reducing environmental degradation (Bene et al., 1977). Agroforestry has come to encompass farm level technical practices that integrate woody plants and crops and/or livestock for environmental and practical benefits (NRCS, 2013), Indigenous stewardship practices based in ecomimicry (Ticktin et al., 2018; Winter et al., 2020), and a landscape approach "to removing the conceptual and institutional barriers between agriculture and forestry" (van Noordwijk et al., 2018). Subsequently, a large body of literature documenting the ecosystem services of agroforestry systems and optimizing system design for production and environmental benefits followed. Research has thus shown forms of agroforestry can diversify livelihoods (Miccolis et al., 2019), conserve biodiversity (Kremen and Merenlender, 2018), and increase pollination services (Bentrup et al., 2019), sediment retention, and nutrient cycling (Torralba et al., 2018). Agroforestry is considered a natural climate solution (Griscom et al., 2017) as these practices also contribute to carbon sequestration (Chapman et al., 2020) and social-ecological resilience (Quandt et al., 2017; Ticktin et al., 2018), or the ability of a system to continue to function over time despite disturbances (Berkes et al., 2002). As a result, institutions ranging from local governments to international agreements are increasingly including agroforestry as a component of their social-ecological resilience strategies (Rosenstock et al., 2019; Griscom et al., 2020), including National Adaptation Plans and Nationally Declared Contributions (Fortuna et al., 2019; Meybeck et al., 2019).

Yet, how to increase agroforestry on landscapes to meet these targets remains a question. A significant body of research has explored existing farmers' decisions to start practicing, or adopt, agroforestry (Pattanayak et al., 2003; Mercer, 2004; Meijer et al., 2015; Amare and Darr, 2020). Research has largely focused on econometric modeling, showing that producers adopt agroforestry to meet economic goals or to circumvent obstacles like limited labor or depressed prices (Amare and Darr, 2020). For example, when a tree crop price declines, producers may start growing a short-term understory crop between their tree rows to augment their income. Fewer studies have intentionally examined the non-economic reasons for deciding to practice agroforestry, yet studies that do can uncover important narratives (Decré, 2021). The concept of adoption has conceptual and operational limitations, namely that it is an oversimplified model of change and detecting adoption may not be as valuable as understanding the context of the decision to adopt (Glover et al., 2016, 2019). Instead, we use "agroforestry transitions" to describe the multi-year process of land use change from active or fallow simplified agriculture or non-native dominant forest to agroforestry (Ollinaho and Kröger, 2021). At the site level, agroforestry transitions can occur when an existing land steward changes their practices, or a steward gains new access to land and begins practicing agroforestry. These transitions are socially and ecologically complex, often involving a succession of different financing mechanisms, labor sources, and plant and animal species over a number of years. Enabling agroforestry transitions that last therefore requires a better understanding of the drivers and constraints to practitioners' ability to not only make an initial change in practices, but also to continue to practice throughout the multi-year transition process.

Constraints to agroforestry transitions are considerable. Some of the most significant obstacles to agroecological transitions include difficulty accessing land, labor, and start-up capital (Anderson et al., 2019). These obstacles are often more acute for agroforestry practitioners because the trees, shrubs, and other perennials in agroforestry systems take longer to mature and provide a return on investment than annual crops. Therefore, secure, long-term tenure can be a major obstacle to agroforestry (Lawin and Tamini, 2019). High start-up costs and longer returns on investments makes persisting after establishment challenging, and this can be a significant source of risk for practitioners (Buttoud, 2013). Accessing plant material is another challenge as agroforestry systems often include native and other underrepresented plant species, many of which are not readily accessible (Lillesø et al., 2018). Lack of financial incentives, limited marketing for agroforestry products, and lack of knowledge can also be barriers (Sollen-Norrlin et al., 2020).

Although the above research is important for understanding and promoting agroforestry transitions, much of the literature neglects the unequal power dynamics shaping who is able to participate in transitions. For example, focusing on the experience of individual landowners can downplay the power relations that shape who can be a land manager and assumes that all farmers have the power to choose sustainable forms of agriculture (Calo, 2020). A major gap is the need to consider the political ecological context of transitions to agroforestry. This includes how politics and power of the global food system affect agroforestry transitions (Ollinaho and Kröger, 2021). A more power centered analysis of agroforestry transitions can, for instance, illuminate how gender disparities in knowledge transfer affect participation (Duffy et al., 2020), how the power of a state agency can constrain local participation (Islam et al., 2015), how agroforestry interventions can alter labor distribution and displace existing social and economic gains (Schroeder, 1999), or how sustainable intensification narratives can constrain equitable outcomes for smallholders (Nasser et al., 2020). Political ecology approaches that critically examine tenure rights and gender and class power can also reveal how, for example, agroforestry transitions contribute to dispossession and

private accumulation, and thus become exclusive (Schroeder and Suryanata, 1996). Additionally, access to political decision-making processes and ideology in agricultural research and development limit agroecological transitions (Isgren et al., 2020), but have received less attention in research on agroforestry transitions. Considering the institutional and social factors that influence agroforestry transitions remains a major gap (Rocheleau, 1998; Molina, 2013; Meek, 2016).

We use a case study of agroforestry in Hawai'i to examine the politics and power dynamics of agroforestry transitions. Indigenous agroforestry was widespread in Hawai'i for nearly a millennia prior to European colonization (Kurashima et al., 2019) and was characterized by a diversity of perennial understory and tree crops that were used for food, medicine, ceremony, tools, clothing, and building (Kurashima and Kirch, 2011; Lincoln, 2020). Yet, following European contact in 1778, the Kānaka 'Ōiwi (Native Hawaiian) population declined an estimated 84% by 1840 (Swanson, 2016). In 1848, a process called the Māhele (division of land), led to land privatization and accumulation by non-Hawaiians (Kame'eleihiwa, 1992). Sugar and pineapple plantations came to dominate the agricultural and political landscape, and, in 1893, a group of American-backed white businessmen overthrew the Hawaiian monarchy. As a result, today Hawai'i for the most part lacks a tradition of smallholder farms growing diversified crops (Suryanata et al., 2021). This legacy combined with the high costs of land, labor, water, and other structural infrastructure significantly impedes the regeneration of diversified agriculture in Hawai'i (Suryanata, 2002; Heaivilin and Miles, 2018). Now, less than 8% of the state's agricultural zoned lands are used for growing crops, most products are exported (Melrose et al., 2015; USDA-NASS, 2019), and nearly 88% of food is imported (Loke and Leung, 2013). In response, the state department of forestry, state resilience office, and other public and private institutions have included agroforestry in their resilience strategies, and public discourse in support of agroforestry as a multi-benefit solution is building (Caulfield, 2019).

We interviewed agroforestry practitioners in Hawai'i to understand how agroforestry transitions are occurring today. We asked: (1) why do people transition to agroforestry, (2) what are their obstacles, and (3) who is able to participate? We find that people's motivations for transitioning to agroforestry are largely non-economic and values-based—most practitioners chose agroforestry intentionally as a form of ecological restoration and/or cultural reclamation, rather than as a means to production or economic goals. The contested values between practitioners and dominant institutions manifests as a suite of obstacles that lead agroforestry practitioners to fall through the cracks, and subsequently to have insufficient access to appropriate information. We highlight how resources external to practitioners and sites—both financial and social capital—are what allow practitioners to circumvent the many obstacles they face, which constrains equitable participation. Finally, we discuss potential solutions to creating more just pathways to agroforestry in this context and transferable lessons for similar transitions.

METHODS

Sampling Frame

We conducted non-probability sampling of agroforestry sites in Hawai'i. We define agroforestry as a continuum of systems that integrate woody plants and crops or livestock (or other tended and harvested plant or animal species) (Hastings et al., 2020). We included people practicing agroforestry for subsistence and/or non-economic benefits as well as practitioners who sell products, including those designated as farms by the USDA, defined as any size plot of land that produces $1,000 or more of agricultural products per year. According to the 2017 Census of Agriculture, 347 of the total 7,228 farms in the state indicated that they practice at least one of the following types of agroforestry: alley cropping, silvopasture, forest farming, riparian forest buffers, or windbreaks (USDA-NASS, 2019). In the 2012 Census of Agriculture, the question about agroforestry only included two practices—alley cropping and silvopasture—and 38 farms in Hawai'i reported having these practices (USDA-NASS, 2019). We aimed to sample from practitioners who answered yes to the 2017 Census question; who completed the Census and practice some form of agroforestry but answered no to the Census question (e.g., because they did not know or identify with the practice names used in the Census questionnaire); and those excluded from the Census (e.g., because they did not sell enough product to qualify as a farm).

We developed an initial list of 15 businesses, non-profit organizations, and subsistence farmers practicing some form of agroforestry from informal interviews conducted between August 2016 and June 2020 with farmers, farmer support personnel, and land managers. We then used purposive sampling to request interviews, stratifying by agroforestry practice type and island. We used snowball sampling with initial interviewees to increase the diversity of the participant pool (Bernard, 2018). We also emailed eight extension agents to help identify additional practitioners, which produced a total of three additional interviewees. We continued interviewing participants until we reached saturation, or the point where no new themes arose from additional interviews (Bernard, 2018), in this case 31 interviews.

Interviews and Focus Group

We used a qualitative, inductive approach to develop a relational understanding of both individual and contextual factors influencing agroforestry transitions in Hawai'i. We used information from informal interviews conducted between August 2016 and June 2020 with farmers, farmer support personnel, and land managers in Hawai'i and a review of the academic literature on agroforestry transitions to develop a semi-structured interview guide. The interview guide included questions about how the practitioner came to steward land in that place using agroforestry practices, what was involved in the transition to agroforestry, what their agroforestry practice is like today, why they integrate trees, what challenges they face, and what would help them and others overcome the challenges to transitioning to agroforestry.

We interviewed a total of 38 agroforestry practitioners representing 31 sites across five of the main islands of Hawai'i; seven interviews included multiple stewards of the same site. We held interviews via Zoom (due to COVID-19 safety restrictions) from August 2020 to May 2021. Interviews followed the open-ended guide described above, with similar questions and probes for each interview. At the end of each interview, we collected demographic information: highest level of formal education, age, gender, and race/ethnicity. Interviews lasted between 50 minutes and two hours. We recorded the interviews on a local computer using Zoom.

We used the software otter.ai to transcribe the interviews, and then we checked and edited each transcript for accuracy. Next, we imported text transcriptions into the NVivo data management and analysis software package. We used constructivist grounded theory analysis to code themes on the motivators for, and obstacles to, agroforestry practices as well as the ways in which practitioners are circumventing these obstacles (Charmaz, 2014). A single coder (Z.H.) performed the initial coding. Subsequently, the other study authors evaluated the codes, discussed disagreements with the initial coder, and quotes were re-coded as necessary. We recorded all coding procedures to create transparency. To check the coding scheme, we used member checking and looking for negative evidence (Bernard, 2018). We also extracted quantitative data from the interviews to create tables of site and practitioner characteristics.

Finally, we held a focus group meeting via Zoom with a total of seven practitioners from four sites who participated in the first round of interviews. The goal of this meeting was to share preliminary findings with interview participants, facilitate reflection, and discuss possible solutions and pathways forward. This step facilitated knowledge co-creation and social learning among practitioners (Eelderink et al., 2020).



FIGURE 1 | Practitioners in Hawai'i integrate trees and shrubs with other plants and animals in agroforestry systems ranging from cacao and windbreak systems, to multi-story forests including a range of native and non-native plants for multiple products, to silvopasture with native trees and cattle. Pictured here is an example of a multi-story agroforestry plot in the establishment phase at Kāko'o 'Ōiwi, He'eia, O'ahu. Key visible plants include a native, culturally important tree, wiliwili (*Erythrina sandwicensis*); Polynesian introductions ti (*Cordyline fruticosa*) and mai'a iholena lele (*Musa* sp.; banana); and an introduced medicinal plant, comfrey (*Symphytum officinale*).

RESULTS

Agroforestry Practices and Practitioners Are Diverse

The 38 practitioners we interviewed ranged in age, gender, and ethnicity. Practitioners ranged from 25 to 75 years old, with a median age of 46. Most (68%) identified as male. Practitioners who self-identified as Kānaka 'Ōiwi (Native Hawaiian) made up 50% percent of the interviewees. Individuals identifying as white alone were the next most represented group (37%), followed by Asian and Pacific Islander (not Kānaka 'Ōiwi) (13%).

The practitioners represented 31 sites—families, businesses, or non-profit organizations with land access. The median land area each site tends using agroforestry is 10 hectares, excluding one site that tends over 405 hectares. Over half of the sites are on Hawai'i Island. Sixty-one percent of sites own or co-own the land they steward. Of the 39% of sites that rent land, most of them (67%) lease from the state's largest private land owner, Kamehameha Schools. The majority of practitioners gained access to former plantation agriculture or ranching lands that were fallow and transitioned from non-native grasses, shrubs, and/or trees to agroforestry. Only four practitioners had been practicing a less diverse type of agriculture (e.g., monoculture vegetable or tree crop) on the same parcel before transitioning to agroforestry. Two sites transitioned actively managed pasture land to agroforestry by planting trees (i.e., silvopasture). Three practitioners inherited family legacy lands that already had agroforestry.

The agroforestry practices at each site are diverse. Half of all sites integrate trees and other plants at the plot level, meaning multiple plants are grown together in one field (e.g., multi-story cropping, alley cropping, or food forest) (**Figure 1**). Other sites integrate woody and non-woody plants at the field or margin levels (e.g., windbreaks). All sites intentionally grow at least 10 species of plants. The most common plants grown for harvest include canoe plants (plants first brought to Hawai'i by Polynesian navigators) such as 'ulu (*Artocarpus altilis*), mai'a (*Musa* sp.), 'awa (*Piper methysticum*), and kalo (*Colocasia esculenta*); introduced "cash" crops including coffee (*Coffea* sp.) and cacao (*Theobroma cacao*); and native forest plants such as māmaki (*Pipturus albidus*), koa (*Acacia koa*), and 'iliahi (*Santalum* sp.). Nine sites integrate animals into their system, including cattle, sheep, goats, chicken, ducks, and fish.

Motivations Relate to Practitioners' Values and the Direct Benefits of Agroforestry

Each person we talked with gave a combination of reasons for transitioning to agroforestry that related to their values and the direct or practical benefits of agroforestry (**Table 1**). The first reasons most people gave for transitioning to agroforestry related to two values-based dimensions: (1) to restore relationships with 'āina (land), culture, and ancestors, and (2) to strengthen local

TABLE 1 | Factors motivating people to transition to agroforestry in Hawai'i. Some motivators represent values and visions for change that could be achieved through multiple forms of agroecology or sustainable agriculture, not just agroforestry. Practitioners also gave reasons that related to agroforestry specifically (denoted with asterisk).

Dimension	Theme	Illustrative quote
Values		
Restore relationships to 'āina (land), ancestors, culture	Reverse damage of plantation agriculture and ranching Kuleana (responsibility) to 'āina The template was created by our ancestors* Bring the forest back* Reclaim identity* Have materials for cultural practices* It's for future generations*	*"So, what motivated us to take on a farming practice like this, part of that for me always goes back to the 'olelo no'eau [Hawaiian proverb], I ka wā ma mua, I ka wā ma hope, the answers to the future lie in the past…And so I believe that in order for us to look at planning for our future, we need to, at the very least, understand our history and learn from it. Or in what I believe now is more to go back to most of it…"*
Strengthen local communities	Feed our community Community's health and wellness Grow young people Create more jobs, change stigma Create a model and inspire others	*"We're trying to elevate our community to the status of being able to be autonomous, to be able to be sovereign. And so we have to start with growing food."*
Direct benefits		
Direct or practical benefits of agroforestry	Personal health and wellness* Need multiple types of products* Build soil fertility and health* Strength of planting an 'ohana (family)* Protect the crop* Aesthetic value* Less maintenance* Hold back invasive plants and weeds* Make the most of steep areas and areas between trees* It's better to work in the shade* Diversify income* Prevent erosion*	*"I think that's what really drove [our] method is really having a really biodiverse system, having different personalities helping each other out. So, if you put a tree out by itself to take on all the different elemental things like the wind or rain, the environment, the ungulates, the chances of that one tree out there alone surviving is not as high as the one that is planted together with family. So we'll look at the 'ohana [family] environment, you get your mo'opuna [grandchild], you get the 'opio [child], you get the makua [parent], the kupuna [grandparent]; your whole family protecting the most vulnerable one…"*

Themes are listed in order of most referenced.
**Indicates that practitioners discussed this motivator as a reason for tree-based practices specifically.*

communities. The third dimension of themes was the direct or practical benefits of agroforestry. Although not all of the values-based themes are linked exclusively to agroforestry, each practitioner expressed a suite of themes, including agroforestry-specific reasons. The combination of more general themes (e.g., feeding community) and agroforestry-specific themes (e.g., bring the forest back), are what led a practitioner to agroforestry specifically. In the sections that follow, we discuss the themes within each dimension of motivators in detail (**Table 1**).

Values: Restore Relationships

The first dimension of values-based motivators for agroforestry was to restore relationships to 'āina (land), culture, and ancestors (**Table 1**). The most referenced theme in this dimension was to reverse the damage caused by plantation agriculture and ranching. Practitioners lamented how *"the cattle system has decimated this valley," "how abused the soils were,"* that *"what humans have been doing for a long time is taking, taking, taking,"* and that *"we're in the middle of the sixth great extinction."* The damage they saw was not just environmental. As one practitioner recounted,

> *"…what I saw was a lot of social injustice, and maybe even in a racial context. And I saw that pretty much against Hawaiians, and that was very disturbing to me. And so that as my ends, have led me to agroforestry as a means."*

Many practitioners saw the links between environmental and social damage as systemic, resulting from colonialism and capitalism. Therefore, their practices were a way to not only *"regenerate 'āina"* and *"solve a whole bunch of [social] problems that were entrenched in [our community],"* but also to assert their values. For example, one practitioner articulated how the drive to accumulate financial wealth that is dominant in *"American Western culture"* is a major cause of damage and conflicts with their values. Their goal is *"to take it back the other way."*

Thus, another theme practitioners expressed was being motivated by the need to take back *"kuleana [responsibility] to*

'āina," restoring reciprocity with land and the environment rather than valuing money and extraction. One practitioner identified this as their *"conservation ethic."* They described how they use regenerative agriculture because it allows them to conserve open space, native plants, and water outside of protected areas. Another practitioner identified that they were initially motivated to farm this way by the *"back to the land movement."* One practitioner, whose land had mixed native-non-native forest on it when he and his wife bought it, recounted how they came to practice *"conservation agriculture,"*

> *"Well see, originally we were gonna plant corn. We were gonna be like regular dirt farmers [laughter] [. . .] But then we realized that we didn't want to destroy [the forest]. It was so peaceful and beautiful. We didn't want to destroy it. [. . .] We are proud of what we do, and we do it because it's a way of giving back and preserving the environment. As a Hawaiian, I believe that I'm doing the right thing. Because that's what I was taught by my elderly people. You don't get rich off what we're doing. But it's rewarding."*

Rather than allowing profit to dictate their practices, this story illustrates how many practitioners prioritize their kuleana (responsibility) to ʻāina first. This practitioner, like many others, chose to restore a reciprocal relationship with ʻāina and culture, rather than remain disconnected from the negative environmental effects of conventional agriculture. Similarly, another practitioner articulated,

> *"We like to believe there's a balance, there's a way we can be growing the food and taking care of the forest at the same time; we don't need to clear the forest just to grow the food, we keep doing both."*

Relatedly, some values rooted in Indigenous culture and ʻike kupuna (ancestral knowledge) motivated people to practice agroforestry specifically, rather than another form of regenerative agriculture. First, was the theme that *"the template was created by our ancestors."* For example, practitioners described going through historical records to find that *"historically, the space was known to have a very large food forest system, for lack of a better term."* The template for agroforestry already existed pre-colonization. Practitioners articulated how they wanted to use this template because of the immeasurable value of the knowledge held in these systems, pointing out, *"our people have been collecting data for 1000s of years."* Trying to re-establish these systems was therefore an easy decision: *"if it's not broken, don't change it."* Second, a reason for practicing agroforestry following ʻike kupuna was *"to bring back a part of that history"* and to reclaim Kānaka ʻŌiwi identity from colonialism and plantation agriculture. One practitioner described how the sugarcane plantations were *"a really decorated piece of history"* in their childhood. They saw their access to land now as an *"opportunity to change that historical fabric"* and *"reaffirm our identity."* Similary, another practitioner echoed, *"I'm learning, or sometimes I think that I'm re-learning, how to be a mahiʻai [farmer], because, you know, we have these agricultural roots as kānaka."*

Next, many practitioners articulated that they wanted to bring the forest back. This was described again as a response to degradation of ranching and plantation agriculture, and a way to reconnect with ʻāina. One practitioner expressed that when they were able to buy land, *"it was an opportunity to try and change what had happened and go back to a system that was more sustainable; so the whole drive behind this project is to re-establish the forest."* Their business views sustainable harvest of timber and non-timber forest products as a way to make forest restoration economically viable. Speaking about native forest restoration he said, *"That's the goal; and the goal is not having to go out and beg somebody for money to do it."*

Relatedly, another motivation for agroforestry was to have materials for cultural practices. One practitioner grew forest plants in partnership with a hālau hula (Native Hawaiian dance school), so that they could limit the amount they harvest from remnant native forests above their site. Bringing back the plants in this case was not just about the harvest. The practitioner described how increasing access to the plants was also about bringing back culture, *"Kumu [Teacher] always says that some of the holier chants that we do there hasn't been heard in that area for maybe a couple 100 years."* Practitioners were themselves, or had relationships with, carvers, hula practitioners, lei makers, and weavers. The wood, gourds, ferns, flowers, and other plants that practitioners grow reinforces their ability to restore relationships with ʻāina, ancestors, and culture.

Finally, practitioners described practicing agroforestry because *"it's for future generations."* One practitioner described using Indigenous agroforestry to *"make sure that this mountain will be able to gather and retain water for our great, great, great, great grandkids right down the line."* Many of the trees that practitioners grow, like ʻiliahi (sandalwood; *Santalum* sp.), take at least 30 years to mature. Instead of putting pressure on himself to have an abundant agroforest in his lifetime, one practitioner said this work requires a *"generational mindset."*

Values: Strengthen Local Communities

The second dimension of values-based motivators for agroforestry practices that emerged from the interviews was to strengthen and elevate local communities (**Table 1**). The first theme in this dimension was choosing agroforestry to *"feed our community,"* which was articulated by over half of the practitioners we spoke with. Although practitioners could feed their communities through other types of agriculture, many practitioners expressed that they chose agroforestry as a way to produce a diversity of food, over a long time. For example, agroforestry was the specific way one practitioner chose to feed their community because, *"the agroforestry that we do is mostly just trying to think long term, like, how do you feed your community longer than just for one grant cycle?"*

Second, and interrelated with the first, practitioners were motivated by their community's health and wellness. For instance, one practitioner expressed that they practiced agroforestry because, *"healthy land and healthy people, can't really separate those two things."* Another practitioner explained how agroforestry aligns with their goals to support healthy communities:

> *"…the laʻau lapaʻau [medicine] aspect, like seeing that the ʻāina [land], the forest, is our medicine, is our pharmacy. That is a big part of what we do. A lot of us might think agroforestry is just agriculture and forests, but it's also medicine. Right, because a lot of those food crops like mountain apple, for example, is a medicine itself."*

Next, practitioners expressed how they were motivated by youth development and job creation. One practitioner said, *"my motivation is always children"* and another, *"…we see the growing of food as a means to growing young people in our community."* A Kānaka ʻŌiwi practitioner shared, *"working and being conditioned to do only certain jobs for local boys, I wanted to kind of change that stigma."*

Finally, almost a third of practitioners were motivated to inspire others and to create a model of how to practice agroforestry today. For several practitioners this involved inspiring others to grow food at home. For example, one practitioner explained that *"what I'm focused on building here, on my land, is a demonstration center, an educational center for tropical subsistence farming."* Others were more focused on larger models. One practitioner said, *"the mission was to create a model to revitalize agriculture in Hawaiʻi that was economically viable and could be scaled."* Although many of these same practitioners identified that a template for agroforestry was created by their ancestors, they also experienced the challenges to reclaiming this history and knowledge in the current political-economic context and wanted to create a model to make it easier for others.

Direct or Practical Benefits

While it was common for practitioners to open with how their values motivated them, many also went on to share motivations related to the direct benefits of agroforestry. First, almost half of practitioners discussed how they practice agroforestry for their own health and wellness. Practitioners shared testimonials such as, *"I have not had to go to a therapist or a psychologist ever since I started agroforestry."* They also described how mixed forest systems *"nurture us on a spiritual and emotional level," "really ground you,"* are *"so peaceful,"* and *"make us feel super good."* Other practitioners expressed, *"I'm definitely motivated to plant more trees just because I like trees," "we're tree people,"* and *"I just feel safe in a forest."*

Second, almost half of practitioners expressed that they were motivated by the need for multiple types of products. Practitioners talked about how agroforestry, especially traditionally in the Pacific and other parts of the world, is *"out of need,"* for example, for food, medicine, fiber, and fuel. Agroforestry also allows practitioners to *"diversify the food that we're growing"* and incorporate *"succession harvesting."*

Third, nearly half of practitioners chose agroforestry to build soil fertility and health. Many practitioners talked about using trees to produce organic matter to incorporate into the soil, for instance through *"chop and drop."* Some practitioners incorporated animals or nitrogen fixing trees to reduce the need to buy expensive fertilizers. In this way, agroforestry was a means to overcome an obstacle to conventional agriculture.

Next, practitioners described choosing agroforestry because of the strength of planting an ʻohana (family). For example, one practitioner observed about their trees, *"when they're with each other they thrive as opposed to being out in the pasture alone."* Another practitioner acknowledged this as the importance of *"symbiotic relationships."* A few practitioners discussed how they incorporate a diversity of perennial plants, especially natives, to host beneficial insects for pollination and pest control.

Relatedly, practitioners explained that they incorporate trees to protect a crop, particularly through wind protection and shade. Although most practitioners started stewarding land with the intent to transition the site to agroforestry, a few practitioners made the decision later in their stewardship of a site. Two practitioners cited that their values led them to initially grow a single perennial or culturally important crop (i.e., cacao or kalo), yet a few years into stewarding, severe wind damage to the crop led them to incorporate trees as protection. As the cacao farmer explained, *"So the agroforestry component of it, on the farming side, really came totally out of necessity. It wasn't like I set out to build a forest, I had to learn that I needed a forest."*

Finally, practitioners described choosing agroforestry as a means to decreasing labor costs and maximizing productivity, both indirect economic motivations. One theme was that agroforestry requires less maintenance, in large part because tree cover decreases growth rates of weeds. For example, when asked why did you decide to integrate trees and crops, one kava (*Piper methysticum*) grower explained, *"My kava buyer asks me that question all the time. He's like, 'Oh, they grow faster in the full sun.' Well, they do. But there's a lot more maintenance."* Similarly, another theme echoed by several practitioners was that, *"agroforestry is definitely part of a strategy to hold back invasive plants and weeds in some areas."* A third theme was to make the most of steep areas not suited for annual crops and areas between trees in existing orchards. A practitioner who transitioned an orange orchard to agroforestry described how the previous steward had planted the tree rows too far apart, wasting sunlight, and creating more area to mow. She explained how she decided to transition to agroforestry, *"I'd rather put something there, but it's not quite enough to plant another row of orange trees, so it's good for rotation of bananas, or pineapples, or some of those shorter term crops that never get too big."*

These last three themes show how some practitioners chose agroforestry as a means to circumvent obstacles like limited labor or unfavorable site conditions and achieve economic productivity rather than choosing agroforestry as a purposeful destination itself. Only one practitioner cited that they transitioned to agroforestry to diversify their income, a direct economic benefit.

Agroforestry Practitioners Face Common and Unique Constraints

Some of the obstacles interviewees expressed are not unique to agroforestry; they are shared by other agricultural producers in Hawaiʻi, especially small farmers. Top themes of structural obstacles included access to land, labor, capital, and infrastructure. For example, the high cost of living, regulations that prevent living on agricultural land, agricultural theft, and

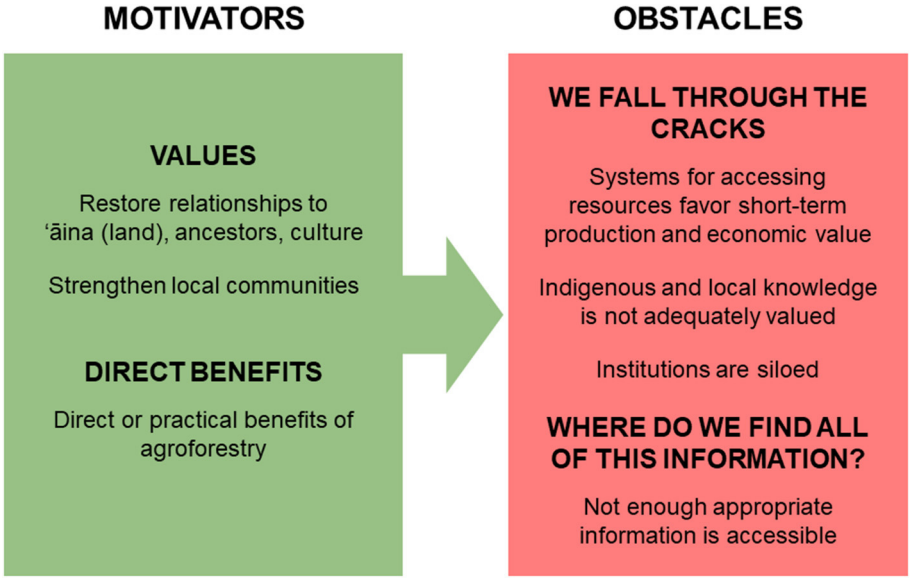


FIGURE 2 | Practitioners in Hawai'i were motivated to practice agroforestry largely by their values, but also the direct or practical benefits of agroforestry (green box). These motivations, and the resulting diverse agroforestry systems, directly conflict with the dominant values, institutions, and systems of resource access, which produces a suite of agroforestry-specific obstacles (red box). Institutions include local, state, and federal agencies and organizations that support and regulate practitioners as well as social norms and worldviews. For themes and illustrative quotes, see **Table 1** (motivators) and **Table 2** (agroforestry-specific obstacles).

the pressure to prove value relative to real estate development were important challenges throughout agroforestry transitions. Practitioners expressed that the lack of policymaker support for agriculture and forestry challenged their ability to establish and persist. Failure of the government to enforce regulations, for instance around environmental protections for land clearing which can cause erosion and poor water quality on practitioners downstream, was another challenge.

Practitioners also identified common ecological and practical management obstacles. The top referenced theme was nonnative or invasive plants and weeds. As one practitioner lamented, *"the more we clear, the more we have to maintain."* Several practitioners who had more established agroforestry practices felt burdened by the risk of new pests and diseases being introduced and viewed this as a failure of government regulation. Disturbance from pigs and deer was another obstacle at all stages of transitions, requiring many practitioners to invest in costly fencing. Lack of water rights and poor soil quality, legacies of the plantation era, especially challenged practitioners in the establishment phase. Additionally, climate change, drought, wind, floods, and fire were key obstacles.

However, our interviews revealed that agroforestry practitioners in Hawai'i face an additional set of unique constraints. As described in the previous section, most interviewees chose agroforestry intentionally, primarily for values-based reasons rather than as a means to achieving production or economic goals. These values conflict with the dominant values, institutions, and systems of resource access in Hawai'i today causing practitioners to *"fall through the cracks"* and subsequently ask, *"where do we find all of this information?"* (**Figure 2**). In the following sections, we describe the four dimensions of themes of agroforestry-specific obstacles that emerged from the interviews (**Table 2**).

Systems for Accessing Land, Capital, and Markets Favor Short-Term Production and Economic Value

The first dimension of themes was that systems for accessing land, capital, and markets favor short-term production and economic value. Many practitioners echoed the theme that *"it's not easy to find those kinds of leases."* Agroforestry practitioners struggle to secure long-term tenure, due to high land prices and landowners only offering short-term leases.

Even with land access, agroforestry practitioners still face other economic obstacles, which fell into three themes. The first was having the start-up capital. The second was keeping up with maintenance and expenses while waiting for perennial plants to mature. For example, one practitioner described how windbreaks need to be established at least a year before planting cacao, and then the cacao takes 3–4 years to mature, *"So, it's a good four-to-five- year window of nothing but negative cash flow."* Third, practitioners felt constrained by the pressure to turn a profit in the short term. While this pressure can motivate agroforestry transitions, such as when orchardists plant annual crops between their trees for short-term income, the practitioners we interviewed primarily chose agroforestry as an intentional system, not just for economic benefits, and thus saw this pressure primarily as a barrier. Because of pressure to turn a profit in the short term, the cacao farmer first planted cacao in monoculture, which left the the crop vulnerable to wind: *"ironically, everything that led us to our first big mistake, that led us to where we*

TABLE 2 | Obstacles specific to agroforestry that practitioners in Hawai'i face.

Dimension	Theme	Illustrative quote
We fall through the cracks		
Systems for accessing land, capital, and markets favor short-term production and economic value	It's not easy to find those kinds of leases Having the start-up capital Keeping up with maintenance and expenses while waiting for long-term benefits Pressure to turn a profit in the short term Lack of supply chain infrastructure It's hard to do education and production Being tied to fiscal year deliverables	*"There's not many people that want to take up projects like this, because it doesn't make the economics…So it's almost like you got to work with whoever can provide you with the capital structure to really even get going. If I could do this in my own backyard, that would be ideal."*
Indigenous and local knowledge is not adequately valued	Local practitioner knowledge is not valued Agroforestry is viewed as a technical practice Money is what talks	*"They basically have these cookbook recipes on how to responsibly manage land and deal with erosion and all of that. And some of its good, but I think it just takes the creativity and some of the experience and maybe some of the wisdom out of managing something, some of the relationship, all of that stuff that's hard to touch, and put your finger on but those are maybe more important than just like, 'everything must be 14 feet apart and here's your list of appropriate species'."*
Institutions are siloed	Polarization between conservation and agriculture The government doesn't know how to categorize us	*"When you're trying to get ag exemptions, and it doesn't look clear to them like a pasture, you know, it's not clear to them that this is an orchard because agroforestry doesn't look like that. Agroforestry in the true form that we practice looks like a mess, like rows that are in a mess with mowed rows in between kind of. So, they just don't know what's agroforestry, they don't know what's in production, what we're using for the house. So because it's difficult for them to categorize us, they just don't."*
Where do we find all of this information?		
Not enough appropriate information is accessible	So much knowledge is lost Not too much people doing this Resources based on continent examples No place for people with knowledge to share What to plant It's so place specific Diversity-efficiency trade-offs How do we scale up	*"When they planted the coffee, they got rid of a lot of the Indigenous plants they were growing. And they forgot about them….during my father-in-law's generation, I mean, he grew some of the biggest taro I've ever seen, and it's dryland, so they know where to plant. And because you don't have water, you have to plant at a certain time. They had the knowledge. Right now we're just kind of experimenting."*

finally are now, had to do with trying to run fast enough to make money."

Two themes related to how practitioners try to circumvent economic obstacles. The first theme was *"it's hard to do education and production."* Some practitioners use agricultural production or education grants to augment cash flow. Yet, practitioners expressed that time spent on education programs takes away from time spent in the field, growing plants for harvest. Many practitioners felt stuck relying on grants to cash flow their sites instead of becoming financially self-sustaining through production. Second, *"being tied to fiscal year deliverables"* limits practitioners' ability to manage *"when nature is ready for me to do it, as opposed to when the fiscal year requires me to do it."* Grants can be good for start-up, but without proper planning, it can be difficult to keep up with maintenance and cash flow until the perennials start to produce. One practitioner expressed, *"one of the things that's really hard is whenever you get grants and things from nonprofits, it lasts a few years, and then you have to re-compete; to grow a forest, you need 100 years."*

Indigenous and Local Knowledge Is Not Adequately Valued

Second, many agroforestry practitioners fall through the cracks because of a lack of value for Indigenous and local knowledge. The most referenced theme was that local practitioner knowledge is not valued. For example, practitioners described how agroforestry definitions and recommendations center knowledge and experience from the continental U.S. One practitioner expressed this frustration about a funder, *"their thing was they wanted us to be following American forestry practices, so, for example, planting koa on a 10 foot by 10 foot grid, and for us, and on our terrain, that's just not really realistic or practical and didn't really make sense to us."*

Another example of how practitioners experienced the lack of value for local knowledge was through cultural appropriation. Agroforestry does not have one parallel Indigenous agroecosystem. Instead, it is a Western construct that is an umbrella term for a variety of place-based practices that integrate trees and other plants in various arrangements and intensities. For example, in Hawai'i forms of agroforestry

may be called pākukui (Lincoln, 2020), kaluʻulu (Menzies, 1920; Kelly, 1983; Quintus et al., 2019), or ka malu ʻulu o lele. One practitioner explained how using the term agroforestry can therefore exclude the participation of Indigenous people who are familiar with integrated forest-agriculture practices, but not the term agroforestry. Another expressed that labels like permaculture and agroforestry are *"just whitewashing Hawaiian culture."* Many of the Kānaka ʻŌiwi practitioners we spoke with felt uncomfortable with the use of the term. One explained the source of their discomfort,

> *"And most of that has to do with the fact of our historical references show of this older style and technique and this exact thing [. . .] In the end, I still want to be able to find a term that can credit our works that we do to the people that are of the place, the other Indigenous organisms that had that same relationship and style and study that we're all today putting scientific terminology labels on."*

Another related theme in this dimension was that agroforestry is generally framed as a technical practice. One permaculturalist commented, *"Agroforestry is an excellent system, but it doesn't include those ethics."* A Kānaka ʻŌiwi practitioner explained that their stewardship system contains significant cultural knowledge, so *"a lot of the difference between agroforestry and [our system] is just that, 'culture'; And what we stress is no more agriculture without culture."*

Then, the theme *"money is what talks"* further illustrated the conflict in values constraining practitioners. A Kānaka ʻŌiwi practitioner said it had been challenging *"in a world that's really driven by economics in numbers"* to make initiatives like theirs fundable, because they *"want to look at the social good of what they're doing."* A major challenge is the mis-match in metrics of success: *"How do you measure our kupuna [elders] planting a tree with their moʻo [lineage], that feeling, that reciprocal exchange between environment, their relationship to the environment and us, kānaka [Hawaiians]?"* The extra work that local and Indigenous practitioners do to translate between value systems is a major constraint to equitable transitions. Another Kānaka ʻŌiwi practitioner described how in a new field that they had recently opened up, they had to choose between planting ipu (gourd; *Lageneria siceraria*), which has important cultural value for hula (dance) and food, or lilikoi (passion fruit; *Passiflora edulis*), which a company that makes value-added products for tourists already committed to buying. Although they are motivated to practice agroforestry as an act of resistence to capitalism, practitioners still struggle to acheive financial sustainability within the system.

Institutions Are Siloed

Finally, agroforestry practitioners fall through the cracks because their practices do not fit within the silos of regulatory, funding, and other support organizations, and of dominant worldviews that separate agriculture and forests. The first theme in this dimension was the polarization between conservation and agriculture within government, private organizations, and social norms. One silvopasturist described this as an issue of *"philosophy,"* explaining, *"I think one of the greatest challenges for both the livestock industry and for the conservation community is trying to find the middle ground that exists between the two; you know, we're polarized."*

The second theme was that *"the government doesn't know how to categorize us."* Because agroforestry crosses sectoral silos, government agencies and other organizations that remain siloed often struggle with how to categorize agroforestry practices, limiting practitioners' access to support. For example, one practitioner described how they struggled to qualify for agricultural exemptions because the property tax office could not tell what part of the land was "in production" because the agroforestry practice did not look like an orchard. Another practitioner explained how they fail to qualify for federal farm benefits because they produce a native forest plant, which is not on the approved list of crops. They added another reason they struggle is because their approach is to restore the forest ecosystem around the plant: *"that's one reason why we fall through the cracks, because we're not looking at it as we're producing one particular crop."* Additionally, policymakers' siloed conceptualizations of agriculture limit practitioners' access:

> *"When you're talking to policymakers, and they have no idea what you're talking about, as far as agroforestry, it's very difficult to try and get them to attach to the idea that we need leases extended. You know, for them, it's just like, 'Well, why don't you just go do farming the way everybody else does farming?'."*

Not Enough Appropriate Information Is Accessible

The dimensions of agroforestry-specific structural obstacles produce a secondary dimension of challenges: not enough appropriate information is accessible (**Table 2**). The most referenced theme was *"so much knowledge is lost."* Colonization, land dispossession, plantation agriculture, and ranching severely marginalized Indigenous agroforests and their stewards in Hawaiʻi. Many practitioners motivated to restore these systems explained how the lack of Indigenous and local knowledge was a major barrier to their ability to transition to agroforestry. While many practitioners are reclaiming this knowledge, practitioners expressed two additional themes of obstacles: *"there's not too much people doing this"* and *"there's no place for the people with knowledge to share."* Further, practitioners expressed difficulty knowing what to plant and that agroforestry is *"so place specific."* Another theme was challenges related to how to balance diversity-efficiency trade-offs. For example, one practitioner acknowledged that *"that's why there's monocrop; it makes everything easier."* Thus, practitioners are continuously experimenting to figure out, *"how can we create an agroforestry system where we can still keep some of that principles, easy harvest and stuff, in place and still have a biodiverse system."* Finally, a theme was *"how do we scale up?."* Many people have retained home garden practices, but figuring out how to practice on the scale of 5, 10, or 100 acres raises many questions.

Access to External Resources Shapes Who Gets to Practice Agroforestry

Practitioners rely on resources external to their site, especially financial and social capital that are unequally distributed, and a strong commitment to their values in order to participate in

TABLE 3 | Factors influencing practitioners ablity to participate in transitions to agroforestry in Hawai'i related to each dimension of agroforestry-specific obstacles.

Dimension	Theme	Illustrative quote
We fall through the cracks		
Systems for accessing land, capital, and markets favor short-term production and economic value	Can write grants Can self-fund Have people who kākoʻo (support) Have partnerships Have access to equipment Can create new markets Have cheap or volunteer labor Someone else takes on the marketing Bought land at the right time Inherited land Take on the risk of uncertain land tenure	*"You know, we're lucky. I think one of the benefits of working for a private enterprise like a ranch is that we can self-fund, and that's really important. We have more control over the project and project timeline."* *"That's what helps to overcome that challenge is partnerships with our community members with other resources."*
Indigenous and local knowledge is not adequately valued	Can act as translator between community and institutions Have the mindset 'we don't just walk away' Aloha 'āina (love of the land) discourse	*"The sugar companies inherited some of the most fertile, abundant lands in Hawai'i, and they completely ruined it. But we don't accept that. We can't accept that in our generation to just say, they're ruined, and they're done. [….] And if we accept that, then it's done, we're done. And so, we said, no, we'll figure it out, we have to figure it out, otherwise, who is going to do it?"*
Institutions are siloed	Can self-fund Can act as self-advocate, translator, and educator	*"So over the last 20 years, it's almost like 20 years and a month, we've been working with Farm Service to establish ourselves as a legitimate farm producing a product."*
Where do we find all of this information?		
Not enough appropriate information is accessible	Experienced traditional agroforestry first hand Have a mentor Have access to 'ike kupuna (ancestral knowledge) Have a practitioner network Create your own opportunities Existing books and information resonate Ma ka hana ka 'ike (learn through doing)	*"I have to say that that kind of diverse farm is not possible without having the diverse background that I had, right? Most people would not be able to do that, because they don't have the resources at hand with people around the world that, you know, we traded seeds, we traded information, we traded knowledge. […] These are resources that were there, not for the taking, but were available to certain people."*

agroforestry transitions (**Table 3**). Reliance on external resources, especially financial capital, translates to new farmers on the whole in Hawai'i being *"older, wealthier, and less diverse than the general population"* (Suryanata et al., 2021). Yet, we interviewed a higher Kānaka 'Ōiwi population by percentage than the general population. This provides an opportunity to understand the resources, networks, and institutions that allow these practitioners and others to participate in agroforestry transitions. Here, we describe these factors as they relate to each dimension of agroforestry-specific obstacles.

Systems for Accessing Land, Capital, and Markets Favor Short-Term Production and Economic Value

Four themes arose as factors broadly influencing access to land, capital, and markets. First, nearly a third of practitioners cited their ability to write grants as an advantage. Eighty percent of practitioners we interviewed had attended at least some college, and almost half of those practitioners had graduate degrees. The skills gained through academic education helped people access financial resources: *"we were lucky because of our professional background, that we can write grants […] that's a disadvantage that other farmers have."* Yet, access to academic education is unequally distributed. Further, grants are often tied to educational programming deliverables, which align with values-based reasons for choosing agroforestry, yet reproduce obstacles such as taking time away from production and being tied to fiscal year deliverables. This theme also included other forms of financial assistance like incentives and cost-share programs. Yet, again, accessing these funds required extra time, knowledge, and persistence to learn the rules and figure out how to leverage the funds to support their vision of agroforestry. Although grant funds have allowed many people to begin to transition to agroforestry, there was a sense that the burden of administration was unsustainable, and the amount of time left to actually tend their agroforestry systems was insufficient.

Second, the ability to self-fund influenced who could participate. This looked different in each case. Some practitioners held a full time off-farm job, had a spouse with a full time off-farm job, used retirement funds or other personal savings, or used a cash inheritance. Next, many people spoke to the value of two interrelated themes: having people who kākoʻo (support) and having partnerships. People who kākoʻo share their time, skills, equipment, and other resources in support of the practitioner transitioning to agroforestry. Similarly, partnerships and collaborations between sites, organizations, and/or institutions provided access to resources. For example, six

practitioners either engaged other partners to help purchase land or partnered with wealthier individuals who already owned land, often through employment. Although in these cases practitioners have long-term tenure, this comes with a trade-off of decision-making power. As one practitioner said of other Kānaka ʻŌiwi in their position, *"A bunch of us got people watchin' over our shoulders."*

Three themes emerged around land access specifically. First, was that practitioners *"bought the land at the right time,"* often referring to when land was less expensive after the sugar plantations closed. This was the case for some of the eight practitioners who owned land as a single ʻohana (family) unit and said they would not have had the means to self-fund today. Another theme was inheriting land as a group of descendants. In these four cases, shared decision-making challenges and pressure to sell by some co-owners challenged secure land tenure. A third theme specific to land access was taking on the risk of uncertain tenure. Nearly one third of sites leased the land that they steward, and of those, only a few had leases longer than a few years, including three commercial cacao enterprises with 30-year leases. Short term leases can carry a significant burden of risk. For example, one practitioner described how they recently lost access to the land they had been transitioning to agroforestry: *"we're just now getting to the point where this piece of land is giving us the most special fruits that we've been waiting years on, and now we have to leave that land."*

Finally, two themes related to market access. First, practitioners expressed that their ability to create new markets has helped them persist. For example, one grower explained how they created markets for dye plants and lei flowers by building relationships with cultural practitioners. The second theme was having someone else take on the marketing. For example, a māmaki grower explained that *"those kinds of regulations is on them [the buyer], the value added processing part, they're taking it on"* and as a result, practitioners can just grow, harvest, and sell the wet māmaki. She added, *"it's such a joy."* Having an intermediate buyer who handles distribution and marketing to consumers is key and well established for ʻulu (breadfruit; *Artocarpus altilis*), māmaki (*Pipturus albidus*), and ʻawa (kava; *Piper methysticum*) on Hawaiʻi Island. But this is still a major obstacle for most other crops.

Indigenous and Local Knowledge Is Not Adequately Valued

The ways practitioners deal with the lack of value for Indigenous and local knowledge fell into three themes. First, practitioners expressed the theme that they persist by being able to act as a translator between community and institutions, such as policymakers, funders, and government agencies. The extra unpaid work is disproportionately required of Indigenous practitioners and takes them away from production. This means Indigenous practitioners get behind non-Indigenous practitioners in agricultural skill development and production. One Kānaka ʻŌiwi practitioner expressed that, "*We're lucky because, brah, Hawaiians is very resilient. And we can adapt, and we figured out how to communicate [. . .], but it's so exhausting. . . "*

The second theme was that practitioners have the mindset *"we don't just walk away."* Despite their success in transitioning to agroforestry hinging on their ability to dedicate extra unpaid time, practitioners expressed their feeling of responsibility to persist. For Kānaka ʻŌiwi practitioners especially, this responsibility and persistence is interlinked with their motivations to restore relationships with ʻāina, ancestors, and culture.

Finally, practitioners' strength also comes from aligning their work with aloha ʻāina discourse and the Hawaiian sovereignty movement. Aloha ʻāina is a discourse and set of practices that organizes and engages a diverse Kānaka ʻŌiwi community for political action (Trask, 1987; Baker, 2021). This discourse is enacted through other forms of Indigenous agroecosystems such as loʻi kalo (wetland taro; *Colocasia esculenta*) and loko iʻa (fishponds). However, in the case of loʻi kalo, for example, there is a clear vision of what these systems are and how they are both a form of cultural revitalization and food production. Since agroforestry does not have a single parallel Indigenous land use practice, and so much of the knowledge is lost on how Indigenous agroforestry systems were managed to be a significant form of food production, practitioners still struggle to persist despite the support from aloha ʻāina discourse.

Institutions Are Siloed

Two themes emerged illustrating who is able to transition to agroforestry despite siloed institutions. First, practitioners who can self-fund are able to transition. This included practitioners with the financial resources to persist without the support of tax exemptions, cost-share incentives, grants, and other funding. The second theme was practitioners who can act as a self-advocate, translator, and/or educator. In these cases, practitioners took extra time to translate their motivations and practices into the current production-focused system and educate institutions about how their practices fit. This is similar to how practitioners deal with the lack of value for Indigenous and local knowledge. One practitioner stressed that rather than reaching out for support from government agencies, they are now taking the approach of just *"doing it on our own."* The few strategies that practitioners use to circumvent this dimension of falling through the cracks—the ability to self-fund and extra time—has an exclusionary effect on practitioners who lack the resources to go at it alone.

Not Enough Appropriate Information Is Accessible

Several themes arose surrounding practitioners' ability to circumvent the lack of accessible appropriate information. First, nearly a third of practitioners had experienced traditional agroforestry, mostly through visiting other Pacific Islands like Fiji, Tonga, Samoa, Micronesia, and the Philippines—either on self-funded trips or for an off-site job. Seeing other agroforestry systems provided *"good inspiration"* and a way to gain *"first-hand knowledge,"* yet requires significant time and funds to do so.

Second, almost a third of practitioners identified the theme that having a mentor helped them. Then, for practitioners trying to build from Kānaka ʻŌiwi models of agroforestry, many went through a process of *"triangulating knowledge"* since no

complete information source is available. Practitioners described combining information from different sources including those falling into the themes of experiencing traditional agroforestry first-hand, accessing ʻike kupuna (ancestral knowledge), having a practitioner network, and ma ka hana ka ʻike (learning through doing). Practitioners accessed ʻike kupuna through archival research or, in only a few cases, from family members. Although historical records are a valuable source of information, it can take significant time to find and translate from ʻŌlelo Hawaiʻi (Native Hawaiian language), which practitioners are not compensated for, although some conducted this research as a part of an academic degree program to circumvent this obstacle. Similarly, another theme was that practitioners persisted in part because of their ability to create their own opportunities to learn. Finally, some practitioners also identified that existing permaculture and agroforestry resources helped them, pointing to how this information resonates with some people.

DISCUSSION

We interviewed agroforestry practitioners in Hawaiʻi to understand motivations for, and obstacles to, agroforestry transitions and the factors that influence who is able to participate in these transitions. We found that most transitions occurred when practitioners gained new access to land, due in part to the historical context of land dispossession and accumulation by non-Hawaiians and colonialism. Most practitioners we interviewed chose agroforestry intentionally for non-economic, values-based reasons, with direct or practical benefits as secondary reasons. Practitioners' values and resulting practices, based in relationships and reciprocity, conflict with dominant institutions' values, which prioritize short-term production and economic profit. These contested values and an imbalance in power between practitioners and landowners, government agencies, policymakers, and other institutions cause agroforestry practitioners to fall through the cracks. To participate in agroforestry transitions, practitioners rely on resources external to their site, especially financial and social capital that are inequitably distributed, and a strong commitment to their values. **Figure 3** illustrates these major findings and emphasizes the social and ecological potential of removing constraints to agroforestry regeneration.

Our case study highlights three interrelated key points with important implications for realizing just agroforestry transitions: (1) practitioners transition to agroforestry to restore ecosystems and reclaim sovereignty, not just for the direct benefits; (2) a major constraint to agroforestry transitions is that the term agroforestry is both unifying and exclusionary; (3) structural change is needed for agroforestry transitions to be just.

Practitioners Transition to Agroforestry to Restore Ecosystems and Reclaim Sovereignty

Our results highlight how practitioners' are motivated to transition to agroforestry by their values, not just the direct or practical benefits of agroforestry. In this way, for many of the practitioners we spoke with, both Indigenous and non-Indigenous, transitioning to agroforestry was a political act through which practitioners sought to reverse social and ecological damage. Practitioners chose agroforestry purposefully as a form of ecological or biocultural restoration (Kimmerer, 2011). The values many practitioners held aligned with new agrarianism articulated in other diversified agriculture transitions (Mostafanezhad and Suryanata, 2018). Importantly, our case study also highlights a population of agroforestry practitioners motivated to reclaim Indigenous agroecosystems and food and cultural sovereignty, an aspect of agroforestry transitions that is often overlooked in the adoption literature (although see Dove, 1990). This points to the need for agroforestry research to more explicitly examine how social movements engage with agroforestry transitions, which is more common in agroecology research (Gliessman, 2016). Our findings thus reaffirm the importance of applying political ecology (Robbins et al., 2015; Robbins, 2019) and political agroecology (Molina, 2013) approaches to the study of agroforestry transitions. Given that our initial list of agroforestry practitioners included a significant number of Kānaka ʻŌiwi organizations and practitioners, this might have translated to a higher representation of these groups as study participants than the population of agroforestry practitioners as a whole in Hawaiʻi. Yet, this should not downplay the importance of their voices. Instead, our findings highlight the need to revise how agroforestry is framed in outreach, policy, and programs to be more inclusive of people trying to restore and adapt historical Indigenous agroforestry systems, rather than simply transition to agroforestry as a means to acheive production and economic benefits. Combining power sensitive and feminist approaches could further illuminate how not only capitalism and colonialism, but also heteropatriarchy affect these transitions (Espinal et al., 2021). Future research could explore the extent to which the Pacific Islander diaspora in Hawaiʻi engages in Indigenous agroforestry practices and what obstacles to participation they face. Future studies could also investigate what other actors—land owners, existing farmers and land managers who do not practice agroforestry, and other people interested in transitioning—perceive as drivers and or constraints to agroforestry transitions.

The Term Agroforestry Is Both Unifying and Exclusionary

The unique motivators that emerged from our interviews create obstacles that do not exist for other types of agriculture, and that are not widely recognized. Importantly, one overarching constraint is the contradiction arising from how the term agroforestry is framed and used. Institutions like philanthropic organizations and federal and state government agencies who have the power to set resilience agendas often frame agroforestry as a multi-benefit land use linking agriculture and forest conservation (Ollinaho and Kröger, 2021). Practitioners use this frame to align their initiatives with funder priorities, making "agroforestry" a gateway to accessing resources. However, as

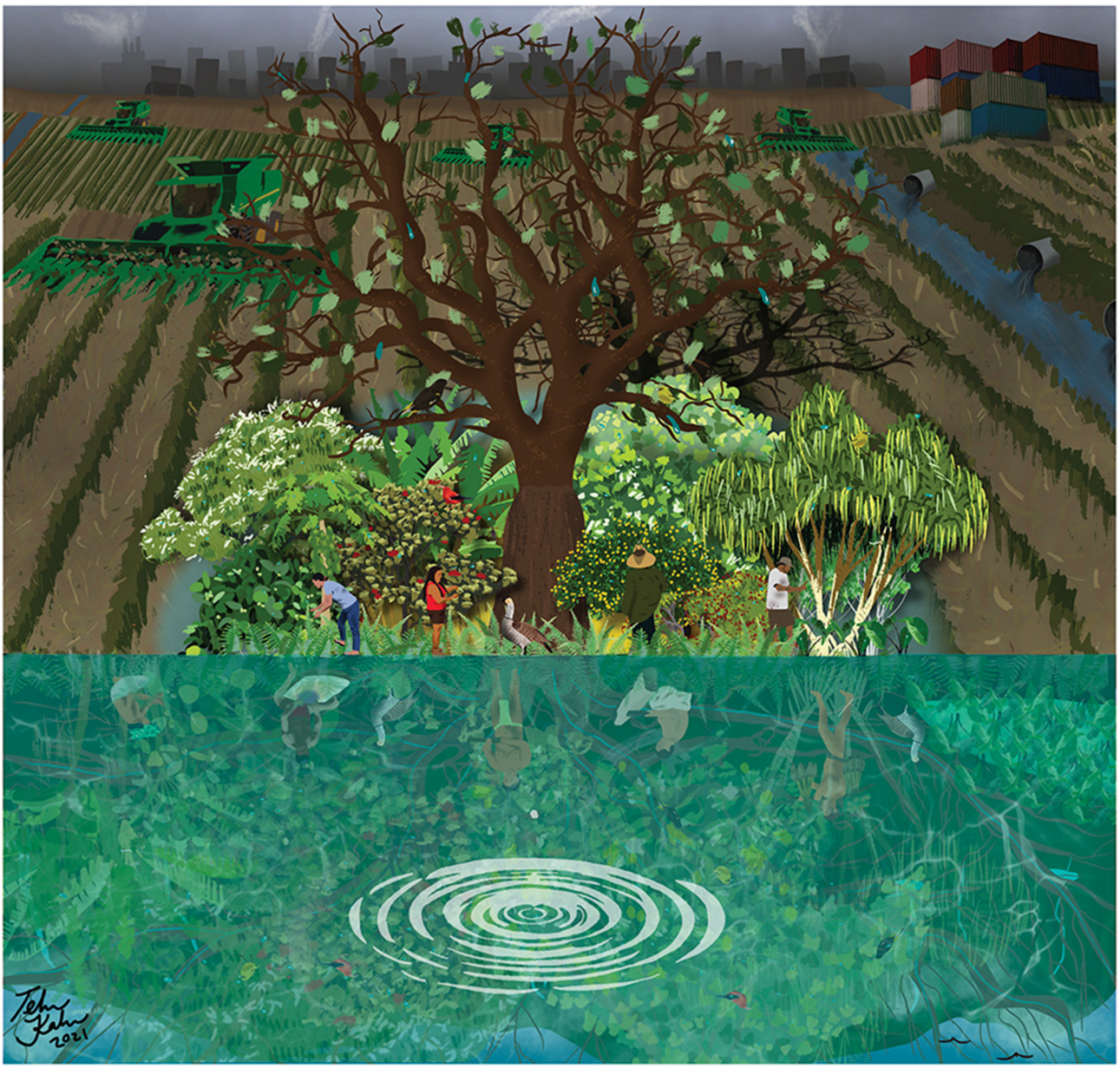


FIGURE 3 | Practitioners' values and resulting agroforestry practices, based in relationships and reciprocity, conflict with dominant institutions and systems of resource access in Hawai'i that value short-term production and economic profit. These contested values and an imbalance in power between practitioners and landowners, government agencies, policymakers, and other institutions cause agroforestry practitioners to fall through the cracks. This illustration depicts how the conflict of values and power is like a tree whose top has been cut off and a new top grafted on, but the two trees (value systems) are incompatible, so the grafted tree struggles to survive and never produces fruit. Many Indigenous and local practices of agroforestry (area below the graft wound) are rooted in ancestral knowledge (roots and reflection below ground) and are impeded by the values of the dominant regime (grafted top). Some Indigenous and local practitioners are able to circumvent obstacles (push past the graft wound), yet structural change is needed to create more equitable access to participation and enable more just agroforestry transitions. Artwork by Tehina Kahikina.

illustrated in our interviews, the cultural norms and policies of these same institutions are still largely siloed and favor short-term production and economic value, which constrain agroforestry practitioners. Agroforestry in principle belongs to all sectors, but in practice, it belongs to none (Buttoud, 2013). This contradiction challenges inclusive participation in agroforestry. Further, many interviewees viewed the term agroforestry as a form of cultural appropriation, which can add to its exclusivity. To move beyond this contradiction requires de-siloing institutions and allowing for plurality in framing. One way to start is to increase communication, cooperation, and coordination between agriculture, forestry, conservation, and cultural organizations that support land stewards. Acknowledging and using culturally appropriate names

for agroforestry locally is another incremental step. Future research could examine existing agriculture and forestry policies at local, state, and national levels and consider how their framing may drive or constrain inclusive agroforestry transitions and what changes are needed.

Structural Change Is Needed for Agroforestry Transitions to Be Just

This case study illuminated that without the means to self-fund, practitioners' ability to start practicing agroforestry and persist through the transition process is tenuous. The continuous struggle over values and imbalance in power between practitioners and institutions constrains the ability for agroforestry transitions to be just. We emphasize that structural change is needed to address these issues. Some changes may support all diversified agriculture since agroforestry practitioners share many obstacles with other producers. Yet, some solutions are unique because agroforestry practitioners' motivations and practices are different. Practitioners we interviewed emphasized the need to create more relationships, partnerships, and collaborations to increase inclusive participation in agroforestry. This reinforces other findings that transformations require not just changes in land use practices, or the adoption of technological practices, but the re-thinking of social relations and structures (Galt, 2013). And, while the practitioners we spoke with are working locally to transform the dominant agricultural system, additional support from institutions is needed to ensure local level domains of transformation can affect broader regime change (Anderson et al., 2019).

Restore Long-Term Land Access That Empowers Indigenous Practitioners

Our results highlighted that secure, long-term land access is a major constraint to agroforestry. Therefore, solutions are needed to increase the duration of leases and other access agreements, increase Indigenous practitioners' access to these tenure arrangements, and empower practitioners with decision-making autonomy. Opening up land access, especially under longer tenure agreements, needs to focus on restoring Kānaka ʻŌiwi access to ensure just outcomes. As one practitioner questioned, *"if we open up trust lands to everybody, what protects Kānaka ʻŌiwi interest?"* and expressed his concern directly, *"we keep losing as Hawaiians and other people keep benefiting."* Future research needs to examine how potential interventions to improve land access for agroforestry practitioners will affect Kānaka ʻŌiwi. We found that in Hawaiʻi, private and public policies meant to protect landowners from risk and/or agricultural land from mismanagement, such as short-term leases and policies against living on agricultural land, put a higher burden of risk on tenants, especially those practicing agroforestry. Although the leases of many practitioners are bolstered by public discourse around the value of farming (Mostafanezhad and Suryanata, 2018), short-term leases still place a significant burden on practitioners to continually prove their worth relative to other land uses, like development. Tenants hold little power to negotiate lease arrangements, and therefore participation in stewardship practices like agroforestry is constrained.

Re-value Indigenous and Local Knowledge

Our findings also underscore how the lack of value placed on Indigenous and local knowledge is a major constraint to agroforestry transitions. Therefore, one strategy to enable more equitable agroforestry transitions is to re-honor the role of farmers as not only feeders, but also land and water protectors and public health stewards. Colonialism, and the low value placed on labor in plantations, de-valued the important role that mahiʻai (farmers) played in the Hawaiian Kingdom and have contributed to an enduring process of erasure (Peralto, 2013). Interviewees described how this legacy and the physical struggles of farm labor feed the stigma that farming is a less desirable job than higher paying, less physically strenuous jobs, which constrains the re-generation of agroforestry today. As such, (re)honoring farmer livelihoods, lifestyles, and knowledge is critical to restoring Indigenous crops (Kagawa-Viviani et al., 2018), the foundation of many agroforestry systems. In turn, developing metrics for the contributions agroforestry practitioners make to their communities and society is another way to re-value their role. Future research could include co-developing biocultural indicators (Dacks et al., 2019) with agroforestry practitioners to honor place-based metrics of success. Although bringing attention to the societal benefits is important, it is critical not to downplay the cost of producing these benefits, so as not to undervalue farm work, which can normalize self-exploitation and lead to burnout (Suryanata et al., 2021).

Rebuild Resilient Support Infrastructure for Agroforestry Practitioners

Our results highlighted the importance of developing stronger infrastructure to support practitioners so that they can focus on stewardship. This reinforces other findings that increasing resilience of agricultural production systems requires supporting farmers as individuals so that they can grow food (Rissing et al., 2021). For example, practitioners we spoke with pointed to the need to better align investment capital with agroforestry initiatives. Additionally, practitioners expressed the need for support to get their products into markets including processing and distribution infrastructure, as well as buyers and consumer demand. This is a common constraint with agroforestry in other contexts because agroforestry products often lack existing markets and one practitioner may produce multiple products with lower volumes of each (Amare and Darr, 2020; Sollen-Norrlin et al., 2020). Additionally, there is a need to value not only capitalist markets, but also other modes of alternative market and non-market forms of exchange. Creating standards for agroforestry products may assist with marketing (Elevitch et al., 2018), although more research on the power dynamics and who benefits from these initiatives is needed to ensure equitable outcomes (Anderson et al., 2019). Structured demand or mediated markets are also a possible alternative (Guerra et al., 2017; Valencia et al., 2019).

Finally, our results emphasized the need to support practitioners in accessing place-based information and learning

from each other, rather than knowledge deficit interventions that overlook structural barriers (Calo, 2018). Creating practitioner networks, particularly for Indigenous practitioners would be a key first step. In Hawai'i, similar networks already exist for limu (seaweed) gatherers (The Limu Hui), loko i'a (fishpond) practitioners (Hu'i Mālama Loko I'a), and taro growers on Kaua'i (Wai'oli Taro Hui), providing possible templates for agroforestry practitioners. Additionally, compiling place-based land use history into readily accessible formats for practitioners, following a historical restoration approach (Kurashima et al., 2017), could lower the burden to transitioning. Finally, increasing funding for research on place-based diversified farming systems could increase structural support for agroforestry transitions (Carlisle and Miles, 2013) and disrupt the lock-in of economic and policy forces that incentivize low diversity cropping systems (Mortensen and Smith, 2020). Future research could analyze social networks to identify further leverage points for change.

CONCLUSION

Agroforestry is widely promoted as a resilient land use. Yet, contested values and unequal power dynamics between practitioners and dominant institutions constrain just transitions to agroforestry. Our case study illuminates three interrelated key points that have important implications for realizing resilient and just agroforestry transitions. First, we find that agroforestry is intentionally chosen as a form of restoration and reclamation of sovereignty, not only as a means to production and economic benefits. Second, agroforestry faces an important contradiction: the same institutions that promote agroforestry also perpetuate the dominant systems of resource access, values, and silos that constrain agroforestry practitioners. Third, structural change is needed to enable just and lasting participation in agroforestry transitions. This work reinforces the need to consider the politics and power dynamics in agroforestry transitions and points to numerous future directions for participatory, action-oriented research.

DATA AVAILABILITY STATEMENT

Original data generated for this study will not be made publicly available in their entirety to protect the privacy of interview participants. Inquiries can be directed to the corresponding author.

ETHICS STATEMENT

This study was reviewed and approved by Institutional Review Board at the University of Hawai'i at Mānoa. The participants provided their informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZH, MW, and TT contributed to conception and design of the study. ZH and MW conducted interviews, focus group, and transcriptions. ZH performed the initial coding, and MW and TT revised. MW and ZH collaborated with the artist to develop **Figure 3**. ZH wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Food Security and Climate Change: Differences in Impacts and Adaptation Strategies for Rural Communities in the Global South and North

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This research highlights the mismatch between food security and climate adaptation literature and practice in the Global North and South by focusing on nested case studies in rural India and the United States during the COVID-19 pandemic. The United States is one of the wealthiest countries in the world, but also has one of the largest wealth gaps. Comparatively, India has one of the largest populations of food insecure people. To demonstrate how adaptive food security approaches to climate change will differ, we first review the unique climate, agricultural, demographic, and socio-economic features; and then compare challenges and solutions to food security posed by the COVID-19 pandemic. While both countries rely on rural, low-income farmworkers to produce food, the COVID-19 pandemic has highlighted how agricultural and food security policies differ in their influence on both food insecurity and global hunger alike. Emphasis on agricultural production in developing regions where a majority of individuals living in rural areas are smallholder subsistence farmers will benefit the majority of the population in terms of both poverty alleviation and food production. In the Global North, an emphasis on food access and availability is necessary because rural food insecure populations are often disconnected from food production.

Keywords: climate impacts, COVID-19, food access, food availability, India

INTRODUCTION

Climate change will affect both food security and the livelihoods of those engaged in production systems and their value chains. Already, the number of people affected by hunger globally has been on the rise since 2014 despite food production doubling over the last 3 decades (FAO, 2020). Over the course of 2019 "two billion people, or 25.9% of the global population, experienced hunger or did not have regular access to nutritious and sufficient food" (FAO, 2020, viii). Multiple pathways increase the number of food insecure people by shaping poverty, disaster recovery and migration patterns (Hertel et al., 2010; Lobell and Burke, 2010; Vermeulen et al., 2012; Wheeler and Von Braun, 2013; Porter et al., 2014).

Climate change also impacts agricultural production, supply chains and pricing. Production is projected to decline in tropical regions, while temperate regions will see some gains (Hertel et al., 2010; Lobell and Burke, 2010; Hertel and Lobell, 2014); but warming beyond crop thresholds will induce yield declines even in temperate regions (Peet and Wolfe, 2009; Wolfe, 2013). Countries bearing the brunt of changes in arability and production losses are also home to some of the poorest and most food-insecure (Fischer et al., 2005; Mendelsohn et al., 2006, 2007; Hertel et al., 2010; Lobell and Burke, 2010; Akter and Basher, 2014; Hertel and Lobell, 2014). Some models predict 120 million more people will become undernourished and under a high population growth pathway we can expect to see 175 million more undernourished individuals by 2080 (Fischer et al., 2005).

In order to meet future food needs scholars must consider changes not only in global demographics and climate impacts on food security (Lobell and Burke, 2010) but also the degree to which food and production systems can adapt (Lobell and Burke, 2010; Porter et al., 2014). Downstream, food access is linked to a stable food supply chain. Climate impacts disrupt the food supply chain and cut-off physical access to markets in several ways. Extreme weather events such as heavy precipitation—floods and snow—and storms affect public infrastructure, damaging roads and bridges, inundating transportation networks, and creating hazardous conditions for people to physically access markets (Koetse and Rietveld, 2009; Nissen and Ulbrich, 2017). In the U.S, post Harvey, Sandy, and Katrina, supermarkets struggled with limited stock as flooded infrastructure kept distribution centers from resupplying (Zeuli and Nijhuis, 2017; National Academies of Sciences, Engineering, and Medicine, 2020), in turn spurring intermittent spikes in food prices (Vermeulen et al., 2012). Following Tropical Cyclone Pam in the South Pacific, researchers noted that food prices increased three times the normal price in both Fiji and Vanuatu, making staples unaffordable for most (Magee et al., 2016). Price increases in food and food related services will especially affect low-income agricultural dependent economies who are net food importers (Hertel et al., 2010; Brown, 2014). Subsistence food resources are also undermined (Brinkman et al., 2016). For example, erratic and extreme weather conditions in arctic communities lead to increased injuries and deaths while hunting and fishing (Laidler et al., 2009).

Rural communities make for interesting case studies as they are paradoxically sites of both food production and food insecurity for both the Global North and the Global South (Hertel and Rosch, 2010). While there is little consensus on what constitutes rural, the United Nations Department of Economics and Social Affairs (UNDESA, 2019) estimates that close to 3.4 billion people live in rural areas globally. Africa and Asia are home to 90% of the world's rural population and a majority (70%) of the rural population is considered poor (UNDESA, 2019). While in the Global North, only 22% of the population is rural and poverty is not as pervasive or entrenched relative to the Global South (UNDESA, 2019). Globally, those that live in rural areas rely predominantly on smallholder subsistence farming for sustenance and livelihood (Baez et al., 2013; Brown, 2014). Despite being involved in food production, food makes up the largest portion of the budget for these individuals (Hertel and Rosch, 2010).

In both the Global South and North, rural and impoverished people will be particularly vulnerable to climate change impacts on food security (FAO, 2020). While rural communities in the Global North have more adaptive capacity and social safety nets to buffer them from climate change effects, the majority of rural poor in the Global North are often not directly involved in farming for their livelihoods (Primdahl et al., 2013; Zasada et al., 2013; Verhoeve et al., 2015). We hypothesize that the rural poor in the North will not directly benefit from adaptation efforts focused exclusively on food production. In contrast, the vast majority of the rural population in most Global South countries are small landholder subsistence farmers who will directly benefit from research and outreach efforts focused on farm-level adaptation. The determinants of food security also differ globally and hence we hypothesize that unique, case-specific strategies for adaptation are required.

To understand potential adaptive responses to food insecurity during climate change, we draw on two case studies of emergency food provisioning in rural communities during the COVID-19 pandemic. In so doing, we review unique climate, agricultural, demographic, and socio-economic features of rural populations in the Global South and North through the case studies based in the United States and India, countries which are both important to the global food supply chain and have large acreages of land in agriculture. In the case of the US, we use an agriculturally dependent, rural community, Madera County, California as an illustrative example of the American food system, while in India we chose the agrarian state of Kerala. We describe food system attributes of the nested cases below in **Table 1**[1]. Due to a mismatch in geographical boundaries and lack of data for district level food system mapping in India, we use state level data. In the case of India, because State and local government policy is so closely mirrored, we believe State level data captures local conditions sufficiently for the purposes of this study.

Global North Case Study

The American Food System: Disconnected and Disparate

In the United States reliance on agriculture and food production in rural areas for livelihoods is much less pronounced relative to rural communities in the Global South. The United States comprises, 50 states, and 3,143 counties (Parker, 2015; USDA, 2015). Only 14% of these counties are dependent on agriculture (USDA, 2015). Of the agriculturally dependent counties, 67 have persistent poverty (USDA, 2015).

The current American food system is a reflection of a century of food system modernization. Early 1900's was a time of laboriously intensive agriculture that employed 41% of the workforce, on small diversified farms producing *on average 5 commodities* per farm (Dimitri et al., 2005). A third of the

[1]Data for this table is sourced from Menon et al. (2009), Government of Kerala (2016), Government of India (2019), U.S. Census Bureau (2019), USDA (2019), and FAO (2020).

TABLE 1 | Comparative nested case study area attributes.

Food system attribute	United States	Madera County	India	State of Kerala
Number of farms	2,042,220	1,386	146 million	7.5 million
Land in agriculture	364 million hectares	261,167 hectares	194 million hectares	1.4 million hectares
Value of agricultural products	$388 billion	$1.49 billion	$38.5 billion	$6.54 billion
Direct sales	Only 6% of US farms sold directly to consumers	Only 4% of Madera County's farms sold directly to consumers	98% of the population buys food and produce from traditional markets (farm stand and farmers markets) supplied by farmers	
% food insecure	10.7% (35.2 million people)	13% (20,500 people)	14% (189 million people)	28.6% (9.4 million people)
% rural population	14% (46.1 million people)	47% (73,157 people)	65% (people)	53% (17.5million people)

country lived on farms and farming sustained their livelihoods, whereas today only 2% of the population lives on a farm (Dimitri et al., 2005). The rise of farm mechanization—the green revolution of the 1960's—was especially powerful in changing the dynamics of family farming (Lobao and Meyer, 2001). The increased efficiency and productivity of mechanization reduced labor requirements from 11 hectares/worker in the beginning of the twentieth century to 299 hectares/worker in 1990 (Spittler et al., 2011). Farm numbers have dwindled—from 6.8 million farms in 1935 to 2.1 million farms in 2002 (Spittler et al., 2011) but farms are more productive today than before due to availability and increased use of agricultural inputs: chemicals, fertilizer, pesticides and herbicides to reach the current levels of productivity (Dimitri et al., 2005).

Despite the domination of family farms, there is much inequality among farmers and concentration of wealth (Lobao and Meyer, 2001). Family farms are responsible for 85% of agricultural production in the U.S., but two-thirds of family farms earned <$50,000 in sales and made up only 3% of U.S agricultural production sales (USDA, 2014, 2015). While 4.5% of farms had sales of $1 million or more and produced 97% of agricultural products sold in 2012 (USDA, 2015). More and more farmer households are pursuing off farm income to offset farm risks: ∼33% in 1930 to 93% of farms earning off farm income 2012 (USDA, 2014). These changes in structure, wealth, specialization and technology have transformed agriculture, farming, and the American food system.

The changes in the structure of the food system, also changed how people interact with the food system. Americans procure groceries from food retail outlets and direct purchasing of food from farmers and farms remains extremely low. Through initiatives such as "Know Your Farmer, Know Your Food," and the 2008 Farm Bill (The Food, Conservation, and Energy Act of 2008. HR 6124), the US government has made a concerted effort to reconnect food producers and consumers (Park et al., 2014). However, although such initiatives have allowed *some* food producers to engage in different sales tactics such as direct marketing to consumers, though the results have not been as fruitful as hoped (Park et al., 2018; O'Hara and Low, 2020; Plakias et al., 2020).

Overall, the United States is a net exporter of food; on average there is more than enough food produced in the country to meet the dietary needs of all people in the country (Maxwell, 2019). Despite the level of food production and abundance of food in the United States, in 2019 10.5% of households were considered food insecure (Coleman-Jensen et al., 2020). Given the degree of separation between food production and consumption in the American food system, climate impacts on food production alone will not immediately impact consumption patterns or levels of food security in U.S. communities.

Determinants of Food Insecurity in the United States

Multiple factors contribute to high levels of food insecurity in rural areas in the U.S.: policy oversight of rural food systems, socio-economic dynamics of rural areas, and structural inequities. We explain the structural and policy mediators that lead to food insecurity by modifying the construct of availability in the North American context—access and use remain the same. Availability in this case is described as the presence of healthy and nutritious food at the neighborhood level. Most individuals living in rural areas, even those that are involved in agriculture, are not subsistence farmers but purchase a large amount of their food from food retailers (Jones et al., 2014; Sibhatu et al., 2015; Sibhatu and Qaim, 2017). Hence understanding the spatial distribution of food retail in rural areas and how this spatial distribution can impede the availability of healthful and nutritious food is important (Raja et al., 2008).

Rural areas in the United States are synonymous with consolidation of grocers (Sharkey, 2009; Piontak and Schulman, 2014). Between 2007 and 2011 rural counties lost 5.7% of its grocery stores (Piontak and Schulman, 2014). In a study looking at rural counties with high rates of poverty, researchers found supermarkets were more prevalent in urban counties than in rural counties (Morris et al., 1992). Supermarkets were also distributed in close proximity to each other in urban counties in comparison to rural counties: one supermarket every 75 square kilometers in an urban county while supermarkets were on average 686 square kilometers away in rural counties (Morris et al., 1992). Small and medium stores that are more prevalent in rural settings also offer limited selection of healthy produce: 23% of retail in the study stocked no vegetables and one in three did not have fruits (Morris et al., 1992). Residents in rural counties are frustrated with the lack of choice available to them both in terms of retail options and food options available in-store (Sharkey, 2009; Smith and Morton, 2009; Ramadurai et al.,

2012). This pattern of food retail distribution gives rise to large swaths of development without supermarkets or grocery stores in a 16 kilometer radius at the neighborhood level, described as "food deserts" by the USDA (Sharkey, 2009). There are 448 counties in the United States designated as food deserts and 98% of these are in non-metropolitan counties (Morton and Blanchard, 2007). The uneven spatial distribution of food retail reduces the availability and easy access to healthy food for rural residents.

The consolidation of food retail in rural areas has left residents with longer travel times to access food (Piontak and Schulman, 2014). The sprawling nature of the rural landscape makes public transit unfeasible, adding the burden of car ownership to the rural poor in order to access adequate food (Sharkey, 2009). One study in rural Central Texas found that residents would have to drive up to 80 km to be able to purchase groceries (Ramadurai et al., 2012). Given the spatial distribution of food retail, residents in Central Texas purchased most of their food from outside the county (Ramadurai et al., 2012). The price of gas impedes these trips as does the distance (Smith and Morton, 2009; Ramadurai et al., 2012). Similarly results from a study looking at food access among low income rural residents in Minnesota found transportation to be critical in eating healthy (Hendrickson et al., 2006; Smith and Morton, 2009). Lack of transportation was a greater impediment to rural residents eating healthy than to urban residents (Hendrickson et al., 2006). Residents in these low income rural counties also pointed out that if they did not have the money to purchase the higher priced items in the county, it was unlikely they had the resources to make the trips outside the county to purchase groceries (Smith and Morton, 2009). Food access is inhibited by the long travel times and a lack of transportation options to get to these far flung markets in rural areas (Dean and Sharkey, 2011).

Financial capital is a prerequisite for food access. Poverty in rural counties is more prevalent than in urban ones, and decline in poverty rate was more significant in urban and metro counties than in rural and remote counties (Kusmin, 2013). Additionally, while real income has grown over the years in metro counties, real income has declined in completely rural and non-metro adjacent counties in the U.S. between 2015 and 2017 (Kusmin, 2013). Through the Agricultural Improvement Act of 2018 ("Farm Bill") the US government has tried to provide food safety nets in the form of Supplemental Nutritional Assistance Program (SNAP) and various other smaller nutritional programs, including Women, Infant, and Children (WIC) to households and individuals who live in poverty (Lusk, 2018; Mozaffarian et al., 2019). However, these food safety nets are inadequate as multiple studies have demonstrated (Hendrickson et al., 2006; Ramadurai et al., 2012). The amount allocated to families and individuals is based on the thrifty food plan's market price calculations, and not on recipients' real food and nutritional needs and has been critiqued as being inadequate, especially in rural areas (Hendrickson et al., 2006; Ramadurai et al., 2012). While individuals in urban areas can benefit from other food safety nets such as meals on wheels, soup kitchens, food pantries and banks, these social safety nets are limited in the rural setting (Piontak and Schulman, 2014). Even when rural residents are able to access safety nets such as SNAP and WIC, their choices in redeeming these services is limited (Smith and Morton, 2009). While fruits and vegetables may be available in rural areas, most roadside vegetable and fruit stands do not accept SNAP and WIC (Smith and Morton, 2009).

Additionally, food costs more in rural areas in the U.S. In persistently poor rural counties food cost significantly more than the allocation for food stamps under the thrifty food plan to recipients (Morris et al., 1992). Generally, it costs more to eat healthy in the United States: energy dense fats, sweets and grains (cheap calories) are cheaper to purchase than lean meats, fruits and vegetables (Liese et al., 2007; Monsivais and Drewnowski, 2007). The price of fruits, vegetables, and other less energy dense foods has increased over the years while the price of energy dense foods has been resistant to inflation (Monsivais and Drewnowski, 2007). Cost of food for most people is key determinant of food choices (Hendrickson et al., 2006; Ramadurai et al., 2012), and food tends to cost more in small and medium food retail stores in rural areas in comparison to prices available in supermarkets and grocery stores in urban areas (Morris et al., 1992; Liese et al., 2007). The lack of competition in rural areas drives up local food prices, persistent poverty and inadequate safety nets make it difficult to afford foods according to individual nutritional needs.

While there are many aspects of the use dimension of food security, we focus on the availability and access to culturally appropriate foods. The U.S. is home to 40 million foreign born residents accounting for 12.9% of the total population—this is a rise of 50% points between 1980 and 2010 (Grieco et al., 2012). The lack of culturally appropriate foods makes it difficult for people to utilize available food. This fact is compounded in rural counties where spatial inequities and lack of transportation makes food choices limited and inadequate to meet the cultural appropriateness of all its residents. A study of Latinx and Hispanics in North Carolina shows food insecurity is higher for those who live in rural areas and lower for Hispanics and Latinx in urban areas (Haldeman et al., 2008). The study highlights that the level of food security is associated with time in the United States in rural areas (Haldeman et al., 2008). The less time they had spent in the United States, the more food insecure they were. The study sample identified a lack of familiarity with foods and ability to read food labels as a constraint to eating healthy (Haldeman et al., 2008). Food available is also hard to use when it is of poor quality. Residents in rural areas point out that a lot of the food available locally is not just over priced but also of poor quality (Smith and Morton, 2009; Ramadurai et al., 2012). In Minnesota for example residents report stale, out of date and spoiled food on their local food store shelves (Smith and Morton, 2009). The sub-standard foods in rural areas further impedes roads to addressing food security.

Madera County Case Study

We offer a look at Madera County (**Figure 1**) in California as an exemplar of the disconnected American food system. Madera County spans 5,561 square kilometers and is located in the Californian Central San Joaquin Valley and the Central



FIGURE 1 | Map of Madera County, California.

Sierras (Madera County EDC, 2013). Madera is bordered on the north by Chowchilla River and on the south by the San Joaquin River, and has some of the richest agricultural lands in the nation. The county is home to 157,327 people: 33% white, 58% hispanic, 4% African American (U.S. Census Bureau QuickFacts, 2019a). A fifth of the population is also foreign born (U.S. Census Bureau QuickFacts, 2019a). The median household income for the county is US$57,585, with 17.6% of the population living in poverty (U.S. Census Bureau QuickFacts, 2019a). The county has two urban centers (Madera and Chowchilla) and 11 unincorporated communities (Madera County EDC, 2013). People are spread across the urban centers and unincorporated areas: half the population lives in the unincorporated areas and the other half in the urban centers (U.S. Census Bureau QuickFacts, 2019b).

Agriculture plays an important role in Madera's economy, earning over a billion dollars each year in gross farm income (USDA, 2017). Agriculture accounts for about 46% (261,167 hectares of farmland) of land in the county, with farms averaging 188 hectares (USDA, 2017). Madera is home to over 1,300 farms, with many 3rd and 4th generation farm families (Madera County Farm Bureau, 2015). The county's top three products by acreage are almonds, grapes, and pistachios. There is an abundance of fruits, vegetables, grains, and dairy products harvested and processed in Madera County (USDA, 2017). Madera also ranks 8 in the state for milk production and earned over $254 million from milk sales in 2017 (USDA, 2017). Despite the agricultural abundance and wealth in the county, almost 20% of households (8,797 households) in Madera county received Supplemental Nutrition Assistance Program (SNAP), 24,000 households are low-income, and about 20,500 people in the county are food insecure (Feeding America, 2019; U.S. Census Bureau, 2019).

When we look at Madera County's community food system,[2] actors in the community food system are loosely connected (Raj et al., 2021). According to the USDA's food environment atlas (USDA, 2017), only 4% (62) of farms in the county directly sell to consumers. The number of farmers involved in direct sales has also been decreasing; between 2007 and 2012, there was a 22% decline in the number of farms participating in direct sales in Madera County (USDA, 2012). The Community Food Guide for Madera County reports that the community food network for Madera County is supported through farmers' markets, with restaurants being the second most important connection for local farmers and grocery stores coming in third (Raj et al., 2021). Most of the farmers' markets and restaurants that support Madera County farmers are in the San Francisco bay-area, a wealthier jurisdiction nearly 322 kilometers (a 3-hour drive) away. Some Madera County farmers travel as far as Southern California, over 402 kilometers away (a 4-hour drive) to sell their produce (Raj et al., 2021). Even when farms are listed as selling directly to people, the clientele tends to be outside the county boundaries, to wealthier, more affluent communities. Madera County's community food network illustrates how disconnected local agricultural production is from local consumption, and despite the county producing an abundance of fruits, vegetables and dairy products, much of it is funneled out of the county.

As case in point, Covid-19 presented a flashpoint for food systems globally. In Madera County, while small businesses, including restaurants were shuttered due to the pandemic, agricultural production held steady and remained the county's most economically valuable industry (Promnitz, 2020). However, food insecurity skyrocketed, with food distribution increasing 150% in Madera County, according to the Central California Food Bank (Ugwu-Oju, 2020). The most impacted were farmworkers, migrants, communities without easy access to food retail, and people who lost their jobs (Ugwu-Oju, 2020). While food banks had to turn people away due to the increased demand, farmers in Madera and neighboring counties, disced lettuce and other perishable produce back into the soil (Tobias and Rodriguez, 2020). With restaurants and large institutions closed that would otherwise buy the produce and milk, farmers found it more cost-effective to leave crops in the field and dump the excess milk, than to harvest. The state has facilitated re-routing of excess crops and milk to food banks in California, but local governments have been (un)surprisingly absent.

To enhance the adaptive capacity of communities experiencing job losses and business closures, the Federal Government stepped up food security protections countrywide

[2]Community food system refers to a connected and integrated system of sustainable food production, processing, distribution, and consumption that works together to enhance the ecological, economic, social and nutritional health of a community (Garrett and Feenstra, 1999).

through the enactment of the Families First Coronavirus Response Act (2020). The Families First Act ensured that children were able to receive free school meals despite school closures (Families First Coronavirus Response Act, 2020). In Madera County, the Madera Unified and Chowchilla Elementary school districts participated during school closure to provide free school lunches to eligible children—preschool through to year 12 (Madera Community College, 2020). The Families First Act also gave low-income families food dollars in the form of pandemic electronic benefits transfer (P-EBT), to compensate for meals missed due to school closures (USDA Food and Nutrition Service, 2021a). SNAP benefits were increased by 15% monthly in January 2021 to offset losses in income (USDA Food and Nutrition Service, 2021b). In California, SNAP benefits were expanded to include online food purchases at select stores including Amazon (USDA Food and Nutrition Service, 2021c). Federal expansion of unemployment benefits and loan forbearance programs during the pandemic also added to the vast blanket of social protection programming (Cooney and Shaefer, 2021). There were programs for paycheck protection available to businesses, as well measures put in place at the State level to prevent rent hikes and eviction protections. These measures have been extended or strengthened in the 2021 "American Rescue Plan" (USDA Food and Nutrition Service, 2021b). Additionally, in October 2020, California State legislated a farmworker relief package, which among many things, provided temporary isolation spaces to sick or at-risk farmworkers (Cimini, 2020).

The Madera County case is illustrative of the fact that food insecurity is produced by factors beyond food production and has potentially more to do with how community food systems are co-opted through the neoliberal food system, to support affluent communities elsewhere rather than support communities in the county. The outbreak of Covid-19 laid bare that agriculture and food security are loosely connected, and income and underlying structural vulnerabilities play a larger role in the determination of food security status.

Global South Case Study

The Indian Food System: Interconnected and Tightly Woven

India, home to 1.37 billion people, is one of the most populous countries in the world (The World Bank, 2020a). Spread across 3.3 million square kilometers, India is divided into 28 states and eight Union Territories; the States and Union comprise of 718 districts that are further subdivided into urban municipalities and rural villages (Government of India, 2019). Despite strong urbanization trends, a majority of Indians—65%—live in rural areas (The World Bank, 2020b). Additionally, a large proportion of the urban workforce are out-migrants, and due to the pandemic, 30 million of these migrants have returned to their rural homes, adding uncertainty to livelihood opportunities available to them (The World Bank, 2020c). While urban slums are certainly a vista of persistent poverty, poverty is concentrated and more prevalent in rural India (Aubron et al., 2015).

Despite declining agricultural growth, India is still the world's largest producer of milk, pulses and spices (M.S. Swaminathan Research Foundation and World Food Program, 2008; The World Bank, 2012). Globally, India has the largest cultivated land area for wheat, rice and cotton (M.S. Swaminathan Research Foundation and World Food Program, 2008; The World Bank, 2012). India also contributes to the global production of rice, wheat, cotton, sugarcane, tea, fruits and vegetables, sheep and goat, and farmed fish (M.S. Swaminathan Research Foundation and World Food Program, 2008; The World Bank, 2012). Much of the land is cultivated—195 million hectares or 60% of total land mass—of which 63% is rain-fed and 37% is irrigated (M.S. Swaminathan Research Foundation and World Food Program, 2008; The World Bank, 2012). Even though agriculture's importance to the economy has diminished over the decades, it still employs 60% of the rural workforce and remains the main source of livelihood for rural India (Aubron et al., 2015; Pillay and Kumar, 2018). In rural India, livelihoods, agricultural production, and poverty are interconnected.

Following a green revolution in the mid 1960's, agriculture in India focused on creating high yielding rice and wheat varieties, and increasing chemical inputs—fertilizers and pesticides—which in turn increased output per hectare without increasing cultivated land (Chakravarti, 1973; Parayil, 1992). In part the green revolution was driven by famine conditions experienced under British rule. Prior to independence in 1945, Indian agricultural products were exported by the British to support its empire and war efforts elsewhere, while millions of Indians were subjected to famine conditions (Sen, 1981). The great Bengal Famine in 1943 that resulted in the deaths of more than 1.5 million Indians was not a result of production shortfalls; Indian farms produced sufficient food, but the grains were funneled out, and what was made available in the local market was too expensive for poor Bengali's to afford (Sen, 1981). Since independence India has been free of famines, and much of their agricultural reorganization has been to undo British agricultural policies. However, farm sizes have hence remained small; in fact farm sizes have decreased between 1971 and 2011 by ∼1 hectare in India (Fan et al., 2013). Most farmers are smallholder or subsistence farmers in India, owning <2 hectares of land (Government of India, 2019). Agricultural productivity has increased since the green revolution, with India becoming self-sufficient in grain production since the 1970's and producing enough food to meet the caloric needs of its population (Narayanamoorthy et al., 2017).

Not surprising, farmers remain central to the food supply chain in India. Traditional food retail outlets still represent close to 98% of the food retail share with the market penetration of supermarkets remaining low: 2% (Tefft et al., 2017). Essentially, most Indians still participate in traditional food systems, procuring fresh produce and food items from traditional markets that either buy directly from farmers or through rural aggregators. In fact, rural business hubs linking smallholder farmers to rapidly growing urban markets are on the rise in India (FAO, 2020). In addition to food procurement, the hubs also facilitate purchase of farm inputs, equipment, and lines of credit for the farmers (FAO, 2020). Given that traditional markets and direct purchasing from farmers remain central to the Indian food system, disruptions in food production, and

the supply chain would also negatively impact food security outcomes in the populous.

Although India grows and maintains sufficient caloric supply of foods, and is even a net exporter of foodgrains and agricultural commodities, food insecurity is prevalent (Government of India, 2017; Narayanamoorthy et al., 2017). According to the FAO, 14% (189 million) of people in India are undernourished (FAO, 2020). In India food insecurity is also more prevalent in rural areas than urban areas (M.S. Swaminathan Research Foundation and World Food Program, 2008; Ahmad et al., 2011; The World Bank, 2012; Bhuyan et al., 2020). A national analysis of rural food insecurity found 13.2% of the rural population to be food insecure—consuming <1,890 kilocalories per capita per day (see **Figure 2** below). Rural food insecurity in particular is inextricably linked to small and marginal smallholder food production, income and debt, and climate shocks will further exacerbate rural food insecurity (Kumar et al., 2020). Given the connectedness of the Indian food system, we explore the determinants of food security in India.

Determinants of Food Insecurity in India

One key challenge in shoring up food security in India is the availability of food grains to meet dietary needs (M.S. Swaminathan Research Foundation and World Food Program, 2008; The World Bank, 2012). Even though India leads the world in the production of a number of agriculturally important crops, as a nation the average per capita net food grain availability has been variable and uneven across states (M.S. Swaminathan Research Foundation and World Food Program, 2008). To create greater and more equal access across states, the Indian Government instituted a public distribution system (PDS; George and McKay, 2019). The PDS is the largest social protection program globally, providing access to subsidized cereals for 800 million people that can be purchased from over 500,000 fair price shops across India (Pillay and Kumar, 2018). The PDS has had mixed results. As Ali et al. (2012) show in their study of Uttar Pradesh, 20% of households in their sample were unable to obtain food from the PDS despite having proper documentation. Similarly, Dhanaraj and Gade (2016) find that for every 5.43 kg of PDS rice distributed, only 1 kg reached those in need; in the case of sugar, distribution was even less efficient, for every 8.21 kg of sugar distributed, only 1 kg was consumed by those in need in Tamil Nadu. Others also report misclassification of households as above poverty line, as reason for exclusion from the PDS, as well as poor grain quality at the fair price shops, and corruption being a barrier for households purchasing through the PDS (Upadhyay and Palanivel, 2011; Kasim, 2012; George and McKay, 2019). Even though the PDS is touted as a social protection program, it was created to prop up the Indian agriculture sector providing remunerative prices for grains and in doing so supplement household food needs (Pillay and Kumar, 2018). Through the years, the Government of India has modified the PDS system to be more targeted and has added more grains (millets) to diversity the nutritional basis, despite these changes the PDS remains less than efficacious (George and McKay, 2019).

Aside from structural market impediments to food grain availability, crop losses also affect food availability in rural India. Water stress particularly is linked to losses in crop yields (IPCC, 2014). For example, the prolonged drought of 2019 affected over 70% of districts in Maharashtra and Karnataka, including 8.2 million farmers and resulted in crop failure of all major crops, including corn, soy, cotton, citrus lemon, pulses, and groundnuts (Relph, 2019). At current levels of water use, water levels in India are expected to fall below 50% of demand by 2030, placing India's river basins in dire stress (2030 Water Resources Group, 2009). Groundwater is also declining, especially in the North West region of India, notably in the states of Punjab and Haryana that produce the bulk of India's rice and wheat (Shiao et al., 2015). Approximately 75% of India's households are dependent on agriculture and any future losses in food grains is likely to exacerbate food insecurity for the rural poor in India (Ahmad et al., 2011; The World Bank, 2012; Merriott, 2016).

Crop losses not only reduce food availability but also decrease farm income exacerbating food insecurity in rural areas (Sam et al., 2019). Reduced income from crop failures can be devastating on small and marginal farmers. Farmers take on a high degree of debt in order to cultivate; debt that they are unable to pay when crops fail (Bashir and Schilizzi, 2013). Small and medium farmers across India collectively owe about 102,024 crore INR (about 14.7 billion USD) (Raja et al., 2021). The degree of indebtedness has contributed to farmer suicides enmasse (Merriott, 2016; Sathyanarayana Rao et al., 2017). Kennedy and King (2014) find that farmer suicide rates are positively associated with farmers with landholdings of <1 hectare, cultivating capital-intensive cash crops like coffee and cotton that are subject to price fluctuations. In Odhisa, Arora and Birwal (2017) found upper caste farmers with bigger landholdings are able to adapt to the adverse climatic conditions and losses by investing in crop insurance, using short duration varieties, and availing credit but lower caste farmers with smaller landholdings are not able to access such resources and instead either change their occupation, sell agricultural land or migrate out of agriculture. With few safety nets and limited credit available, small and marginal farmers are extremely vulnerable—conditions likely to be exacerbated with climate change (Sam et al., 2019).

Lack of physical infrastructure also impedes agricultural output. Poor food infrastructure in the Global South makes it harder to get perishable agricultural products to market on time (Brown, 2014). Fruits and vegetables are prone to spoilage if not stored and processed adequately. Rural regions in the Global South usually lack sufficient cold storage and processing facilities, necessitating high value crops to reach markets as quickly as possible to reduce post-harvest losses (Mohammed and Tokala, 2018). Provisioning of food infrastructure in rural India is not an easy feat. Consider that much of rural India has unreliable electricity supply: 54% (74 million households or 579 million individuals) of rural households are un-electrified (Kamalapur and Udaykumar, 2011). Shortfalls and outages in supply pose a problem in areas that have been electrified (Kamalapur and Udaykumar, 2011). In a survey of 30 villages in India, researchers found that only 36% of the households received 20–24 h of supply while the remaining majority received between <12 to <4 h of electricity (Krishnaswamy and Chatpalliwar, 2011). Lack of basic service infrastructure impedes upstream food infrastructure

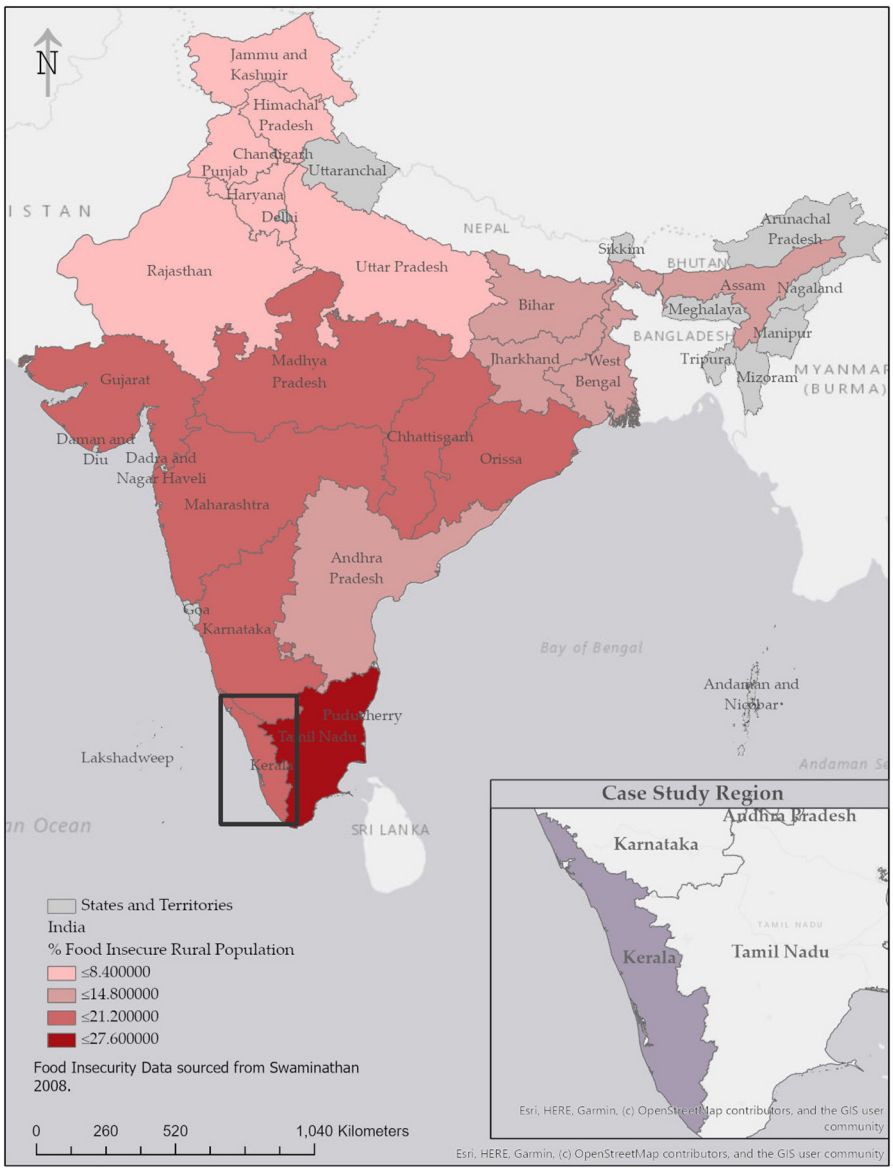


FIGURE 2 | Map of rural population in India consuming <1,890 kilocalories per capita per day.

development and farm modernization, contributing to lost rural purchasing power.

Food access in India is mediated by economic capital (Iram and Butt, 2004; Ali et al., 2012; Khan et al., 2012). Generally, small and marginal farmer households earn about US$843 (Rs 61,138) annually, and medium farmer households earn US$2, 125 (Rs 154, 099) annually (Government of India, 2017). Government estimates show that about 22.5% of farmers live below the poverty line in India (Government of India, 2017). Incomes are so low that it impedes access to adequate food and nutrition for these households (Ali et al., 2012). Iram and Butt (2004) find household income is significantly associated with calorie intake—caloric availability is higher in households with high incomes and lower in low income households. Households with low income are also vulnerable in times of food price increases. During the 2007–2008 global food price crises, household food security in rural Bangladesh suffered—the effect was much greater on rural poor and net food buyer households (Akter and Basher, 2014). In rural India, low income levels continue to impede financial access to available food.

Low income levels in rural India are also attributed to caste discrimination. Small and marginal farmers are from lower and landless castes and do not have access to the same social and financial networks and capital as upper castes landowners (Goli et al., 2021). Ali et al. (2012) find that food insecurity is worse in households of lower castes than upper castes. Goli et al. (2021) found similar results in Uttar Pradesh (UP), almost a decade later. In their study of over 5,000 households in the UP state,

food insecurity is four times worse in households with no or marginal landholdings, and three-four times worse in households of lower castes in comparison to households with medium to large agricultural lands and of higher castes (Goli et al., 2021). In their 2013 regional analysis of rural India, Mahadevan and Suardi (2013) also found belonging to a lower caste group relative to an upper caste group is associated with increased deficits in food security. Decades of cultural and institutionalized discrimination against persons of lower castes has excluded them from attaining economic mobility (Iram and Butt, 2004; Ali et al., 2012; Khan et al., 2012). In rural India the prevalence of caste discrimination continues restricting access to credit, resources and education (Mahadevan and Suardi, 2013; Goli et al., 2021).

The final food security construct—utilization—is quantified in terms of the body's ability to absorb nutrients measured in terms of access to health and sanitation factors. Studies have demonstrated access to water, sanitation, and health services are integral for the body's ability to appropriately utilize the food being consumed. However, many families throughout India lack access to clean, potable water. For example, only 14% of rural India has access to adequate sanitation and only 31% of rural households have access to drinking water (Khurana and Sen, 2008; The World Bank, 2014). Water quality is also a concern, most water sources in rural India are contaminated as a result of agricultural runoff and sewage (Khurana and Sen, 2008). Groundwater also has high levels of arsenic (Khurana and Sen, 2008; The World Bank, 2014). Lack of access to clean water impedes the health status of individuals living in rural areas. Research has shown increasing access to safe drinking water has a positive effect on food security outcomes (Iram and Butt, 2004; Khan et al., 2012). Similarly, lack of sanitation facilities has a negative effect on individual's food security status (Iram and Butt, 2004; Khan et al., 2012). Water and sanitation are proxies for good health and the ability to fully utilize the nutrients being consumed. Diarrhea, a water-borne ailment caused by contaminated water, is a good example of how nutrients are lost even when consumed. In rural India, food utilization is connected to water and energy security.

Kerala Case Study[3]

The state of Kerala, in the Indian South, is bordered by Tamil Nadu and Karnataka in the north and east and by the Arabian Sea on the west (see **Figure 2**). Kerala spans about 38,863 square kilometers, boasts a tropical climate, and enjoys access to abundant water resources (National Academies of Sciences, Engineering, and Medicine, 2020; Government of Kerala, 2021). Kerala is home to almost 33 million people, with the majority of people living in rural areas (17.5 million) (Raja et al., 2021). About 10.5% of Kerala's population are from scheduled caste and tribes, and a fifth of scheduled caste and about half of scheduled tribe work as agricultural laborers (Government of India, 2011). Agriculture employs 1,322,850 people as agricultural laborers and 670,253 people as cultivators (Government of Kerala, 2016). While Kerala has made strides in poverty alleviation, 11% of the population still lives in poverty (Raja et al., 2021). On the flipside, Kerala boasts a higher than national average unemployment rate of 12.5% (Raja et al., 2021).

Despite urbanization, Kerala remains an agrarian stronghold (Singh and Bhogal, 2008; Raja et al., 2021). Majority of land in the state is used for cultivation (51.86%), forests make up 27% of the land use, and non-agricultural uses account for about 11% of land in the State (Raja et al., 2021). There are 7.5 million farm holdings in Kerala, and about 98% of the farm holdings are considered small or marginal (Government of Kerala, 2016). A meager 0.2% of farms were medium to large (>10 hectares; Government of Kerala, 2016). Cash crops like coconut, rubber, tea, coffee, and spices dominate the agrarian economy (Singh and Bhogal, 2008). Coconuts are important both culturally and economically in Kerala, making up 39% of the cropped land area (Government of Kerala, 2016). Kerala also grows grain, with paddy accounting for 11% of land sown (Singh and Bhogal, 2008). However, grain production only reached 50% self-sufficiency in Kerala even at the peak of rice production in the 1980's (Kasim, 2012; Raja et al., 2021). Today the state produces about 10% of the rice it needs, and relies on the PDS to supplement the deficits in grain production (Kasim, 2012; Raja et al., 2021). Despite the state's agrarian aptitude, agriculture's contribution to the state GDP is paltry: 10% of the US$65.4 billion state GDP (Government of Kerala, 2016). With the cost of production increasing, the Government of Kerala estimates that 77% of all agricultural households are in debt (Government of Kerala, 2016). Despite the extensive network of farms, home gardening, and availability of subsidized food grains through the PDS, 17.5% of the rural population was considered food insecure (M.S. Swaminathan Research Foundation and World Food Program, 2008).

It was Kerala where the first case of COVID-19 was detected in India in January 2020 (Harris et al., 2020). By March a 3 months (March - June) nationwide lockdown curbed movement of people and coincided with peak harvesting season across the country, disrupting local food systems (Harris et al., 2020). Paddy harvest in Kerala was adversely affected (Pothan et al., 2020). The state government estimates that the rice sector lost nearly US$2 million due to shortage of farm laborers and truck drivers, and transportation restrictions that delayed harvest and processing of rice grains (Kerala State Planning Board, 2020). Similar losses were experienced throughout the agricultural production system in Kerala (Kerala State Planning Board, 2020). Casual workers and self-employed laborers lost an estimated US$47.9 million in income during the lockdown period - the loss of income had a devastating effect on small and marginal farmers especially who were unable to get their produce to market (Kerala State Planning Board, 2020). The loss in production had an immediate and cascading effect on the food system and food security (Harris et al., 2020; Pothan et al., 2020). As transportation of produce was delayed from the fields to the markets, notable increases in food price was recorded across the state and country (Harris et al., 2020; Pothan et al., 2020). In turn there was a surge for processed food items like instant noodles and biscuits, but even

[3]We chose to look at Kerala, as information for lower levels (districts) of analysis was unavailable. Kerala is still primarily an agrarian state and the example still offers insights into how closely knit agriculture, incomes, and food security are in rural and agrarian communities in India.

food manufacturing was running at low capacity without laborers who had returned to their villages (Pothan et al., 2020). The effect of the abrupt change (Covid-19) had an immediate impact on local food systems and on food security in Kerala.

To counter the food insecurity caused by the pandemic, the Kerala State Government put in place a number of social-protection measures. The State Government directed local governments to establish community kitchens, with the state coordinating supplies and logistics (Pothan et al., 2020; Sarkar, 2021). Distribution of free food kits consisting of 17 food items including food grains, to all households in the state, was instituted in early April (Pothan et al., 2020). Rural childcare centers were also instructed to deliver free mid-day meals to over 300,000 children registered under the Integrated Child Development Services (Pothan et al., 2020; Sadanandan, 2020). Local vegetable vendors partnered with auto rickshaw drivers to create a mobile market, transporting produce from farmers and markets to urban doorsteps (Pothan et al., 2020). Development of an app (Shopsapp) that informed people of open store locations where online ordering was possible was another lifeline for retailers and customers with disposable income (Sarkar, 2021). The State government also deployed existing social protection measures, advancing pensions, and made budgetary provisions to fulfill obligations under the Mahatma Gandhi Rural Employment Guarantee Scheme (Sadanandan, 2020). Unlike the US case, very little relief was received from the Indian Government to shore up social protections, and this lack of investment in social protection programming has been widely criticized (Ghosh, 2020).

The Kerala case study illustrates a tightly woven and highly interdependent food system in India, where adverse effects on food production has a negative cascading effect throughout the food system, including food security and health outcomes. Given the tight knit nature of agricultural production and food security in India, and implications for global food supply, it would be worth paying attention to the current farmer protests in India in response to macroeconomic policies tied to further liberalizing and undercutting Indian farmers.

Comparative Analysis of Determinants of Food Security and Adaptations in the Global South and Global North

Though the United States and India are geographically, socio-economically and culturally different, there are consistencies in the production of food (in)security in the two countries (see **Figure 3**). The similarity lies in the construct of food access. Access to food is impeded by the lack of economic resources and concentration of poverty in rural regions in both the US and India, though the severity of poverty is relatively worse in India. Rural areas in both countries face challenges in attracting development that would improve quality of life. Physical access to markets in both is a key challenge—though the nature of constraint is different between the two countries. In the United States grocery stores and supermarkets are far and few in between in rural areas making physical access to food challenging. In India physical access to markets is impeded by the sheer lack of infrastructure and utilities required by farmers to reach aggregators. Rural areas in both regions have struggled with government policy response to provide functional safety nets to alleviate food insecurity.

There are also key differences in the production of food (in)security between the two countries. In rural India, those that are food insecure are almost always engaged in farming, and their livelihoods are very much connected to gains and losses in agriculture. In the U.S. the rural landscape is different; agriculture is not the primary source of livelihoods and gains and losses in farming does not have as severe an effect on food security, as it does in rural India. Impediments to food security in the United States are structural, created in part by market forces and in part by planning and policy. Food availability in India and much of the Global South is tied to agricultural production as illustrated in this case study. In the United States and most of the Global North, availability of food is a function of neighborhood level factors—physical location of food retail and distance to food retail. Food utilization in India is dependent on the health access to clean water, sanitation and health services. In the United States food utilization is dependent on the quality of food available locally, cultural appropriateness of available food and agency.

While Covid-19 is not a climate related event, the pandemic provides a unique window to understanding how disruptions in the food system in the Global South and North, affect food security. At time of writing of this paper, India had recorded 12 million cases of COVID-19 and about 162,000 related deaths (WHO, 2021). The US had at the same time recorded about 30 million cases and 550,000 related deaths (WHO, 2021). We see two very different stories unfold in Kerala, India and Madera County, U.S. In Kerala, we see the pandemic related lockdown affecting all parts of the food system—production, supply chain, manufacturing and processing, retail, and immediately impacting food security. In part, because the lockdown coincided with peak harvesting times (Ghosh, 2020; Pothan et al., 2020). On the production end, yield losses were experienced as lack of labor prevented harvesting in time, as well as in-time transportation for processing. Farmers, and farm laborers lost income and we can infer accumulated more debt from the inputs required for the season. Transportation woes up and down the food supply chain appeared to be a weak link. Labor shortage also affected food manufacturing and processing plants and affected the availability shelf stable foods. With physical access to food retail cut off, the advent of the veggie rickshaw home delivery service and Shopsapp was a clever adaptation for the times. As was the State Government stepping in to open up community kitchens, and food rationing services that targeted both caloric and nutritional needs of diverse people in the state.

On the flip side, during the height of the pandemic in Madera County, there appeared to be minimum impact on the food system. Food retailers were stocked, and online delivery services were in high demand. A number of factors buffered the county's agricultural production sector from being adversely affected by the pandemic. While some farmers experienced on farm losses due to labor shortages, this was not widespread in Madera County, and on farm losses were underwritten by the USDA

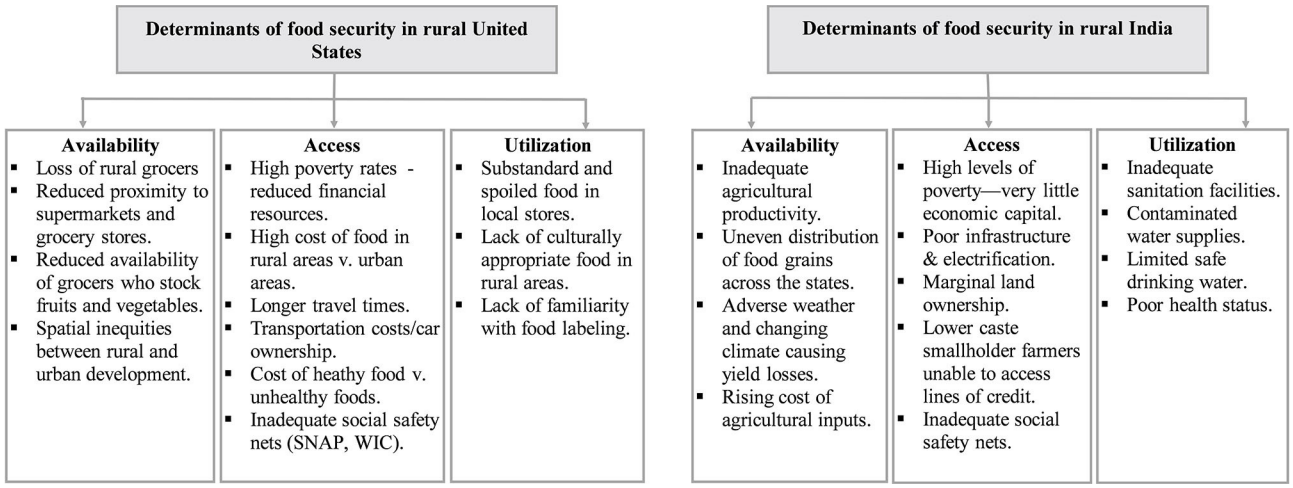


FIGURE 3 | Comparative analysis of food security determinants between the rural United States and India.

through their Coronavirus Food Assistance Program (CFAP 1) initially, and then through the CARES Act, with payments made directly to producers (Johansson, 2020). Additionally, many of the top agricultural crops (almonds, olives, pistachios, and corn) grown in Madera County are mechanically picked, and are less prone to spoilage than produce. Even if it was slower, the supply chain was still operational in Madera.

However, job losses were noted in Madera County. The most impacted were people who worked in a food related industry, majority of whom are Latinos (Ugwu-Oju, 2020). Latinos also experienced higher rates of COVID-19 infections and deaths in California relative to other races and ethnicities (California Department of Public Health, 2021). At a time when deportation was very much a reality, it is possible farmworkers, immigrants and restaurant workers from the Latino community avoided institutional support and were more at risk of contracting and dying from COVID. Recent work by Lusk and Chandra (2021) shows Madera County as having one of the highest rates of COVID-19 among migrant workers in the country. While unemployment benefits were expanded and stimulus checks mailed to tax filing citizens as a safety net, those in the above high risk groups in Madera may have been left out of the US Government response due to tax filing and immigration status. Food insecurity increased, especially among Latinos in Madera during the pandemic, and reliance on food banks grew (Ugwu-Oju, 2020).

Further analysis into the two case studies illustrates that communities adapted in different ways to the pandemic (see **Figures 4**, **5**). In Kerala, India there was a heightened focus on food security and ensuring people had sufficient food rations. We see State and local governments playing a critical role in coordinating food and ration distributions. There were also entrepreneurial adaptations with rickshaws being converted to mobile food vendors. In rural Kerala low and lost income were key determinants of food insecurity during the pandemic, followed by reduced access to traditional markets. While prepared meals and food rations were distributed, we could not find additional measures that protected livelihoods, on farm losses, the food supply chain, or safety nets that would give the rural poor disposable income for basic needs.

Despite the attention to food security in Kerala, the lockdown had a profound impact on rural livelihoods and food systems in Kerala and elsewhere in India. Other than the State led food distribution program, other coping mechanisms and adaptations mentioned in the literature appear to be sporadic and it is unclear how widespread their coverage has been. Without additional disposable income to make up for lost livelihoods during this period, families and individuals did not have improved means of coping with the vast impact of the pandemic on their health and security. Rural actors in the food system, especially small and marginal farmers of lower castes, with their limited ability to cope with the pandemic's impacts, were likely more vulnerable to the second wave of COVID-19 raging in India (Ghosh, 2020). As Ghosh (2020) points out in her paper, the timing and nature of the lockdown, the lack of Government stimulus funding to boost the rural sector, and other macroeconomic decisions contributed to increasing vulnerability of rural communities to the second wave of the virus, and did nothing for increasing their adaptive capacities.

In contrast, in Madera County, at the onset of the pandemic it was food banks and civic minded individuals who came to the assistance of the poor and vulnerable (Ugwu-Oju, 2020). Financial access to food, reduced transportation options to procure food, and lack of safe jobs in the food system were major hurdles faced by individuals in Madera County. Community adaptive capacity did receive a boost from the Federal Government with assistance targeting agricultural producers, underwriting production losses and food security measures through strengthening existing food security mechanisms. It is unclear what the participation rates were for the modified school lunch programs, or the P-EBT, or how information regarding the modified benefits were communicated to those in need. Federal

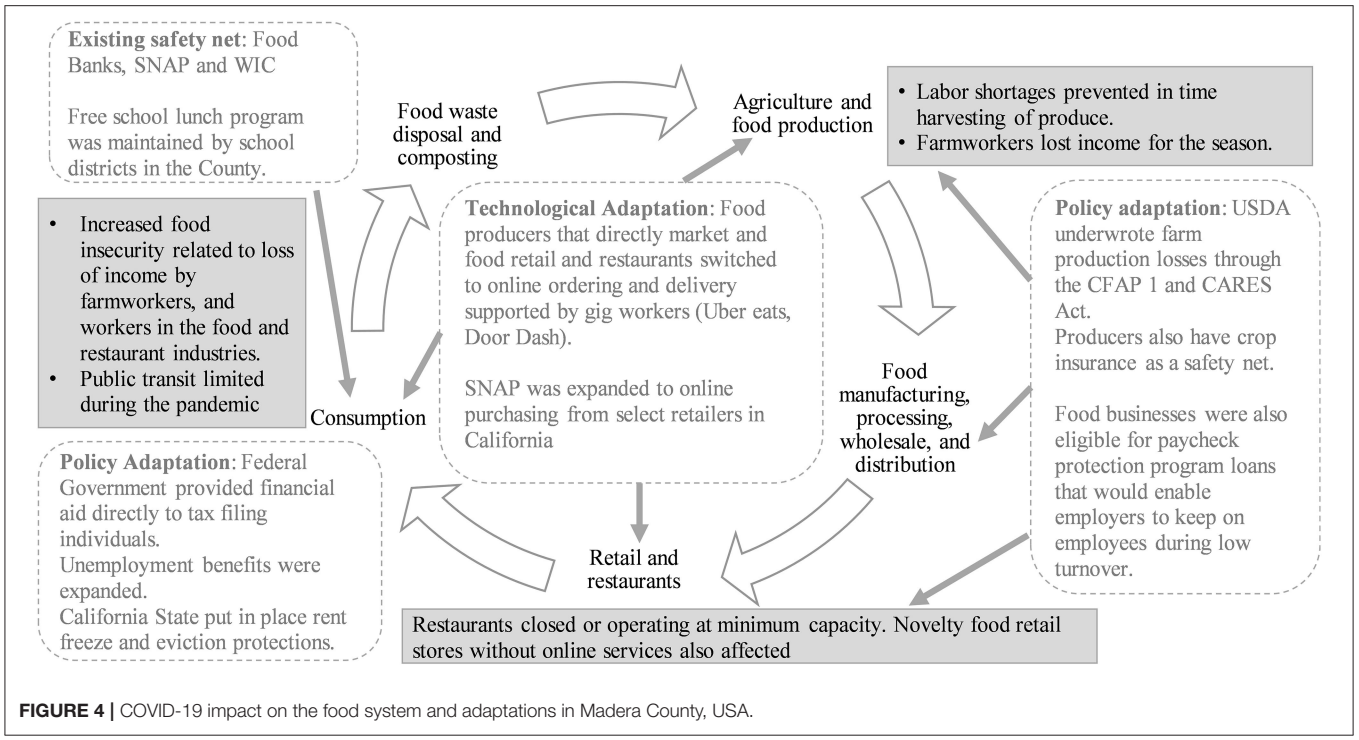


FIGURE 4 | COVID-19 impact on the food system and adaptations in Madera County, USA.

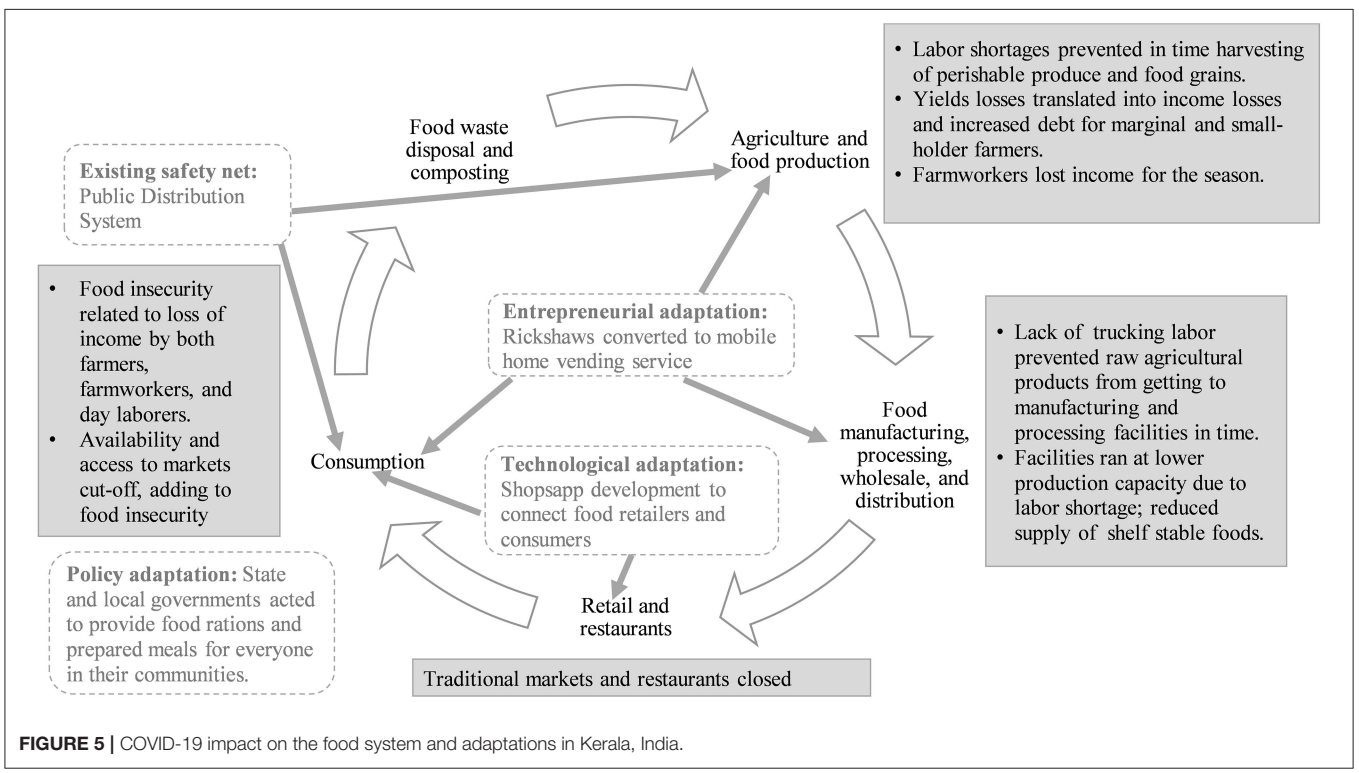


FIGURE 5 | COVID-19 impact on the food system and adaptations in Kerala, India.

legislation also supported food businesses through paycheck protection loans, as well as additional legislation that rebranded food workers as frontline workers, allowing food businesses to operate as essential services. Large scale direct payments to tax filing individuals and families also contributed to increasing community adaptive capacity. There were however people who fell through the safety nets—farmworkers, and migrant workers. Federal assistance for existing measures did not have expanded

eligibility to include farmworkers and migrant workers, despite them being the very people who grow and harvest food in the county and the country. While California finally provided some relief for farmworkers, the relief package did not put dollars' in individual's hands. Overall, the large swathe of Federal and State programming, alongside local actors in the emergency food system propped up communities and their ability to cope with and recover from pandemic related losses.

ADAPTATIONS FOR THE FOOD SYSTEMS TO IMPROVE FOOD SECURITY: A DIFFERENTIATED APPROACH

The two case studies presented in this research demonstrate the need for context-based adaptation strategies in the Global North and South to shore up food security against climate change and other large scale disasters. We note that most propositions for increasing food security tend to focus on food production and the availability component of food security (Schmidhuber and Tubiello, 2007). However, optimal adaptation will depend on the determinants of food security (Ziervogel and Ericksen, 2010; Myers et al., 2017): availability of food, accessibility (financial and physical), and the ability to utilize food and nutrients.

For example, in Kerala, India, supply chain considerations are critical to adaptation planning. Agricultural losses could have been alleviated with some on farm infrastructure adaptations, and modified policy responses. A degree of deference to rural producers at peak harvesting period, to match the community transmission of COVID at the time, may have prevented the extent of losses reported in the Kerala agricultural sector. It is also possible that the extent of post-harvest losses could have been reduced if small and marginal farmers had easy and localized access to cold storage or value adding facilities. Without supply chain considerations built in, post-harvest losses will continue to be a bottleneck (Pillay and Kumar, 2018). To this end, small and marginal farmers in the Global South are economically constrained and most do not have the resources required to invest in on-farm infrastructure and technology (Hertel and Lobell, 2014). If available, micro-credit financing and crop insurance for small and marginal farmers could have been key to coping with the losses incurred during the pandemic. Moreover, research shows investment in small-holder and subsistence agriculture has the greatest potential to reduce poverty than any other sector (de Janvry and Sadoulet, 2009). Underwriting yield losses due to disasters and extreme events, as a means to increasing adaptive capacity in the food system, has been an effect strategy as illustrated by the U.S. case study.

Conversely, in the U.S. the rebranding of food system labor as frontline workers, helped keep the system going. Allowing movement of labor and food products ensured that products continued to have a market domestically, and alleviated further production losses. Yet, while policy and planning kept the food system moving, COVID protections for food system workers were not institutionalized. After advocacy from farmworker justice organizations, in October 2020, California, passed legislation supporting prioritization of farmworker access to testing and personal protection equipment, as well as safe isolation safes. In the U.S. case it would be pertinent to develop more stringent farm and food worker protections that ensure worker safety and health, especially with extreme heat and air quality issues becoming prevalent with climate change.

While supply-side agricultural adaptations will help protect farmer yields, in the long-run addressing food insecurity requires a focus on rural infrastructure investment and poverty alleviation. Both case studies illustrated the benefits of cash transfers during disasters. The cash transfers in the U.S. helped families and individuals overcome material hardship, food insecurity, and reduced anxiety. As a counter point, the lack of cash transfers to the rural and agricultural communities in India, reduced rural purchasing power further, especially for those from lower castes. Since shocks like COVID can happen at any point, social protection programming, like SNAP and WIC need to be flexible. Benefits should be transferred as and when the event takes places, and should be topped up to reflect the magnanimity of the disaster. Benefits should also be increased to reflect current costs of nutritious food by locality. Expanded social protection programming is necessary both in the Global South and North, as the case studies illustrate. While India may not have similar financial reserves as the U.S. to take such an approach, any level of cash transfers to the poor in India would have helped. In the future, Global North countries, can redirect their overseas development aid and climate financing to Global South Countries as direct budgetary support to prop up social protection programming for poverty alleviation. The experience with COVID, and the results of cash transfers in the U.S. makes a great case for universal basic income as an adaptation measure.

Additionally, technology played a role in COVID adaptations. SNAP has strict guidelines about where and how it can be used. During the pandemic, California adapted its SNAP use guidelines to allow for online purchasing at select retailers. Online food purchasing would save families time, and transportation costs, and for those without transportation options, online purchasing and deliveries in Madera would have been a welcome recourse. Similarly, restaurants, retail, and even community supported agriculture models pivoted to online ordering and deliveries. Similar, roll-out of technological adaptations in India was hampered by the low levels of electricity and internet infrastructure and instability of the electricity grid in rural India.

These policy, technological, and on farm adaptations certainly helped communities in U.S avert a much larger socio-economic disaster, it did not however consider or address the inequities in the food system that continue to perpetuate disproportionate burden on the already vulnerable. Take for example, the lack of farm and food worker protection mandates during the pandemic or the lack of a Federal mandate for hazard pay for these workers. The lack of any concerted effort to provide farmworkers with cash benefits, or other social protection programming speaks volumes. The rate of COVID related infection and death in farmworker population is telling of who bore the brunt in the pandemic and where the gaps are. While tenuous, the U.S. food system relies on farmworkers, and regardless of their status in the country, in the midst of a global pandemic, farmworkers should have received

more deference. Similarly, in India, small and marginal farmers are the heart of Indian agriculture and should have received higher degree of consideration and protections.

CONCLUDING REMARKS AND FUTURE RESEARCH

The comparative analysis has laid out differences in the determinants of food security in the United States and India as proxies for Global North and South countries respectively. Despite the differences, food insecurity is likely to worsen in both places, especially with climate change (Birthal et al., 2014; Sun et al., 2019). In both India and the U.S., those that are vulnerable are also food insecure, experience persistent poverty, and will be unable to weather shocks from both market failures and extreme climate events (Wheeler and Von Braun, 2013; Brown et al., 2015). While food security scholars have recently started to integrate a food systems approach to their work, scholars have not paid as much attention to considering climate impacts on food security. As a result, there are knowledge gaps in shoring up resilience in food systems against climate impacts—both slow and abrupt changes.

Through this literature review and case analysis, we illustrate that the modernized community food systems in the Global North, dominated by grocery stores for food retail, are largely disconnected from local food production. As a result, food security is a determinant of financial and social capital to access food—food in itself is available abundantly if you can afford it and get to it. In the Global North, as pointed out in the case review, the most food insecure are the consumers, disconnected from land. Climate protective measures in the Global North should lean toward responsive social protection programming and universal basic income to overcome the economic shock brought on by climate disruptions, as was done with the COVID-19 response.

On the flip side, traditionally oriented food systems of the Global South with a heavy reliance on traditional markets that depend on deliveries from local farmers are tightly woven and interconnected to the fortunes of small and marginal farmers. Small and marginal farmers are also the most climate vulnerable and if they are adversely affected, so is food security for everyone downstream in the food system, as illustrated by the Kerala case study. The question of climate and food insecurity is more tightly connected in both problem and solution in the Global South.

Given the differences in vulnerability and the different ends of the spectrum of the food system that are affected by climate shocks, adaptations to protect food security outcomes need context and nuance. In short, although individuals in both the Global South and North are vulnerable to climactic stressors on their food ways, the impacts are unevenly distributed. As such, one-size-fits-all strategies and policies will invariably fail or work only for a subset of the population. While we have offered some ideas about what context driven food security adaptations could look like in the two regions, more research is needed to elucidate what works in what context. Future research should consider analyzing on the ground, situated, empirical relationship between social protection programing during natural disasters and food security outcomes as well as long-term social-ecological projects in the Global South that can highlight strategic options for food security and climate adaptation in the food systems.

AUTHOR CONTRIBUTIONS

SRa and DWW made substantial contributions to the conception and design of the study. SRa and SRo contributed to the data collection and SRa performed the analysis. SRa and CB revised the work critically and SRo contributed to the revisions. All authors read and approved the final manuscript.

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Sustainable Intensification Practices Reduce Food Deficit for the Best- and Worst-Off Households in Ethiopia and Mozambique

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An adequate food supply is widely recognized as a necessary condition for social development as well as a basic human right. Food deficits are especially common among semi-subsistence farming households in eastern and southern Africa and farm productivity is widely regarded as the locus for enhancing household food outcomes. However, knowledge gaps surrounding benefits associated with climate smart, productivity-enhancing technologies require attention. This study evaluates benefits associated with sustainable intensification farm management practices (crop residue retention, minimum tillage, manure application and use of herbicides, pesticides, fertilizer, and improved seeds) for household calorie and protein supplies and demonstrates their scope across households with high-, moderate- and low- likelihoods of calorie and protein deficits. Household-level calorie and protein deficits were estimated from survey data on food production, acquisition and consumption for households in Ethiopia and Mozambique. Multinomial logistic models were used to identify drivers of household food deficit status and logistic model trees established "rules of thumb" to classify households by food deficit status as low, moderate or high likelihood. In Ethiopia, especially wet seasons were associated with a high likelihood of a food deficit while especially dry seasons were associated with a high likelihood of food deficit in Mozambique. The practices associated with sustainable intensification and related technologies substantially enhanced food outcomes in groups with a high- and a low-likelihood of food deficit, and associated benefits were high for the best-off households. Benefits associated with sustainable intensification technologies were not observed for households with a moderate likelihood of a food deficit and some technologies even increased risk. The sustainable intensification practices assessed here were associated with improved food outcomes yet benefits were limited in scope for households of intermediate status. Thus, there is a need to expand the technical options available to reduce food deficit.

Keywords: Eastern Africa, poverty-trap, semi-subsistence, Southern Africa, sustainable intensification

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INTRODUCTION

Food shortages in Ethiopia and Mozambique remain widespread and erratic despite long term positive food availability trends from 1990–92 to 2014–16 (FAOSTAT, 2020). Although food security indicators are rarely reported in Ethiopia, optimistic government-led projections of food availability estimated that 5.6 million individuals (i.e. 13% of the population) were food insecure following an above-average rainy season from July-September of 2016 (FSIN, 2017). A subsequent drought during the Meher season of 2017 started a prolonged dry spell with crop losses of 50–90% leaving an estimated 9.7 million people in need of urgent food assistance (FAO et al., 2019). Recent food crises in Mozambique resulted from a resurgence of political disputes and armed conflict in central and southern Mozambique (WFP, 2018), a severe drought during the 2015/2016 El Niño years and the occurrence of extreme weather events including cyclone Idai, known as "the worst climate-related disaster to hit Mozambique this millennium" (WFP, 2019). Access and reliability of food supplies were especially precarious for semi-subsistence households, where food availability was especially sensitive to crop failure and high-food prices (FSIN, 2017). The number of undernourished people rose rapidly with resultant food shortages and elevated food prices from 2.7 million in 2010–12 to an estimated 8.8 million in 2015–17 (FAO et al., 2019). The number of moderately or severely food insecure people increased from a three year average of 19.4 million in 2015–2017 to 20.4 million in 2016–2018 (FAOSTAT, 2020). This establishes an urgent need to identify mechanisms that enhance household food-related outcomes in these regions.

Increased household production is widely considered the main mechanism for overcoming food shortages among semi-subsistence household farmers, where an estimated 60% of the household food supply is produced by the household and own production provides the major income source for purchasing food (Frelat et al., 2015; Marenya et al., 2018). Here, sustainable intensification is understood to encompass the wide range of practices including, where appropriate but not limited to conservation agriculture, with potential to produce more food from the same area of land in a variable and changing environment, while maintaining or improving the resource base. This definition, fully consistent with definitions of Pretty (2009), requires potential for increased production in a region, rather than absolute certainty which is justified given the highly temporal and spatial variability of growing conditions that a region can encompass. Sustainable intensification (SI) practices, including fertilizer and herbicide application, crop residue retention, reduced tillage and improved seeds, have potential in many regions to enhance production outcomes. They have been associated with increased yield and reduced risk of crop failure among semi-subsistence households in Ethiopia (Abebe et al., 2014) and Mozambique (Nyagumbo et al., 2016, 2017). In addition to direct production benefits, SI has resulted in income gains and poverty reduction (Teklewold et al., 2013; Zeng et al., 2017). Although the substantial contribution of on-farm production to the household food basket is clear, literature relating SI to household food-related outcomes and their scope across diverse production systems is less established (Webb et al., 2006; Qaim, 2014; Webb and Kennedy, 2014).

Various studies have demonstrated food- and nutrition-related benefits associated with a single SI technology (Jones et al., 2014). Cross-sectional data in eastern Zambia showed that adoption of improved maize varieties significantly reduced child malnutrition as proxied by stunting (Manda et al., 2016). Observational panel data from farm households in India showed that adoption of Bt cotton technology significantly increased calorie and micro-nutrient (zinc, iron, vitamin A) consumption per adult equivalent (Qaim and Kouser, 2013). The few studies that consider impacts of multiple technologies suggest that benefits of agricultural technologies are greater when they are applied jointly, rather than individually. In Ethiopia, joint application of maize-legume cropping diversification and improved maize varieties had a greater impact on child stunting, per capita consumption of calories, protein and iron; and dietary diversity compared to benefits from crop diversification or use of improved maize varieties when used alone (Marenya et al., 2018).

The benefits associated with SI technologies have been inconsistent across semi-subsistence production systems of eastern and southern Africa (Giller et al., 2009). Within Ethiopia, substantial variation in benefits have been reported, where soil and water conservation practices have enhanced productivity (Zikhali, 2008; Adgo et al., 2013; Yenealem et al., 2013; Tesfaye et al., 2016), reduced technical efficiency (Oduol et al., 2011) and yielded very low returns (Kassie and Holden, 2006; Kassie et al., 2009). Benefits have displayed a common phenomenon of relatively low returns under high-risk, resource constrained conditions (Stephens et al., 2012). This distribution of benefits have produced low-level stagnation (Tittonell and Giller, 2013). The combined low-return and high-risk conditions act as a self-reinforcing mechanism or poverty trap, where current poverty is itself a direct cause of poverty in the future (Azariadis and Stachurski, 2005). These relationships have generated chronic poverty and food shortages across a large share of the world's population (Carter and Barrett, 2006; Barrett, 2010; Stephens et al., 2012).

There is a growing body of evidence showing a low-return to high-risk relationship when SI technologies are applied across diverse semi-subsistence farmers in ESA. Households that produced on highly degraded (low soil organic matter) soils in western Kenya experienced lower fertilizer use efficiency and returns to fertilizer use than households that produced on rich soils, resulting in persistent yields declines and poverty and food insecurity (Marenya and Barrett, 2009a,b). Farmers in Zimbabwe provide evidence of constraints imposed on productivity by poverty, where some groups of farmers had a productivity advantage over other groups not only because they used more fertilizer per hectare, but because they attained a higher rate of return from its use (Zikhali, 2008). In Kenya, female-headed households experienced lower returns from increasing land area under cultivation compared to their male counterparts putting them at higher-risk of a food deficit than their male-headed household counterparts (Kassie et al., 2014).

A critical step in understanding the consequences of SI for household food supplies, is to understand who, among

semi-subsistence household farmers, is positioned to take advantage of those technologies (Adato et al., 2006; Barrett et al., 2006). This study spans a demographically diverse set of households and agroecological regions to assess the scope of benefits associated with SI technologies. We hypothesize that (i) SI technologies are associated with reduced household food deficit, (ii) and the magnitude of the benefits depends on the baseline likelihood of a food deficit. We characterize differences in the demographic composition and structural characteristics of households with a high-, moderate- and low-likelihood of food deficit in Ethiopia and Mozambique. We then present evidence that these differences have consequences for the benefits (reduced food deficit) of SI technologies.

MATERIALS AND METHODS

Household Selection

The analysis used three waves (2010, 2013 and 2016) of household survey data collected across all the maize-growing agro-ecological zones of Ethiopia ($n = 1940$) and Mozambique ($n = 1145$) under the Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) Program. The SIMLESA Program was a regional agricultural Research for Development (R4D) program anchored on the collaboration and support from the national agricultural research institutes (NARIs) and many partners, institutions, and farmers. Since 2010, all households included in the study were exposed to SI technology through demonstration plots and through these outreach activities, encouraged to adopt SI practices namely, crop residue retention, minimum tillage, manure application and use of herbicides, pesticides, fertilizer, and improved seeds. All households in the sampled population were included in under the SIMLESA Program and thereby had equal exposure to technologies and information.

Purposive and stratified sampling methods were used to select semi-subsistence households, for which household production played a major role in supporting household food supply and where households had equal exposure to the SIMLESA Program initiatives. Household selection was stratified across agroecologies with distinct maize production potentials. In Ethiopia, households were selected from the Southern (SNNP) region and western parts of Oromiya, where maize–legume-based farming systems were common. In the first stage of household selection, nine districts were purposely selected (five from Oromiya, three from SNNP and one from Benishangul-Gumuz): Bako Tibe, Gubuesyo, Shalla, Dudga, Adami Tullu, Mesrak Badawacho, Meskan, Hawassa Zuriya and Pawe. Seven of these districts (Shalla, Dudga, Adami Tullu, Mesrak Badawacho, Meskan and Hawassa Zuriya) represent the low-potential agroecological zone, where rainfall is generally low and erratic; while the remaining districts represent the high-potential zone with adequate rainfall. In the second stage, households were randomly selected from 69 farmer associations with populations proportional to the size of the association. These regions spanned a wide range of household food supply conditions. Food insecurity indices for these regions have been reported at levels as low as 10 to 0 food insecure people per km^2 and as high at 1000 to 100 food insecure people per km^2 (Potgieter et al., 2013).

Households in Mozambique span four districts (Sussundenga, Manica, Gorongosa and Angonia) and 154 villages. Two of the districts (Sussundenga and Manica) are situated in the province of Manica, while Gorongosa and Angonia are found in the provinces of Sofala and Tete, respectively. A multistage random sampling procedure was used to select households from each district. Proportionate household sampling, using census data for the selected villages, identified survey households. All households in Ethiopia and Mozambique provided oral consent to participate in the study prior to their involvement and households were de-identified to ensure confidentiality, using a password secured file that linked household identifiers to a separate file containing contact information.

Households were georeferenced with the aim of sampling identical households over time. However, the surveys were not treated as a panel dataset because the survey data did not satisfy a key assumption of fixed and random effect regression models for analysis of panel data (i.e. unique attributes of individuals which, may or may not be correlated with individual dependent variables, are constant across time). Multiple household characteristics changed from one survey period to the next so that too few household characteristics were consistent enough to be considered the same house. So household surveys are statistically independent across the three years of sampling. In contrast to a longitudinal study, the year was removed from the analysis, while major covariates including climate data were included. Attrition due to changes in household composition, out-migration and deaths likely explained significant changes in households over time in this region as well as high levels of both adoption and dis-adoption (Marenya et al., 2018).

Climate Data

The study spans the severe drought of the 2015/2016 El Niño years. Rainfall data from a gridded (0.5×0.5 degree) CRU TS4.01 dataset spanning 1901–2016, (Harris and Jones, 2017), were assigned to each surveyed household based on household GPS coordinates. Two sets of rainfall indicators were derived to capture two timescales that cover the production, harvest and post-harvest periods captured in the household surveys: the entire calendar year and a country-specific growing season. In Mozambique, annual rainfall data covers the 12 months of rainfall from January to December (thus including maize establishment), while seasonal rainfall in Mozambique includes rainfall from October to May. The surveys were conducted between June and October in Mozambique. In Ethiopia, annual rainfall was calculated for the year prior to the survey year and seasonal rainfall is the cumulative rainfall between March and November. The surveys in Ethiopia were conducted between October and December.

Absolute and relative indicators of water stress were derived and included in the analysis to identify predictors of household food supply. In absolute terms, rainfall is expressed as; total rainfall (mm) within the annual or seasonal period and the range (mm) and median (mm) of historical (1901:2016) averages,

where range is the difference between the smallest and largest observations. An anomaly ratio, calculated as the difference between the specified timeframe and the long-term average divided by the averaged difference between the specified months and the long-term average provides a relative measure of water-related stress. A large positive anomaly ratio reflects especially wet conditions for the region at the time (e.g. flooding) while a large negative anomaly ratio reflects especially dry conditions for the region at the time (e.g. drought). The rainfall percentile was also reported in the descriptive analysis. The percentile is determined by ranking all historic observations in order, from driest to wettest. These observations are divided into 100 equal groups where the 0th and 100th percentiles are the lowest and highest on record.

Household Surveys

The same structured questionnaire was used in all three years and the surveyed respondents were interviewed using trained and experienced enumerators with knowledge of the local language. The surveys were carried out by the International Wheat and Maize Improvement Center (CIMMYT) in collaboration with the Ethiopian Institute of Agricultural Research (EIAR) in Ethiopia and the Instituto de Investigação Agrária de Moçambique (IIAM) in Mozambique. Each survey was conducted with the member of the household who was nominated by household members to represent the household. This was typically the household head or the spouse. Enumerators were instructed to ensure that any household representative nominated was thoroughly familiar with the production, consumption and other socio-economic activities of the household. While it is possible that no single person was responsible for all food sources, all the nominated household members were heavily involved in production, purchase and consumption decisions. Household representatives were asked to recall household demographics, productive assets (land, labor and livestock), management practices used, crop production levels, and quantities of food acquired, stored and consumed over the most recent production year (Wilkus et al., 2019). This survey was designed and implemented in a way to minimize recall bias, or the discrepancy between natural systems data and a participants' account of their experiences. The survey period did not exceed an hour and participants were asked to recall the most recent harvest season, which had occurred within months of administering the survey. The head of household was asked if the following crop management practices were used on any subplot in the previous season, reporting yes or no to indicate if: 1. Crop residues were left on the sub-plot the previous season, 2. Minimum tillage was practiced on any subplot, 3. Herbicide was applied, 4. Pesticide was applied 5. Fertilizer was applied, 6. Manure was applied and, 7. Improved seed was purchased and sown.

The survey captured household food items from three sources: household livestock production, off-farm purchases and household crop production (**Figure 1**). Household livestock production, off-farm purchases and household crop production were reported separately for each livestock or meat product and for each crop and produce item. Crop production questions were crop specific and included crop aggregate production per crop (kg) during separate seasons while also accounting for stocks going into each season. In Ethiopia this included the following estimates, stock before the Meher season harvest (kg), Belg season harvest (kg) which amounted to the total available stock after the Belg season harvest (kg). The head of household estimated the quantity consumed (kg) from the total available stock after the season harvest. The survey captured the following to determine the ending stock [stock before the next season's harvest (kg)] from total available stock after the Belg season harvest (kg): the quantity sold (kg), quantity used for seed (kg), gift, tithe, donations given (kg) and post-harvest losses. In addition to estimates from household production, households estimated the amount bought (kg) and food aid/borrowed/gifts received (kg). Specific food products were reported in kilograms and converted into energy (kilocalories) and protein (grams) using product-specific conversion factors (Daba and Shigeta, 2016; US Department of Agriculture et al., 2018), (**Supplementary Table 1**).

Food Sufficiency Estimation

The minimum household food requirement was estimated based on 2100 kcal and 60 g protein per day per consumption equivalent (CE), adjusted using conventional age- and gender-based requirement assumptions (FAO et al., 2015; FAOSTAT, 2020). This adjustment was used in the absence of more accurate data on the health and lifestyle of household members. The minimum food requirement was subtracted from the available food supply to determine the food surplus or deficit, where sufficiency is defined as having consumed and stored at least the minimum energy and protein requirement (**Figure 1**). Household food status outcomes were; 1. Sufficient energy and protein; 2. Sufficient energy and insufficient protein, 3. Insufficient energy and sufficient protein; and 4. Insufficient energy and protein.

Analytical Approach

The analysis combined standard econometric endogenous switching regressions (Di Falco et al., 2011) and predictive public health modeling to identify and compare sub-populations of surveyed households. Consistent with the first step of the endogenous switching regression approach, the analysis began with the estimate of the multinomial logit model to account for any selection bias on household characteristics that impact both the probability of using a SI practice and the probability of a certain household food status outcome. The second component of standard econometric approaches accounts for any selection bias on household characteristics that impact household participation in an agricultural promotion activity and is relevant from impact assessments where a subset of the population is exposed to an intervention. This study assessed a population with equal exposure to SI promotion efforts and required methods outside of the standard econometric approaches for structuring and comparing surveyed households.

The second step of the analysis established comparison groups. The factors identified in the multinomial logit model were used to develop logistic model trees that divided households into homogenous groups within Ethiopia and Mozambique. This

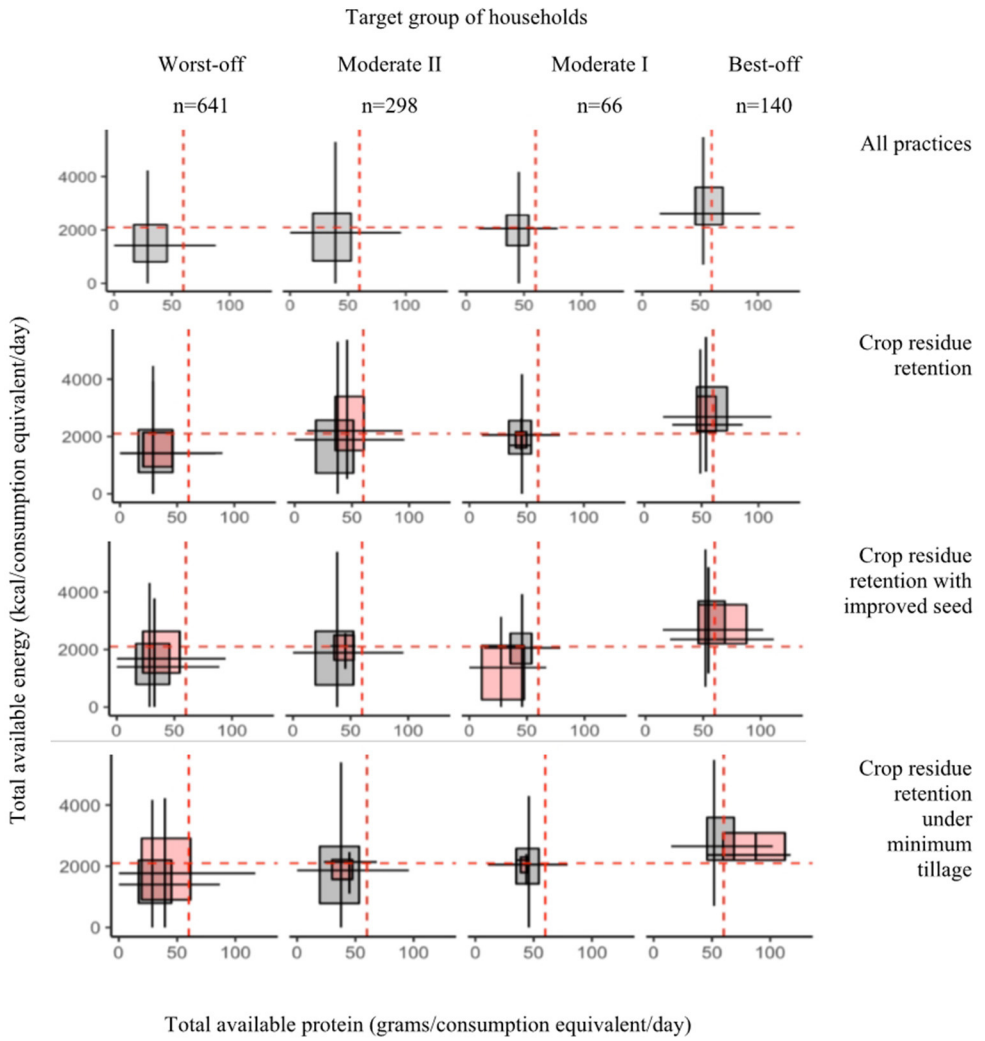


FIGURE 1 | Model for the estimation of food sufficiency showing three sources of food; Household livestock production, food purchase from off-farm activities and on-farm crop production.

allowed for unbiased within group comparisons of food deficit with and without a management practice or set of practices. The method accounts for important interactions in the data and has been used to explain variation of a single response variable, using combinations of exploratory variables displaying non-linear relationships and high-order interaction (Lemon et al., 2003). The approach has been applied extensively on survey data in ecology, socio-economic analyses and agricultural sciences. The method represents the most widely accepted approach for predicting the probability of an adverse outcome in the medical literature and is widely used to establishes clinical subgroups of subjects at very high or very low risk of health-related outcomes (Demir, 2014). Previous work in the same region and on similar survey data applied classification and regression tree analyses (Tittonell et al., 2006). Given the complexity of the data set, Tittonell et al. (2007) used classification and regression trees (CART) to relate biophysical variables (including food production) with management factors. This approach was similarly used here.

Food Sufficiency Models

Food sufficiency models were developed using independent variables that accounted for the largest proportion of the observed variability in the data (Osborne and Costello, 2009). A Principal Component Analysis (PCA) was initially conducted for each country separately to reduce the dimensionality of the analysis and minimize collinearity between predictors of food sufficiency. Variables with the highest loading weights within each principal component having an eigenvalue greater than 1 were retained to model (**Supplementary Tables 2, 3**).

Multinomial logit models (function "multinom", R Core Team, 2017) were developed for each country separately to control from differences in institutional settings that could influence the likelihood of a food deficit. Household food status

outcomes were modeled as a linear combination of predictor variables. The method did not assume normality, linearity or homoscedasticity, which would be required with alternative approaches like discriminant function or canonical analyses. The food sufficiency models were further simplified by iteratively removing variables through backward stepwise AIC analysis. Energy and protein sufficiency is treated as the reference category and is expressed as Equation 1.

$$(Y_i = m) = \frac{1}{1 + \sum_{h=2}^{M} \exp(Z_{hi})} \quad (1)$$

The probability of experiencing one household food status outcome was compared to the likelihood of energy and protein sufficiency, so an increase in the probability reflects an increased likelihood of a food deficit. This required the calculation of three equations (Equation 2), one for each category relative to the reference category (energy and protein sufficiency). Three predicted log odds – or logit coefficients (β), were generated with one for each food sufficiency outcome relative to the reference category.

$$P(Y_i =) = \frac{\exp(Z_{mi})}{1 + \sum_{h=2}^{M} \exp(Z_{hi})} \quad (2)$$

Classification of Households Into Best-, Moderate and Worst-Off Groups

The variables that predicted household food status were used to classify households into groups with a low-, moderate and high-likelihood of a food deficit. The group with a low likelihood of a food deficit was considered "best-off" while the group with a high likelihood of a food deficit was considered "worst-off". This step of classifying farms is necessary for further analysis of distinct subpopulations, rather than a pooled dataset. Through this method of disaggregating the dataset, the analysis controls for any bias distribution of household characteristics that impact household food status. Threshold levels of the food sufficiency predictors were calculated from the food sufficiency models using recursive partitioning trees (Package rpart in R software, Therneau and Atkinson, 1997). The rpart function identified the variable which discriminated most between household groups, partitioning the data on this variable, and then identified splitting criteria which maximized the separation in the data between distinguishable sub-groups. This process was repeated until all groups were distinct. The minimal number of terminal nodes or household groups, was selected to ensure ease of interpretation while maintaining a sufficient number of households (at least three) to represent SI technologies for subsequent analysis.

Benefits of Sustainable Intensification Practices

Similar to the first iteration of food sufficiency models, multinomial logit models were used to predict food sufficiency outcomes from the on-farm application of SI technologies (function "multinom", R Core Team, 2017). These models were developed separately for groups with a low-, moderate- and high-likelihood of a food deficit. Within group comparisons thereby accounted for any selection bias on household characteristics that impacted both the probability of adopting sustainable intensification practices and household food status outcomes.

RESULTS

Climatic Conditions

Total seasonal rainfall levels, relative to the long-term seasonal average, varied across the surveyed households in Ethiopia. In the 2010 main growing season, the majority (75%) of households experienced dryer than normal conditions (below 50% of historical rainfall levels). However, by 2013, the majority (75%) experienced wetter conditions and in 2016, most households (83%) experienced normal conditions (**Figure 2**). Overall, 42% of households reflect normal conditions, 26% reflect dry and the remaining 31% represent wetter than normal conditions. The majority of the dry observations fell within the 20–40th percentile range and the wet observations fell in the 60–80th percentile range. The wettest conditions observed in Ethiopia represent the 90th percentile of historic rainfall levels and the driest conditions represent the 4th percentile.

In the 2010 main growing season in Mozambique, 51% of surveyed households experienced normal conditions and 42% experienced a relatively dry season. In 2013, 95% of households experienced normal conditions and in 2015, 96% had a dry season, reflecting the severe drought of the 2015/2016 El Niño years. The majority of the dry observations fell within the 5–10th percentile range while the few households that experienced a wet year fell within the 80th percentile. The wettest conditions observed in Mozambique represent the 88th percentile of historical rainfall levels and the driest conditions represent the 8th percentile.

Household Food Status Outcomes

Just over half (52%) of surveyed households in Ethiopia had sufficient energy and protein, while 30% of the surveyed households were deficient in energy and protein, 16% were deficient in protein only and 1% was deficient in energy only. In Mozambique, 19% of the surveyed households had sufficient energy and protein, and 59% were deficient in energy and protein, while the remaining 22% were deficient in protein only.

Predictors of Food Deficit

The variables retained from the PCA analysis and evaluated as potential predictors of food deficit in Ethiopia were; age of the head of household, land area under cultivation in the 'short rain' Belg season, tropical livestock units (TLUs), distance from the household to the nearest market, median annual rainfall and the seasonal rainfall anomaly ratio (**Supplementary Table 2**). Out of this set of variables, the likelihood of a household food deficit in Ethiopia increased the seasonal rainfall anomaly ratio (wetter than average years) and the age of the household head and decreased with rainfall level (seasonal rainfall median) and the number of livestock owned (**Table 1**).

The variables retained from the PCA analysis and evaluated as predictors of food deficit in Mozambique were; household consumption equivalents (CE, i.e. family size adjusted for

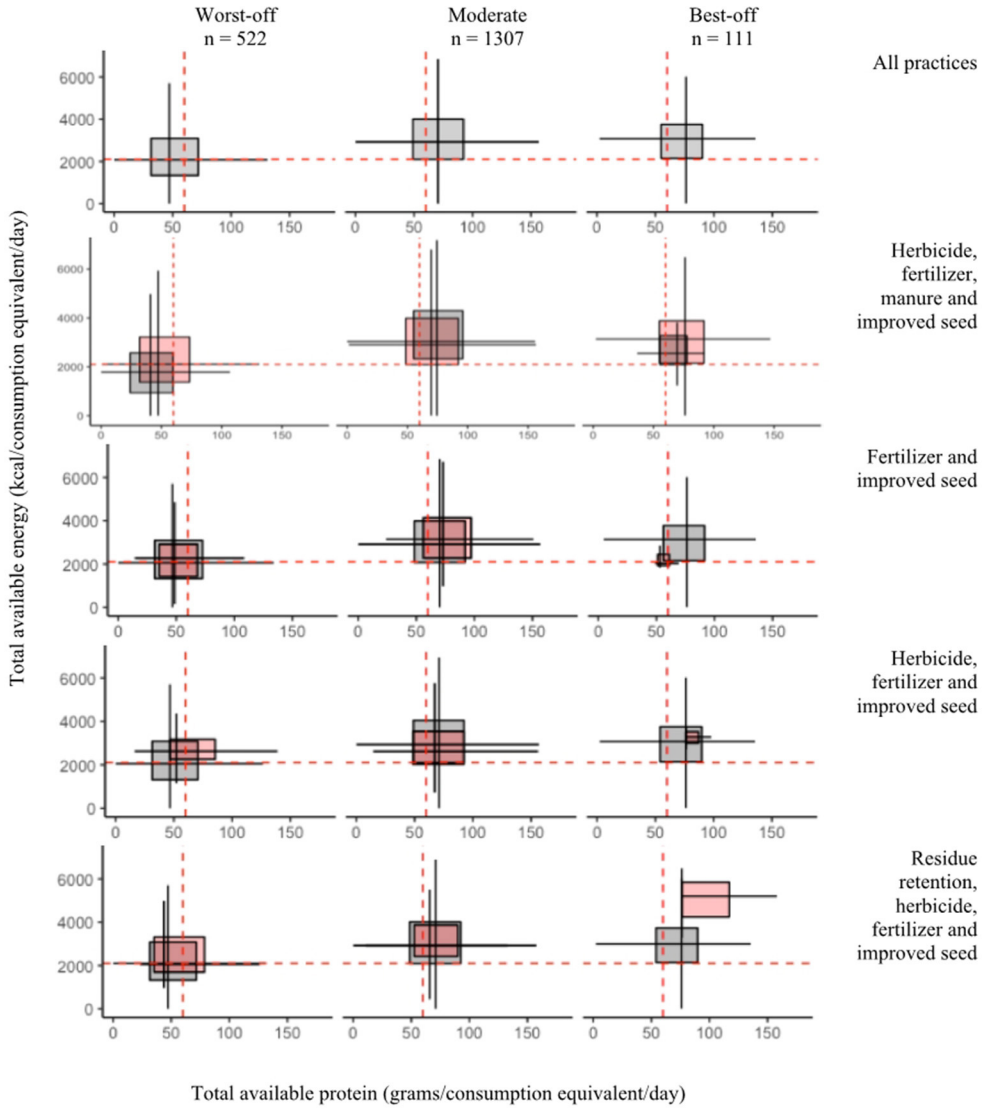


FIGURE 2 | Spatial distribution of the seasonal rainfall anomaly ratio across the sampled households in Ethiopia and Mozambique. The anomaly ratio is calculated as the difference between the survey period and the long-term average, divided by the average difference between the specified months and the long-term average. Seasonal anomaly ratios are shown for each main growing season prior to the survey and demonstrate the range of conditions experienced over the survey years. The histograms plot the rainfall percentile received over the survey period.

age and gender), age of the head of household, education of the head of household, land area under cultivation in the main growing season, land area under cultivation in the second planting, distance from the household to the nearest market, total seasonal rainfall and the seasonal rainfall anomaly ratio (**Supplementary Table 3**). The likelihood of a food deficit decreased with the seasonal rainfall anomaly ratio (wetter than average years) and the age of the head of household in Mozambique (**Table 1**). The likelihood of a food deficit also decreased with land area under cultivation in the main growing season, land area under cultivation in the second planting and with distance to the market.

Best-, Moderate and Worst-Off Groups

The logistic model tree identified "rules of thumb" for establishing groups with distinct likelihoods of food deficit. The number of tropical livestock units (TLUs) provided a first simple rule of thumb to classify households in Ethiopia (**Figure 3**). 60% of the households with at least three TLUs had sufficient energy and protein, whereas only 38% of the households with less than three TLUs had sufficient energy and protein. A rainfall anomaly ratio value of less than −0.1 (where the lowest reported value was −0.37) provided the next rule of thumb to predict food availability status among the households with less than three TLUs. 64% of the households with an anomaly ratio of less

than −0.1 had sufficient energy and protein while only 32% of the households with an anomaly ratio of greater than −0.1 had sufficient energy and protein. This group, had the lowest likelihood of a food deficit and constituted only 6% of the surveyed population or 111 households (**Table 2**). The moderate group in Ethiopia had more TLUs (TLU ≥ 3) than the best- and worst-off groups and constituted 66% of the surveyed households ($n = 1307$).

TABLE 1 | Change in the log odds of a food deficit with household- and environment-level factors in Ethiopia and Mozambique.

Indicators	Logit coefficient (®, signif.)		
	Energy and protein deficit	Energy deficit	Protein deficit
Ethiopia			
Age of the head of household (years)	0.018**	0.017	0.010**
Tropical livestock units (TLUs)	−0.179**	−0.068	−0.060**
Seasonal rainfall median (mm)	−0.001**	−0.000	−0.001**
Seasonal rainfall anomaly ratio	1.372**	−0.160**	2.201**
Residual deviance	3,922		
AIC	3,952		
Mozambique			
Consumption equivalents	0.461**	0.419	0.090
Age of the head of household (years)	−0.009*	−0.064	−0.001
Land under cultivation in the main growing season (ha)	−0.246**	0.535**	−0.085
Land under cultivation in the second planting (ha)	−0.205**	−0.261	0.008
Distance to market (km)	−0.003**	−0.022	−0.002
Seasonal rainfall anomaly ratio	−2.440**	3.093	−0.438
Residual deviance	2,025		
AIC	2,067		

** $p < 0.05$, * $p < 0.1$.

Households in Mozambique were classified into groups with distinct likelihoods of a food deficit based on household consumption equivalents (CE), the anomaly ratio of the last seasons' rainfall and the area of land under cultivation over the last major growing season (**Figure 4**). A consumption equivalent (CE) threshold of 3.9 provided the first simple rule of thumb to predict the risk of an energy or protein deficit (**Figure 4**). 14% of the households with 3.9 CE or greater had sufficient energy and protein, whereas 25% of the households with less than 3.9 CE had sufficient energy and protein (**Table 3**). A rainfall anomaly ratio value of −0.1 provided the second rule of thumb to predict food availability status among the households with less than 3.9 CE. 20% of the households with an anomaly ratio of less than −0.1 had sufficient energy and protein while 31% of the households with an anomaly ratio of at least −0.1 had sufficient energy and protein. A land area under cultivation of 0.4 ha provided the final criterion for predicting food deficits in households with less than 3.9 CE and an anomaly ratio of at least −0.1. 38% of households with greater than or equal to 0.4 ha had sufficient energy and protein while only 20% of households on less than 0.4ha had sufficient energy and protein. Households with at least 3.9 CE were most likely to have an energy and protein deficit (**Table 3**). Two moderate household groups were identified, both of which had smaller households (CE < 3), than the worst-off group. One moderate group (Moderate I) had a smaller household size (<3.9) than the high-risk group and experienced less variable rainfall (Anomaly ratio < −0.1) than the best-off group and the other

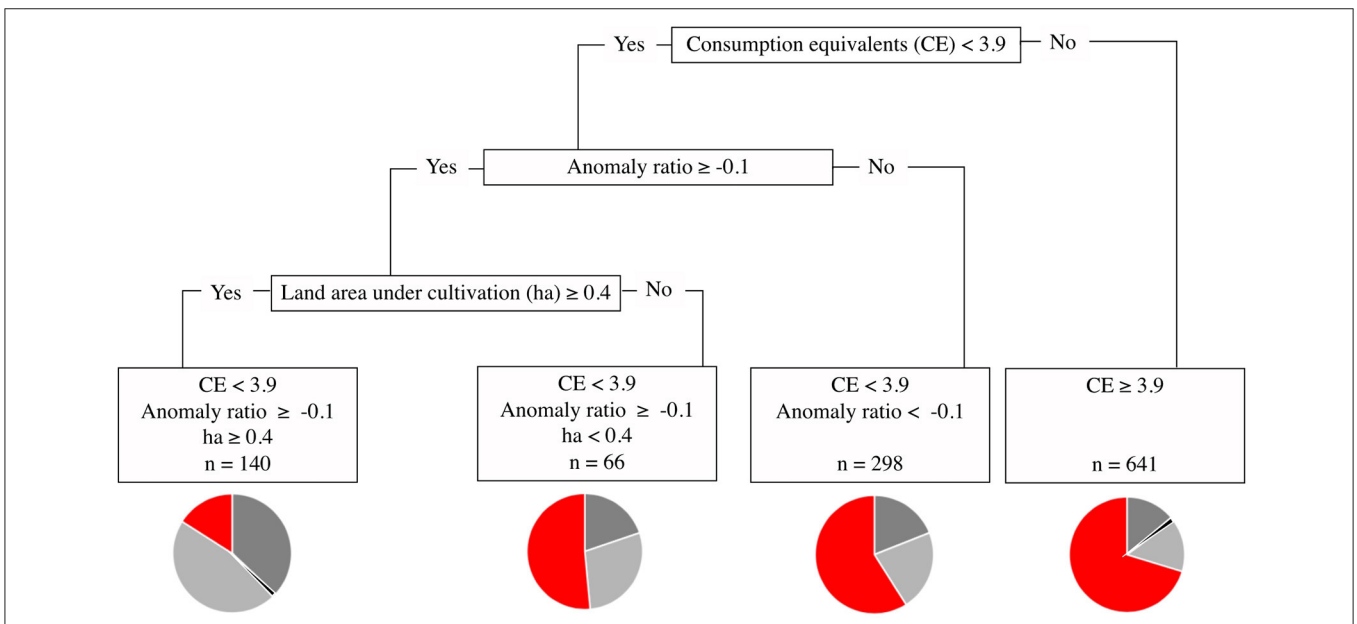


FIGURE 3 | Logistic model tree for households in Ethiopia household. Three groups of households are represented as terminal nodes. Tropical livestock units and the anomaly ratio of the last seasons' rainfall predict food availability status.

TABLE 2 | Food availability status by target population in Ethiopia.

Group of households	Likelihood of a food deficit	Total households (count)	Prevalence of food availability outcome within the target population (%)			
			Sufficient energy and protein	Only energy deficit	Only a protein deficit	Energy and protein deficit
TLU < 3, Anomaly ratio ≥ −0.1	Worst-off	522	32	1	17	49
TLU ≥ 3	Moderate	1,307	60	1	16	23
TLU < 3, Anomaly ratio < −0.1	Best-off	111	64	2	13	21
All households		1,940	52	1	16	30

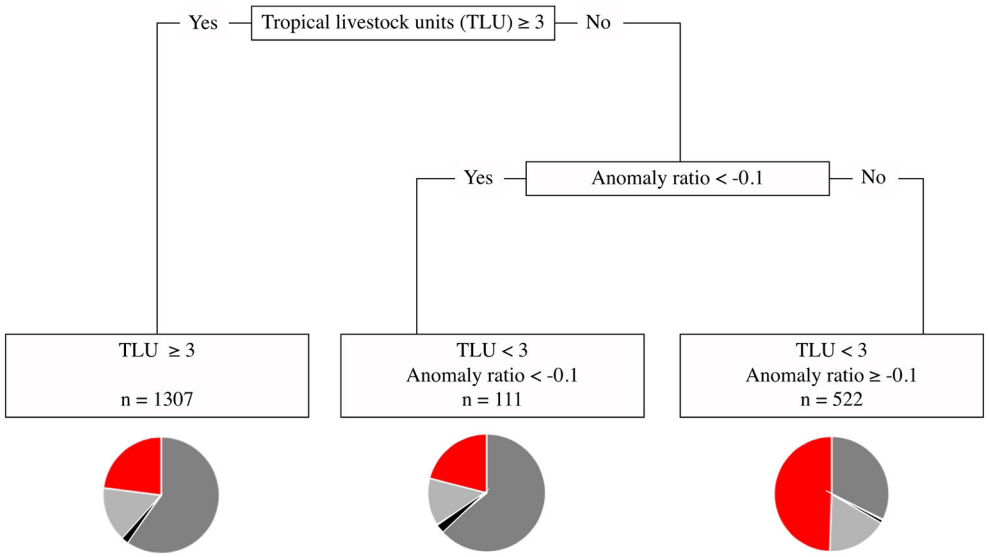


FIGURE 4 | Logistic model tree for households in Mozambique. The tree produces four groups of households, represented as terminal nodes. Household consumption equivalents (CE), the anomaly ratio of the last reasons' rainfall and the area of land under cultivation over the last major growing season predict food availability status.

TABLE 3 | Food availability status by target population in Mozambique.

Group of households	Group	Total households	Prevalence of food availability outcome within the target population (%)			
			Sufficient energy and protein	Only energy deficit	Only a protein deficit	Energy and protein deficit
CE ≥ 3.9	Worst-off	641	14	1	15	71
CE < 3.9, Anomaly ratio < −0.1	Moderate I	298	20	0	23	56
CE < 3.9, Anomaly ratio ≥ −0.1, Cultivated land < 0.4	Moderate II	66	20	0	29	52
CE < 3.9, Anomaly ratio ≥ −0.1, Cultivated land ≥ 0.4	Best-off	140	37	1	46	16
All households		1,145	19	0	22	59

moderate-risk group. The other moderate-risk group (Moderate II) was distinguished from the best-off group by cultivated land area, where the moderate group had less land under cultivation (ha <0.4) than the best-off group.

Food Sufficiency With Sustainable Intensification Technologies

The most common practice observed in Ethiopia was the joint use of herbicide, fertilizer, manure and improved seed (**Table 4**).

TABLE 4 | The number of households using management practices across target groups in Ethiopia. Sustainable intensification (SI) technologies in grey are excluded from further analysis.

SI	Group of households			
	Worst-off	Moderate	Best-off	All
	(*n* = 522)	(*n* = 1,307)	(*n* = 111)	(*n* = 1,940)
Herbicide, fertilizer, manure and improved seed	47	136	12	195
Fertilizer, manure, improved seed	61	123	1	185
Residue retention, herbicide, fertilizer, manure and improved seed	38	129	3	170
Fertilizer and improved seed	52	58	2	112
Residue retention, fertilizer, manure and improved seed	27	75	3	105
Fertilizer, improved seed and herbicide	19	75	3	97
Residue retention, herbicide, fertilizer and improved seed	14	70	2	86

The joint use of fertilizer, manure and improved seed (without herbicide) was the second most common practice. In Ethiopia, the joint use of herbicide, fertilizer and improved seed were associated with a slight reduction in energy and protein deficit in the worst-off group (**Figure 5**, **Table 5**). Energy deficit levels were significantly lower in the worst-off group with the addition of manure to this set of practices. In the best-off group (i.e. TLU < 3, Anomaly ratio < -0.1), the combined use of residue retention, herbicide, fertilizer and improved seed was the only set of SI practices associated with a reduced energy and protein deficit. However, the use of these practices by the best-off group, was associated with the most substantial reduction in food deficit levels of all the practices, across all groups. Among the largest, moderate-risk group (TLU ≥ 3), the SI technologies either had no observable benefit or increased risk. The use of herbicide, fertilizer, manure and improved seed even increased the risk of an energy deficit in this group.

In Mozambique, the most common practice was crop residue retention only and the second most common practice was minimum tillage only (**Table 6**). Residue retention with minimum tillage reduced the energy and protein deficit levels in the best- and worst-off groups (**Figure 6**, **Table 7**). Residue retention with improved seeds reduced the energy and protein deficit in the worst-off group only. The benefits of crop reside retention with minimum tillage were substantially greater for the best-off group than those found in the worst-off group. Food deficit levels did not differ significantly between SI users and non-users in the moderate groups.

DISCUSSION

This study demonstrated variation in the likelihood of food deficit and benefits from sustainable intensification technologies across diverse populations of semi-subsistence households in Ethiopia and Mozambique. Previous work has demonstrated the need to go beyond calculations of total food available in a population to understand the distribution of food. For instance Marenya et al. (2018) found that 50% of the farm households in Ethiopia consumed fewer calories than the recommended daily intake of 2,100 kcal even when the average calorie consumption (2,200 kcal) was sufficient to support the population (Marenya et al., 2018). This study found that substantial portions of the populations experienced energy and protein deficits, reaching 30 and 59% of the households, in Ethiopia and Mozambique respectively. These figures are consistent with previous work showing that an estimated 40% of the population in Ethiopia consumed less than the recommended daily calories and average protein consumption was 14 grams less that the recommended daily intake of 56 grams per person per day (von Grebmer et al., 2015). These figures are critical for ongoing efforts to understand and overcome food shortages and are especially valuable for Mozambique where data on food security indicators is scarce.

Predictors of Food Deficit

The study identifies climate- and household-level factors to predict food deficits and demonstrates that these factors influence benefits associated with from sustainable intensification technologies. Predictors of household food status (i.e. insufficient energy and protein, insufficient energy only and insufficient protein only) were generally consistent with previous studies. Consistent with broader trends observed across 17 countries in sub-Saharan Africa (Frelat et al., 2015), household consumption equivalents was associated with an increased likelihood of a food deficit. Also consistent with Frelat et al. (2015), tropical livestock units and land area under cultivation was associated with a decreased likelihood of a food deficit. While increases in family size can be beneficial, providing various forms of support to the family through on- and off-farm activities, household members may increase household food requirements, necessitating innovations for ensuring food sufficiency for the entire household (for examples refer to Devereux, 2003).

The anomaly ratio, an indication of water stress impacted household food outcomes in different ways in Ethiopia and Mozambique. In Ethiopia, wetter seasons increased the likelihood of a food deficit while drier seasons increased the likelihood of a food deficit in Mozambique. The finding that the rainfall anomaly ratio (an indication of how especially wet or dry the season was for that location) influenced the risk of a

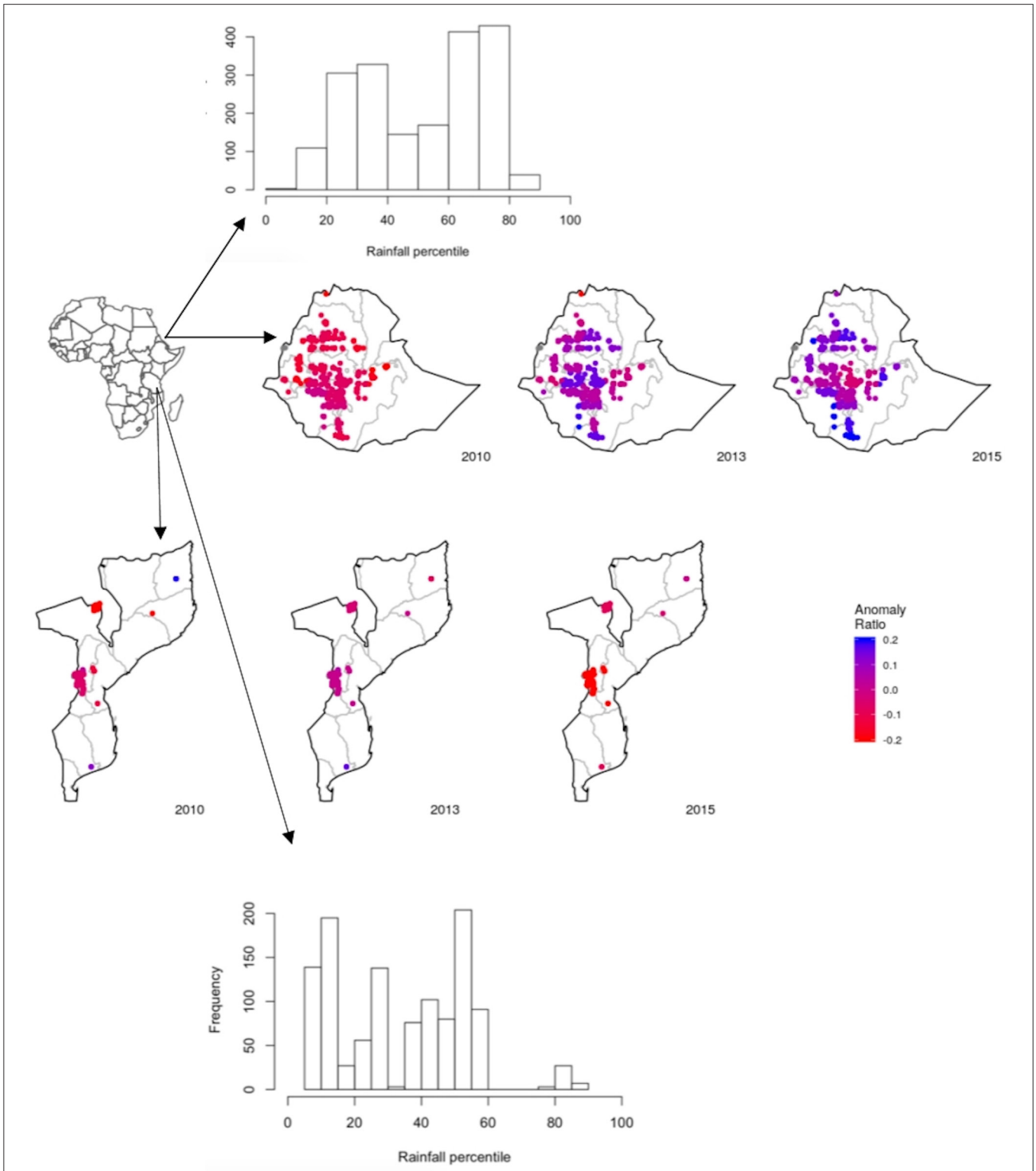


FIGURE 5 | Box plots of food sufficiency with (red) and without (grey) conservation agriculture (CA) practices across target groups in Ethiopia. The food requirement threshold for energetic needs (2100 kcal/CE/day) is indicated with a horizontal line. The food requirement threshold for protein needs (60 g/CE/day) is indicated with the vertical line.

TABLE 5 | Multinomial logistic regression table showing sustainable intensification (SI) management practices associated with food availability in Ethiopia.

SI	Model	Energy and protein deficit (®, signif.)		Energy deficit (®, signif.)		Protein deficit (®, signif.)	
Herbicide, fertilizer, manure and improved seed	All groups	−0.190		−0.270		−0.126	
	Moderate	−0.391	*	−0.657		−0.299	
	Best-off	−0.121		2.181		0.677	
	Worst-off	0.406		−13.934	**	0.406	
Fertilizer and improved seed	All households	0.137		0.915		0.464	*
	Moderate	0.026		1.146	*	0.485	
	Best-off	52.89		−1.142		53.588	
	Worst-off	−0.444		0.190		−0.087	
Herbicide, fertilizer and improved seed	All households	−0.366		1.163	*	0.191	
	Moderate	0.064		1.551	**	0.197	
	Best-off	−41.257		−15.488		−35.768	
	Worst-off	−1.303	**	−10.65		0.201	
Residue retention, herbicide, fertilizer and improved seed	All households	−0.480	*	−7.918		−0.207	
	Moderate	−0.402		−9.926		−0.110	
	Best-off	−31.112	**	−7.670		1.931	
	Worst-off	−0.338		−9.777		−1.186	
All CA			Residual Deviance:			4,072.02	
				AIC:		4,102.02	

** *Significance with $p < 0.05$. * Significance with $p < 0.1$. The reference category is energy and protein sufficiency.*

TABLE 6 | The number of households using management practices across target groups in Mozambique. sustainable intensification (SI) technologies in grey are excluded from further analysis.

	Group of households				
	Worst-off	Moderate I	Moderate II	Best-off	All
	(*n* = 641)	(*n* = 298)	(*n* = 66)	(*n* = 140)	(*n* = 1145)
Crop residue retention only	112	25	3	32	172
Minimum tillage only	54	68	0	0	122
Crop residue retention and improved seed	59	6	5	31	101
Crop residue retention and minimum tillage	57	20	3	4	84
Minimum tillage and fertilizer	27	43	0	0	70
Crop residue retention minimum tillage and fertilizer	26	18	0	1	45

household food deficit is expected as rainfall is one of the most highly cited climatic factors influencing food availability in these rainfed production systems (Afifi et al., 2013). The anomaly ratio is especially relevant for understanding production risks and is supported by previous studies and theory surrounding climate uncertainty, which considers challenges identifying appropriate management practices under uncertain growing conditions and predicts a decline in food security with erratic climate behaviour, through declines in on-farm production (McCarthy et al., 2001; Parry et al., 2004, 2005; Lewis, 2017). Increased rainfall under generally wet and humid conditions may have been associated with an increased risk of mould and other crop damage in the field or in storage in Ethiopia. Dry seasons in Mozambique included the severe drought of the 2015/2016 El Niño years when 96% of the surveyed households experienced drier than normal conditions. These dry conditions may have been especially detrimental to household food status given the extent of the community effected. In contrast to crop failure events that are isolated to one household, broad scale drought events effect the entire community and limit opportunities for individual households to appeal to neighbours for support (Wilkus, 2016). A limitation of this study is that it does not account for the role of social networks in maintaining household food supplies.

An unexpected finding from Mozambique was that the households located closer to markets were less likely to meet

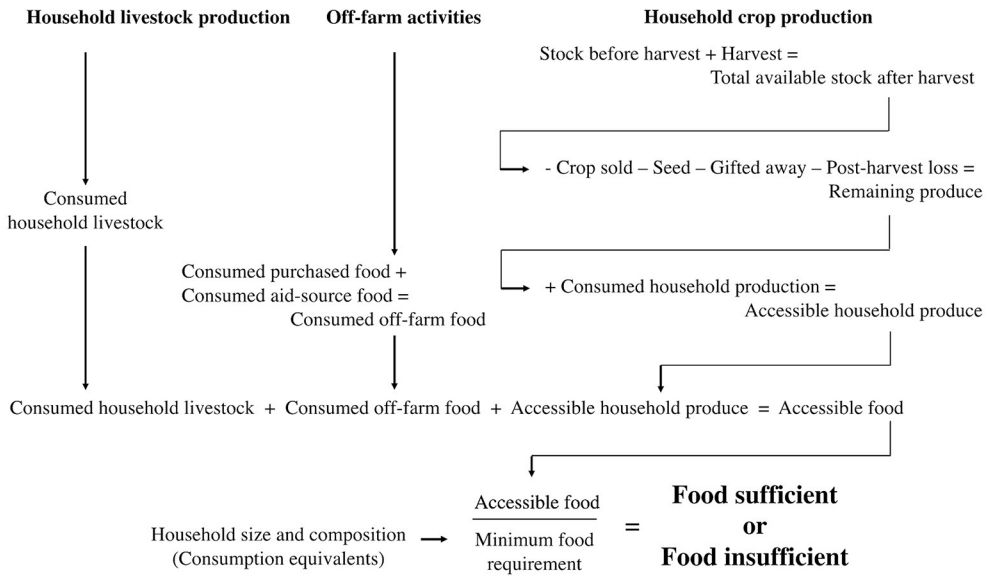


FIGURE 6 | Box plots of food sufficiency outcomes with (red) and without (grey) conservation agriculture (CA) practices across target groups in Mozambique. The food requirement threshold for energetic needs (2100 kcal/CE/day) is indicated with a horizontal line. The food requirement threshold for protein needs (60 g/CE/day) is indicated with the vertical line.

TABLE 7 | Multinomial logistic regression table showing sustainable intensification(SI) management practices associated with food availability in Mozambique.

SI	Model	Energy and protein deficit (®, signif.)		Energy deficit (®, signif.)	Protein deficit (®, signif.)	
Crop residue retention only	All households	−0.152		1.417	−0.102	
	Worst-off	−0.307		0.320	−0.508	
	Best-off	0.405		12.250	0.345	
	Moderate II	9.358		NA	9.289	
	Moderate I	−0.518		NA	−0.288	
Crop residue retention and improved seed	All households	−0.747	**	0.894	−0.285	
	Worst-off	−0.831	**	0.607	−0.557	
	Best-off	−0.145		1.119	−0.231	
	Moderate II	0.251		NA	−0.223	
	Moderate I	0.418		NA	0.560	
Crop residue retention and minimum tillage	All households	−0.630	**	−10.593	−0.610	*
	Worst-off	−1.176	**	−7.304	−1.201	**
	Best–off	−16.858	**	−2.320	−1.329	
	Moderate II	8.576		NA	9.893	
	Moderate I	−0.141		NA	0.272	
All CA			Residual Deviance:		2225.23	
				AIC:	2249.23	

*** Significance with $p < 0.05$.*
** Significance with $p < 0.1$.*
The reference category is energy and protein sufficiency.

their food needs than households further from markets (**Table 1**). Reduced transaction costs associated with proximity to markets along with greater access to accurate market information suggest that household food status would improve with greater access to markets (Gabre-Madhin, 1999; Frelat et al., 2015). Participation in livestock and grain markets have also been treated as a means of securing access to food through different forms of market exchange (Beyene, 2015; Beyene and Kassie, 2015). It is possible that poverty may have the propensity to deny households access to market-sourced food (Mbajiorgu,

2019) or farmers may require additional skills to operate in commercial markets (Hendriks, 2014). Households located close to markets may typically allocate resources to off-farm enterprises that provide inconsistent income. Households located close to markets may therefore, be especially vulnerable to unpredictable and fluctuating markets. Further analysis can evaluate market imperfections in Mozambique that may undermine market-related benefits and compare the stability of on- and off-farm income sources. Off-farm income may be stable relative to the seasonal agricultural income, which was subject to vagaries of weather, as this study shows.

Unequal Benefits From Sustainable Intensification Across Best-, Moderate- and Worst-Off Households

Adoption of SI practices in the surveyed populations was low to moderate. Multiple practices used in concert were most common in Ethiopia where the joint use of herbicide, fertilizer, manure and improved seed (10% of the population) and joint use of fertilizer, manure and improved seed (10% of the population) were most frequently observed. The occurrence of sustainable intensification practices in Ethiopia are consistent with recent adoption studies showing 8 and 29% of the a surveyed population in Ethiopia that jointly adopting sustainable intensification practices in 2010 and 2013, respectively (Marenya et al., 2018). This study identified few household farms that used a single management practice in Ethiopia, while Marenya et al. (2018) found evidence for high levels of adoption of improved seeds only, reaching 46 and 36% of the population in 2010 and 2013, respectively. In contrast to the adoption patterns observed in Ethiopia, the most common practices in Mozambique involved the use of a single SI technology where 15% of the population in Mozambique practiced crop residue retention alone and 11% of the population practiced minimum tillage alone. Joint adoption of multiple practices may be rare in Mozambique because basic agronomic conditions have limited potential benefits of SI practices. Improved agronomic practice represented the largest return on investment for farmers in this region (van Ittersum et al., 2013). For instance, improved planting density explained half of maize yield gains observed over six seasons from 2010–2016 in Mozambique, overshadowing any benefits from SI practices (Nyagumbo et al., 2018).

The benefits associated with of SI technologies and the most beneficial technologies varied across best-, moderate- and worst-off groups. Overall, the benefits associated with SI technologies were greatest for the best-off groups in both Ethiopia and Mozambique. For the worst-off group in Ethiopia, a reduced energy and protein deficit was only observed with joint use of herbicide, fertilizer and improved seed and the reduction was minor. The energy deficit was lowest among the worst-off households that added manure to herbicide, fertilizer and improved seed. These findings may reflect a process by which the worst-off households incrementally improving operations to enhance food outcomes. By primarily incorporating herbicide, fertilizer and improved seed into household management practice might explain the reduced energy and protein deficit and the subsequen addition of manure might explain the reduced energy deficit. Although the associated benefits were minor, this gradual adoption process offers a promising strategy for the worst-off households, with limited investment options to escape poverty traps (Sime and Aune, 2016). Future research research can better determine causality and investigate specific pathways by which these practices enhance household food outcomes would greatly assist in formulating recommendations for strategic and gradual adoption processes. The only management practice associated with a reduced energy and protein deficit for the best-off group in Ethiopia was the joint use of residue retention, herbicide, fertilizer and improved seed. In contrast to the benefits associated with the most promising practice for the worst-off group, the benefits from the most promising practice were substantial for the best-off group.

The study shows that predictors of food deficit can be valuable criteria for identifying groups that respond differently to SI practices. Uneven benefits associated with SI technologies in Ethiopia may reflect different processes and constraints operating in the best- and worst-off groups. The main distinction between the best- and worst-off groups in Ethiopia was in the rainfall patterns observed between them where the worst-off group experienced especially wet conditions and the best-off group experienced especially dry conditions. Evidence from previous studies showing that manure decomposition rates were positively correlated with cumulative precipitation (Zhu et al., 2020), would suggest that benefits associated with manure would be greater for the worst-off households, however this was not the case. While both groups had relatively few livestock and limited access to manure as a consequence, worst-off households may have applied less manure overall compared to the best-off group based on differences in their market participation. Market developments have made maize stover a valuable feed resource, creating an additional competing use for residues that may preclude use as mulch (Tittonell et al., 2007). Worst-off households, experiencing acute food shortage may opt to allocate a portion of manure towards market sales and purchase food with that income. The application rates of 0.5–2t ha-1 of manure is considered necessary to sustain crop yields, yet this level may be unrealistic for the worst-off group. The alternative, application levels of 0–0.5 t ha-1, forego benefits of the practice (Wezel and Rath, 2002). This study does not account for differences in the quantities of manure applied, so it is possible that the best-off group applied larger quantities overall compared to the worst-off group.

Two sets of SI options were associated with benefits for the worst off household in Mozambique: joint use of crop residue retention and improved seed and joint use of crop residue retention with minimum tillage. A slight reduction in energy and protein deficits was associated with these practises for the worst-off group. The only observed benefits associated with SI practices for the best-off group of households were found with the use of crop residue retention with minimum tillage. The main difference between the worst-off and best-off group was family size, where the worst-off group had larger families. While it is possible that production benefits associated with crop residue retention with minimum tillage were equal for the best- and worst-off groups, those associated benefits are diffused in the worst-off households, where household consumption requirements are larger.

Benefits associated with SI technologies were not observed for moderate households in Ethiopia or Mozambique. The moderate households in Ethiopia had more tropical livestock units (TLU $\geq$3) and thus greater demand for crop residue as livestock feed than the best- and worst-off groups and constituted 66% of the surveyed households ($n = 1307$). Tropical livestock units may also operate to stabilize access to food. The SI technologies that were evaluated were either associated with an increased likelihood of a food deficit or had no observable benefit for the largest group. In addition to the smaller household size (CE <3.9), the best-off group was distinguished from one of the moderate groups (II) in Ethiopia by cultivated land area, where the moderate group had less land under cultivation (ha <0.4) than the best-off group. This moderate risk group (II) may benefit from the same SI technologies (residue retention with minimum tillage) as the best-off group however, benefits may not be observable or consequential under the smaller scale of production when those benefits are slight, however impactful to the household. Two moderate groups were identified in Mozambique, both of which had smaller households (CE < 3), than the worst-off group. Although smaller households have lower consumption requirements, they may also have limited labour capacity, resulting in less intensive management practice. The second, moderate group (I) may have relied less on the use of the SI technologies under less variable climate conditions, which allowed household members to better anticipate food sources and availability.

CONCLUSIONS

Sustainable intensification was associated with enhanced food outcomes but also limited in scope. The number of households that experienced benefits associated with SI technologies were large in Mozambique, where the worst-off group represented 56% of the sampled population, compared to only 27% of households in Ethiopia. There was no evidence of risk reduction associated with CA technologies in moderate households, which represented the majority of households in Ethiopia. In both Ethiopia and Mozambique, associated benefits from "best-bet" SI practices were lower for the group of worsts-off households than the group of best-off households. Alternative approaches were necessary to better support households with a high- and moderate- likelihood of a food deficit and ensure equal opportunities for enhancing household food-related outcomes. These findings support a substantial body of evidence on self-reinforcing mechanisms underlying poverty-traps (Barrett, 2010; Naschold, 2012; Stephens et al., 2012; Tittonell and Giller, 2013) and advance our understanding of the role that sustainable intensification plays in supporting household food-related outcomes across diverse populations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SS, JD, and PM provided critical feedback and helped shape the research, analysis and manuscript. EW conceived of the presented idea, developed the theory, performed the analysis, and wrote the manuscript. PdeV prepared the data and images. DR supervised the project. All authors contributed to the article and approved the submitted version.

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Cultivating Community Resilience With Agency and Sociality in Gardens for Health and Healing

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Communities must develop ever greater resilience as they face the climate emergency and concomitant health and food system challenges. Sustainable food systems research tends to adopt broad and often theoretical social-ecological systems perspectives on resilience. Models theorize that community self-organization for mobilizing change and *agency* in taking planned action are key processes for community resilience. Empirically, however, how individuals come together to engage in collective action for community resilience remains little explored. In this research, we examine strategies for resilience employed by 19 participants with multiple chronic health conditions in Gardens for Health and Healing, a community-based participatory research project conducted in southeast Wyoming. Through random assignment, participants either received a home garden or designed their own 16-week wellbeing program from a menu of community health and food systems services (e.g., cooking classes, farmers' market gift certificates, home garden). Using a pre-post wellbeing survey, interviews, and 14 months of ethnographic research, we explored the role of choice—or agency—for participants' wellbeing. Survey results suggest that receiving a garden more greatly benefitted participants' physical health while designing and implementing a wellbeing plan more greatly benefitted mental health. Qualitative results find that participants in both the garden and menu conditions identified their intervention as empowering them to take action to improve their own health and wellbeing. Participants attributed their wellbeing less to what condition they were in (garden or menu), and more to the relational processes they engaged in through the project. These processes included bringing the family together; associating with friends, neighbors, and colleagues; caring for garden environments; and engaging with the community-based organization that supported both the gardens and the wellbeing plans. We find that this *sociality* can help promote and explain a move from individual wellbeing and agency to the collective forms of agency and self-organization necessary to cultivate community resilience for sustainable food systems.

Keywords: community resilience, agency, sociality, self-organization, collective action, multiple chronic conditions, gardens, health

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INTRODUCTION

Communities around the world must become ever more adaptive in the face of the climate emergency and associated challenges to food systems and public health. Their ability to thrive in the face of such uncertainty and change is conceptualized as *community resilience*. More specifically defined, community resilience is the "existence, development, [and/or] engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability and surprise" (Magis, 2010, p. 401). This concept is reasonably well theorized in the literature; however, that literature also calls for greater empirical research about how communities cultivate their resilience (Berkes and Ross, 2013; Ross and Berkes, 2014; Vaneeckhaute et al., 2017).

This study responds to that call. In southeastern Wyoming, we recruited participants who each live with multiple chronic health conditions to Gardens for Health and Healing, a community-based participatory food systems and gardening wellbeing project. We investigated whether and how expanded participant choice—here, conceptualized as agency—supported their health and wellbeing. Through ethnographic research, we explored participants' specific strategies for resilience.

COMMUNITY RESILIENCE AND WELLBEING

Research has linked alternative agriculture and food justice strategies, including gardens, to individual and social-ecological resilience (e.g., King, 2008; Okvat and Zautra, 2011). Food systems resilience draws from these social-ecological perspectives as "capacity over time of a food system and its units at multiple levels to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015, p. 19). While presently little applied in food systems research, community resilience frameworks integrate social-ecological systems with development and psychology perspectives on a specific, place-based scale. Models suggest that strengthening people-place relationships, social networks, and other community characteristics support two key mechanisms of community resilience: agency and self-organization (Berkes and Ross, 2013).

Below, we briefly review the most relevant literature on these key mechanisms of community resilience and the anthropological concept of sociality, which helped us to further explicate participants' strategies for wellbeing and resilience. We also discuss the literature on how gardening enhances social and individual wellbeing as relevant to the broader Gardens for Health and Healing study.

Agency, Self-organization, and Sociality

In the context of community resilience, agency is defined as community members "taking planned action to effect change" (Magis, 2010, p. 404). As one resilience scholar notes, "agency encompasses both individual-level action, premised on confidence among autonomous and able members of society that change is possible, and collective agency, expressed in the cultural, infrastructural, and communicative resources that enable collective action" (Davidson, 2010, p. 1145). Models theorize that agency relates to community self-organization in response to social-environmental changes that are unpredictable and beyond their control (Berkes and Ross, 2013), such as major weather events, climate shifts, and pandemics. In the food systems resilience literature, local self-organization refers to the ability of systems to produce new structures and systems in a specific place (Worstell and Green, 2017).

Empirical community resilience studies have begun to emerge in response to calls in the literature, particularly in disaster and tourism contexts. For example, one study of two United Kingdom flood-affected coastal communities confirmed community resilience is an emergent property of key relational capacities theorized in community resilience frameworks, including community cohesion and networks (Faulkner et al., 2018). Another interviewed New Mexico organic farmers and similarly found that they created social spaces and networks with other farmers, volunteers, customers, and organizations to support community resilience (McDaniel et al., 2021). Fewer, however, have empirically investigated key community resilience mechanisms of agency and self-organization relevant to the present study. One study explored how agency operates in community resilience through Ghanian farmers' various climate adaptation strategies. Findings suggest that reflexivity—individuals reflecting on their adaptive strategies and discussing those actions with others—may facilitate a move from individual to collective agency for resilience (Otsuki et al., 2018). Similarly, White's (2018) historical analysis of black farmers' cooperatives in the U.S. indicates that shared, future-oriented political consciousness is necessary for communities to unify for collective agency and resilience. Scholars have defined community-level agency as "a process of building relationships that increase the capacity of local people to unite, act and adapt to changing conditions," highlighting the role of social interaction in this process (Matarrita-Cascante et al., 2010, p. 738; Matarrita-Cascante et al., 2017).

A bridge between the above literature on social networks and collective action focused on how individuals come together to relate to each other and unify for collective and community agency and self-organization for community resilience, however, lacks both empirical and theoretical support. Due to this gap in the literature and our subsequent findings, we additionally explore the concept of *sociality*. Anthropologists first introduced sociality to focus on dynamic social relations, rather than static concepts of "society" and "community" (Strathern et al., 1990). Some have described it as "the range of possibilities for social coordination with others" (Ochs and Solomon, 2010, p. 69). More recent work suggests that sociality provides a lens to focus on both "the relational matrix in which humans are embedded" and "the ways in which, and the extent to which, humans in any given context come to reflect upon that matrix, and might be driven to act upon it" (Long and Moore, 2012, p. 43). This relational matrix includes not only humans, but other living beings and the environment (Long and Moore, 2012; Solomon, 2012); however, resilience perspectives suggest only humans have the agency and imagination required to act upon it (Davidson, 2010).

Gardening and Wellbeing

Research on home and community gardening suggests that gardens yield multiple positive outcomes for wellbeing. One set of outcomes includes social wellbeing, sense of community, social ties, and community networks (Yee Tse, 2010; Soga et al., 2017; Bailey and Kingsley, 2020). Home gardeners connect with others to share garden produce, labor, and even communal meals (Freeman et al., 2012; Jehlička et al., 2018; Porter, 2018). For example, one home garden study found that gardeners shared about a third of their produce with others (Conk and Porter, 2016). This body of research has found that gardens "forge and reinforce social ties, community networks, and sense of community" (Soga et al., 2017, p. 97); "cultivate specific kinds of citizen-subjects" (Pudup, 2008); and provide a "social bridge to build community cohesion" (Gonzalez et al., 2016, p. 107). Such outcomes align with the social network characteristic of community resilience demonstrated in both the theoretical and empirical literature.

Gardening also helps to bridge people across cultures and people with nature (Longhurst, 2006; Egerer et al., 2019; de Bell et al., 2020). One form of social relationship that emerges from even potentially solitary home gardening is the dynamic one between gardener and garden through which people variably aim to control and collaborate with and even care for a non-human living community (Power, 2005; Okvat and Zautra, 2011; Freeman et al., 2012). People connect with the "natural" environment through relationships with plants and animals in their gardens (Bailey and Kingsley, 2020). In turn, relationships between humans and their garden environments can foster other social connections and shared community identities (Pink, 2008; Freeman et al., 2012).

A large body of research also inidcates gardens contribute to improved individual physical and mental health. Benefits include increasing fruit and vegetable intake (Armstrong, 2000; Twiss et al., 2003; Alaimo et al., 2008; Meinen et al., 2012; Litt et al., 2015), fostering physical activity (Armstrong, 2000; Park et al., 2009; Draper and Freedman, 2010; de Bell et al., 2020), reducing food insecurity (Stroink and Nelson, 2009; Corrigan, 2011; Baker et al., 2013), and improving mental health (Brown and Jameton, 2000; Austin et al., 2006; Wakefield et al., 2007; van den Berg et al., 2010; de Bell et al., 2020). The field of therapeutic horticulture has linked the gardening impacts of improved overall health and wellbeing with relational benefits. For example, a randomized controlled trial of a 15-week therapeutic horticulture program with elderly participants in Singapore focused on psychological wellbeing and found significant improvements, mainly in "positive relations with others" (Sia et al., 2018, p. 2).

MATERIALS AND METHODS

The Gardens for Health and Healing project was a community-based participatory research (CBPR) pilot that began with a randomized controlled trial design. In 2016, a community-based organization in Albany County, Wyoming—Feeding Laramie Valley—partnered with the second author at the University of Wyoming to examine health impacts of home gardens with people living with multiple chronic conditions. That year, Feeding Laramie Valley supported half the participants to start a home food garden right away. The other half, serving as the control group, was to receive a garden the following year if they wished.

Although this design aligned with Feeding Laramie Valley's emphasis on gardening, it excluded their other food justice activities, such as food sharing. More importantly, asking any participant to wait for support was ethically problematic, and even more so for people suffering serious health problems and needing immediate support. In the earlier iteration of recruiting for Gardens for Health and Healing, one potential participant stated that waiting a year for a garden if assigned to the control condition was untenable, as they may be dead within the year due to their conditions. Thus, Feeding Laramie Valley and the co-authors redesigned the study for the 2017 growing season. In addition to being a part of the academic research team, the first author joined Feeding Laramie Valley as a graduate student intern and co-coordinated Gardens for Health and Healing with the organization's Community Engagement Director. The second author continued as principal investigator. We received approval for this research from our university's Institutional Review Board #20140307CP00334.

We randomized participants to one of two conditions. In the pseudo-control condition, participants received a home garden with installation and maintenance support as a basic standard-of-care. In the intervention condition, participants designed their own health and wellbeing plan from a menu of activities within (though not necessarily limited to) Feeding Laramie Valley's programmatic network.[1] In reality, both conditions presented the potential to intervene upon participants' health and wellbeing, and the garden condition did not provide a true control. However, the shift in design addressed the aforementioned ethical issues in the earlier version of the study. Accordingly, the pilot shifted from assessing impacts of gardening on health to investigating the effect of *choice* on health, through the planning and design process in the menu condition.

As in the first year of the study, Gardens for Health and Healing participants were adults living in Albany County, Wyoming experiencing two or more of any self-identified chronic health conditions. Additionally, participants must not have kept a food garden of eight square feet or larger in the last year. Finally, consenting participants agreed to random assignment to either the menu or the garden condition. The four participants assigned to the control condition from the previous year of the pilot were each invited to enroll in the current iteration of the study; one opted to enroll (the others were invited to receive gardens even if not enrolled in the study). In total, 19 participants qualified for and enrolled in the project, providing written informed consent for their participation.

The academic research team randomly assigned 10 participants to the garden condition and nine participants to the menu condition. After randomization, the academic

[1] From here on out, we refer to these study conditions as "the garden condition" and "the menu condition," respectively.

research team gathered pre-program quantitative health measures from each participant. These were body mass index (BMI, calculated from researcher-measured height and weight), waist circumference, hand strength, food security, self-reported pain level, and physical and mental wellness as measured by participant responses to a standardized quality-of-life and wellbeing survey, the SF-12. One textbook describes the 36-question version, SF-36, as the "generic measure of choice across many diseases," with results from the 12-question version closely tracking those of the longer survey (Bowling, 2001, p. 17; Jenkinson et al., 1997).

Participants additionally completed an intake interview with the Feeding Laramie Valley co-coordinator and first author. Across both conditions, intake interview topics included their personal health and wellbeing challenges, past strategies for addressing those challenges, and what had drawn them to the project. Participants assigned to the garden condition subsequently co-designed their garden based on personal preferences and wellbeing needs identified during these interviews. Participants assigned to the menu condition subsequently engaged in a supported health and wellbeing plan mapping process during these interviews. They identified their most pertinent health challenges, how they hoped to feel at the end of the 16-week program (crafting a personalized wellbeing statement based in specific or general outcomes), assets they would bring to realizing that wellbeing statement, potential challenges to be aware of, and specific activities that would help them meet those outcomes.

Following the intake interviews, Feeding Laramie Valley staff installed four foot by eight foot raised bed or equivalent home gardens for participants in the garden condition. Participants in the menu condition began single or multiple activities selected from broad menu categories of farm-to-plate, food access, physical activity, general wellness, and gardens, which included a garden of equivalent or smaller size to those received by garden condition participants.

Menu condition participants selected a range of personalized activities using a guided and constrained choice approach facilitated by suggested activities in the menu (see **Appendix A, Supplementary Materials**) and program co-coordinator support. Activities and wellbeing plans were based on a detailed approximate equivalency of cost and physical, mental, and social wellbeing intensity, which the academic research team designed into the menu to support comparability of intervention and quantitative health outcomes. All but one participant chose some form of garden as part of their health and wellbeing plan, and two opted for only a large garden on par with what participants in the garden condition received.

The garden and menu programs ran for 16-weeks from mid-June 2017 to mid-September 2017 to align with a full southeastern Wyoming gardening season. Throughout the program, the first author supported participants with weekly check-ins across both conditions, including any necessary activity adjustments for menu condition participants. Feeding Laramie Valley staff provided garden maintenance and support through the program, as needed. We considered this regular interaction between participants and the community-based organization an integral part of the program, one that was common to both conditions.

Upon program completion, the academic research team gathered the same quantitative health measures to facilitate pre- and post-program participant health outcome comparison. Participants then engaged in an exit interview with first author and Feeding Laramie Valley co-coordinator, which focused on their experiences gardening or with their various health and wellbeing activities. Topics included how their experiences aligned with their initial expectations for participation in the project, impacts (if any) that the project had on their health and wellbeing, and their experience of assignment to either the garden or menu conditions.

The main focus of the present study is analysis of qualitative data emerging from extensive ethnographic fieldwork that explored whether and how agency impacted menu condition participants' experiences of their wellbeing, including in comparison with those assigned to the garden condition. These ethnographic methods include the person-centered intake and exit interviews described above, which focused on individual participants' experiences in relation to the broader project context (Levy and Hollan, 2015).

Additionally, methods include 14 months of participant observation (DeWalt and DeWalt, 2011) conducted by the first author from August 2016 to October 2017. As a graduate intern and program co-coordinator with Feeding Laramie Valley, she was involved almost daily in supporting and delivering gardens and other food system and community-based wellbeing activities with participants. Her field notes (Sanjek, 1990) included interactions with academic public health researchers from the University of Wyoming and the Feeding Laramie Valley team. Mainly, her field notes focused on interactions with participants. These recorded and reflected upon her engagement with participants including helping to prepare and plant their gardens; checking in at least weekly with each participant via email, text message, or in-person; and both participating in and designing and delivering activities, including cooking classes, farmers' market trips, food shopping and budgeting workshops, and a public presentation through which some participants shared their program experiences.

We audio-recorded all interviews ($n = 38$, including a pre- and post-program interview for all 19 participants) and then created and corrected verbatim transcripts. The first author deductively analyzed interviews (Bernard, 2006) around the central research focus on the role of choice or agency in participants' wellbeing. Analysis compared participants' experiences in each condition generally and with agency, action, and choice within their respective conditions, specifically. This analysis also included participants' related initial reasons for enrollment in Gardens for Health and Healing from pre-program interviews. We also drew on a comparison of pre- and post-program quantitative health outcome measures to further illuminate qualitative analysis of deductive research questions about the role of choice in participants' wellbeing. While this deductive approach shaped initial analysis, inductive analysis based in grounded theory allowed additional themes beyond agency to emerge (Glaser and Strauss, 1967; Strauss and Corbin,

1990; Miles and Huberman, 1994). Relational processes emerged as the most salient element of wellbeing alongside agency for participants in both conditions. We organized these processes into four major thematic and analytical categories as outlined below. In addition to summarized interview data supported with exemplative participant quotes, field notes from the first author's participant observation augment interview data for a synthesized, ethnographic analysis.

RESULTS

Participants' ages ranged from 21 to 65 years old and included 17 people who identified as women and two who identified as men. All were managing at least two chronic health conditions, including fatigue, chronic pain, depression, anxiety, and obesity. We had 100% participant retention.

Participants' Health Perspectives at Enrollment

Upon initial intake to the project, participants across both conditions described feeling as though they lacked control over their health and wellbeing. One participant described how their health and weight had "snowballed" over time. Another participant very directly stated "my diabetes is not under control." One said that previous approaches to addressing her wellbeing were ineffective, and she had all but "stopped trying things about a year ago, because they're not working." Another shared, "my mental, emotional challenges keep me feeling stuck and unhealthy" and shared concerns that those challenges would soon "spiral out of control." Nearly every participant shared their experiences of how physical conditions, along with depression and anxiety, impacted both their personal health and their social relationships.

However, participants shared that simply enrolling in the project provided them with a sense of control and motivation to address their own challenges. Several explained that they hoped the project would help them "get off the meds." Others spoke about wanting support to learn how to garden, for example, to "feel like I have that confidence, like I can actually do something good." One summed up her reasoning for enrolling in Gardens for Health and Healing as wanting to "feel better, so I can actually do something with my life." Another framed his reason for participating as "this summer I want to heal as much as I can. Even if the pain doesn't go away, the mental part, that I can control that. I can do something about that."

Agency and Wellbeing in Menu and Garden Conditions

In exit interviews, participants reflected on their experiences of choosing their own health and wellbeing activities to meet their self-defined health goals in the menu condition or receiving a garden.

Participants in the menu condition ($n = 9$) appreciated the ability to identify their own desired outcomes and then design their health and wellbeing plan to achieve them. As one participant said, "Everybody's different, so you have to adapt to that. You know yourself better than other people do. You know what you need." Another explained that the menu approach worked well for her with "being able to know what I want in the future and then set the goals that lead me to that. I feel I'm kind of a certain person that [if] it's my idea, I can do it, but if it's your idea, ehh…" Several mentioned that setting outcomes and the plan for getting there helped them with "sticking with" the programs they had designed, not only for the 16 weeks but also possibly beyond. For example, one participant encapsulated this by saying she designed her wellbeing plan to intentionally develop new skills for long-term maintenance of her wellbeing:

> *When I was choosing the different things like the shopping, the budgeting, and the cooking classes, I thought it was a good mix of how to help me to probably reduce my stress… To learn how to acquire or sharpen those skills—I knew I needed that.*

Another person shared feelings of shame about her health, which she developed over years of being told what she "needs" to do for exercise and diet. She noted that identifying her own outcomes and developing a plan offered a less shaming and even fun approach to nurturing her own wellbeing.

One appreciated the flexibility of being able to adjust her activities as she moved through the project. Although in practice she largely maintained the same activities, she appreciated knowing she had the option for flexibility, which assignment to the garden condition would not have afforded. Another shared, "I enjoyed the experience of choosing. It was hard to choose, because I would love to do all of those things if I had the time and the ability."

Participants in the garden condition ($n = 10$) did not design their own wellbeing intervention, but the exit interviews suggest they valued their assigned condition nonetheless. Some said that the garden condition was "the one I wanted" or otherwise felt "special" for receiving one. As in the menu condition, participants identified a garden assignment as something that "worked" for them and would benefit them over the long-term. For example, one noted:

> *I'm so happy to have had [the garden] and happy that I can continue doing it. It's not like it was a one-time thing, and now I have to figure out what to do to garden. I already know what to do.*

Some appreciated that gardening was a wellbeing activity they could do on their own time. The responsibility of caring for the plants also motivated them. One said she received "the garden of my dreams," and explained how the garden made her want "to get up and do things, where maybe I didn't want to before." Two other participants shared similar sentiments:

> *The other group would have been okay, but I'm really good at saying "oh you know what? I've been out all week and when I get home from work, I don't want to go back out." It would be really easy for me to say "nah" and skip it. I have a garden; it's facing me every day when I go in and out of my door. You can see the growth and see where it's going to help, and it's just there.*

TABLE 1 | Average change in participant wellness in each condition, on the 0-100 point scale of the SF12v2 quality of life/wellbeing survey. For an individual, a change of 5 points or more is generally considered clinically meaningful.

	Garden participants ($n = 10$)	Menu participants ($n = 9$)
Change in physical wellness	+5.02	+2.38
Change in mental wellness	+1.35	+4.75

> *I think that having time to take some of those other classes, that's why I struggled [in the past], why I don't do it. I think it would have been harder to make sure that I followed my own wellness plan, so having the garden was a good responsibility to have, but it wasn't overwhelming either.*

Another gardener mentioned how gardening motivated her, and she also valued the food choices that gardening provided:

> *[It's] something to do every day. I knew I had a goal every day, that I needed to do it, or I wouldn't have a garden, so I liked that experience and the challenge of it… It really helped me know what I wanted to eat and choose some healthy things, as well.*

Even participants who had initially hoped to receive assignment to the menu condition ultimately reasoned that they were glad to be in the garden condition. One wondered how things might have been different in the menu condition and if she would have realized greater health improvements more quickly. However, echoing sentiments of gardeners quoted above, she was ultimately "glad that I was in the garden group, because that's something I definitely feel like I could sustain." Another participant reasoned that the garden condition turned out better for her than the menu condition due to the opportunity for long-term benefits:

> *I think I could have definitely benefitted from the guidance on the other end of things too, but I was really excited to have the garden, because I think it'll be something long-term moving forward that we can continue to do, whereas in the other group, I probably wouldn't continue.*

Quantitative analyses of self-reported physical and mental wellness on the SF-12 survey also reflect that participants experienced wellbeing benefits in both conditions. Gardening participants may have realized greater improvements in their physical health while menu participants may have had greater improvements in mental wellness (see **Table 1**). Though the small sample size within this pilot study did not provide sufficient power to test for statistical significance, these quantitative trends align with the qualitative results. Also, the mean mental wellness improvement for menu participants and physical improvement for garden participants are generally considered clinically significant and within clinical significance ranges identified in previous studies of specific health outcomes (Busija et al., 2011; Parker et al., 2013; Díaz-Arribas et al., 2017).

None of the other quantitative measures—BMI, food security, hand strength and waist circumference – indicated clinically or statistically meaningful changes with or between groups. Participants in both conditions rated their overall pain slightly lower, on average, after the intervention. On a 10-point self-assessment scale, the gardening group's pain rating decreased by 0.9 points and the menu group by 1 point.

Sociality and Wellbeing Across Conditions

Further analysis of exit interviews showed that relational processes and social connection overwhelmingly emerged as the most salient shared aspect of wellbeing for participants, regardless of the condition to which they were assigned. As outlined below, four themes of relational processes and social connected emerged for participants in Gardens for Health and Healing: bringing the family together; associating with neighbors, friends, and co-workers; caring for and relating to garden environments; and engaging with a community-based organization.

Bringing the Family Together

While Gardens for Health and Healing was an individualized health and wellbeing intervention, many participants reported enhanced relationships with their families. They engaged family members directly and indirectly in gardening or their other wellbeing activities. For example, several participants mentioned calling their mothers for gardening advice, which one described as an opportunity for "bonding."

Other participants experienced direct involvement from family members that they had not initially expected. Penny's[2] boyfriend, for example, had initially been resistant to the project and the garden, telling her, "do your thing." As the gardening season progressed, he increasingly became involved, from giving input, to weeding, to eventually helping her build a greenhouse for the following season. "It's very family inclusive," she said about the garden. Pete, who participated in cooking and ballet classes, frequently described how the experience brought him closer to both of his sisters—one who likes to test new recipes and one who was studying dance. Frisco explained that her oldest son, a junior in college who lived on his own, would call to ask if she had extra vegetables or if he could come over for dinner to eat from the garden. She cited "bringing the family together" as the single greatest outcome from gardening, elaborating:

> *Everybody in the family got involved in working in the garden, watering the garden, pulling weeds, planting, etc., so that was nice. And then, just reaping the harvest of it…I think the huge one for me is the participation from my family and the closeness that I felt like it brought us.*

Sadiejo's experience in the project centered around strengthening family relationships through gardening. Nearly each time the first author visited to help in her garden, one of her two adult daughters would join to garden or take pictures. She particularly enjoyed involving her 5-year-old grandson and explained how excited he was to pick tomatoes and carrots, plant his own pot of beans, and share pictures with Feeding Laramie Valley staff. Now that her health was improving—she no longer needed a

[2]Participants selected codenames during their pre-program health data collection and intake sessions, which we use throughout the Results section to protect participant confidentiality.

cane to walk, for example—she was most excited to spend more active time with her grandson in the garden and elsewhere. As she developed a new lifestyle based in growing and cooking her own vegetable-centric food, she encouraged her daughters and mother, who similarly live with multiple chronic health conditions, to do the same.

Associating With Neighbors, Friends, and Co-workers

In addition to forging and enhancing familial relationships, participants strengthened or even developed new relationships as a result of their wellbeing activities, including with neighbors, friends, and co-workers. Many found that both participating in activities, like gardening, meditation, and hiking with others, and even talking about those experiences with friends and coworkers helped to reduce their anxiety and depression by pushing them to expand their circle of associations.

One participant explained that her garden gave her "avenues to talk to people I normally wouldn't." Previously, her struggles with overeating had prevented her from visiting other peoples' homes if food would be available, because she would experience panic attacks when the potential for deviating from her meal plan was too great. When she was invited to a small party to watch a football game and celebrate a fellow church member's birthday during her gardening experience, she planned together with another party guest and friend how to accommodate her food needs to help her maintain control. She was able to enjoy the event with other people, saying, "I figured out I can do these things… I was able to control that," which she explained as something she never would have been able to previously do.

Other participants engaged in networks of exchange, sharing produce from their gardens. Silver, who experienced severe depression, hosted neighborhood garden dinner parties and shared food with women from her church who she said otherwise "don't have money or the ability to have a lot of fresh vegetables." Raer also shared vegetables with neighbors living in her multifamily rental home. She was particularly delighted when a neighbor who claimed he did not like tomatoes noted how much better tasting Raer's tomatoes were than store-bought ones. She also swapped squash and cucumbers for grapes from a next-door neighbor. Beyond a simple act of exchange, Raer—who was striving to increase her interaction with other people after recently suffering a stroke—noted how sharing "opened up conversation" with her neighbors.

In addition to neighbors, participants formed or enhanced associations with co-workers and friends who gardened. Participants shared knowledge, skills, and even stories of excitement about their wellbeing experiences, including a sense of feeling special for being able to participate in Gardens for Health and Healing. Bird explained, "I never thought I'd be talking about gardening [with my boss and coworker], but it was nice, we could compare notes" and even engage in friendly competition about growing different plants.

Some participants enhanced virtual associations through the project, particularly by sharing photos and anecdotes about their garden challenges and successes via text messages and on social media. One interpreted online associations as "a fun way to connect with people who shared garden stuff, with people in the community." For Kitty, her garden and ballet class activities provided a means to connect with people outside of an online space. When asked about any connections she had made with people during the project, Kitty said:

> *Oh, I actually have some now. Pretty much all of them are online, so getting out into the real world and doing some actual "human-ing" is good, just getting out there and meeting people. I still have a long way to go on that, but it [the project] helped.*

Participants developed entirely new and, for some, unexpected associations through gardening and project participation. After gaining experience and confidence with her own garden, Frisco volunteered to manage the school garden and advise the garden club at the elementary school where she teaches. She described making connections with both students and people otherwise unconnected with the school:

> *We've had people in the community stop by and comment on our garden and how beautiful it is. I currently have 56 children involved in garden club, when I expected maybe six. I have 56 little munchkins around me every other week to learn about gardening. We're kind of learning together.*

While the first author was working with Sadiejo in her garden at her apartment complex one morning, Sadiejo's upstairs neighbor approached her and asked, "How's your day?" After Sadiejo said hello to him in return and he left, she explained that he had autism and had never previously talked with her and rarely spoke to anyone in the complex or anyone he doesn't know. She excitedly further explained her understanding of his newfound engagement with her saying, "It's because of the garden."

Caring for and Relating to Garden Environments

Beyond human social relationships, participants in both conditions who gardened developed relationships with their gardens and the non-human worlds surrounding those gardens. Most frequently, garden relationships manifested in an ethos of care for the garden as a living thing. Despite harsher weather conditions at her home on the prairie on the outskirts of town, including an early season hailstorm that required replanting, HapDay stressed the importance of doing everything possible to support her medium-sized garden, saying, "It was kind of like a baby; you have to keep it alive."

A similar sense of care interwoven with responsibility emerged for several other participants, including an expression of sadness when plants died in the challenging Laramie climate. Bird, for example, explained a sense of loss over watching a zucchini plant die and how she wished her garden was more successful. She stated, "I wanted to make sure that I took care of this garden, because it's another living thing." The responsibility of caring for the garden, much like caring for her dog, additionally helped her to think outside of herself to manage the depression that was further exacerbated by an unexpected surgery that nearly

immobilized her during most of the Gardens for Health and Healing program. Similarly, Purple equated her relationship of care with the garden to caring for her cat. Providing food and water for both living entities at the same time everyday created a consistent daily activity of responsibility and care. She said, "I exceeded my own expectations, because I was able to make sure that was my top priority."

Raer focused on the animal world developing through her garden and shared stories of specific animals who returned throughout the gardening season during her weekly project check-ins. Crows ate her beans and, "Itty Bitty," the wild rabbit she named and watched grow during the season, ate the few peas that actually grew. Raer saw these animals not as pests, but as visitors who "felt safe" because she shared food with them. Similarly, Glorious described an entire social world or living community with which she related in the garden, including "all the sunflowers, and it attracted a lot of pollinators, especially during the butterfly migration last week, lots of visitors, squirrels, birds."

Glorious also equated gardening to being in a relationship. She consistently talked about how, as a middle-aged woman, the loss of her spousal relationship in a recent divorce informed her decision to participate in the project. She recalled times of happiness when she kept a garden in her former shared home with her now ex-husband, and she chose a garden as the sole activity for her wellbeing plan to independently reclaim some of that happiness and heal from the divorce. At the end of the project, Glorious stated:

> *I loved the relationship I had with the food…I think that relationship—and this may sound weird, because I'm single—but it was almost like being in a relationship. It gave me that same kind of emotional connection with my garden…It was right in front of me every day, and actually, it helped me, because I had to interact with it every day. It needed me, and I needed it.*

In this way, her garden provided more than a metaphorical relationship but an actual reciprocal social connection.

Engaging With a Community-Based Organization

Participants in both groups explained during their intake interviews how their chronic conditions affected their relationships and contributed to feelings of isolation. Some participants noted that having a built-in opportunity for developing connections between the first author and Feeding Laramie Valley staff through garden installation and maintenance, wellbeing activities, and weekly check-ins was an unexpected benefit of their participation.

Several participants reported benefiting from their regular interactions with organization staff in their wellbeing activities, both as a motivation and confidence boost for engaging in those activities and for direct companionship. Kitty, for example, who selected a medium garden and adult ballet classes, said that these activities gave her "strength," both physically and emotionally, and "an incentive to actually get out of the house and do something." She highlighted the "friendship element" of her activities with the first author and Feeding Laramie Valley staff and wanted to "stay involved in the future, as I like you all and had some fun." Others shared that meeting new people through weekly activities helped to reduce their anxiety.

Many participants said that they valued the weekly project text messages and emails from Feeding Laramie Valley for all wellbeing and gardening activities. This supported developing a connection and providing a sense of potential availability of staff to answer questions and troubleshoot challenges together if they arose. For example, Frisco said:

> *The support from you all in coming out with your smiling faces each time, and being willing, even if we didn't choose to have you come out, just knowing that support was there was very nice to have and not expected at all. I just felt like that [support] was a wonderful thing to feel successful as a gardener.*

Pete, a university student, chose cooking, shopping, and budgeting classes. He valued learning through weekly visits to Feeding Laramie Valley and markets across town about multiple opportunities to connect with the "community" that he had not previously known about. Penny similarly viewed Feeding Laramie Valley staff availability and engagement with her garden as a potential opportunity for other people to also connect with "the community," saying:

> *You guys' excitement when you'd come out and help put the garden in, it's so contagious. I just appreciate you guys' enthusiasm. And, moving forward with these things and building this and making it grow, I think it's an amazing resource that I hope Laramie as a community can tap into, because I learned a lot, and I had so much fun doing it.*

Some participants identified social connections with Feeding Laramie Valley in its larger role as a community-based food justice organization, not just as the service provider in Gardens for Health and Healing. They began to look for reciprocal opportunities to engage with the organization and "give back" to other people. Pete, for example, mobilized dozens of volunteers from his church to volunteer with Feeding Laramie Valley after his summer wellbeing program ended. For another participant, this kind of "giving back" was a central focus of her wellbeing reflection:

> *It was wonderful to be able to come here and drop food off and have that connection…It felt good to donate food. That was also really good for my self-esteem, feeling like I was giving back…It was reciprocal…the sense of connection, service, and like I mentioned, bringing food and feeling like a part of something bigger than myself.*

Another participant in the garden condition who was unaware of Feeding Laramie Valley's existing food sharing programs at the time actually recommended food sharing for the future:

> *I would say in the future that could be an avenue: if there's so much that we can't use it for our family, are there other families that could*

use it? Or, could it be brought down [to Feeding Laramie Valley] for the community?

Toward the end of the project, Feeding Laramie Valley hosted its annual Higher Ground Fair, which celebrates rural living in the Rocky Mountains. Staff invited three participants to publicly share their experiences with Gardens for Health and Healing in a presentation panel. One wrote and read out loud a short story about her garden and ballet classes. Another narrated a picture slideshow of her garden. The third screened a short garden video she had produced. In her exit interview, the videographer explained her eagerness to participate in the panel, to give back and help engage other people in gardening:

I feel like you guys have brought all the experience, all the supplies, all of the knowledge, all of that groundwork that I needed. For me to offer something back, I just felt like that's something I wanted to do to tell other people about it, if they didn't know about it, and hopefully they can get involved too.

Finally, one participant closed her exit interview with a challenge for Feeding Laramie Valley indicative of hopes for next steps for collective action beyond the project, saying, "Where do we go from here? You started something. Are you going to finish it?"

DISCUSSION

As our results show, participants reported that Gardens for Health and Healing was beneficial or even integral to their wellbeing, regardless of the condition to which they had been assigned. They provided similar reasoning for the project's contribution to their wellbeing across conditions, such as manageability, long-term sustainability, and providing an opportunity for acting on their multiple chronic conditions and challenges. Ethnographic analysis of these shared experiences of agency and wellbeing across conditions found that relational processes and social connection overwhelmingly emerged as the most salient shared aspects of wellbeing for participants in both the menu and garden conditions.

Participants understood their respective conditions as key to supporting their health and wellbeing. In the menu condition, participants described having an expanded choice set through which to exercise their agency as integral to their wellbeing. They identified both having a choice of activities and being able to identify their own outcomes and activities as key components of that wellbeing. Additionally, participants identified choice as contributing to their motivation to engage in activities and their ability to develop long-term wellbeing strategies. Participants in the garden condition also found assignment to that condition was just as valuable to their wellbeing. For many, receiving a garden was what they had hoped for in their participation, and they described constrained choice as beneficial to them. Several identified opportunities to act for their own wellbeing through the garden and asserted that the garden provided them a manageable task to commit to each day and a sustainable pathway for wellbeing in both the near and long-term. In both conditions, participants actualized individual agency to support their wellbeing and resilience, both within and beyond the project. The actuality of action is key to agency in community resilience (Magis, 2010).

Additionally, across both conditions, participants developed relationships that they identified as integral to their wellbeing. They engaged in four main modes of relational processes through Gardens for Health and Healing: bringing the family together; associating with neighbors, friends, and co-workers; engaging with a community-based organization; and, for those who either received a garden through their condition assignment or otherwise selected some form of garden, caring for and relating to garden environments.

Our findings indicate that community resilience frameworks can benefit from the dynamic understanding of relationships provided by the concept of sociality, moving beyond more static, theorized community characteristics of people-place relationships and social networks. The concept of sociality illuminates these processes as occurring within the dynamic sociocultural matrix that participants developed through the Gardens for Health and Healing project. Sociality is a means for otherwise loosely connected individual agents, such as Gardens for Health and Healing participants, to forge new connections or strengthen and deepen existing ones. Participants reflected on and acted within and through this community-based participatory project as a dynamic relational matrix that undergirds sociality (Long and Moore, 2012). Within their growing sociality matrix, participants began to engage in reflexivity by performing individual actions, reflecting on them, and communicating with others about those actions. We provide an empirical basis for how reflexivity, otherwise only hypothesized in community resilience models, can support a move from individual to collective agency for community resilience (Otsuki et al., 2018).

Reflexively coordinating and communicating with others requires actively building relationships with a range of human and non-human beings (i.e., sociality). Models note the importance of self-organization in response to change and uncertainty for community resilience but do not explain *how* it occurs in specific contexts (e.g., Berkes and Ross, 2013; Worstell and Green, 2017). Investigating unique forms of sociality, as we have done here, can clarify the myriad ways in which self-organization for community resilience becomes possible. As with community garden spaces that cultivate "emplaced sociality" and the *potential* for agency (Pink, 2008), the project provided opportunities for self-organization to emerge through participants' social connections. The relationships that participants developed with Feeding Laramie Valley as a community-based organization, particularly those that prompted participants to "give back," share their experiences at a public event, and inquire about next steps upon the project's completion, are notable. They are indicative of the potential provided by the project for moving from individual wellbeing practices to collective action and self-organization for community resilience.

A "worlding" perspective on sociality, wherein participants create social worlds together through lived relationships with others that support fuller participation in those worlds (Haraway, 2008; Solomon, 2012), provides a useful lens here. Worlding

allows that humans relate with other entities such that their "agencies are formed dialectically through co-participation in activities, performances, and discourses" (Solomon, 2012, p. 115). This shared agency-based aspect of sociality is also particularly relevant to its potential role in catalyzing a move from individual to collective agency for community resilience. Our results suggest that participants' reported benefits across both conditions emerged from taking individual action for their wellbeing. Perhaps even more importantly, however, those benefits emerged from co-produced, shared agency that they developed through their participation in Gardens for Health and Healing.

Furthermore, sociality can deepen understandings of social aspects of health in the gardening and food systems literature. Beyond developing generic social ties and networks of exchange, participants engaged in various and unique modes of sociality as relational processes with family, friends, their gardens and the living environments surrounding them, and with a community-based organization through gardening and related food system and wellbeing activities. These modes suggest the range of possible "socialities" between humans, each other, and other life in particular configurations (Long and Moore, 2012; Solomon, 2012). As other gardening studies have shown, even potentially solitary activities like home gardening allowed participants to create new social worlds.

In addition to sociality, we suggest community resilience frameworks themselves can provide an important contribution to food systems resilience research on a place-based scale. This research tends to employ the broad social-ecological systems resilience perspectives we previously mentioned more so than those on a community scale (e.g., Tendall et al., 2015; Prosperi et al., 2016; Walsh-Dilley et al., 2016; Worstell and Green, 2017). Even studies of smaller scale regional and local food systems resilience often adopt these broader social-ecological systems perspectives as opposed to community resilience frameworks (e.g., Biehl et al., 2018; Jehlička et al., 2018; Skog et al., 2018). Those earlier gardening and food systems studies that do employ the terminology of "community resilience" predate the conceptually robust, integrated frameworks that we use and advance here (e.g., King, 2008; Okvat and Zautra, 2011). However, we posit that fostering community resilience builds necessary (though not sufficient) foundations for larger systemic resilience.

We suggest that more empirical investigations aimed at operationalizing theorized community resilience models will add practical depth to food systems resilience research. This study and our related research on intergenerational resilience for Indigenous food sovereignty (Budowle et al., 2019), provide examples of these kinds of empirical, contextualized, community-based approaches to both that scholarship and related practice. Moreover, a similar study with a larger sample size and a delayed-intervention control group may help discern if either menu or garden conditions yield any statistically significant quantitative health outcomes within or between groups. Additionally, following the participants for more than one season would help to trace long-term outcomes, whether and how participants sustain activities after interventions or programs end, and the broader role of sociality in contributing to community resilience.

Now that Gardens for Health and Healing has ended, disjuncture—an aspect of sociality in which people disengage from associations and shift or end relationships—is possible (Amit, 2015). The relational process developed by participants through the the project have likely changed or even discontinued. Though many participants talked about the sustainability of their health and wellbeing actions, we do not know whether or not participants remain engaged in individual or collective action surrounding gardens and food systems. Regardless, participants built richly textured social worlds through the project, which provided the possibility and a pathway for collective action for community resilience.

In sum, we suggest that this kind of empirical research on community resilience is helpful for understanding and developing overall food systems resilience. We found that both gardening and designing and implementing menu-based health interventions fostered agency and helped participants engage in a range of relational processes. We conclude that sociality can help promote and explain a move from individual wellbeing and agency to the collective forms of agency and self-organization necessary to cultivate community resilience for sustainable food systems.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available, because interview and ethnographic data are highly personal and difficult to fully de-identify. However, SF-12v2 data are available upon request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The University of Wyoming Institutional Review Board reviewed and approved this study involving human participants. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

RB conducted the interviews and ethnographic research, analyzed qualitative data, and wrote the first version of this manuscript as part of her dissertation research. CP was the principal investigator of the overall Gardens for Health and Health study, mentored the first author's work, and co-wrote this version of the manuscript. All authors co-designed the study reported here, including the menu of suggested options for participants in the menu condition, with support, review, and approval by Feeding Laramie Valley.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.685384/full#supplementary-material

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Farming Households' Satisfaction With Quality of Agricultural Extension Services: A Case Study of Quang Binh Province, Vietnam

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Agriculture is an important sector of Vietnam, in which agricultural extension (AE) is a long-standing activity but was officially institutionalized in 1993 when Vietnam reformed its economic model. The AE system in Vietnam is organized quite closely from the central to local levels with various forms of AE. This study assesses the satisfaction of farmers with AE services in Quang Binh province, Vietnam. The results of a survey of 455 farmers show a positive relationship between quality and satisfaction. Factors such as assurance, reliability, and sympathy are important factors in AE service quality. The study also provides recommendations to strengthen AE services, including updating technical information, organizing demonstration models, and stronger investment in AE systems at all levels.

Keywords: agricultural extension, service quality, farming household, factor analysis, Vietnam

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INTRODUCTION

Agricultural extension services have been globally considered as an critical input for promoting agriculture and enhancing rural development (Awatade et al., 2019; Bruce and Costa, 2019). AE is defined as "the services offer technical advices on agriculture to farmers, and also supplies them with the necessary inputs and services to support their agricultural production. It provides information to farmers and passes to the farmers new ideas developed by agricultural research stations." (FAO, 2020). As time goes by, the term "agricultural extension services," while still commonly employed, has been gradually replaced by the term "agricultural advisory services." Some researchers even extend the concept more broadly to "rural advisory services" to emphasize the facilitation beyond technological transfer and to include other sources of livelihood than agriculture only (Faure et al., 2012; Kassem, 2015; Gwala et al., 2016; Baiyegunhi and Majokweni, 2019).

In Vietnam, agriculture is one of the most important economic sectors. Besides producing to serve the growing domestic demand, Vietnam is also a country that exports many agricultural products each year. The dominant crops include coffee, rubber, cashew, and rice. In recent years, aquaculture and fruit production has developed significantly and are geared toward foreign exports. With a significant contribution to gross domestic product (20%), agriculture will continue to play a significant role in Vietnam's transition to a market economy. Vietnam's agricultural output strength is built on a large rural base (66% of the population), where agribusiness makes up 70% of the workforce (Nguyen and Nguyen, 2016; World Bank, 2020). To enhance agricultural development, in 1993, the Vietnamese Government issued Decree No. 13/ND-CP on Agricultural Extension, and the AE system was officially formed during the "Renovation" period. The Decree defines "AE is an activity

of transferring technical advances, information, spreading knowledge and training skills to farmers to improve the capacity and efficiency of agricultural production and business, protect environmental protection and new rural construction" (Nguyen and Nguyen, 2016).

After nearly 30 years of operation, AE has grown strongly and has become an asynchronous system from the central to the grassroots level, closely linked with agriculture, farmers, and rural areas. At the central level, the Center for Agricultural Extension, established in 1995 under the Ministry of Agriculture and Rural Development (MARD), is the focal point for unifying direction and guidance on AE skills for the whole country. Extension organizations have also been formed and developed from the provincial to district and commune levels in the locality. AE has become an effective tool and an important bridge in transferring technical advances and new technologies, contributing to the successful growth of agricultural production in Vietnam (Dang et al., 2012; Ministry of Agricultural Rural Development, 2019).

Empirical evidence worldwide shows that AE provide timely information which support farmers in solving farming issues and in making better decisions (Buadi et al., 2013; Gwala et al., 2016; Nahayo et al., 2017). AE services also facilitate farmers' networking with management agencies and other stakeholder in agricultural value chain (Lalhmachhuana and Devarani, 2016; Morris et al., 2017; Awatade et al., 2019). In addition, AE plays an important role in organizing farmers formally or informally into groups to assist them mobilize collective actions and improve their competitiveness in local, national and international markets (Yazdanpanah et al., 2013).

However, in the face of new challenges for sustainable agriculture, AE work in Vietnam still reveals certain limitations such as the low efficiency of the extension program, the lack of diversified forms of activities, the lack of technical information and financial resources, etc. (Nguyen et al., 2016). This study aims at measuring the satisfaction level of farmers with the service quality of AE programs. The study is conducted in Quang Binh, a typical agricultural province in the central part of Vietnam. From that, some policy implications are drawn to improve the service quality of AE in the Quang Binh province and Vietnam.

STUDY AREA

Quang Binh is a province on Vietnam's North Central Coast located at the narrowest point in the east-west direction of the country's S-shaped strip (40.3 km following the shortest path from the Lao border to the East Sea—**Figure 1**).

Quang Binh has a total land area of 9,065.27 km^2. Quang Binh's mainland is located between 16°55′ and 18°05′ north latitude and 105°37′ to 107°00′ east longitude. Quang Binh has a 116.04 km long coastline in the east and a 201.87 km long borderline with Laos in the west, as well as Hon La Seaport, Dong Hoi Airport, National Route 1A, Ho Chi Minh Highway, North-South Railway, National Route 12, and provincial routes No. 20 and No. 16 that run from west to east, passing through Cha Lo International Border Gate and some border gates with Laos. The landscape of Quang Binh is narrow and hilly from west to east. Mountains and hills cover 85 percent of Quang Binh's natural land. The province is split into four major areas: high mountainous, hill and midland, plain, and coastal sand. Quang Binh is located in the tropical monsoon climate and is influenced by the north and south climates. Thus it has two different seasons: the rainy season, which lasts from September to March, and the dry season, which lasts from April to October. The yearly average rainfall fluctuates between 2,000 and 2,300 mm. The dry season lasts from April through August, with average temperatures ranging from 24 to 25°C. June, July, and August are the warmest months (Nguyen et al., 2015).

In 2019, the population of Quang Binh will be 8,63,350 people. Kinh ethnic people make up the majority of the population. The population is unevenly dispersed, with rural regions accounting for 84.80% and urban areas accounting for 15.20%. The province is divided into six districts (Bo Trach, Le Thuy, Minh Hoa, Quang Ninh, Quang Trach, Tuyen Hoa, and Ba Don town), each having 159 communes, wards, and towns (Quang Binh People Committee, 2020).

METHODOLOGY

Analytical Model

So far, many studies have established the relationship between service quality and customer satisfaction. Perceived service quality has been widely considered as an antecedent of customer satisfaction. Previous studies have ascertained its significantly positive relationship (Getty and Getty, 2003; Hossain, 2012; Chavan and Ahmad, 2013; Faramarzi and Langerodi, 2013; Nguyen et al., 2015). Various scales and indexes to measure service quality such as SERVQUAL (Parasuraman et al., 1985, 1988), Technical and Functional Quality model (Gronroos, 1984), Synthesized model of service quality (Brogowicz et al., 1990), Antecedents and mediator model (Dabholkar et al., 2000; Mittal and Kamakura, 2001) have been developed and extensively used by academics and practitioners. SERVQUAL is often considered the most commonly applied in numerous empirical studies in many countries (Aphunu and Otoikhian, 2008; Ladhari, 2009; Cameran et al., 2010). SERVQUAL scale was originally developed by Parasuraman et al. in 1985 by comparing expectations with perceptions on 10 service quality aspects. By 1988, this scale was further identified with five service quality dimensions: Tangible, Reliability, Responsiveness, Assurance, and Empathy (Hamzah et al., 2015). In this study, the conceptual framework is developed following various empirical and theoretical studies such as Parasuraman et al. (1985), Anderson et al. (2008), and Nguyen et al. (2015). The linear structural model (SEM) is used to estimate the relationship between the factors reflecting the quality of extension services and the farmers' satisfaction. From previous studies, we selected five factors as mentioned above reflecting the quality of AE services (**Figure 2**).

Six variables measure the factor of tangible: Full teaching equipment (TG1); Modern teaching equipment (TG2); Convenient place to study (TG3); The venue for well-organized classes (TG4); Good combination of AE organizing

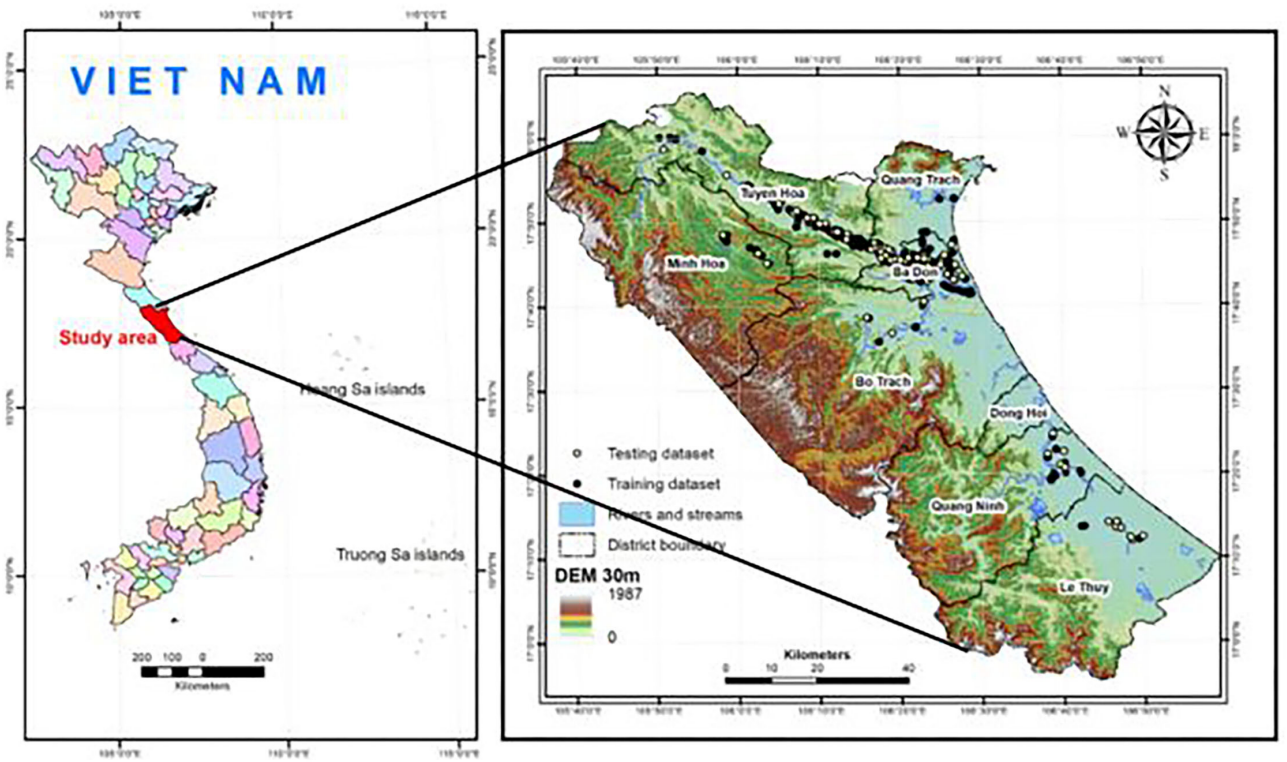


FIGURE 1 | Quang Binh province in Vietnam's map.

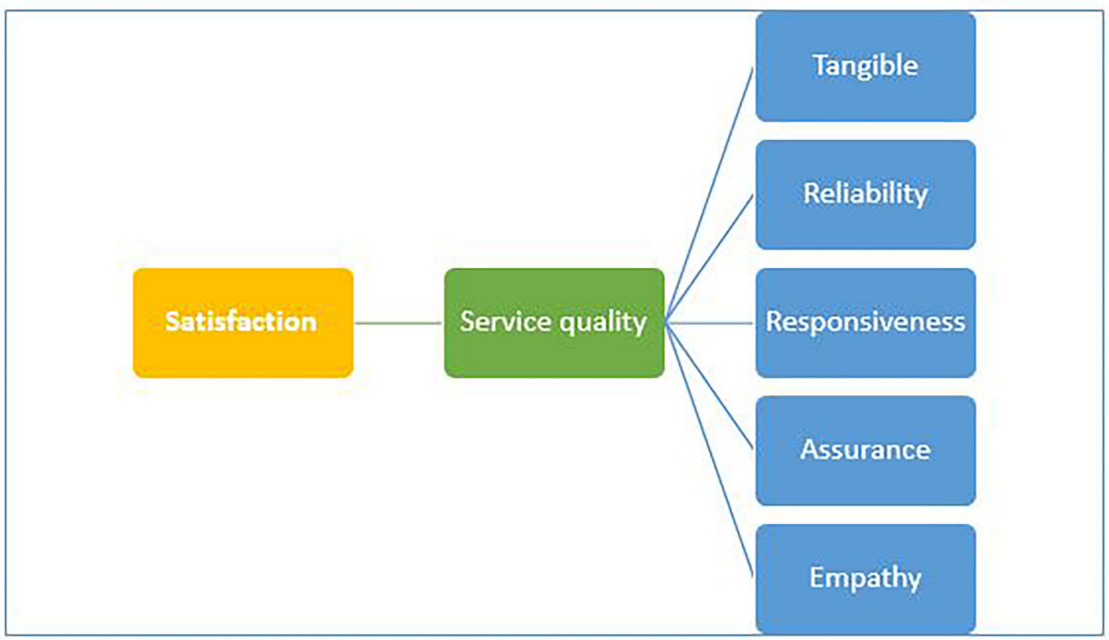


FIGURE 2 | Conceptual framework of the impact of service quality and farmer's satisfaction.

committee (TG5); The center's support in the programs is appropriate (TG6).

Five variables measure the reliability factor: AE Center always fulfills its commitments (RLA1); The AE Center is always interested in farmers' problems (RLA2); The AE Center provides accurate information that farmers need (RLA3); AE Center provides information at the right time (RLA4); The AE Center always announces the program implementation time (RLA5).

Four variables measure responsiveness factor: AE staff with good professional knowledge (RSP1); AE officers always help farmers (RSP2); AE staff answer questions thoroughly (RSP3); AE staff enthusiastically guide farmers in practice (RSP4).

Five variables measure assurance factor: Farmers feel secure when applying advances in production (ASR1); Clear presentation and easy to understand instructions (ASR2); Lively, relaxed classroom communication (ASR3); Experienced AE Officer (ASR4); Matching field trips (ASR5).

Four variables measure empathy factor: AE program activities are suitable for farmers' needs (EPT1); AE staff sympathize with the difficulties of farmers (EPT2); AE activities with convenient working time (EPT3); Close and friendly extension staff (EPT4).

The Likert scale is used to assess the level of farmers' satisfaction: 1: Very dissatisfied; 2: Dissatisfied; 3: Normal; 4: Satisfied; 5: Very satisfied.

The estimation process consists of two stages: the first stage is to evaluate the validity of the measurement model, and the second stage is to test the structural model. Confirmatory factor analysis (CFA) was used in the first stage. Two necessary criteria for the measurement model to be valid are the acceptability of the model fit and the validity of the factors (Mittal and Kamakura, 2001; Hair et al., 2012). Regarding the fit of the model, there are many indicators classified. The rule of thumb is to use the Chi-square test and at least 1 criterion from each group (Hair et al., 2012). Other SEM studies often use the Chi-square test and one or more indicators from groups (Flynn et al., 1990; Lee et al., 2000; Van der Veen and Song, 2013).

The second stage is to run the SEM model and use the same evaluation criteria as the CFA. Then there are interpretations of the path coefficient, structural model fit (R^2), direct, indirect, and total effects.

Data Collection

Secondary data were collected from DARD, AEC of Quang Binh Province, and Districts' Agriculture Departments. Primary data was collected by stratified sampling method combined with randomization. In each district in the province, the study randomly selected two communes to investigate (total 12 communes for six districts). According to Moore's formula (Moore, 2003), the sample size was estimated based on the total number of households in each district, and the error allowed 5%. The sample size was determined to be 455 households. Households are selected randomly from the list provided by the Commune People's Committee. They were interviewed using a prepared questionnaire. The content of the interviews included general information about farmers, agricultural production, participation, and satisfaction with different aspects of local AE services.

RESEARCH RESULTS

Overview About AE System in Vietnam

The Vietnamese Government's public extension system was established in 1993, and it is divided into five levels: Central (National), Provincial, District, Commune, and Village/Hamlet.

The Vietnam Extension System was formally created on March 2, 1993, under Government Decree 13/N-CP. According to this order, MARD was designated as the management's primary focal point. Based on these findings, the Government founded the National Agriculture Extension Center in 1998. The Center is responsible for the following tasks, according to current regulations: (i) Developing management policies and management mechanisms for AE, forestry, fishery, and rural industry; (ii) developing economic-technical cost-norms for extension works; leading, organizing, and guiding the transfer of advanced techniques through demonstration models, information dissemination, training, and service provision. (iii) establishing economic-technical cost-norms for extension works; leading, organizing, and guiding the transmission of innovative methods through establishing demonstration models, information dissemination, training, service provision, and international collaboration in relevant sectors.

The total number of public extension workers in Vietnam (as of December 31, 2018) is 34,747, equating to one public extension worker for every 280 agricultural families. Each of the 63 provinces/cities has its own Extension Center, with an average of 30 people percenter. Only 585 of the total 648 districts have Extension Stations (90,3 percent) under the supervision of the provincial extension Centers (average six people per station) (Ministry of Agricultural Rural Development, 2019).

Current extension activities are centered on the following topics:

(i) Creating models that demonstrate sophisticated approaches for transmission to farmers. The models emphasize the introduction of new kinds, methods, and technologies. Parallel to this, extension personnel arranges field days to teach farmers and answer their concerns.
(ii) Planning farmer training. Because not all new techniques are shown in the fields, training swiftly transfers them to farmers. Furthermore, the extension system provides possibilities for farmers to use innovative technology from other countries.
(iii) Hosting science and technology forums and particular festivals and exhibitions, where farmers may interact directly with scientists, managers, and examples of successful cases of using new technology.

Aside from transferring technology and training, the extension system is also in charge of communicating new agricultural policies to farmers, rural regions, and markets. Meanwhile, extension workers gather input on shortcomings and restrictions from practices to propose new technologies or change rules (Nguyen and Nguyen, 2016).

Today, the following players participate in extension duties: (i) the government extension system (Extension centers); (ii) research institutions; (iii) universities; (iv) businesses;

(v) non-governmental organizations (NGOs); (vi) volunteer extension organizations.

The future of extension in Vietnam is to foster "socialization of the extension program." The goal is to promote two-way information exchange and develop farmer-led and demand-driven extensions (Ministry of Agricultural Rural Development, 2019).

Analysis of Factors Affecting the Quality of AE Programs in Quang Binh

The main objective of the AE policy is to impart knowledge to farmers in the locality, helping them make the right decisions in the face of situations arising in the production process. Local AE forms in Quang Binh are quite diverse (**Table 1**).

The results show that the most common form of AE is training directly guided by extension center staff (41.5%). In addition, farmers have access to technical advances through information and communication channels, demonstration models, and consulting services for extension services (32.9%). Regarding the level of participation of farmers in the AE program, each household participates on average twice a year (58.2%) and three times (26.1%).

Evaluation of the Reliability of the Scale With Cronbach's Alpha Coefficient

The quality of the AE program is measured by five factors: Tangible, Reliability, Responsiveness, Assurance, and Empathy. The results of testing the reliability of the scale with Cronbach's Alpha coefficient (**Table 2**) show that all service quality factors have the accepted Cronbach's Alpha coefficient of > 0.6 (Peterson, 1994). The total correlation coefficient of the variables in the scale is > 0.3, and it is satisfactory (Hair et al., 2010), so the measurement variables of these factors are used for EFA analysis.

TABLE 1 | Local AE forms in Quang Binh.

Forms of AE	Number of households	Percentage
Training	189	41.5
Information and communication	135	29.7
Demonstration model of AE	38	8.3
Consulting AE services	150	32.9

TABLE 2 | Cronbach's Alpha factors of service quality scale AE.

Factors		Cronbach's alpha
Tangible Media	TG1, TG2, TG3, TG4, TG5, TG6	0.760
Reliability	RLA1, RLA2, RLA3, RLA4, RLA5	0.869
Responsiveness	RPS1, RPS2, RPS3, RPS4	0.728
Assurance	ASR1, ASR2, ASR3, ASR4, AR5	0.832
Empathy	EPT1, EPT2, EPT3, EPT4	0.851
Service quality	SQ1, SQ2, SQ3	0.759
Satisfaction	STF1, STF2, STF3	0.839

Exploratory Factor Analysis (EFA)

EFA results with factor extraction using Principal Axis Factoring, and Promax non-perpendicular rotation showed five factors extracted with the extracted variance of 68.52% (>50%) meeting the requirements. However, in 24 observed variables, seven observed variables (TG5, TG6, RLA4, RLA5, RSP3, RSP4, ASR5) have factor loading <0.5, so they are excluded from the model (Fornell, 1992; Fornell et al., 1996; Allen and Rao, 2000; Amin and Isa, 2008). After eliminating seven unsatisfactory variables, the final EFA results are presented in **Table 3**. KMO and Ballett's test in EFA factor analysis shows that KMO = 0.668 is satisfactory due to > 0.5 and Sig. = 0.000. The TLI = 0.872, CFI = 0.912 $\geq$ 0.9, RMSEA = 0.055 $\leq$ 0.08, then the model fits the research data. The model's fit with the research data shows that the necessary and sufficient conditions for the observed variables are unidirectional (Saravanan and Rao, 2007). The factors Assurance, Empathy, Reliability, and Responsiveness achieve unidirectionality.

Farmers' Satisfaction With the Quality of the AE Program

Research results (**Table 4**) show that the quality of the extension program has a positive influence and strongly correlates with the satisfaction of farmers, as shown by the coefficient $\beta = 0.715$. This estimate reaches statistical significance at $p = 0.000$. This means that farmer satisfaction increases as the quality of local extension programs is improved. Extension program quality includes factors such as assurance, empathy, credibility, tangibles, and responsiveness. In which the Assurance has the greatest influence on the quality of the AE program, the estimation results of the SEM show that the assurance factor has the

TABLE 3 | EFA results of service quality scale.

Variables	Factors				
	1	2	3	4	5
ASR4	0.815				
ASR3	0.779				
ASR2	0.771				
ASR1	0.692				
ASR5	0.630				
TG3		0.908			
TG4		0.898			
TG1		0.865			
TG2		0.792			
EPT1			0.831		
EPT3			0.811		
EPT2			0.771		
EPT4			0.768		
RLA2				0.801	
RLA1				0.796	
RLA3				0.742	
RSP2					0.859
RSP1					0.833

TABLE 4 | Relationship between AE service quality factors and satisfaction.

	B Coefficient	SE	*p*-value
Tangible	−0.773	0.075	0.328
Assurance	0.666	0.052	0.000***
Empathy	0.079	0.031	0.003***
Reliability	0.121	0.048	0.018**
Responsiveness	−0.012	0.062	0.686
Service quality	0.715	0.076	0.000***

***Statistically significant at the 1% level.*
***Statistical significance at 5% level.*

coefficient $\beta = 0.666$ and the reliability level of 99%. Thus, the quality of the AE program will be improved when factors such as the experience of the extension staff, presentation methods, classroom discussions, application of advances in production, and field trips are more improved. Moreover, the SEM model also shows that the Reliability and Empathy factors significantly influence the quality of the local AE program.

However, the model shows that tangible and responsiveness factors are negatively related and not statistically significant to the quality of the extension program. This may be because the facilities and learning conditions in AE activities have not met the expectations of participating farmers and the professional quality of local extension workers.

DISCUSSIONS

The results of the analysis of the linear structural model (SEM) show the suitability of the theoretical model with the quality of the extension program and the satisfaction of farmers with local AE services in Quang Binh province, Vietnam. Research has shown that, as the quality of the extension program increases, the satisfaction level of farmers will also increase. On the other hand, the service quality of the AE program depends greatly on the assurance factor, the reliability factor, and the empathy factor. On the contrary, it does not depend on tangible factors and responsive factors.

These findings are consistent with the results of Gwala et al. (2016), Baiyegunhi and Majokweni (2019) and Awatade et al. (2019), who associated assurance factor with farming households' satisfaction with AE services. In spite of the importance of diversify farming activities for using resources efficiently, reducing economic risks for farmer and setting stabler ecosystem for farming effect positively on farmer satisfaction. This result is consistent with results by Buadi et al. (2013). Moreover, reliability factor and farmers' participation in AE services influenced significantly farmer satisfaction (Damisa et al., 2008; Suvedi et al., 2017). As AE the main source of farming households' information on innovations, their participation increased in frequency. AE services in Vietnam mainly arrange group methods such as meetings to transfer extension information. Farmers can attend these meetings because of the active role of local authorities. This result is consistent with those of previous papers (Kassem, 2015; Lalhmachhuana and Devarani, 2016; Nahayo et al., 2017) which showed the significant roles of participating in AE in improving farmer satisfaction.

The results also indicate that empathy factors are significant positively correlated with satisfaction. The fact that AE program activities are suitable with farmers' needs, AE staff sympathize with the difficulties of farmers and AE activities are convenient working time increase famers' satisfaction have been confirmed in some related studies as one of the main factors influencing satisfaction (Yazdanpanah et al., 2013; Gwala et al., 2016). In Vietnam, local agricultural extension organizations often have very close relationships with farmers. Through regular interaction with local organizations such as women's unions, veterans' unions, farmers' unions, and youth unions, these extension organizations are able to grasp the difficulties in the production process. local agriculture, needs and information to be shared with farmers. This makes it possible for extension organizations to design shares, suggestions and messages to suit farmers' needs, in the way they expect.

Results showed that tangible factor is not significant determinant for satisfaction. This is may be attributed to the fact that the several farming households in Quang Binh province do not want to rely too much on modern farming equipments. They also don't need formal classes or tangible support such as lectures, handouts or demonstration clips. What they want are messages that are short, clear, and make their farming operations productive. This is consistent with the study by Yazdanpanah (2016) that when the education level of farmers is not high, the tangible factors in AE do not have too much influence on their satisfaction with extension services. However, other studies (e.g., Gwala et al., 2016; Morris et al., 2017; Bruce and Costa, 2019) reported the significant effect of education on increasing farmer satisfaction.

CONCLUSIONS AND RECOMMENDATIONS

The mission of AE is to bridge farmers with science, production techniques, optimal farming, opening new opportunities, and creating sustainable values. In Vietnam, when the agricultural sector is facing a change in growth pattern in the context of globalization and climate change, AE work needs to revolve around farmers, understanding the problems they are facing, providing suitable advices and supports to help farmers cultivate more efficiently. Good knowledge may help to increase the productivity of crops and livestock, to get the more output and profit. However, knowledge and skills alone are not enough, it is the attitude in work that is decisive. When farmers are optimistic and firmly believe that they can do it, they can definitely do it, agricultural extension work will have many advantages. When farmers are pessimistic, lack confidence in themselves, and trust in the community, it is difficult for agricultural extension work to be widely deployed. AE, besides providing technology, must also instill confidence in farmers through factors such as reliability and empathy.

This study assesses the satisfaction of farmers with AE services in Quang Binh province, Vietnam. The results of a survey

with farmers show a positive relationship between quality and satisfaction. Factors such as assurance, reliability, and sympathy are important factors in AE service quality.

These are the bases for building an effective solution in training farmers to achieve the requirements of transferring scientific and technical progress and satisfying the needs of farmers participating in the program. In this analysis, for farmers to confidently apply scientific advances to agricultural production, AE activities need to add other support policies such as product consumption, lending policies, agricultural insurance. In addition, the model of socialization of AE should also be replicated to mobilize capital from the people and businesses trading in agricultural materials to reduce the budget burden and take advantage of the resources of the private sector. AE activities are often related to application and technology transfer, requiring investment in facilities and funding to maintain and replicate the model. Therefore, AE agencies should actively cooperate with research organizations and enterprises to test and demonstrate local models.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Scanning Models of Food Systems Resilience in the Indo-Pacific Region

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The Indo-Pacific is a region of the world experiencing rapid growth in population and development. However, it is also exposed to a number of social, economic, geopolitical, and biophysical stressors, which may undermine the region's ability to support its population, ensure food security, and sustain livelihoods. In response to the complex suite of stressors, a number of development initiatives and research programs have been established to build resilience in the region's food systems. These initiatives vary in scope and scale, but also in what they mean by the term resilience and the components of the food system they address. This variation has implications for the outcomes of these efforts and how well they match a theoretical ideal of resilience. This review examines how resilience and food systems are defined, conceptualized, and applied within research studies and projects or initiatives on food systems resilience funded or supported by national, regional, or multilateral government, and non-governmental institutions in the Indo-Pacific region. It also compares how the concepts are treated from an academic or theoretical perspective vs. in practical applications. We take a two-pronged approach: first, identifying organizations engaged in the Indo-Pacific region and developing an inventory of initiatives and projects that have bearing on food systems resilience; and second, carrying out literature searches to record research studies in the region that examine resilience within food systems. We then identify any formalized frameworks or definitions of resilience and/or food systems guiding these projects and studies. The results indicate there is a heavy focus on climate change and natural disasters, and to a lesser extent health-related shocks, in food systems resilience research and practice. Definitions, however, are inconsistently reported, and are often more simplistic than resilience theory depicts, favoring resilience conceptualizations around adaptation and a production-oriented food systems framing. While the specific definitions vary between research and applied projects, the fragmented and ambiguous use of terms presents a challenge for policy applications and coordination. Overall, establishing some clear guiding resilience principles, modified according to contextual factors, could enable more streamlined resilience work in Indo-Pacific food systems.

Keywords: climate change, adaptation, sustainable development, food systems, Pacific Islands, Southeast Asia, resilience

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INTRODUCTION

East Asia and the Pacific face a unique combination of challenges and opportunities, which shape the region's food production and consumption. In the last decade, the region has seen major infrastructure and economic development leaps (Rathbone and Redrup, 2014), conspicuously shifting consumption patterns (Hodgson, 2013), and substantial donor aid supporting poverty alleviation and economic developments through investments in transportation, infrastructure, and agriculture (Dornan and Pryke, 2017; Ingram, 2020). Yet at the same time, the region continues to be plagued by persistent poverty, social and economic inequalities, and environmental vulnerabilities (Palanivel et al., 2016; UNDP, 2020). Food systems play a critical role in the maintenance and growth of society, supporting food security, livelihoods, and wellbeing, particularly under these conditions.

Food systems are crucial because they not only provide sustenance to ensure food security, but also form the backbones of people's livelihoods from production all along the broader value chain of processing, transporting, and selling food products (Ericksen et al., 2009). Shocks and stresses, most recently the COVID-19 pandemic, have highlighted certain underlying vulnerabilities and current levels of resilience in food systems in the region, particularly when these systems are faced with compounding risks arising from coincidence of extreme events, trade disruptions, and interruptions in supply (Béné, 2020; Farrell et al., 2020; Naidoo and Fisher, 2020). Yet there are still major gaps in our understanding of what constitutes resilient food systems, and how those concepts are applied in practice. This paper discusses the state of resilient food systems research and practice in the Indo-Pacific sub-region (here inclusive of countries in Southeast Asia [SEA] and Pacific Island Countries and Territories [PICTs]), focusing primarily on work carried out by international, intergovernmental, donors, and academic institutions, taking stock of the strengths and shortcomings of the current conceptualizations of "resilience" and "food systems" in the regions.

The Indo-Pacific includes regions experiencing rapid growth in population and development (Palanivel et al., 2016), which has implications both in terms of exposure and sensitivity to shocks and stressors, and capacity to respond to them. Both regions have integrated regional bodies, such as the Association of Southeast Asian Nations (ASEAN), and the food system-related CROP agencies (Council of Regional Organizations in the Pacific) of the Pacific Islands. Countries in SEA and PICTs face a number of risk factors relevant to food systems, including dependence on food imports, pre-existing gender, health, and economic inequities, fragmented value chains and food governance systems, poor biosecurity infrastructure, growing informal and marginalized labor markets, and climate change impacts (Robins et al., 2020). That said, these two regions also differ in terms of their interactions or physical connection with mainland Asia, their levels of urbanization and population densities, and modes of governance and regional cooperation, as examples. In turn, this suggests that even prior to carrying out the scan, we expected to find different opportunities and hurdles for the two regions, relating to food systems resilience.

In Southeast Asia (SEA), which houses over 600 million people, levels of development range from "medium-low" (for Human Development Index, HDI) in countries like Myanmar, Lao People's Democratic Republic, and the Philippines, to "high" in Singapore, Brunei, and Malaysia (Sadeka et al., 2018). Half the population lives in urban centers, although this ranges from less than one-quarter in Cambodia to 100-percent in Singapore (UNESCAP, 2019). Regional disparities like these exist due to both geographic characteristics, such as areas that are drought-prone in Indonesia or exposed coast in the Philippines, and socioeconomic context, for example densely-populated urban centers like Singapore or Kuala Lumpur (Hijioka et al., 2014). Climate shocks include rising sea levels and risks of flooding, extreme monsoonal rainfall, and increased landfall of cyclones (Hijioka et al., 2014).

Pacific Island countries and territories (PICTs) are composed of 22 Pacific Islands – of which only two-percent is landmass and 98% is ocean – and approximately 12.5 million people reside in the region (UNESCAP, 2017; SPC, 2020). Levels of human development vary across the PICTs - ranging from high-very high HDI in countries like Palau, Fiji, Tonga, Samoa, to medium in Papua New Guinea and Kiribati (UNDP, 2020). A reliance on tourism, remittances, and international trade for income-generation is common across the PICTs. With an increasing reliance on calorie-dense and nutrient-poor imported foods, the Pacific has one of the highest Non-Communicable Disease death rates in the world (Bell et al., 2016). The Pacific region is also a high risk natural disaster area, experiencing an increasing number and intensity of extreme weather events such as tropical cyclones and flooding, and the highest rates of sea-level rise globally (UNESCAP, 2017).

Food and livelihood insecurity and persistent poverty in the Indo-Pacific regions have prompted the establishment of a number of research studies and project-based initiatives to build resilience in food systems. Here we have focused on those led by national or regional government bodies, international organizations or NGOs, research institutes, and donors, rather than community or local grass-roots initiatives. Because these institutions have a diversity of objectives and outcomes, efforts related to food systems resilience vary in scope and scale, but also in what they mean by the term "resilience" and the components of the "food system" under consideration. This variation has implications for the outcomes of these efforts and how well they match a theoretical ideal of resilient food systems. As such, it is important to understand how resilience in food systems is being conceptualized in different contexts, so as to better tailor such initiatives to meet local needs, establish common expectations of scope and scale, and achieve desired outcomes.

Resilience and Food Systems Frameworks

Both the terms "resilience" and "food systems" are difficult to put boundaries around; however, there are frameworks that provide a starting point from which to build context-specific conceptualizations (Ericksen, 2008; Evans, 2011; CARE International, 2016; USAID, 2018; HLPE, 2020). We drew on

several frameworks and conceptual pieces to help define the scope of this study, as well as develop the coding framework used in this analysis.

Food systems have been broadly defined as comprising the different drivers (e.g. urbanization, technology development, economic growth), components (e.g. environment, people, processes, infrastructure, institutions), and activities (e.g. production, processing, distribution, preparation, and consumption) that contribute to food security outcomes (Ericksen, 2008; Brouwer et al., 2020; HLPE, 2020). As one primary objective of a food system, achieving food security is considered the circumstances when "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for a healthy and active life" (Pinstrup-Andersen, 2009). Our working definition of food systems also includes the achievement of other goals, such as improved conservation outcomes, gender equity, livelihoods, and local capacities, which align with the Sustainable Development Goals that have been implicated in high-level food security and nutrition discourses (HLPE, 2020). Despite this inherent complexity in food systems, they are often approached piecemeal; studies often examine food systems from the supply/production, mid-stream processes, or demand perspectives, rather than at a systemic level (Brouwer et al., 2020).

A food system risks failing to deliver on its primary objectives when confronting current or future disturbances or stresses, such as economic shocks, institutional failures, actors in conflict, and environmental changes (Ericksen, 2008; Evans, 2011; Hoddinott, 2014). Resilience in the face of such stresses may be context-specific, but also often requires consideration for an approach that encompasses complexity and systemic interactions. In addition to environmental constraints from soil degradation, biodiversity loss, land conversion, and pollution, structural risk factors – from trade agreements and governance structures, corporate consolidation and existing value chains, and persistent injustices and food sovereignty struggles - have been suggested as critical for food system resilience (Mooney et al., 2021).

While scholarship on resilience spans multiple disciplines, and varies accordingly, the concept as applied to the food and agricultural development contexts shares many similar terms and fundamental principles. At its heart, a resilient food system is conceptualized as supporting food security and related objectives over time and in spite of various and possibly unforeseen disturbances, by ensuring sufficient, accessible, and stable supplies of food (Tendall et al., 2015; Béné, 2020). Resilience can be understood through a common set of capacities of the system: to *avoid* or prevent exposure to disturbances, *absorb* the effects of disturbances, *recover* and restore after disturbance, *adapt* and learn moving forward from a disturbance, and *transform* a system in the long-term (Folke et al., 2010; Tendall et al., 2015; Doherty et al., 2019). Common phrasing in the literature conveys the sentiment of "bouncing back better", denoting that resilience is a subjective concept that is not merely about maintaining the existing function of a system, but learning from and improving upon it (Béné, 2020; Walker, 2020).

We acknowledge that "what a resilient food system is" depends on the context. As such, we take an inductive approach for this study to determine how these terms have been defined or conceptualized within the research studies and on-the-ground projects that are reviewed, pointing to the terminology employed in existing definitions whenever possible.

OBJECTIVES AND METHODS

This review aims to identify the ways in which research studies and projects conceptualized and applied the notions of "resilience" in "food systems", focusing on two sub-regions in the Indo-Pacific (Southeast Asia and the Pacific Islands). We focus the review on work undertaken by academic, national, regional, or multilateral government, and non-governmental institutions, as the monitoring and evaluation of these projects is often better documented; projects tend to be undertaken across a range of different case studies, allowing scalable outcomes to be determined; and resources from these organizations are growing in the resilient food systems space. Specifically, the review seeks to understand:

1. How resilience and food systems are defined or conceptualized by the reviewed projects and research studies in the Indo-Pacific;
2. How these concepts compare in research studies vs. applied in projects; and
3. What differences or similarities arise between the definitions and applications of these concepts within the reviewed projects and research studies in Southeast Asia and the Pacific Islands.

Structured Search

We took a two-pronged approach to identifying projects/initiatives and research studies (see **Table 1** for terms). During stage 1, we identified organizations in the regions implementing projects that addressed issues of relevance to food systems resilience. In stage 2, we looked at the landscape of applied and exploratory research on resilience in Indo-Pacific agri-food systems.

Web searches were carried out between December 2020 and April 2021. For stage 1, we initially identified regional organizations/bodies through keyword searches, and the websites of regional coordinating bodies, such as the Association of Southeast Asian Nations (ASEAN) and the Council of Regional Organizations in the Pacific (CROP). This was followed by snowball sampling to identify additional projects and research studies not originally included in the inventory. We consulted organizational websites to identify projects or broader initiatives that related to some aspect of the food system and dealt with resilience, and then extracted information from the websites, reports, project documents, and other media. For stage 2, we carried out a series of keyword searches on Google Scholar (see **Supplementary Table 1**) and looked through the first 100 results of each search, to identify research studies to be examined as representative of the research in the region.

Search results were only included if they covered at least one country in Southeast Asia (SEA) or a Pacific Island Country or

TABLE 1 | Descriptions of main terms used in the methods for the structured search, data extraction, and analysis.

Term	Description
Project	A time-bounded activity carried out *in-situ* with the objective of building resilience in a food system. A project may have a research component or apply the results of previous research.
Initiative	Compendium of related projects, funded under the same banner, led by the same organization, and all contributing to the same overarching objective. Projects may focus on different aspects.
Research study	Individual output from a desk-based, synthetic, or empirical research activity. This can be in the form of a peer-reviewed journal article or a report, brief, or working paper published as gray literature by an organization.
Organization	Body leading the project, initiative, or study. Organizations include multilateral, governmental, and non-governmental organizations, universities, non-academic research institutions, and donor agencies or funders with a presence in SEA and/or PICTS.
Theme types	This term is used to describe the three broad areas of data extracted: "main topic" captures the shock/hazard and/or driver/motivation of the project or study; "food system" includes the aspects of the food system under consideration; "resilience" covers the way(s) in which resilience is conceptualized.
Coded themes	Specific terms identified under each theme type to capture what the project or study was about.

Territory (PICT). SEA includes Brunei; Cambodia; Christmas Island (Australia); Cocos (Keeling) Islands (Australia); Indonesia (and West Papua[1]); Lao People's Democratic Republic; Malaysia; Myanmar; Philippines; Singapore; Thailand; Timor-Leste; and Vietnam. PICTs comprise the 22 Pacific island member countries and territories (American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas, Palau, Papua New Guinea, Pitcairn Islands, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis & Futuna).

Results of the search were only included in this analysis if they met the following criteria:

- At least one country in the region of interest was present;
- Either a project on-the-ground (or the umbrella initiative), or a research study in the form of a peer-review article, white paper, report, or similar;
- Project completed or study published after 2009, or current/ongoing initiative;
- Explicitly addressed some aspect of resilience within some component of the food system;
- Not at a global level or focused solely on international trade;
- Existing syntheses of projects in the region and empirical research were included, but not solely conceptual or theoretical publications.

[1]Considered a politically contested space, although technically under sovereignty of Indonesia.

A total of 61 projects and 53 research studies in SEA and 58 projects and 37 research studies for PICTs were included in the analysis. Of these, ten of the projects and nine of the research studies had countries from both regions represented. See **Supplementary Material** for a breakdown by country, and the data table with more details of each data point.

Analysis and Comparison

Data generation and analysis were based on the project descriptions and supporting documents, or the study publication. For both the projects and the studies, we documented:

- The lead organization, and project or research partners;
- The stressor(s) (e.g. climate change) and/or motivation or desired outcomes (e.g. sustainable development) being addressed;
- Which aspects of the food system were involved; and
- How resilience was conceptualized, assessed, and/or measured.

  For "food system" and "resilience", we noted an exact definition when provided.

We applied mixed methods to the analysis of projects and research studies, combining qualitative content analysis and the use of thematic coding, with social network analysis. From the compiled documents and materials (including publications and project reports), we inductively coded themes, which fell under one of three main theme types: *main topic* was the focus (a stressor and/or motivation), and *resilience* and the *food system* were how these terms were being conceptualized or defined. Coding was done iteratively, with related topics aggregated under common codes after initial coding, and codes for "resilience" and "food systems" refined to employ terms used in the definitions presented in Section Resilience and Food Systems Frameworks whenever possible, for the purpose of comparability. The final codebook can be found as **Supplementary Table 3**.

For each project or research study, the theme codes were entered as a tie, and the type of theme was delineated as a tie attribute. This allowed for the generation of different networks showing the relative importance of specific topics under the different theme types (i.e. main topic, resilience, food system), for the two regions, and comparing projects to research studies. Networks were created and degree and betweenness measures of centrality for the different topics calculated using the "igraph" package (Csárdi and Nepusz, 2006) in R Studio (R Core Team, 2021). These were then visualized using the "GGally" package (Schloerke et al., 2021). All centrality measures are included in the **Supplementary Materials**, as only degree centrality scores are presented in the results section. Results were similar using either degree or betweenness centrality scores.

In comparing Southeast Asia and the Pacific Islands, and projects vs. research studies, we considered commonalities and whether there were consistently themes or terms over- or underrepresented, particularly in relation to the frameworks described earlier.

RESULTS

Main Topics

On the whole, climate change was the overwhelming focus of most projects reviewed, and still dominant for research studies (see **Figure 1**). Our results in both regions show themes of economic or geopolitical shocks and nutrition have been under-examined. In Southeast Asia, sustainable development was a major objective, and gender equity was a topic of greater prevalence than in PICTs. While the results show a few efforts in Southeast Asia addressing the COVID-19 pandemic as a stressor, in this region none of the resilient food systems projects or research studies we reviewed were motivated by general health-related outcomes. In the PICTs results, food security and health were comparative contrasts to their meager appearances in Southeast Asia's results (**Table 2**). Global change was also a more prominent theme in the results from PICTs, perhaps due to the connections between globalization, shifting diets, non-communicable disease patterns, and climate change.

Some areas of divergence between the main topics of the reviewed projects vs. research studies in both regions included: a greater emphasis placed on i) gender equity, sustainable development and livelihoods, and ii) natural disasters for projects. Conversely, global change (or globalization), nutrition, and health were more frequently topics explored in research studies.

Agriculture and Food Systems

Generally, the reviewed projects and research studies conceptualized food systems predominantly in terms of food production (see **Figure 2**). The results for Southeast Asia featured primarily land-based production and smallholder systems, whereas those from PICTs demonstrated a more balanced approach with fisheries and aquaculture, as well (**Table 3**). Value chains, markets, and infrastructure were more frequently included in the conceptualizations of food systems for the SEA results, while in the PICTs results, food supply and food storage were marginally more prevalent components. This may relate to small island nations' challenges around imports and food self-sufficiency. Few of the reviewed projects and studies in either region included urban settings in their food systems framings, although there were hints of Southeast Asia's growing attention to urbanization. Other components, particularly food processing, infrastructure, transportation, and loss and waste were also only included in a small number of the reviewed projects and studies. While this could point to critical gaps in research and practice on food systems, it could also indicate that these food system components may play only a minor role in the regions.

Social-ecological systems were almost only included in the food systems framings of research studies, highlighting the lack of social components targeted by projects. In Southeast Asia, the reviewed projects dealt more with food processing, supply, infrastructure, and value chains than research studies. In PICTs, the research adopted a more holistic view of food systems than the projects by including food processing, storage, supply, consumption, and trade.

Resilience

Conceptualizations of resilience outlined here are based on standard terminology discussed earlier, with the inclusion of some additional terms around risks and vulnerability. Across the projects and research studies reviewed, resilience was most often framed as or used synonymously with adaptation and adaptive capacity (see **Figure 3**). Framing resilience in relation to disturbance or a disruption was also popular, which hearkens to a history of resilience applied in the hazards and natural disasters field. In addition to the adaptation/adaptive capacity framing, absorbing and recovering from shocks were more frequently used to frame resilience within the Southeast Asian projects and studies (**Table 4**), whereas for PICTs, the generic term resilience was prominent, without a formal definition or indication of what was included in that conceptualization. This could reflect the need the Pacific Community has identified for developing its own working definition of the concept. Transformation was infrequently part of any of these conceptualizations.

Projects tended to use either ambiguous or amorphous conceptualizations of resilience, or they focused on responses to disturbance. On the other hand, research studies took a comparatively broad approach to resilience, more often including the avoid and absorb aspects mentioned earlier, and socially-oriented resilience concepts. This could be indicative of the stronger ties research has with theory and building on existing frameworks.

Formal Definitions

Conceptualizations of resilience may be inferred by the terminology employed in documents and descriptions; however, in order to accurately discern the intended vision of a resilient food system, explicitly defining the concept is critical. Yet definitions or frameworks of resilience were infrequently referenced, though this varied substantially between the research studies and projects reviewed. Formalized definitions were more likely to appear in research studies than in project descriptions or documents. Of the 53 research studies identified in Southeast Asia, just under half ($n = 25$) included some explicit definition, while nearly one-third of the 37 research studies ($n = 11$) in PICTs did. In contrast, of the 61 SEA projects identified about one-fifth ($n = 13$) included a definition of some sort, while less than ten percent ($n = 5$) of the 58 projects in PICTs included a definition or a framework. Although this discrepancy is not surprising, it does indicate a need for clearer notions of what resilience means in context, when applied to projects or on-the-ground activities.

While formalized definitions drawn from other work varied by study or project, certain scholars were more prominently cited than others. In research studies, works by Walker, Holling, Carpenter, and Folke were regularly referenced, drawing on the social-ecological systems perspective to situate resilience (Folke et al., 2002, 2010; Gunderson and Holling, 2002; Folke, 2003, 2006; Walker et al., 2004; Walker and Salt, 2006; Carpenter and Brock, 2008). Intergovernmental Panel on Climate Change (IPCC) definitions also appeared a few times in research studies (Denton, 2002; Denton et al., 2014), but were more specifically climate-focused and often refer to "climate-resilient pathways".

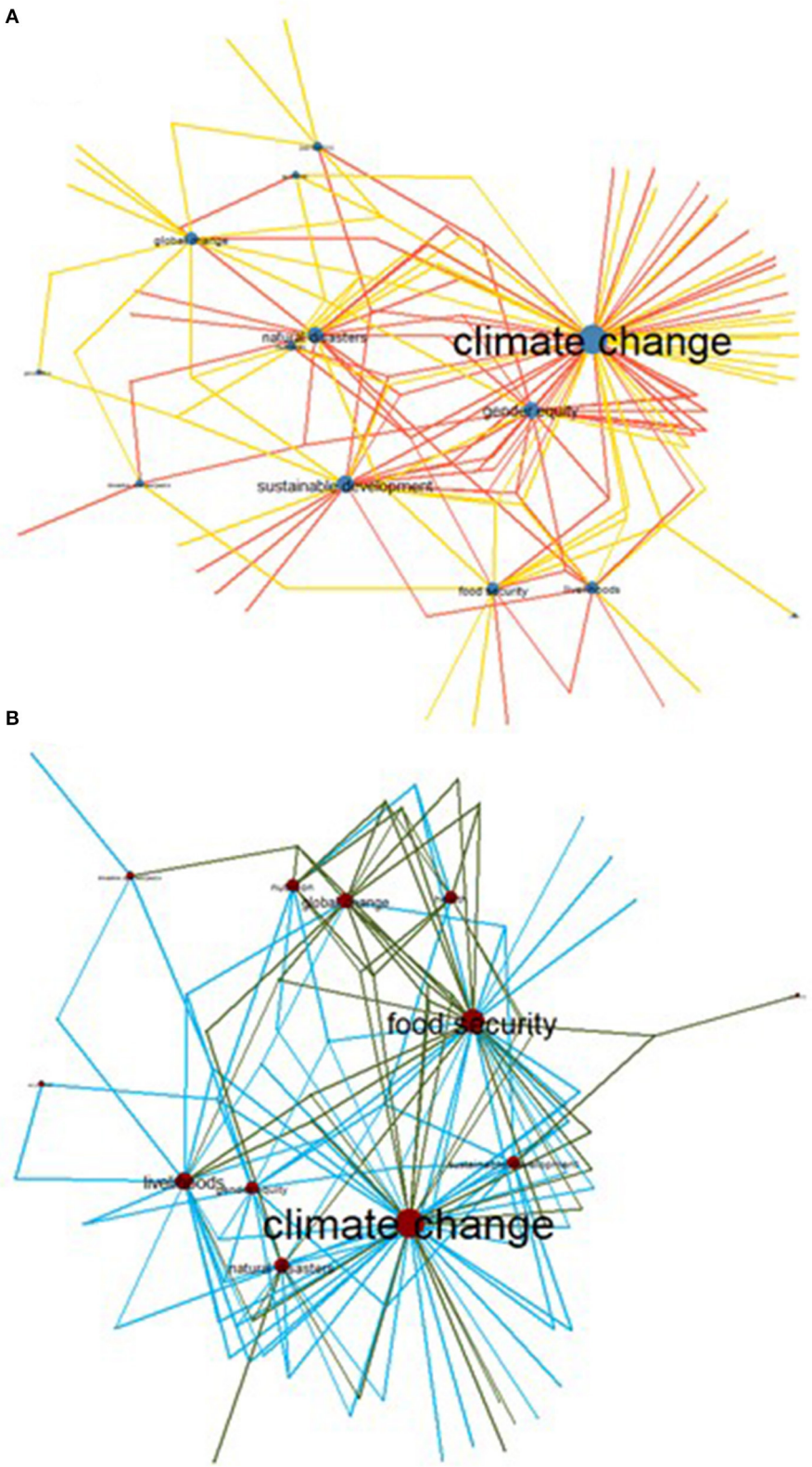


FIGURE 1 | Main topics in **(A)** Southeast Asian projects/initiatives (red) and research studies (yellow), and **(B)** PICTS projects/initiatives (blue) and research studies (green). Chart shows degree centrality scores based on networks disaggregated by region.

TABLE 2 | Main topics ordered by degree centrality score a) Southeast Asia and b) Pacific Island Countries and Territories, and for projects vs. studies.

a) Southeast Asia				b) Pacific Island Countries and Territories			
Topic	**Total**	**Projects**	**Studies**	**Topic**	**Total**	**Projects**	**Studies**
Climate change	0.60	0.61	0.48	Climate change	0.61	0.61	0.49
Sustainable development	0.20	0.25	0.11	Food security	0.41	0.32	0.46
Gender equity	0.18	0.26	0.05	Livelihoods	0.22	0.27	0.11
Natural disasters	0.17	0.21	0.09	Global change	0.16	0.05	0.30
Food Security	0.12	0.08	0.14	Natural disasters	0.16	0.16	0.14
Livelihoods	0.10	0.11	0.07	Gender equity	0.12	0.18	0.00
Global change	0.10	0.02	0.18	Sustainable development	0.12	0.16	0.03
Nutrition	0.07	0.03	0.09	Health	0.11	0.04	0.19
Pandemic	0.06	0.03	0.07	Nutrition	0.11	0.07	0.14
Invasive species/pests	0.05	0.05	0.04	Invasive species/pests	0.05	0.05	0.03
Economic	0.04	0.02	0.05	Economic	0.02	0.04	0.00
Geopolitics	0.02	0.00	0.04	Pandemic	0.01	0.00	0.03
Health	0.01	0.00	0.02	Geopolitics	0.00	0.00	0.00

Where projects provided a definition, no particular scholarly work was referenced. That said, these definitions for the most part depicted elements outlined in the literature discussed earlier, namely - avoiding, anticipating and preparing for, and recovering from or adapting to disturbance. In their definitions, only two mentioned transformations, and three included reference to social resilience through the importance of institutions, social networks, or community resources.

DISCUSSION AND CONCLUSIONS

Resilience Is More Than Responding to Climate Change

The results of this review indicate there is a heavy focus on climate change and natural disasters in food systems resilience narratives of the projects and studies examined for the regions. Yet resilience is more than preparing for and responding to climate change, and recognizing this is critical to ensuring that other non-climate stressors or drivers of vulnerability are accounted for in resilience planning (e.g. van der Ploeg et al., 2020). In research studies, we see a broadening of this perspective through examination of global change or globalization as a disturbance, but these studies are still in the minority and do not do justice to what has been broadly considered in the conceptual literature (Rockstrom et al., 2020). In addition to climate change, expert assessments have elaborated on other forces that shape global food systems, and could therefore be avenues for disturbances or building resilience. These include degradation of natural resources, urbanization and demographic change, globalization and industry growth, consumer behavior, culture and traditions, government policies and trade agreements, conflict and fragile states, and scientific and technological innovation (IAASTD, 2009; Denning and Fanzo, 2016).

Such a broad suite of forces shaping food systems, and the current focus of the reviewed projects and research studies on a limited set, suggests ample opportunity to expand the scope of resilience to address multiple or compounding stressors. In fact, some researchers have argued that accounting for multiple stressors is necessary for resilience over time (Zanotti et al., 2020). The United Nations Conference on Trade and Development (UNCTAD, 2018) made the case that countries must grapple with multiple shocks in large part because of the complexities and interdependencies within a system, pointing to the concurrent impacts of the 2008–2009 financial crisis and natural disasters as an example. The Conference also noted that to address multiple stressors requires considering the impacts of shocks on vulnerable groups (e.g. women, children, impoverished). Although gender, for instance, appeared to some extent in this review, there is considerable room for research to understand how gender equity contributes to building resilience and addressing multiple stressors within food systems, especially beyond food production.

We have started to see more acknowledgment of the role of multiple stressors in undermining resilience with the emerging reflections on the COVID-19 pandemic. For instance, COVID-19 inevitably tied food systems resilience to health crises, as well as the social and economic challenges that arise as a consequence (Bisoffi et al., 2021; Davila et al., 2021). Noticeably, the pandemic has demonstrated how restrictions on people's movement both within and between countries can undermine a number of components of food systems, from the labor to produce food to household finances and capacity to access food (Béné, 2020). Others have pointed to the pandemic as bringing to light the opportunities to address social, economic, and environmental failings that have been systemically eroding food systems resilience (Savary et al., 2020; WEF, 2020). Integrating considerations for multiple stressors into large food systems projects and initiatives therefore has the potential to scale-up more comprehensive strategies for building resilience.

Taking a Systems Approach to Resilience

The heavy focus of the results from both Southeast Asia and the Pacific Islands on food production, whether on land or at sea, suggests there is still substantial opportunity for resilience

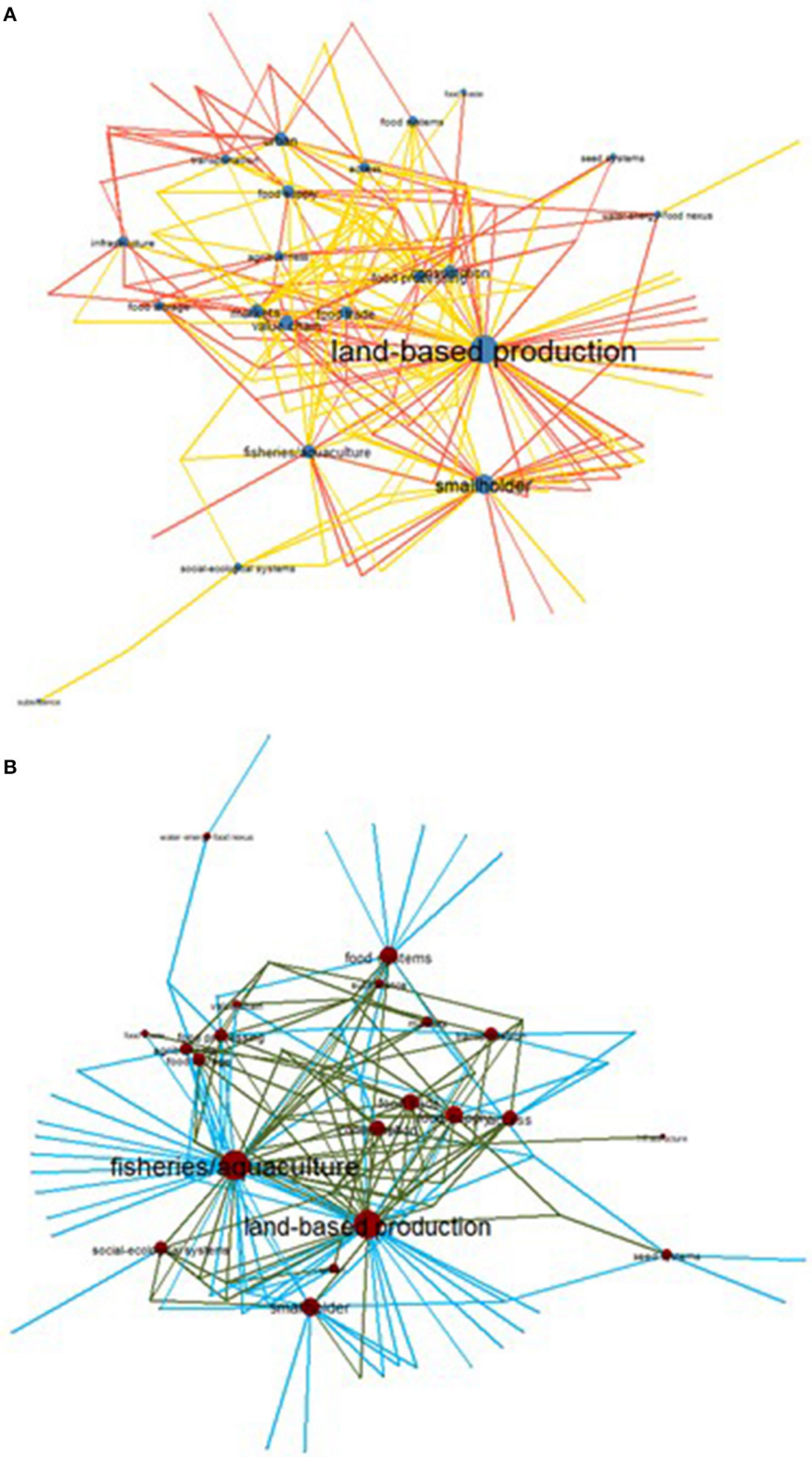


FIGURE 2 | Food systems definition codes used in **(A)** Southeast Asian projects/initiatives (red) and research studies (yellow), and **(B)** PICTS projects/initiatives (blue) and research studies (green). Chart shows degree centrality scores based on networks disaggregated by region.

TABLE 3 | Food systems codes ordered by degree centrality score a) Southeast Asia and b) Pacific Island Countries and Territories, and for projects vs. research studies.

a) Southeast Asia				b) Pacific Island Countries and Territories			
Code	**Total**	**Projects**	**Studies**	**Code**	**Total**	**Projects**	**Studies**
Land-based production	0.57	0.46	0.52	Fisheries/aquaculture	0.43	0.33	0.41
Smallholder	0.28	0.25	0.23	Land-based production	0.42	0.32	0.41
Value chain	0.14	0.15	0.10	Smallholder	0.17	0.21	0.07
Consumption	0.14	0.07	0.16	Food systems	0.15	0.14	0.11
Fisheries/aquaculture	0.14	0.10	0.13	Food supply	0.14	0.05	0.22
Markets	0.14	0.09	0.15	Food trade	0.13	0.00	0.26
Urban	0.14	0.13	0.10	Access	0.11	0.06	0.13
Food processing	0.11	0.12	0.06	Consumption	0.11	0.03	0.17
Food trade	0.11	0.07	0.11	Food processing	0.09	0.05	0.11
Food supply	0.10	0.10	0.06	Social-ecological systems	0.09	0.03	0.13
Access	0.07	0.04	0.08	Food storage	0.08	0.03	0.11
Infrastructure	0.07	0.09	0.03	Transportation	0.08	0.05	0.09
Agribusiness	0.06	0.07	0.03	Agribusiness	0.06	0.05	0.07
Transportation	0.06	0.06	0.05	Markets	0.05	0.02	0.09
Food storage	0.05	0.06	0.03	Seed systems	0.05	0.06	0.02
Food systems	0.05	0.03	0.06	Subsistence	0.04	0.00	0.09
Social-ecological systems	0.05	0.00	0.08	Urban	0.04	0.03	0.04
Water-energy-food nexus	0.04	0.04	0.02	Value chain	0.03	0.03	0.02
Seed systems	0.03	0.03	0.02	Food waste	0.02	0.02	0.02
Food waste	0.02	0.01	0.02	Water-energy-food nexus	0.02	0.03	0.00
Subsistence	0.01	0.00	0.02	Infrastructure	0.01	0.00	0.02

work to adopt a stronger "systems" perspective, in which the interactions between components of a system are considered and studied (Ericksen, 2008). In PICTs, the discrepancy between the reviewed research studies and projects is especially pronounced, with the latter generally framing food systems around only one or two components (primarily production), and the former taking a more holistic approach by examining multiple components of food systems. Less pronounced differences exist between the projects and research studies identified in Southeast Asia, although studies more regularly draw on social-ecological systems frameworks. Even still, social and ecological interactions are underrepresented in the food systems framings employed by the activities reviewed for this study. As such, there is understandably a strong need for more interdisciplinary, multi-scalar, and dynamic conceptualizations of food systems, particularly in the context of resilience (Doherty et al., 2019).

Not taking a systems perspective can have implications for how resilient a food system actually is, and whether multiple stressors can be addressed. For instance, Davis et al. (2021) outlines the different environmental and economic forces that affect each component of the food supply chain, and the cascading impacts and feedback loops that could result. Without accounting for the system as a whole, these interactions would be overlooked. Furthermore, a systems perspective allows for the consideration of trade-offs that may exist. For instance, trade can increase the diversity of options within a food system to complement domestic production, processing, and storage; however, an over-reliance on trade may lead to vulnerabilities when a disturbance impedes trade flows (Kummu et al., 2020), or if imported foods are not socially or culturally appropriate.

One of the apparent omissions in food systems framings within the reviewed resilience research studies and projects in the Indo-Pacific deals with the relation of food loss and waste to resilience. Approximately one-third of food intended for human consumption is lost or wasted (FAO, 2017), contributing to greenhouse gas emissions and environmental degradation, as well as reducing food supply to meet food security needs. Yet our results showed that in terms of food systems conceptualizations, food loss, processing, and storage are all rarely included. Processing and storage are important for reducing the chance of food spoilage (Augustin et al., 2016), and food loss and waste can include both post-harvest and post-consumer waste (Hodges et al., 2011). In less developed countries, food loss mainly occurs during production, the post-harvest period, and storage or processing stages (Vilariño et al., 2017). For instance, in Southeast Asia, nearly three-quarters of food loss happens during agricultural production or right after harvest (Kummu et al., 2012). Conceptually, the role of food loss and waste in resilient food systems points to the importance of storage and processing, as well as the potential tensions between efficiency and resilience (BajŽelj et al., 2020).

Finally, urban and peri-urban components of the food system not only account for a large portion of the population, but also draw on all other components. Including urban and peri-urban areas is particularly important considering the trend toward urbanization globally and the rapidity with which it

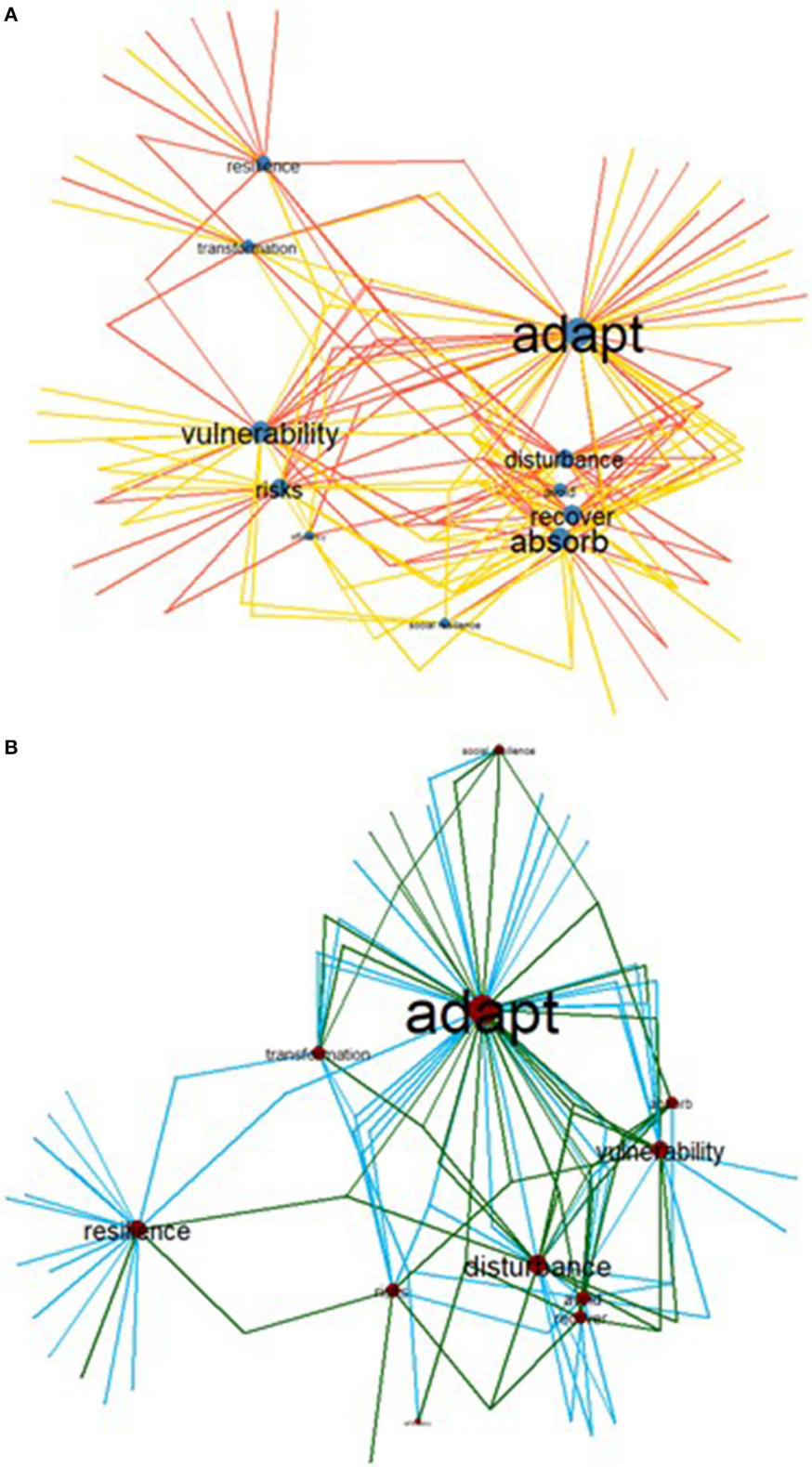


FIGURE 3 | Resilience definition codes used in **(A)** Southeast Asian projects/initiatives (red) and research studies (yellow), and **(B)** PICTS projects/initiatives (blue) and research studies (green). Chart shows degree centrality scores based on networks disaggregated by region.

TABLE 4 | Resilience codes ordered by degree centrality score a) Southeast Asia and b) Pacific Island Countries and Territories, and for projects vs. research studies.

a) Southeast Asia				b) Pacific Island Countries and Territories			
Code	**Total**	**Projects**	**Studies**	**Code**	**Total**	**Projects**	**Studies**
Adapt	0.48	0.47	0.41	Adapt	0.55	0.45	0.57
Absorb	0.28	0.18	0.33	Disturbance	0.24	0.16	0.30
Vulnerability	0.26	0.22	0.26	Resilience	0.20	0.24	0.08
Recover	0.21	0.20	0.19	Vulnerability	0.20	0.16	0.22
Disturbance	0.19	0.25	0.09	Avoid	0.12	0.14	0.05
Risks	0.19	0.17	0.19	Risks	0.12	0.10	0.11
Resilience	0.13	0.18	0.04	Transformation	0.12	0.10	0.11
Transformation	0.11	0.08	0.11	Recover	0.11	0.05	0.16
Avoid	0.10	0.08	0.09	Absorb	0.08	0.05	0.11
Social resilience	0.06	0.02	0.09	Social resilience	0.06	0.02	0.11
Efficiency	0.05	0.05	0.04	Efficiency	0.02	0.02	0.03

is taking place in the Indo-Pacific. However, it only plays a role in a small number of resilience projects and research studies examined in this paper. As Schipanski et al. (2016) notes, the urban components of food systems face particular challenges and vulnerabilities stemming from characteristics like dependency on imported (often internationally) food products and high incidence of social and economic inequality. Case studies in other parts of the world, such as the USA (Zeuli and Nijhuis, 2017), have shown how efforts to reduce food waste can contribute to urban food systems resilience by improving access for the food insecure and reducing strains on the environment. Similarly, Blay-Palmer et al. (2021) discussed how the City-Region Food System (CRFS) approach developed by the Food and Agriculture Organization of the United Nations facilitated resilience in the face of COVID-19, by supporting strong networks and multi-stakeholder groups, building necessary logistical infrastructure, and fostering coherent laws and policies.

Defining Resilience

Overall, establishing clear guiding resilience principles, modified according to contextual factors, could enable more streamlined resilience work in the Indo-Pacific's food systems, as well as provide clarity about the goals of projects and research. However, the projects we surveyed more often used resilience without definition or any indication of what was meant by the term, and the research studies cited a formal definition only around half the time. From the prevalence of references to adaptation in relation to resilience, and without clear indication of a definition, we might conclude that the terms are being used interchangeably. This conflation is evident even within policy documents at the international level, such as the UN Framework Convention on Climate Change's explanation of National Adaptation Plans, in which building adaptive capacity and resilience are used in tandem (United Nations Climate Change, 2021).

In relation to terms used to conceptualize resilience, transformation was underrepresented, which may be a reflection of how recently this term has come into use. However, it is also a growing area of interest in sustainability studies, and will likely be an important component of food systems resilience research and programmes moving forward. Transformation involves fundamental structural, systemic, and enabling systems changes (Scoones et al., 2020), and it is also seen as necessary for long-term food systems sustainability (Lawrence et al., 2019; Sperling et al., 2020). A recent report of the Consultative Group on International Agricultural Research (CGIAR) illustrated the importance of mobilizing a large number of actions to achieve the required level of food system transformation (Steiner et al., 2020). This is further argued by Rockstrom et al. (2020), who call for food systems transformation in order to operate within planetary limits and meet sustainable development goals and climate change commitments. In their view, a global food system transformation entails shifting to diets that support both human health and ecological sustainability, altering policy and investments so they reconfigure food value chains and change consumption patterns, accounting for external environmental and social costs in the food system, and taking a truly interdisciplinary approach to food systems challenges.

Finally, social resilience was poorly represented in the resilience conceptualizations used in the reviewed projects and research studies. This observation aligns with the lack of inclusion of social components in the food systems framings, as well. While a socially-oriented resilience framing may be more common amongst grassroots and community-led activities not included in this review, it is also critical for projects and studies led by international and governmental institutions to broaden their approaches. Bringing in a social resilience perspective speaks to the importance of good governance and leadership, trust and social networks, empowerment, social justice, and collaborative learning and knowledge, in order to build capacities of individuals, groups, and organizations to respond and flourish in the face of adversity (Obrist et al., 2010; Maclean et al., 2014). The complex, multilayered, and inherently anthropogenic nature of food systems consequently requires attention for these social and cultural considerations. Expert panels have argued these social considerations, alongside embracing agro-ecological principles and innovations, are pivotal to ensuring sustainable transformations in food systems (HLPE, 2019).

Steps Forward and Caveats

This review provides a snapshot of the state of resilient food systems development projects and research studies carried out by academic, national, regional, or multilateral government, and non-governmental institutions in the Indo-Pacific region. It highlights areas to build on for future research and programs, particularly as the institutions scale up funding for sustainable development activities over the coming years. At this level, efforts to enhance food systems resilience in the PICTs require further attention to gender equity, whole value chains and markets, and urban-rural connections, while in SEA, more attention could go toward health and food security objectives, food storage and processing, and fisheries/aquaculture.

The results show an opportunity for future work to embrace complexity and interactions, as well as social considerations. Overall, resilience should be approached in a way that goes beyond adaptation and includes transformation and social resilience. Furthermore, considering that stressors can act as multipliers, and compounding disruptions can make those who are vulnerable even more so, systems approaches to understanding resilience are critical to developing and implementing appropriate interventions. Future research is also merited, which examines approaches that the private sector and local and traditional organizations offer to enhance resilience, which were not explicitly targeted in this review.

There are a number of caveats to this study that also point to areas of future work. First of all, this study is not exhaustive, and has likely overlooked some themes. For instance, some institutions have broad research programmes or themes on topics related to food systems resilience, but we only captured discrete initiatives, projects, and research studies. Examining these broader strategic priorities of lead and partner organizations could provide more guidance on future directions. Further research may also unearth additional themes related to political and social contexts - such as the state of participatory and democratic processes, land rights, and conflict – which were not evident in the projects and research studies included in this review.

Second, we focused on just two regions, and therefore did not capture opportunities that may apply more to South Asia and beyond. This review could be expanded to other regions, for further comparison. Third, as a desktop analysis, this study took any documentation at face value, potentially overlooking what manifests on-the-ground in actuality. Complementing text analysis with key informant interviews would corroborate and enhance our understanding of the gaps and opportunities for resilience within Indo-Pacific food systems. Finally, while this study explored how researchers and project leads conceptualize food systems and resilience, this does not necessarily reflect how these concepts are understood and applied locally. An important next step would be to identify grassroots and community projects and to undertake qualitative research at local and community levels within the Indo-Pacific to gather how well the conceptualizations reviewed in this study reflect the local understandings and experiences.

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SC and LL-C developed the original idea for the study. RF and RE designed and implemented the methods, analyzed the data, and wrote the manuscript. RF conducted the network analysis and created the figures. KR, LL-C, MW, and SC provided editorial input. All authors have read and approved the final manuscript.

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A malleable workflow for identifying the issues and indicators that define and measure sustainability in food systems

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A variety of stakeholders are concerned with many issues regarding the sustainability of our complex global food system. Yet navigating and comparing the plethora of issues and indicators across scales, commodities, and regions can be daunting, particularly for different communities of practice with diverse goals, perspectives, and decision-making workflows. This study presents a malleable workflow to help different stakeholder groups identify the issues and indicators that define food system sustainability for their particular use case. By making information used in such workflows semantically-consistent, the output from each unique case can be easily compared and contrasted across domains, contributing to both a deeper and broader understanding of what issues and indicators define a resilient global food system.

KEYWORDS

raw material sourcing, Semantic Web (Web 3.0), indicators & metrics, materiality analysis, stakeholder decision-making

Defining and measuring sustainable food systems: A historical context

The landmark definition of sustainable development set forth in the Brundtland Report more than three decades ago—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"—has helped to solidify the concept of sustainability as a necessary and worthwhile policy goal (Brundtland, 1987). Yet practically, this definition provides little tangible guidance for comprehensively defining and measuring sustainability—in this case in the context of global food systems—and has been the source of much debate in subsequent decades (Dixon and Fallon, 1989; Howarth, 1997; Connelly, 2007).

First, sustainability is a multi-dimensional concept that crosses the traditional institutional boundaries that commonly divide economic, social, and environmental spheres, leading to characterizations of sustainable food systems that are often one-dimensional, or partial to one sphere over others. Definitions of sustainability stemming

from economic foundations are derived from concepts of maintaining the discounted capital stock for future generations (Hotelling, 1931; Dasgupta and Heal, 1974) in attempts to maintain intergenerational wealth over long periods of time (Solow, 1974; Hamilton, 1999; Dasgupta, 2007a). This foundational research has led to the expansion of the concept of capital to include other forms such as natural and social capital, assuring that wealth in the form of ecosystem services, natural resource stocks, knowledge, and social institutions can be included as well (Pearce, 1988; Goodland, 1995; Dasgupta, 2007b). Such work has led to further criticism of those defining sustainability from primarily one-dimension, such as the common approach of using traditional economic indicators of human welfare (Hamilton, 1994; Bell and Morse, 1999; Ayres et al., 2001) or the lack of focus on important human, social, and political dimensions such as poverty, public health, women's rights, property rights, and governance (Chambers and Conway, 1992; Sen, 1997; Bebbington, 1999; Scoones, 2009). Fortunately, global sustainability assessments include issues from all of these dimensions in setting goals, benchmarking indicators, and suggesting strategies (Millennium Ecosystem Assessment, 2005; UN, 2008). Springer et al. (2015) looked at a number of sustainability communications from a variety of sources and found that the degree of focus on these different sustainability categories can vary greatly depending on one's perspective and specific focus.

This multi-dimensionality becomes even more complex when one considers the possible conceptual frameworks that may link issues together and highlight those of particular importance. For instance, one framework for assessing the importance of particular issues is to isolate the issues that are directly impacted by a particular action or strategy (Millennium Ecosystem Assessment, 2003; Tomich et al., 2010; Brown et al., 2015). On the other hand, a corollary framework for assessment could isolate those issues that impact a particular system of interest, such as a supply chain. In other words, this second framework conceptualizes sustainability as the reduction of one's vulnerability and the growth of one's resilience or adaptive capacity to any given variable, either directly or indirectly due to a reaction within the system of relationships (Folke et al., 2002; Turner et al., 2003; Perrings, 2006; Seekell et al., 2017). This includes consistent ways to measure the resiliency of sustainable food systems, which we see as the "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances" (Tendall et al., 2015). For instance, considering climate change: under the first framework, one should adopt a strategy to reduce one's impact by mitigating emissions (IPCC, 2014b) while under the second framework one may choose to increase resilience by adopting a new technology that is more adaptable to possible climate variations (IPCC, 2014a). Frameworks can also embed both impacts and resilience components simultaneously (Beddington et al., 2012; Garnett, 2013).

Sustainability is also a multi-scale concept that must be defined and measured at various scopes from local to global levels of spatial resolution and decade to century levels of temporal resolution (Ostrom et al., 1999; Scholes et al., 2010). Multi-scale measurement is particularly relevant for food systems since globalization has increased the connectivity across the globe related to sourcing, processing, transport and storage, and consumption demands (Brown et al., 2015; Seekell et al., 2018). The issues that are important and how they are accurately and usefully measured may differ substantially depending on these scales and scopes. For instance, sustainability defined at a broad scale and scope may result in more macro-indicators at the national policy level (Millennium Ecosystem Assessment, 2005; UN, 2008) while sustainability defined at a specific location may result in more detailed indicators at the individual or community level (Stewardship Index for Specialty Crops, 2011; COSA, 2012). Inclusion of multiple scales and scopes becomes even more difficult if the chosen conceptual frameworks include driving forces that span both local and global systems, such as ecosystem management or technological change (Scholes et al., 2010; Brown et al., 2015).

Furthermore, achieving a sustainable global food system requires input, buy-in, and coordination from a vast array of stakeholders—public and private, profit and non-profit, consumer and producer, owner and worker, poor and rich—to successfully agree on issues, choose indicators, collect data, develop strategies, implement projects, improve practices, and ultimately achieve a sustainable path forward (Pretty, 1995; Cash et al., 2003; van Kerkhoff and Lebel, 2006; Beddington et al., 2012). Defining and measuring sustainable food systems, therefore, must be an inclusive, "bottom-up" effort that allows all interested parties to provide input. Evidence shows that the "co-creation" of transdisciplinary research and conceptual frameworks can improve credibility, relevance, and legitimacy, ultimately helping overcome traditional social and political boundaries, and improving the chances of strategy implementation (Ostrom et al., 1999; Lucas et al., 2010; Clark et al., 2011).

The necessity of an inclusive and comprehensive approach also becomes apparent when one considers the volume of potential tradeoffs between issues that must be considered. For instance, if a strategy is implemented to address a specific set of important issues, this strategy may have unintended and adverse effects on other issues not within the scope of the framework considered. Such results are especially relevant for non-linear, complex systems where socioeconomic and ecological drivers can interact to produce tipping points and emergent properties that affect the system in unintentional and unforeseen ways (Costanza et al., 1993; Beisner et al., 2003; Dasgupta and Mäler, 2004).

As a result of these complexities, many within the sustainability community have promoted multi-criteria decision-support tools that allow groups of stakeholders to address multiple, orthogonal objectives simultaneously to more comprehensively assess issue tradeoffs (Keeney and Raiffa, 1976; Romero and Rehman, 1987; Zander and Kächele, 1999; Munda, 2005). For instance, researchers within the integrated assessment community attempt to achieve a more comprehensive assessment of sustainability impacts by linking planning and scenario models across the natural and social sciences, allowing them to assess multiple, often incongruent issues simultaneously (Lotze-Campen, 2008; Tschakert et al., 2008; Rosenzweig et al., 2013). Still, such modeling efforts are often integrated to assess a few important issues—such as the impacts of climate or nutritional status—and are not set in the context of a larger conceptual framework that includes the comprehensive set of sustainability issues and tradeoffs one could potentially consider (van der Linden et al., 2020).

Each one of these challenges can lead to incongruities between issue and indicator sets that are used by various stakeholders to define and measure sustainability for any particular context, and these incongruities can deepen since our understanding of sustainable food system issues is not static. Our information base is constantly advancing and changing, even for established issues such as water scarcity or poverty. New issues arise as other issues are addressed, and the definition of sustainable food systems must be flexible enough to deal with this dynamic foundation. Although indicator sets and indices have been proposed to define and measure food policy goals such as increased food security various contexts (The Economist, 2013), these remain specific to scales, scopes, and communities of practice. Lacking is a consistent template for formalizing decision workflows for selecting this information to not only assure completeness, but allows information to be linked and shared across different communities of practice (Olde et al., 2016).

To address these questions about the definition and measurement of sustainable food systems—and present some insight into possible solutions—this paper presents a malleable workflow to define stakeholder-specific definitions that can be linked together to enhance both local and global definitions of concepts such as sustainability and food security. This workflow template, here called the "checklist generator" workflow, is comprised of a set of tools that can be used define and measure sustainable food systems for any specific stakeholder group, particularly in a way that transparently (1) engages the different communities of practice (CoP) involved, (2) captures and clarifies key information (3) ensures completeness while reducing dimensionality (or ensuring complete coverage of all issues while reducing dimensionality in the number of indicators needed to measure them). The purpose of this process is to give stakeholders the ability to interface with a consistent and transparent network of sustainability information and iteratively select issues and indicators that measure progress toward increasingly sustainable practices.

We present three hypothetical examples to illustrate how different workflows can arise from different applications of this system of tools. To show the diversity of potential outcomes, each of the three examples typifies an archetypal community of practice: a food company, a global government organization, and a regional government planning board. Unique checklist generator workflows may be derived at different temporal and spatial scales, from a disparate set of actors, and have widely different goals; yet the outcomes of these workflows can be compared to enhance our understanding of sustainable food systems across regions, scales, and commodities.

Three key aspects needed for a successful checklist generator workflow

Stakeholder engagement across communities of practice

Many different communities of practice (CoP) are part of the global food system, including farmers, traders, food producers, policymakers, educators, and researchers. Opinions about which issues matter differ both within and across communities, yet each community has specific norms and concepts for thinking about the impacts of their decisions and the impacts of other's decisions on them. Trying to choose and agree on the sustainability issues that matter and ways of measuring them is difficult to negotiate within a CoP, and become even more difficult when multiple CoP are involved in stakeholder groups. Characterizations of the sustainability of food systems that are partial to one community of practice over another may serve a specific function, but can be problematic for ensuring participation in a broader strategy.

A checklist generator workflow that allows different CoP to identify a recognizable set of issues and indicators in parallel with other stakeholders would allow the results of the studies to be interoperable, no matter the commodity, region, or language. The power of interoperability of sustainability issues such as food security will inform the next group of stakeholders through the use of indicators, data, and results, as well as increase transparency of previous stakeholder's progress. New knowledge generated through scientific research, cultural exchange, social development, and practical experience is constantly revealing new issues as other issues are addressed. Consistent approaches to identify sustainability issues of importance and indicators to measure them must be flexible enough to incorporate emerging issues, insights, and data sources (Springer et al., 2015).

Semantics and organization of food system information

Although the multitude of available information on food system sustainability gives stakeholders many ways to define and measure important issues, a central challenge becomes finding, sorting, and choosing key pieces of information that fit the perspective of the communities of practice involved in a given case. Previous work (Springer et al., 2015) presents an information strategy for doing this, organizing the extensive amount of sustainability information from different CoP into a network of semantically consistent sustainability issues and indicators. The database that resulted from this work contains 44 "integrated" sustainability issues, along with 318 more specific "component" sustainability issues, that are linked with a network of 2,000+ sustainability indicators that have been used to measure them in various contexts.

Although this proof-of-concept database is large and fairly comprehensive, in reality it must be connected to broader networks of information to be truly useful. Using controlled vocabularies, like FAO AGROVOC or CABI (Caracciolo et al., 2013; CABI, 2014), can give stakeholder groups flexibility to do this in real time: new issues can be added; new links made to existing issues; new indicators can be searched for, updated, or changed; and new ontological relationships between issues and indictors can be made. The malleability of this Semantic Web of food sustainability information will be necessary for most use cases, and hence this open, linked-data framework will be essential for interoperability within and across communities of practice.

Completeness and reducing dimensionality

Utilizing a semantically linked network described above can ensure that stakeholders have access to a dynamic, global set of indicators and issues and have the ability to communicate across CoP. Yet a useful workflow must help stakeholder groups sort through this global network for the issues and indicators that will be most useful for their group, while simultaneously ensuring (1) completeness in access and consideration of potential issues and indicators (2) reduced dimensionality of chosen issues of material importance to their use case and (3) reduced dimensionality of the set of indicators that can still completely represent all material issues. On one hand, it is unrealistic and unnecessary to track the global set of indicators in each case; on the other, determining material issues and indicators in isolation creates barriers for communication, and it would be beneficial for any issues and indicators chosen to be recognizable and used by the broader community, and also ideally by other stakeholder groups working on similar lists of issues, commodities, and regions. By using sets of information that are semantically linked to all other CoP, one can help assure completeness by accessing the broadest set of possible issues and indicators available. And if issues and indicators could be compared across different stakeholder groups and CoP, the sustainability community as a whole could begin to more comprehensively address questions such as:

- Is there a minimum set of sustainability issues that comprehensively address the complexity of global food systems across all frameworks and contexts?
- What are the key differences across scales, scopes, sectors, commodities, etc.?
- If there are common issues addressed across communities of practice, what indicators should be used to measure progress on each issue and how much similarity do they have across contexts?

Methods: The checklist generator workflow

We present a malleable workflow that addresses these three aspects of CoP engagement, semantics, and completeness by allowing stakeholders to interface with a transparent network of information and iteratively select issues and indicators that makes sense for their use case. Such a workflow has been successful in the conservation community at creating "best-practice" decision-support systems for conservation projects (The Conservation Measures Partnership, 2013). Information technology tools such as MIRADI (https://miradi.org/) help conservation partners develop boundaries, measurements, goals, and strategies for specific uses that can be shared across user groups without a loss of generality. The workflow presented here provides the basis for a similar decision-support and negotiation-support (Van Noordwijk et al., 2001; Clark et al., 2011) platform within the food system sustainability community, helping stakeholders align the issues, indicators, and strategies they will address, track, and implement, thereby improving chances of success. In Figure 1, this workflow fits within the decision and negotiation support boxes for multiple communities of expertise (two boxes on bottom-right).

The checklist generator building blocks

To describe the malleable workflow that can achieve these three aspects of CoP engagement, semantics, and completeness, we need to first define the base set of information and tools that can be used to design a workflow: a group of decisions makers, a graph database, a minimum covering set algorithm, and a software interface.

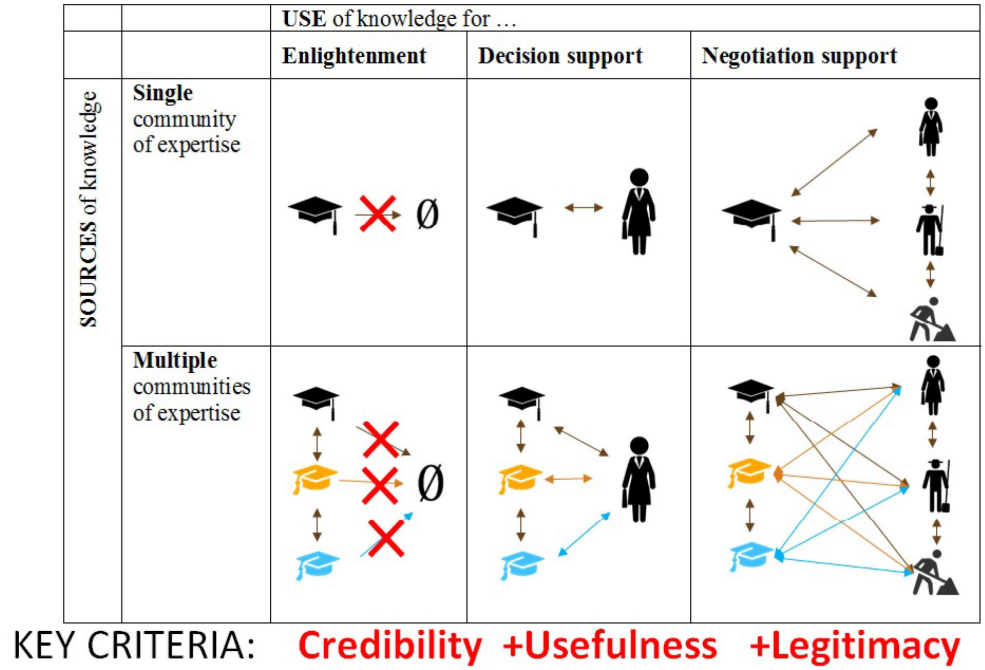


FIGURE 1
The checklist generator workflow is both a decision support and negotiation support tool, ideal for navigating multiple communities of practice (middle-bottom and bottom-right squares). Figure modified from earlier version published. Source: From Clark et al. (2011).

Group of decision makers

The first requirement is to agree upon a set of actors that will be included. Ideally, this would be a stakeholder group representing the key players within the region and commodity to be addressed. But this group could also be a single institution, such as a company or government agency.

Graph database

The next requirement is an information set, in the form of a graph database with a semantically linked ontology which as the very least requires an overarching set of issues, possible indicators for measuring them, and how each indicator can be used to measure each issue (see Supplementary material for information about this type of data format). For instance, the dataset developed by Springer et al. (2015) provides a set of indicators linked to the issues that they can provide information about. Additional or different datasets could be used as long as they define, for both issues and indicators, the three pieces of the triplestore structure (subject, predicate, object) that make up a semantically-enabled graph database.

Additional information can be specified to help give context to this network of issues and indictors and assist in the selection process. For instance, the dataset developed by Springer et al. (2015) specifies relationships between overarching "integrated" issues and more specific "component" issues to give users more nuance in selecting issues. One could develop a more detailed ontology that adds more specific relationships (predicates) between issues and indicators, and even add new "classes" of subjects and object beyond these two categories, such as spatial data, goals, and strategies. One could even expand the information set to the global Semantic Web of information using defined ontologies and controlled vocabularies used to extract the relevant information for a specific case.

Minimum covering set algorithm

A central tool for ensuring completeness while reducing dimensionality is a minimum covering set (MCS) algorithm. Such an algorithm uses the information provided in the graph database, such as the one presented in Springer et al. (2015), and selects the minimum set of indicators required to represent the issues selected in step two (Huber et al., 2015). Different algorithms can be used to solve the MCS problem, each with distinct advantages as well as computational requirements. The algorithm used by Huber et al. (2015) is based upon the conservation planning tool MARXAN and has its own distinct advantages.

Another more efficient option utilizes the integer programming (IP) method (Balinski and Quandt, 1964), which can be applied in this case to minimize the number of indicators while ensuring that all selected issues are covered

by at least one indicator. The IP approach is computationally faster and hence allows users to revise inputs in real time and calculate many different outputs. The IP approach also allows us to add additional constraints to help users in the selection process. For instance, we add a constraint that allows users to define important attributes and then ensure that the selected indicators have these particular attributes such as units, frameworks (measure "impacts" and/or "vulnerability"), or sustainability types (environmental, social, political, physical, financial, and human).

The details of this IP algorithm are described in the Supplementary material, including how to use the graph database as the algorithm input, how to define and select issue and indicator attributes that are required in the minimum set, and how to access open source code and data for running the MCS algorithm.

User interface

This tool allows users to iteratively adjust and modify the graph database and MCS algorithm inputs and outputs, both immediately during the selection process and over time during long-term progress tracking and information updating.

The "front-end" of this application is an user interface that allows users to view the data and run the MCS algorithm. It presents the graph database as lists of issues and indicators, which can then be "checked" on or off depending on the relevance of each issue or indicator to their specific context. The user can then click a button to run the MCS algorithm, view a list of the indicators that cover the issues and attributes they selected, and further adjust the indicator set based on the suggested output. A prototype of this software has been created using R-Shiny, see Supporting Information for details.

The "back-end" of this application allows users to interface with the graph database, adding information and adjusting ontological relationships. This capability is essential for users who may want to use an existing database, such as the one presented in Springer et al. (2015) but want to adjust and update the issues, indicators, and relationships to better fit their use case. Such an interface is useful in transparency and sharing information, as will be considered further in the discussion. A prototype of this interface has been created, see Supplementary material for details.

Checklist generator workflow key steps

These four building blocks are used alongside four key steps to create a checklist generator workflow that produces a manageable set of issues and indicators (Figure 2). Each checklist generator workflow can be unique, and the following four key steps are not exhaustive or in any particular order. But these pieces will be central aspects of helping each stakeholder group define and measure food system sustainability for their particular context.

Identify material issues

Here, users select the specific issues that are relevant for their use case from the standardized and organized list of all possible sustainability issues. This can be as heuristic as choosing a few important issues through discussion with the group, straightforward as using the entire issue set, practical as using a set defined by another group, or detailed as systematic consideration of each issue in the database to assesses its relevancy to the chosen region, commodity, and framework. The subset of issues that result from this step defines the food system sustainability boundaries for that particular group.

Select indicators

In this step, users select the indicators they will use to measure their material issues. The MCS algorithm and interface is essential here, ensuring completeness of issue coverage but also assisting stakeholder in identifying overlaps and efficiently building possible sets. Users may select some indicators upfront, "lock-in" good indicators that the MCS tool selects, or eliminate those that stakeholders cannot agree upon or don't makes sense. The tool can be run as many times as necessary with different iterations to help stakeholders agree on the most useful set for their case.

Modify data

After going through the issue list, stakeholders may feel that there is an issue missing they want to add. Or maybe the group creates a conceptual framework to define issues that drive change within their particular food system boundaries. Such changes and additions can be made to the "back end" interface to the graph database at any time during the workflow process.

Refine selections using attributes

If members of the stakeholder group have certain qualifications that must be met, these can be specified different points in the workflow. For instance, if members agree that data must be available for the study area of all indicators chosen, this can be selected using the MCS tool and any indicators that don't specify this data are removed from the choice set.

Three "checklist generator" workflow examples

To illustrate these steps and how these tools can be applied in unique ways for different use cases, we present three different

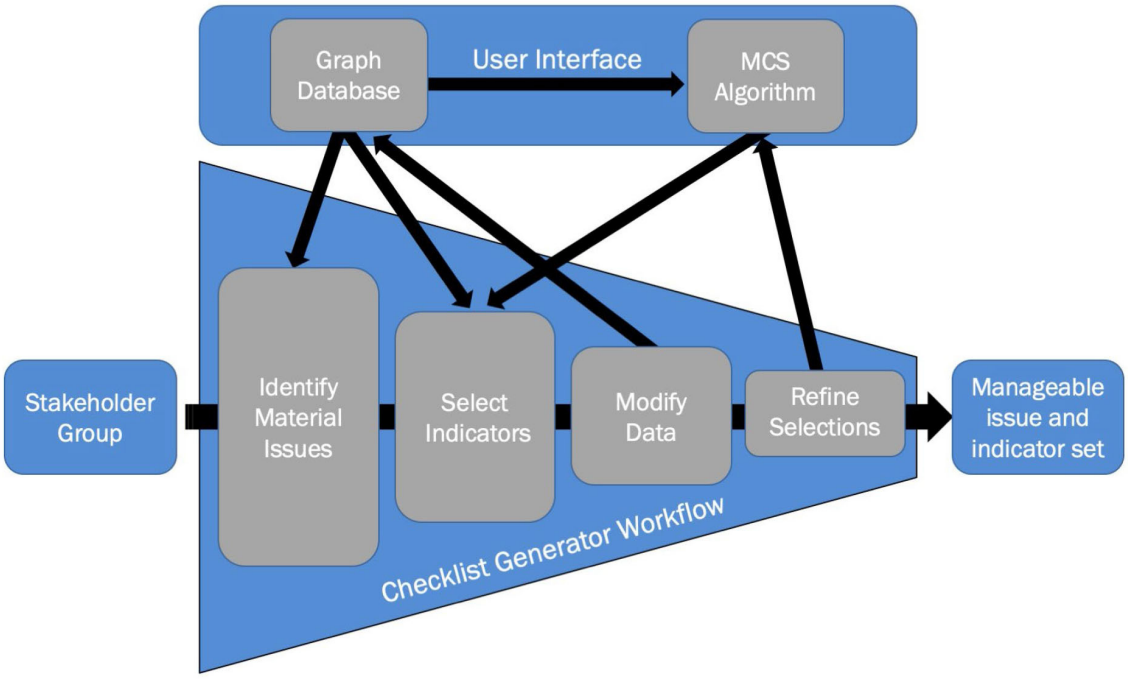


FIGURE 2
Process map connecting the four key steps in the checklist generator workflow with the four checklist generator "building blocks."

stories that show how the checklist generator workflow could unfold. The main goal of presenting three different hypothetical cases is to show how this workflow is malleable depending on the specific commodity and region, as well as the goals of the stakeholders involved. Note that these stories are only illustrative of our workflow template and do not represent outcomes of real cases.

A multi-national private food company

Consider a global food production company deciding how to define and measure the vulnerability of their peanuts sourcing networks in Nigeria. The stakeholders in this case are limited to people within the company itself. Say the company has historically tracked some key environmental impacts of their sourcing operations around the world, but now some stakeholders have become concerned about the long-term economic, social, and environmental vulnerability of the company, as well as the vulnerability of the network of producers and traders they depend upon. The company realize that their previous efforts to assess their sustainability impacts have been criticized for not being comprehensive, but are unsure how achieve comprehensiveness while maintaining conciseness. For a database, they decide to use the existing Springer et al. (2015) database, as they want to consider all possible vulnerability issues to peanut sourcing, including those not directly important to the company. From the 36 vulnerability issues in the database, the stakeholders select a subset of 24 issues directly relevant to peanut sourcing in Nigeria. From this dataset, they start the indicator selection step with a list of seven issues they are already addressing and 10 indicators they are using to measure them (Figure 3A). Three of these 10 indicators are not in the database, so before running the MCS tool these indicators are added using the back-end interface, and the stakeholders form the linkages to issues, ensuring that each linkage comes from a scientifically-validated, context-specific source. They use the front-end interface to select the remaining 17 issues as well as the 10 indicators they already use.

They now run the MCS algorithm, which identifies a set of indicators that represents all the vulnerability issues. Yet some of these indicators don't fit their goals, and so they eliminate them from the set and run the MCS algorithm again. This process is iterative until they arrive at an indicator set of 14 indicators that cover all 24 issues.

Upon further discussion, they decide the indicator set it too large and they can't afford to collect data and track that many indicators. As a way to shrink the set, they use the graph database to see how many issues they can cover with a smaller set of indicators. They find that they can cover 80% of the issues with only six of the selected indicators, recognizing the need to address the other eight in the long term to address the remaining 20% of issues (Figure 3B).

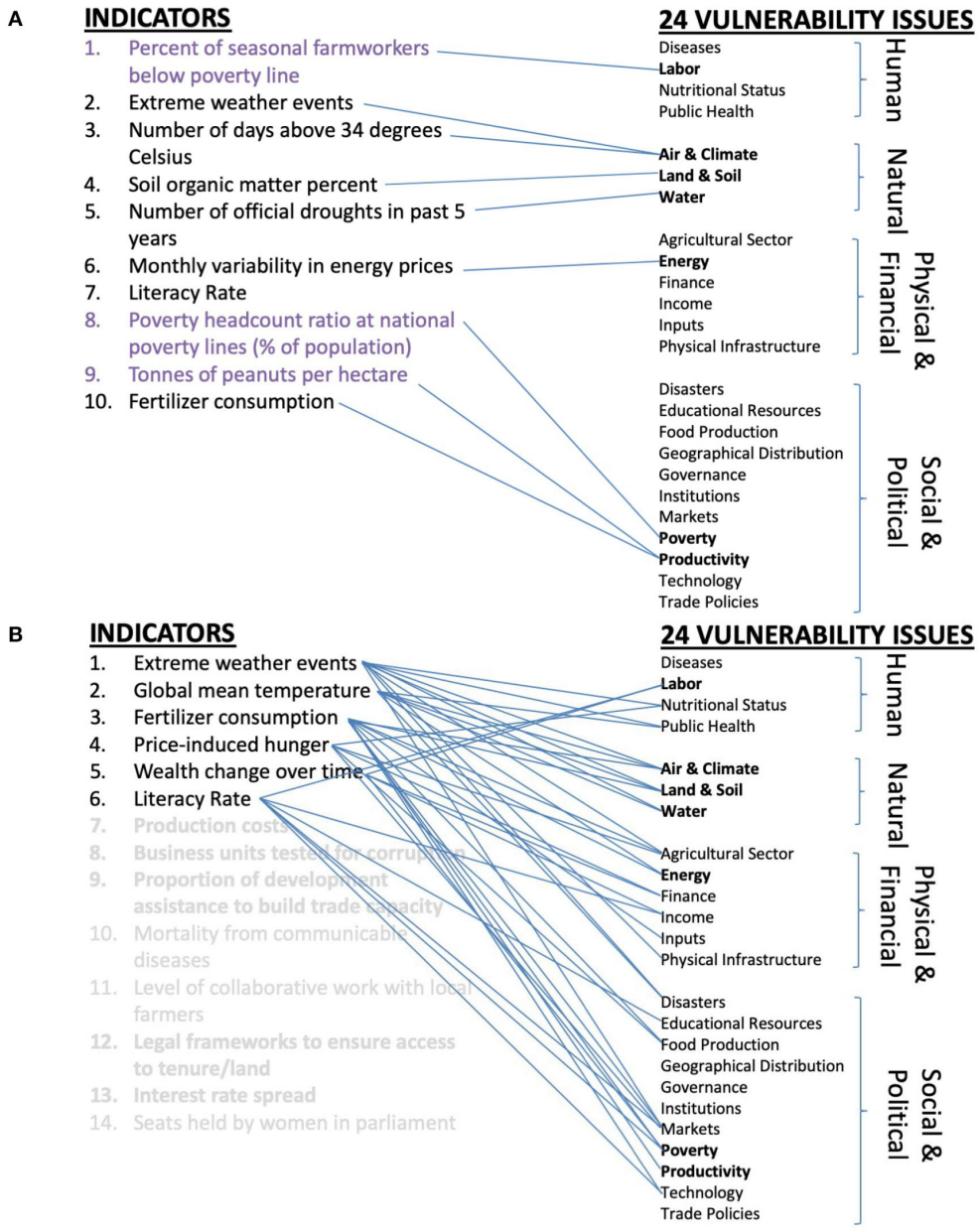


FIGURE 3
Beginning of checklist generator process in Case 1 with ten indicators covering seven issues **(A)** compared to end of checklist generator process with six indicators covering 80% of the 24 relevant vulnerability issues **(B)**. Indicators highlighted purple are the three indicators added to the graph database by the stakeholder group, bolded issues are the initial issues covered by the food company, and the grayed-out indicators are those covering the remaining 20% of issues.

A global government environmental organization

Consider a global initiative has spent the past 4 years creating a large set of indicators to measure and track categories of issues that are matched with a set of long-term policy goals. These goals have been formulated to track improvements to the sustainability of food systems around the world. These goals are matched up with issue categories, which are then measured by unique indicators. Yet the group has chosen over 100 indicators to represent their issues and goals, and they have received feedback from the public to reduce the number of indicators. Still, the organization does not want to compromise the number of issues or goals they have chosen, for they want to be comprehensive in their definition of sustainable food systems.

The stakeholder group in this case includes not only the organization but any stakeholder interested in the selection of goals, issues, and indicators. The dataset is their own set of issues and indicators, which they enter into the graph database using the back-end interface. Yet since each issue is measured by a unique indicator, there is no way to reduce the size of the indicator set unless they allow each indicator to represent more than one issue. They therefore decide to "recode" the links between issue and indicators using the back-end interface, looking at each indicator and making a link to every issue that it can be used to measure.

Once this relinking is done, they use the front-end interface to eliminate all issues and indicators except their set, and then run the MCS algorithm. Although this is the minimum set, a few stakeholders protest that some very important indicators have been eliminated, and so there is a negotiation about which ones should be added back in and before the MCS algorithm is run one more time. This set, although a few indicators above the minimum set, includes far fewer indicators than the original set, and the stakeholders agree to use this more efficient outcome.

A local government land planning board

Consider a region with a local economy mainly driven by agriculture. The municipal government in this region is concerned about the potential sustainability impact of their nascent long-term land use plan on the local food system. The planning is done by the local committees and consultants but the decisions are made by the regional planning board. The board has the key issues selected and approved, which are limited to mainly environmental issues but also a few social issues, and want input on choosing indicators (with existing data) to measure sustainability impacts of three alternative land development strategies they could implement during the next 20 years.

The stakeholder group is mainly the board, but there is some negotiation that must happen with the committees and consultants. The graph database is limited to the issues they have already defined, but requires indicators to be linked to those issues. The first step is to semantically cross-reference their issues with the issues from the Springer et al. (2015) dataset, which by transitivity links their issues to the 2,000+ indicators in that dataset. But the planning board also undertakes an additional external search for indicators that (1) have small-scale spatial data for their region or that (2) could feasibly and cost-effectively be collected. Once the search is complete, they add these indicators and metadata for the spatial datasets to the graph database using the back-end interface.

The planning board then uses the front-end interface to select the key issues that have been approved, as well as a few of the regional indicators they found that they are sure they want to use because of the good data available. They then also enable the indicator attribute for "dataset," which assures that each indicator selected has been tagged to have an available dataset to use. The board runs the MCS and finds the solution "infeasible," meaning that there are not enough indicators with datasets to represent the issue they care about. The board decides to run the MCS algorithm again without the dataset attribute selected, and it immediately finds a baseline set of indicators, some with datasets and some without. They then lock-in those indicators with datasets, eliminate the others, run the algorithm again, and repeat the process iteratively. They are able to represent 80% of their issues using indicators with available data before they receive an infeasible solution again. This indicator set allows them to analyze the spatial data for the majority of their issues to assist in their scenario planning, while also communicating to other government authorities the data gaps that remain for key issues.

Discussion

These examples illustrate the flexibility of the checklist generator workflow and the potential to adjust the "building blocks" depending on the goals and strategies of the stakeholder groups. This flexibility would be even more evident if comparing the differences in indicator sets between runs. As shown by Huber et al. (2015), eliminating one or two indicators and running the MCS again may produce an indicator set that is markedly different than the previous one. This not only highlights the possibility of countless acceptable indicator sets, but the importance of a user-driven workflow to guide indicator selection. This workflow is designed so that actors are forced to engage in careful discussion at various points throughout the user-defined workflow to assess for themselves whether the indicator list being generated adequately covers each aspect of the issues they care about.

One can imagine many other ways of combining and adapting these building blocks for any number of cases, along with the advantages that would come more and more lists being generated. For instance, consider another example: five different groups of stakeholders are concerned with the sustainability of sourcing of a commodity X, but each group is on a different continent and produces commodity X in distinctive agroecosystems, with disparate technologies, and in different social and institutional contexts. As each group goes through their own unique checklist generator workflow, they will generate their own issue and indicator lists to define and measure the sustainability of sourcing commodity X from their respective regions. By continually adding to and utilizing the growing network of issues and indicators, similarities and differences between the resulting lists could be compared and would provide insight into what sustainability issues have global significance and which are locally specific.

We hypothesize that a significant subset of sustainability issues is applicable in all contexts, although this subset cannot currently be determined *a priori*. Yet as multi-scale commodity- and region-specific sets are generated for more contexts, patterns in these similarities and differences may begin to elucidate a global picture of sustainable food systems. When considered together, a global set that defines and measures global food system sustainability, given current knowledge, will emerge.

As more sets are generated and additional knowledge on important and useful issues and indicators becomes available, stakeholders can use this new information to update their sets to include issues increasingly deemed as important by other groups and indicators that are often used and becoming particularly established. Consider again the example of commodity X: if one region generates an issue and indicator list, the other four regions might find it useful to see these lists while creating their own. This information can then be stored in the growing Semantic Web of data by using the back-end interface to tag issues and indicators that show up again and again, further strengthening both the indicator attributes and the usefulness to users. While maintaining user privacy, such an open-data Semantic Web platform can allow sharing of previously searched commodities and regions at various scales, the issues the user is concerned with, and the indicators that were chosen in real time.

In this way, the iterative nature and flexibility of the checklist generator workflows allow the global definition and measurement of food system sustainability to emerge and evolve over time, growing from the unique knowledge and experience of the people addressing the issues on the ground. Furthermore, transparency of these workflows using the Semantic Web has the potential to empower communities of practice often left out of the decision making workflow: if their sets are consistently different from those with the influence to change practices, it will become evident to the global community that comprehensive sustainability is not being achieved by this group, putting pressure on those in power to iteratively adjust their sets and expand their stakeholder groups and decision making workflow.

Conclusions and future work

The three examples presented in this study show the potential for the checklist generator workflow to take disparate sustainability information and build context-specific and globally-relevant definitions of food system sustainability. The flexibility of the workflow allows different disciplines and stakeholder groups to contribute to a shared informatics platform, while at the same time giving stakeholders a practical tool to communicate with researchers and negotiate with other interest groups. Our next step for this work is to generate issue and indicator checklists for comparison in partnership with stakeholder groups involved in the supply chains of specific commodities and regions.

A number of further steps are envisioned to improve the usefulness of the existing graph database and checklist generator workflow. Our team has developed a draft typology of indicators that, if applied to each indicator (useful scale, available data, leading/lagging, etc.), would populate the attribute table in the MCS algorithm and allow them easy sorting of indicator types before running the MCS. The continued development of the front-end and back-end application interfaces, alongside the continued development of the controlled vocabularies, allow our tools to be more closely linked to global Semantic Web of sources and data. Furthermore, we are developing an ontology to improve the description of the relationships between issues and indicators. In this current study, a link is only made if an indicator can provide useful information about a given issue. Other relationships could be defined among issues, such as causation between issues, allowing the isolation of underlying drivers. Coupling of these underlying drivers to mechanistic frameworks or models would then allow for explicit testing of actionable solutions such as management practices, policy interventions, and livelihood decisions. Building these complex relationships into the graph database would give users even more information and options, helping them choose issue and indicator sets with even more precision and confidence.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

NS led the writing of the manuscript. All authors conceived the foundation of the study, design of the methodology, design of the illustrative case studies, contributed to the preparation, and revision of the manuscript at all stages. All authors contributed to the article and approved the submitted version.

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Supplementary material

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Traditional ecological knowledge to traditional foods: The path to maintaining food sovereignty in Hutsulshchyna

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The various ecosystems of the Carpathian Mountains spanning Europe, are a rich refuge for culturally important, endemic plant species as well as large carnivores. These biologically diverse landscapes are a principal source of subsistence to 16 million people, including various ethnographic groups. This paper focuses on a case study involving Hutsul communities, an ethnographic group of traditional pastoral highlanders, in the Southeastern Carpathian Mountains of Ukraine. Given ecosystem, climatic, and cultural challenges, especially the rise of illegal logging, commercial harvesting, increased frequencies of flooding, and now a war, Hutsul communities face extensive threats to maintaining socio-ecological resilience in the region. A contributing factor to the region's centuries-long resilience is traditional ecological knowledge upholding food sovereignty as seen through traditional foods derived from Carpathian Mountain ecosystems. Traditional ecological knowledge (TEK) is as a dynamic, generationally-held knowledge base, where language, gathering practices, landscape and culture inform livelihoods. In this article, we seek to answer the following series of questions within Hutsul communities: (1) What does TEK look like in the region? (2) What are the regional environmental challenges? (3) Given these challenges, what are coping mechanisms and adaptive strategies grounded in TEK, ensuring a resilient food sovereign system? Mixed methodologies guided by community-based participatory action research methods (CBPAR) between 2017 and 2019 provide a rich, context-driven perspective on regional TEK. Radiating out from the historical, cultural Hutsul capital, Verkhovyna, 40 experts (including knowledge holders, elders, foresters, and community members) were interviewed in 8 neighboring villages. We, along with Hutsul experts, explore the presence of traditional ecological knowledge (TEK) in Hutsulshchyna by identifying 108 culturally important species including wild plants (74 species), cultivated plants (23 species), fungi (9 species) and lichens (2 species); these species are gathered in 10 habitats with varying degrees of human interaction. We analyze species' presence in traditional foods in the past and present day, as well as contextualize regional environmental challenges impacting TEK practices, and responses to these challenges (coping mechanisms and adaptive strategies). Despite various regional challenges, we conclude that TEK provides a resilient foundation for supporting food sovereignty as seen through the presence of traditional foods.

KEYWORDS

fallback food, Carpathian Mountains, traditional foods, traditional ecological knowledge (TEK), food sovereignty, culturally important species, resilience

Introduction

With climate change impacts not evenly distributed across the globe but felt more drastically over land, the poles, and more arid regions (Main et al., 2008; Wheeler and von Braun, 2013), areas and communities already experiencing food insecurity will be hit hardest. This reality deserves attention, as well as thoughtful and mindful action, especially for marginalized, communities worldwide, specifically Indigenous Peoples and underrepresented ethnic groups, who may experience these impacts more immediately. Many Indigenous and underrepresented ethnic communities are both societally and spatially marginalized, living in edged biomes near forests, oceans, and deserts. Although Indigenous peoples make up 5% of the world's population, these same communities steward an estimated 85% of the world's remaining biodiversity (Hoffman et al., 2021). Additionally, they are overrepresented among the world's poorest, most marginalized populations, as well as those displaced or threatened by environmental encroachment, wars, disasters, and socio-political stressors (Wheeler and von Braun, 2013) and climate change (Abate and Kronk, 2013). Climate change impacts threaten communities' access to land, water, and natural resources which are crucial for livelihood practices (Ford et al., 2020), ultimately threatening regional food sovereignty. Yet, many communities continue to survive and thrive. It is deep relationship with place that grounds identity, knowledge, belief systems, and livelihood practices, ultimately informing how communities experience, respond, and adapt innovatively to diverse regional changes.

In this case study, Hutsul communities, an ethnographic group of traditional pastoral highlanders, in the Southeastern Carpathian Mountains of Ukraine, illustrate a socio-ecological approach to maintaining food system sovereignty. Oak groves, spruce and beech forests, alpine grasslands, gardens, rivers, and community-derived resources including agricultural animals dot these Mountains (Figure 1); Hutsuls maintain a continual dialogue with these habitats seasonally, gathering culturally important species including *Vaccinium sp.*, *Ribes sp.*, mushrooms, and others to make traditional foods, such as *kulesh* and *banosh* for holidays (Figure 2). Hutsuls continue to survive, thrive, and adapt in the face of today's colonial invasions, current war, food shortages, regional challenges in addition to the synergistic impacts of climate change, especially regional illegal timber harvest causing an increase of regional flooding. Many Hutsul communities in the Carpathian Mountains are guided by traditional ecological knowledge (TEK) in their daily lives. Communities stress that ecosystem health is deeply tied to personal and community health, and continually reiterated in the phrase, "food is medicine". Lived and experienced by local and Indigenous communities worldwide, TEK is cultural, spiritual, intergenerational, dynamic, place-based, environmental knowledge, wisdom, and oral history; TEK, is an empirical knowledge base gained from continual observation of the environment which is revisited, reinterpreted, and re-evaluated (Molnár et al., 2008; Berkes, 2012). Monitoring environments including habitats, species, climatic conditions, and landscapes emerges as a result of place-based cultural practices. TEK acts as a well of stored experience and environmental knowledge (climatological, ecological, biological, and spiritual); it establishes a foundation of resilient practices to meet community needs, while adapting to environmental changes.

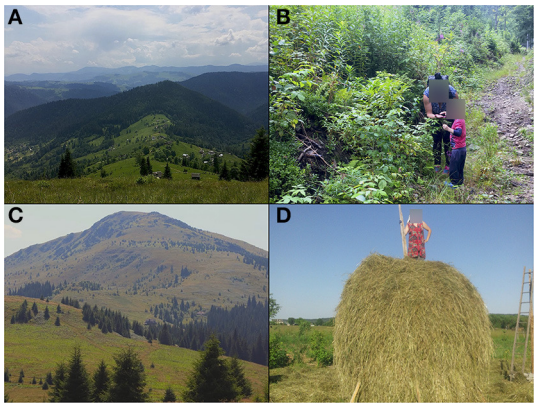


FIGURE 1
(A) A common landscape in Hutsulschyna (Photo credit: N. Fontana); **(B)** Nadia Perepelytsia and her son, Maxim, picking bilberry (*Vaccinium myrtillus*) in their nearby woodland and forest areas (Photo credit: N. Fontana); **(C)** *Polonyna*—an alpine grassland and culturally important ecosystem in Hutsulshchyna (Photo credit: O. Pohribnyi); **(D)** Work on a *toloka* (a culturally important field for grazing cattle). Here, Ivanna Kovaliuk is using her feet to compact grass into a haystack (Photo credit: M. Pasailiuk).

In this context, the path to achieving food security is informed by TEK; this path grafts cultural, place-based community needs with a resilient, ecologically-grounded approach, known as food sovereignty. While food security is mainly concerned about the distribution and protection of current food systems, food sovereignty advocates for an environmentally-just as well as an ecologically and culturally appropriate food system. Food sovereignty, as a term, can be controversial in its various meanings and origins (Coté, 2016; Hoover, 2017). Here, we refer to the definition stated in the Declaration of Nyéléni (2007) at the Forum of Food Sovereignty. "Food sovereignty is the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and the right to define their own food and agriculture systems." Within this definition emerges a powerful recognition of community self-determination in how food is grown, managed and sourced. In addition, a food sovereign approach affirms the importance of socio-ecological



FIGURE 2
(A) Local gathering trip (summer 2018) Mushrooms seen in this photo include red pine mushroom (*Lactarius deliciosus*), birch bolete *(Leccinum scabrum)* and Bare-toothed Russula (*Russula vesca*) (Photo: N. Fontana). **(B)** Traditional celebration basket with fruits, berries (*Rubus fruticosus*) and flowers on August 19th, Apple Spas, an Eastern Slavic folk holiday (Photo credit: M. Pasailiuk). **(C)** Traditional Food: *Kulesh* prepared from corn flour and *polonynska bryndza* (cheese made from sheep on the *polonyna*) (Photo credit: O. Pohribnyi). **(D)** Traditional Food: Holubtsi—stuffed cabbage rolls (Photo credit: M. Pasailiuk).

relationships, rooted in sustainable practices. Lastly, it infers that access to healthy environments and culturally important foods are inextricably linked.

Food sovereignty is not an endpoint in achieving food security; rather, it is an ongoing, adaptive capacity for a community to overcome food system threats, leading to resilience. The term resilience was first framed within boreal ecosystem functioning, attributed to Holling (1973). Since then, many nuanced definitions surrounding resilience have arisen (Folke, 2006). We will focus on the general characteristics of resilience which inform the "capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and shocks, and even transform when conditions require it" (Holling, 2001; Berkes et al., 2003; Brown, 2016). In our case study, socio-ecological stresses and shocks are various regional challenges, which Hutsul communities encounter both in the past and present-day. In the face of these stressors, resilience emerges as a combined result of coping, adaptive, and transformative capacities, which leads to incremental adjustments, persistence, or transformative responses. We explore these resilient responses grounded in TEK, which include coping mechanisms (short-term responses) and adaptive strategies (transformative long-term responses). Referring to terms commonly used in developmental studies (Singh and Titi, 1994) and anthropology (McCay, 1978), coping mechanisms are short-term, quickly implemented strategies to situations that threaten livelihoods. Conversely, adaptive strategies are long-term changes implemented by communities, modifying local rules, institutions, and productive activities to ensure livelihoods. Coping mechanisms tend to emerge on individual or household levels, while adaptive strategies tend to emerge on community levels. Both coping mechanisms and adaptive strategies exist across temporal scales, whereby over time, coping mechanisms can become adaptive strategies (Berkes and Jolly, 2001).

In this article, we seek to answer the following series of questions within Hutsul communities: (1) What does TEK look like in the region? (2) What are the regional environmental challenges? (3) Given these challenges, what are coping mechanisms and adaptive strategies, ensuring a resilient food sovereign system? The information included here is drawn from long-term participatory research, personal and participatory observation, literature reviews, interdisciplinary approaches (both qualitative and quantitative) and includes co-authorship of Hutsul scientists. We, along other Hutsul experts, explore the presence of TEK in Hutsulshchyna by identifying 108 culturally important species and their presence in traditional foods in the past and present day, as well as distinct regional environmental challenges triggering resilient community responses (coping mechanisms and adaptive strategies). Therefore, the aim of this study is to trace the path to maintaining food sovereignty by exploring TEK in Hutsulshchyna and as a result the presence and sustainable management of culturally important species used in traditional foods (Figure 3).

Research area and methods

Regional background

The Carpathian Mountains span countries including the Czech Republic, Poland, Slovakia, Hungary, Serbia, Romania, and Ukraine. Containing Europe's largest remaining old-growth forest ecosystems outside of Russia, the Carpathians are a biodiversity hotspot, harboring one-third of all European vascular plant species. Considered the "Amazon of Europe", this region is one of Europe's last fully undeveloped landscapes, a rich refuge for large carnivores and a principal source of subsistence to 16 million people (Gurung et al., 2009). The Carpathian region in Ukraine covers 3.5% of Ukraine's area and 10.3% of total area of the Carpathian Mountains (Elbakidze and Angelstam, 2013). The flora species composition of the Carpathian alpine forest provides key indicators of ecosystem health in response to climate change (Geyer et al., 2010). As an ancient corridor and refuge for humans, the cultural landscape mirrors the breadth and depth of the biological landscape. Beginning over 2,000 years ago, many tribes established cultural roots in this region (Kibych, 2010).

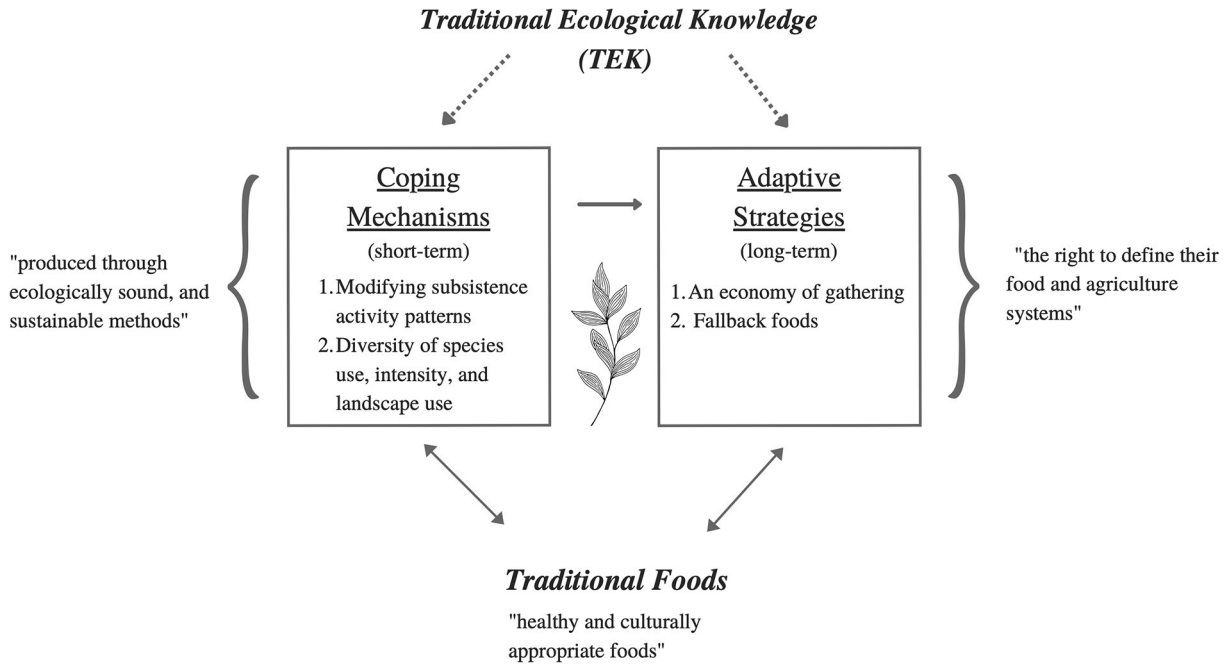


FIGURE 3
The path to food sovereignty in Hutsulshchyna. Using the definition stated in the Declaration of Nyéléni (2007) at the Forum for Food Sovereignty, as a framework to guide our study. "Food sovereignty is the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and the right to define their own food and agriculture systems."

In Ukraine, there are various Indigenous, ethnographic groups, ranging from the Tatars in Crimea, who are currently facing intensified persecution due to Russia's occupation (Coynash and Charron, 2019), to the highlanders in the eastern Carpathian Mountains: including Hutsuls in Hutsulshchyna (Figure 4), Boykos, in the Bystrytsia Solotvynska River Basin, and Lemkos, in the Low and Middle Beskyd Mountains (Magocsi, 1997). Archaeological evidence points to human existence in the region dating back to 100,000 years before present (Stech, 2007). This study is centered in the cultural, historical center (Verkhovyna) of Hutsulshchyna, which translates to "Land of Hutsuls", a mountainous area of the Carpathian Mountains in Ukraine (Northern Bukovina) and in northern Romania (Maramureş and Southern Bukovina areas) (Figure 4). As Ukraine faces a current colonial war of aggression, financial insecurity, food scarcity and increasingly expensive medical care, trade, and direct consumption of NTFPs (non-timber forest products) in local diets has increased in the Carpathian region (Stryamets et al., 2015). According to the Food and Agriculture Organization of the United Nations, 80% of developing countries rely on NTFPs for nutrition and health purposes (Sorrenti, 2017). NTFPs, seen in this study, are culturally important species like wild plants and mushrooms; they contribute to the local economy, diversify diets, present possibilities for genetic research and development in new domesticated crops, and provide a lens for understanding cultural worldviews, language, and knowledge.

At a landscape scale, Hutsuls, traditional pastoral highlanders of the Ukrainian Carpathians, have maintained alpine grasslands (*polonynas)* through mountain shepherding of cows and sheep (Figure 1). There is a continuing threat of cultural loss of this practice due to low economic competitiveness and increasing disinterest among younger generations (Amato, 2020). Maintenance of these alpine grasslands is declining quickly with newer pressures including tourism infrastructure and emigration of younger generations to cities. This decline of grazing on secondary grasslands has led to reforestation of previously cleared areas (Elbakidze and Angelstam, 2013). However, mountain shepherding and other ecological practices, such as gathering of NTFPs, like wild edible plants and mushrooms, although threatened, have survived. Forests and other habitats (gardens, roadsides, pastures, fields, woodlands, alpine areas, meadows, *polonynas* (culturally-managed alpine meadows), and *tolokas* (generationally-held pastures)), bordering village settlements provide an integral zone of nourishment through the gathering of wild and cultivated species. Flowers, birch sap, resin, honey, mushrooms, and berries gathered in these diverse habitats form an essential part of the social fabric and political economy of Ukrainian culture (Bihun, 2005; Elbakidze and Angelstam, 2007; Demeter, 2016), particularly in forest-dependent Hutsul communities.

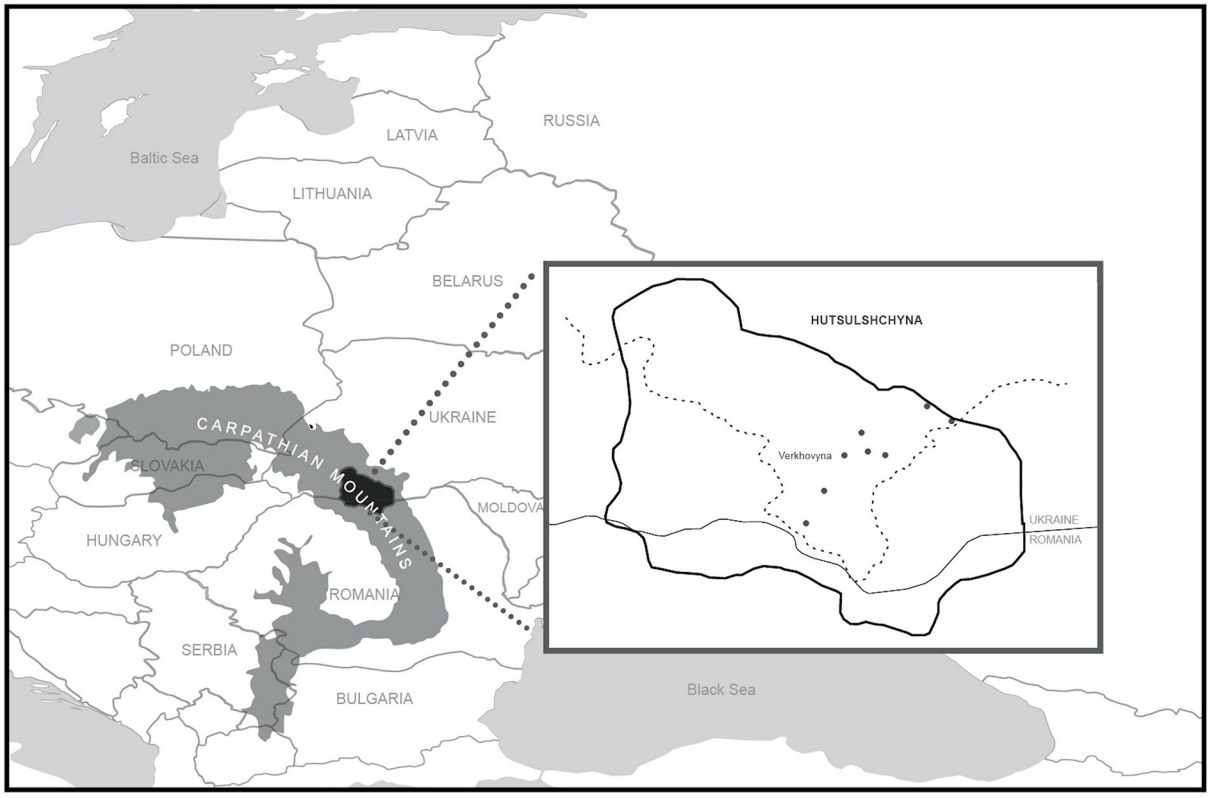


FIGURE 4
Map of Hutsulshchyna. The bolded outline marks the current area of Hutsulshchyna, the land of Hutsuls (Adapted from Figlus, 2009). Hutsulshchyna today borders both Ukraine and Romania. The dotted line transecting Hutsulshchnya represents borders established before World War II whereby Hutsulshchyna was split between Romania, Czechoslovakia, and Ukraine. In 1940, borders split Hutsulschyhna between the Soviet Union (now Ukraine) and Romania. The dots represent villages visited and places of interviewing. Verkovyna, the historical cultural center of Hutsulshchyna, and the surrounding villages all fall within a centralized area between borders established before World War II.

For centuries, local Hutsul people have creatively and effectively managed culturally important species in the Carpathian Mountains (Griffiths et al., 2014) maintaining their productivity and availability, thus creating a socioeconomic safety net to sustain them in times of scarcity. In this region, 59–91% of the population lives in rural areas (Bosch et al., 2008); this broad range is due to the socioeconomic inequality between rural and urban areas in the region (UNEP, 2007). The interdependence between nature and need is explicit. While most houses have electricity, most water is taken from nearby wells and rivers (Geyer et al., 2011) and most villages have no sewage system (Bosch et al., 2008). People trek to natural mineral water springs, which is an old spiritual tradition. There are over 800 natural mineral sources in this region (Kolodiychuk, 2008). Communities are self-sufficient in terms of their nutritional needs, relying on a diversity of habitats nearby. Food is grown, gathered, and stored (dried, pickled, canned, and fermented). Many households in this region rely on subsistence-based agriculture and additional income derived from family members going abroad for work. Low salaries demand multiple avenues of revenue from subsistence farming, gathering, and selling of culturally important wild species, as well as opening one's home to tourist stays (ecotourism).

Hutsulshchyna has been a place of extensive ethnographic work starting in the early 1800s and continuing well into the 1930s, when this region was under various colonial regimes (including Poland and the Austro-Hungarian Empire) (Falkowski, 1938; Łuczaj, 2008; Kujawska et al., 2015). In the last 6 years, a group of scholars have centered ethnobotanical research in Bukovina, the southeastern corner of Hutsulschyna (which falls along the Ukrainian-Romanian border) with studies focusing on Hutsul ethnobotany (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2020, 2021a,b; Stryamets et al., 2021b), and ethnomycology (Stryamets et al., 2022a). Excluding their most recent study, their methodologies generally consist of qualitative interviewing followed by quantitative analyses including detailed use reports (DUR) and calculations of the Jaccard Similarity Index (JI) to cross-culturally compare ethnobotanical uses on either side of the border.

Their studies suggest that the establishment of the border between Ukraine (under the Soviet Union) and Romania in 1940 and the resulting impacts of Soviet policies in Ukraine contribute to differences in ethnobotanical use (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2021a; Stryamets et al., 2021a), and knowledge transmission between Hutsuls in North Bukovina (Ukraine) and Hutsuls in South Bukovina (Romania) (Mattalia et al., 2020). Additionally, their other studies analyze differences between wild and cultivated species' use between Romanians and Hutsuls in Bukovina (Mattalia et al., 2021a), ethnomycological differences (Stryamets et al., 2022a), revitalization of ethnobotanical practices in religious holidays of Hutsuls in Northern Bukovina (Ukraine) and Ukrainians in Roztochya, western Ukraine (Stryamets et al., 2021b) as well as noting the biocultural diversity present in Ukraine (Stryamets et al., 2022b).

Recent studies infer that Hutsuls in Northern Bukovina (Ukraine) exhibit greater reliance and dependence on forest habitats than Hutsuls in Southern Bukovina (Romania) (Mattalia et al., 2021b; Stryamets et al., 2022a). The splitting of Hutsulshchyna between Ukraine (under the Soviet Union) and Romania in 1940 and the resulting policies implemented on each side of the border guide the narrative of these studies; differences seen in species uses, range of species as well as ethnobotanical knowledge transmission are attributed to this border creation. Broader questions arise: to what extent do these ethnobotanical and ethnomycological gathering practices inform and support Hutsul communities in maintaining food sovereignty? What are regional environmental threats and how are communities responding? Building upon these rich ethnobotanical studies, our study radiates from the heart of Hutsulshchyna, the cultural, historical Hutsul center. Unique to our study, we weave qualitative and quantitative mixed methodologies, include habitat diversity (recognizing the importance of place) in our analysis, and incorporate Hutsul voices through authorship. We explore TEK as seen through dynamic, generationally-held ecological knowledge, language, traditions and how it informs resilient responses to ecosystem challenges (coping mechanisms and adaptive strategies) to support regional food sovereignty.

Methods

Data collection

We framed our study through a community-based participatory action research (CBPAR) lens (Ballard and Belsky, 2010), utilizing mixed methods—in-person semi-structured interviews, ethnographic literature review, participant observation (Musante and DeWalt, 2010) including gathering trips, voucher collection/verification, and a community ecology approach (presence-absence species data); these methods generated quantitative and qualitative data for analyses.

This article, co-authored by Hutsul scientists, Mariia Pasailiuk and Oleh Pohribnyi, facilitates dissemination of knowledge on their terms, and serves as published affirmation of the importance of Hutsul TEK in regional economic development and environmental policymaking. We attempt to understand the synergistic social, economic, and eco-cultural spheres that inform Hutsul community livelihoods. By publishing this research, we show the interdependence between Hutsul communities and their own landscapes through TEK, while voicing Hutsul community members' perspectives on regional environmental challenges.

Incorporating CBPAR approach, connections and relationships with community members and colleagues were made 4 months prior (between August 2017 and December 2017) to our extensive field seasons (2017–2019) in order to center in-depth participation, research framing, and ethical considerations in the research process. There were ethical considerations made when thinking about how this publication could harm and benefit communities, especially since eco-cultural and economic livelihoods are dependent on culturally important species mentioned here. To address these issues, community members are not named here, unless explicit permission was granted; current prices for species sold for economic purposes are also not listed. Oral consent was obtained prior to each interview. All authors strictly followed guidelines prescribed the International Society of Ethnobiology (2006). However, since there is no official ethical review process regarding the protection of human participants in Ukraine, the first author obtained a local ethical review and approval of the project from the Verkhovyna National Nature Park in Ukraine (since most villages visited were centered around Verkhovyna). The local ethical review of the project was translated into English and then approved by the Institutional Review Board Committee at the University of California, Davis.

Between December 2017 and August 2018, the first author conducted in-depth, semi-structured, in-person interviews of 40 Hutsul experts (including elders, foresters, and community knowledge holders) in eight villages, and two national parks (Verkhovyna National Nature Park and Hutsulshchyna National Nature Park) through snowball sampling methods (Höft et al., 1999; Martin, 2004). Interviews were conducted in Ukrainian, and participants responded in Hutsul and Ukrainian. All interviewees were over the age of 18 (aged 25–93), with an average age of 53, with each interview ranging from 30 min to 4 h. The gender ratio was 43% men and 57% women. Participants were intentionally selected for their expert knowledge and were recognized by community members as highly knowledgeable. Throughout both field seasons, key elders and knowledge holders were interviewed multiple times. To understand the extent and depth of regional TEK, question topics included species' uses, parts used, names (Hutsul and common names), stories/rituals, habitats found, gathering methods, ecological cues, and ways of preparation.

In discussions, all participants shared information about environmental, climatic, and cultural threats to gathering practices and resulting strategies (coping mechanisms and adaptive strategies).

Between June and August 2019, all authors participated in follow-up interviews and participant observation (gathering trips) to further clarify TEK surrounding species use, gathering methods, names, habitats and more specifically to interview elders about species gathered during times of scarcity. To understand species' use during times of scarcity in the past, the first and second author conducted an extensive ethnographic literature review (in English and Polish) comparing our findings on a species-by-species basis with noted fallback foods (species) identified in the past (Falkowski, 1938; Fischer, 1939) and current studies (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2020; Stryamets et al., 2022a).

In interviews and participant observation, knowledge holders clarified plant names and plant uses with the aid of photographs and specimens. Alignment of common names with botanical names, and plant identification of specimens were confirmed and cross-referenced with existing voucher specimens, botanists (Lyubomyr Derzhipilsky, Roman Lysiuk), forest ecologist Oleh Pohribnyi, and mycologist Mariia Pasailiuk. Taxonomic texts from the Hutsulshchyna National Nature Park library were also used to identify species including plants, mushrooms, and lichens. Additionally, throughout both field seasons, guided by elders and specialists, the first author participated in trips throughout the gathering seasons (typically, fall, spring, and summer) to the Chornohora Mountain range and local areas to better understand gathering practices in the region.

Data analyses

Interviews and data from participant observation were audio recorded, transcribed, and translated into English; data were organized in Excel and in R. The ethnobotany R packaged developed by Whitney (2020) was used to calculate quantitative ethnobotanical indices. The first field season provided data for calculations to derive indices including use report (UR), frequency of citation per species (FC), cultural importance index (CI index), number of uses per species (NU), relative frequency of citation index (RFC), fidelity level per species (FL) for wild species (including plants, lichens, and fungi) and commonly cultivated plants. In this study, we focus on species' cultural importance derived from the cultural importance index (CI index), which is the sum of use reports divided by the number of participants to account for the diversity of uses for each species (Tardío and Pardo-de-Santayana, 2008). The diversity of uses include food (alcoholic beverage, fruit, recreational beverage, seasoning, vegetable, tea, fungi), medicine (tincture, topical treatment, ground) and other uses including ecological marker, symbolic, toxic, veterinary, textile, repellant, and economic (Table 1).

TABLE 1 Gathering site types or habitats.

Gathering site types	Description
Roadside	Roads provide thoroughfare to buses, cars, motorcycles, bicycles and people. People walk along and sell local products (berries, mushrooms, crafts) along roadsides. Harvesting along roadsides happens but is undesirable due to pollutive effects.
Forest	A dynamic ecosystem consisting of trees and understory plants, with various interactions and species composition changes including: (1) firewood harvest, (2) collection of berries and mushrooms, (3) introduction of hitchhiker species, (4) recreation (hiking), (4) occasional livestock grazing, and (5) logging.
Garden	A field planted with fruit trees (apples, cherries, plums, peaches). It is planted once and harvested every year, resulting in a relatively static species composition.
Toloka (*Толока*)	This culturally place-based fenced field is held within families intergenerationally near homes. It typically borders forests and serves as a grazing area for small cattle year-round.
Polonyna (*Полонина*)	This culturally place-based high alpine meadow on a forestless mountain peak. Every year, there is a festival marking the transfer of cattle to high mountain shepherds. Grazing animals have a significant influence on plant species diversity.
Field	A place where plowing and agricultural work occurs. Hay is harvested and vegetative propagation of plants and species composition is impacted by hay harvesting.
Pasture	This is a meadow where cattle graze together but no mowing occurs. Due to land privatization (after the collapse of the Soviet Union), there are not a lot of pastures. Pastures and fields have similar plant species composition.
Meadow	A field of grass that is used specifically for gathering hay. Cattle do not graze here and this habitat supports native vegetation.
Woodland	These are edge habitats with more open canopies than forests.
Alpine	Human and animal impact is minimal. There is no grazing. Minimal shrub and grass vegetation.

Quantitative indices, based on in-depth and semi-structured interviews, assess passive knowledge and "participant consensus", the degree of agreement among interviewees (Albuquerque et al., 2006). When analyzing the indices, we found that context-driven understanding of species use, like habitat, are valuable in understanding species' impact on the day-to-day lives of people but are not incorporated in ethnobotanical indices. To amend this knowledge gap and get an understanding of human interaction and species distribution across habitats, we used a community ecology approach by noting each species' presence or absence (Gaston, 2009) in various habitat types (roadside, pasture, *toloka*, meadow, woodland, forest, field, *polonyna*, alpine area, and garden).

Additionally, the range/gradient of human interaction or structuring in each of these habitats (gathering site types) was also noted. Each of these habitats (gathering site types) encompasses a range and gradient of human interaction (from high-roadside to low-alpine) as seen in Table 1.

After calculating these indices, knowledge was further organized by using a mix of inductive and deductive codes (Saldaña, 2021), derived from interviews, and participant observation. The first field season captured qualitative data on general TEK including current species use, gathering practices and ecology, while the second field season of interviews focused on species relied on in times of scarcity. A discussion emerged from data collection from the two field seasons—between species currently gathered and used to those relied upon during times of scarcity, which was coupled with data from our extensive ethnographic literature review.

Coded information included species' use in holidays, songs and stories, plant knowledge acquisition, use in traditional foods, economy of gathering, environmental challenges, and habitat distribution. Coping mechanisms and adaptive strategies emerged from these analyses. Outings, informal group discussions, and long-term presence in Hutsulshchyna with key elders allowed for the development of shared trust and the witnessing of lived knowledge. By delving into these qualitative experiences, context and meaning emerge to provide a deeper understanding that cannot be captured in strictly quantitative ethnobotanical indices. By merging these collaborative, qualitative approaches with quantitative indices, a richer perspective can be gained, based not only on informant consensus on species use, but on how this knowledge forms a broader dynamic knowledge base (TEK), and the resulting strategies that support a food sovereignty.

Results

With the direction, guidance, and cooperation from Hutsul experts, we recorded a total of 108 species from 79 genera and 48 families (Supplementary material 1) in 10 different habitats (Table 1). While the goal was to understand wild plant use and resulting TEK in Hutsulshchyna, other species arose such as use of cultivated plants (23 species), mushrooms (9 species), and lichens (2 species) in discussion. Interviewees noted species as wild or cultivated. Additionally, we noted instances where observed wild species were seen growing in cultivated spaces such as gardens. Among the wild plants, the most well represented families included Rosaceae, Asteraceae and Gentianaceae. Among the cultivated plants, the most well represented families include Apiaceae and Asteracea. A total of 1,508 UR for wild plants, a total of 220 UR for cultivated plants and a total of 68 UR for mushrooms were provided by participants. Out of 97 plant species examined, 23 plants were cultivated, and 74 plants were wild. Out of 97 plants stated as culturally important (as indicated by the CI index), there are 4 species of evergreen trees, 11 species of deciduous trees, 15 species of shrubs, 62 species of perennials, 4 species of annuals, 1 aquatic plant species along with 2 species of lichen.

Culturally important species and their habitats (quantitative ethnobotany meets a community ecology approach)

The Cultural Importance index (CI index) is useful since the measure is independent of the number of informants and can be used for comparing regional botanical knowledge (Tardío and Pardo-de-Santayana, 2008). Overall, St. John's wort (*Hypericum perforatum*), bilberry (*Vaccinium myrtillus*), and raspberry (*Rubus idaeus*) were considered the most culturally important wild plant species (Table 2). The top three cultivated species with the highest noted cultural importance and highest noted use reports (UR) were chamomile (*Matricaria chamomilla L.*), apple (*Malus* spp.), and chokeberry (*Aronia melanocarpa*). Unique to this study are two noted lichen species: *Cetraria islandica* and *Cladonia rangiferina*.

Among the nine fungi species, Boletaceae was the most well represented family. Considering cultural importance (CI), frequency of citation (FC), relative frequency of citation (RFC), relative importance (RI), and use reports (UR) among mushrooms noted, fly agaric (*Amanita muscaria*) ranks first followed by penny bun (*Boletus edulis*). Chanterelle (*Cantharellus cibarius*) ranks third in terms of cultural importance (CI) and relative importance (RI); it also ranks fourth in terms of relative frequency of citation (RFC). Mushrooms indicating the most uses (NU) were penny bun (*Boletus edulis*) followed by fly agaric (*Amanita muscaria*) and chanterelle (*Cantharellus cibarius*). While fly agaric was discussed the most, it is very sparingly gathered. Its bold presence in the analysis has more to do with its symbolic importance and ecologically presence in the region than its use in everyday life. This dataset is small since it was incidental knowledge gathered through interviews and participant observation on plant knowledge; it does not fully capture the extensive deep and rich mycological knowledge rooted in this region. Incidental gathering of wild plants typically occurs when mushroom hunting, hence their inclusion in the analysis. This incidental gathering of knowledge presents a starting point in understanding the importance of ethnomycology in Hutsulshchyna.

In addition to species' cultural importance and use, an understanding of human interaction within various habitats/gathering sites emerged through a community ecology approach. There is a gradient of human interaction across habitats (from most to least): roadside, forest, garden, *toloka*, *polonyna*, field, pasture, meadow, woodland, and alpine area (Figure 5). Many of the same culturally important species are found in a variety of habitats with different degrees of

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TABLE 2 Top 20 species of noted cultural importance in Hutsulshchyna.

Botanical name	Habitat	Mode of use	NU	FC	UR	CI index
**Hypericum perforatum*	RD, PAS, TOL, MEA, WD, POL, FIE, (GAR)	Medicine: TEA, TIN (stomach, antibacterial) Other: TOX, ECO, SYM	6	28	87	2.175
****Vaccinium myrtillus***	TOL, WD, FOR, POL, ALP	FOOD: ALC, FRU, REC (juice, jam), SEA Medicine: TIN, TEA (stomach) Other: ECO, SYM, ECON	8	22	81	2.025
****Rubus idaeus***	RD, WD, FOR, POL, ALP, (GAR)	FOOD: FRU, REC Medicine: TEA, TIN (liver/inflammation/female reproductive organs) Other: ECO, SYM, ECON	6	23	77	1.925
****Arnica montana***	MEA, WD, ALP, POL, (GAR)	FOOD: TEA Medicine: TIN (lungs, stomach), TOP Other: ECO, TOX, ECON	7	26	69	1.725
****Mentha* spp.**	WD, POL, FIE, (GAR)	FOOD: TEA Medicine: TEA, TIN (calming) Other: ECO, SYM, REP	7	22	53	1.325
****Thymus serpyllum***	RD, PAS, TOL, MEA, WD, POL, (GAR)	FOOD: REC, SEA, VEG Medicine: TEA (colds) Other: ECO, SYM, ECON	8	18	51	1.275
**Gentiana lutea*	MEA, ALP, POL	FOOD: FRU, REC Medicine: TEA (heart disease)	5	16	50	1.250
****Fragaria vesca***	RD, PAS, TOL, MEA, WD, FOR, POL, (GAR)	Medicine: TEA, TIN (stomach) Other: ECO, SYM, ECON	7	14	50	1.250
**Rosa canina*	RD, PAS, TOL, MEA, WD, (GAR)	Medicine: REC (juice), TEA, TIN (liver, Vitamin C) Other: ECO, SYM	5	19	48	1.200
Rubus idaeus	RD, PAS, TOL, MEA, WD, POL, (GAR)	FOOD: FRU, REC (juice) Medicine: TEA, TIN (intestine/hypertension) Other: ECO, SYM, ECON	5	20	45	1.125
Rhodiola rosea	POL, ALP	Medicine: TEA, TIN (stomach) Other: ECO, SYM, ECON	4	16	43	1.075
****Vaccinium vitis-idaea***	TOL, WD, FOR, POL, ALP	FOOD: ALC, FRU, REC (juice, kvass), SEA, TEA Medicine: TIN (blood pressure) Other: ECO	6	18	43	1.075
****Tilia cordata***	MEA	FOOD: REC (juice) Medicine: TEA (cold) Other: ECO, ECON, SYM	7	16	41	1.025
Cetraria islandica (Lichen)	FOR, POL, ALP	Medicine: TEA (bronchitis) Other: ECO, ECON, SYM	6	10	38	0.950
****Carum carvi***	RD, PAS, TOL, MEA, POL, (GAR)	FOOD: SEA Medicine: TEA (immunity, digestion) Other: ECO, SYM	5	11	35	0.875

(Continued)

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TABLE 2 (Continued)

Botanical name	Habitat	Mode of use	NU	FC	UR	CI index
***Origanum vulgare**	RD, PAS, TOL, MEA, WD, FOR, POL, (GAR)	FOOD: SEA, VEG, TEA Medicine: TEA (stomach) Other: ECO, SYM, VET, REP	7	12	33	0.825
Chamaenerion angustifolium	MEA, WD, FOR, POL, (GAR)	Medicine: TIN, TOP Other: ECO, TOX, SYM	5	12	32	0.800
Amanita muscaria (Fungi)	FOR	Medicine: TEA (restorative) Other: ECON	5	10	32	0.800
Pinus cembra	FOR, POL, ALP	FOOD: REC (syrup) Medicine: TEA, TIN (bronchitis) Other: ECO, SYM	6	7	29	0.75
Arctostaphylos uva-ursi	TOL, WD	FOOD: TEA Medicine: TIN (kidneys) Other: ECO, ECON	7	12	27	0.675

*Plants that show consistent use on both sides of the border of the Ukrainian-Romanian border, as well as the historical region of Hutsulshchyna; Bold—Species with a food use.
NU, Number of uses; FC, Frequency of citation; UR, Use report; CI index, Cultural importance index. Mode of use codes: Food includes alcoholic beverage—ALC, fruit—FRU, recreational beverage—REC, seasoning—SEA, vegetable—VEG, tea—TEA, and fungi—FUN. Medicine includes tincture—TIN, topical treatment—TOP, and ground—GRD. Other modes of use include ecological marker—ECO, symbolic—SYM, toxic—TOX, veterinary—VET, textile—TEX, repellant—REP, and economic—ECON. Habitats—RD, Roadside; PAS, pastures; TOL, toloka—local family pasture land; MEA, meadows; WD, woodlands; FOR, forests; FIE, fields; POL, polonyna—summer shepherding pastures; ALP, alpine areas; GAR, gardens. Species noted as (GAR) show extended and observed ranges for typically wild plants seen growing in gardens. This exemplifies their potential extended range.

human interaction, providing accessibility in times of need or disturbance. For example, if a particular habitat becomes impacted (flooding, logging, and pollution), there are other habitats harboring that same species. No specific habitat harbors all or even a majority of culturally important species, providing a layer of redundancy, accessibility and ensures resilience within communities.

Use categories: "Food is medicine" and the tie between ecosystem and human health

The highest use category was medicinal use (30.8%), followed by food use (30.6%), along with subsequent use categories (Table 3) (96% of culturally important species exhibit at least two or more uses). Fifty-eight percent of culturally important species exhibit a food use, while 49% of species serve as food uses either as their primary or secondary use, as determined by fidelity level calculations (Supplementary material 1). Primary and secondary uses of each species were based on the fidelity level calculations (FL), which calculates the percentage of informants who use the plant for the same purpose as compared to all uses of all plants (Friedman et al., 1986), signifying use consensus among community members.

The phrase, "food is medicine", came up continually in discussions relating to regional environmental changes; community members described impacts of pollution on habitat health, gathering practices and ultimately peoples' health. Areas exhibiting high areas of pollution (roadsides), or disturbance tend to be avoided; species gathered there have deleterious properties, impacting human health, if consumed. Many of the highest ranked culturally important food species were noted for their medicinal qualities, such as bilberry (*Vaccinium myrtillus*), raspberry (*Rubus idaeus*), and various mushroom species. Thirty-point six percent of species shared both medicinal or food use categories as either their primary or secondary use. Thirty-five-point two percent of species shared both medicinal and "ecological use" as either their primary or secondary use. "Ecological use" denotes specific ecological significance surrounding a particular species. For example, certain species that are primarily gathered for medicinal purposes were continually noted by interviewees to be gathered in higher, more remote areas, therefore exhibiting ecological importance. There is a convergence of importance and connection at the intersection of food, medicine, and ecological use categories. Diverse ecologically healthy habitats, as preferred gathering sights, harbor species that are more sought-out for their medicinal quality. Gathering species from various culturally important landscapes that are directly used as medicine or food reinforces the clear tie between ecosystem and human health.

Species of economic importance: Traditional forest foods and medicines

In the calculation of ethnobotanical indices, one of the use categories listed was economic use (Table 4). Out of 108 culturally important species, 9 species are consistently

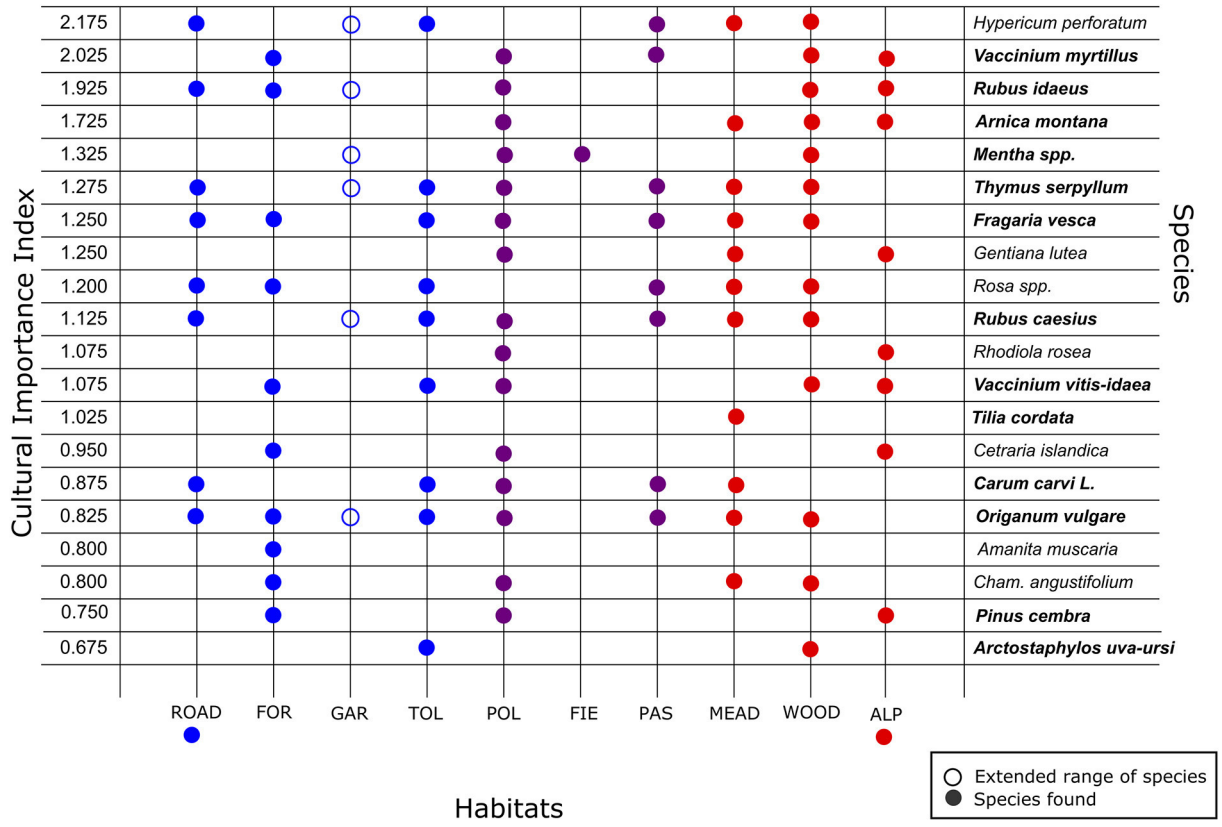


FIGURE 5
Top 20 culturally important species (according to the CI index) and the habitats found from most impacted (blue) from human structuring to least impacted (red) (ROAD, roadside; FOR, forest; GAR, garden; TOL, toloka; POL, polonyna; FIE, field; PAS, pasture; MEAD, meadow; WOOD, woodland; ALP, alpine). Bold—Species with a food use.

mentioned as sold or traded in small markets, personal contacts, or pharmacies. They include *Cetraria islandica* (lichen), *Arnica montana, Cantharellus cibarius* (mushroom), *Boletus edulis* (mushroom), *Vaccinium myrtillus, Rubus idaeus, Rubus caesius, Rhodiola rosea*, and *Gentiana lutea*. As noted in Table 4, seven of nine economically important species are in the top 20 culturally important species in Hutsulshchyna. Fifty-five percent of economically significant species are food, while 77% of species are used medicinally. *Arnica montana*, *Rhodiola rosea*, *Boletus edulis*, *Gentiana lutea*, and *Cantharellus cibarius* are species that sell at the highest prices. It is also worthwhile to note that two profitable medicinal root species, *Gentiana lutea* and *Rhodiola rosea*, are also listed as endangered species and are significantly impacted by external commercial harvesting efforts.

Bilberries (*Vaccinium myrtillus*), are one of the most culturally important plants in Hutsulshchyna (according to the CI index), and are the most popular product for sale and household consumption. Along with bilberries, mushrooms (specifically *Boletus edulis* and *Cantharellus cibarius*) are also traditional forest foods for which demand is consistent and their price remains stable. Fresh mushrooms are sold continuously from summer until fall, while dried mushrooms are sold during the winter months. The variance in price is dependent on yearly harvests. However, the demand for these species is continual and does not change, due to their importance as traditional foods. Berries and lichens are typically sold in the summer, while roots and mushrooms are sold all year round (dried or fresh).

Species use of the past and present: A comparative analysis of fallback foods

Two well-known Polish ethnographers, Adam Fischer and Jan Falkowski, led several Carpathian Mountain expeditions in the 1930s (Patsai, 2018), and tangentially addressed wild food use during scarce times in Hutsulshchyna in the last century. In one study, Adam Fischer sent out a total of 235 ethnobotanical questionnaires; 70 of them were sent to primary school teachers in three Hutsul counties in the Carpathian Mountains (Fischer, 1939; Łuczaj, 2008; Kujawska et al., 2015). The questionnaires contained one question asking about wild plant consumption during periods of food shortage. The most common cited taxa in Hutsul counties were the leaves of *Chenopodium album*, *Rumex*

acetosa, *Urtica dioica* and *Tussilago farfara*. In a later study led by Falkowski (1938), the same plants including *Chenopodium album*, *Rumex* spp. and *Urtica dioica* were also mentioned. Also noted in Fischer's earlier study were mushrooms that grow on beech (although no species was listed). Coltsfoot leaves (*Tussilago farfara*) were used for wrapping cabbage rolls (a traditional food called *holubtsi*) and often mentioned in Hutsul villages (Figure 2). Unique to Falkowski's study was the mention of berry gathering for holiday and personal sale. Here, the convergence of berries as fallback traditional foods, contributing to a diverse local economy is recognized. These studies provide a mention of a few fallback foods used in times of food shortage and colonization in Hutsulshchyna.

Interestingly, some of these same plants mentioned by Adam Fischer, a Polish ethnographer, in his 1934 questionnaire are still used today, not necessarily noted as fallback foods, but for other uses including food and medicine (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2020, 2021a,b; Stryamets et al., 2021b). By referring to Fischer's list of fallback foods used in 1934, there are certain plants that still hold significance and importance in the region today (Table 5). *Chenopodium album, Ribes* spp., *Rumex acetosa, Thymus* spp., *Tussilago farfara,* and *Vaccinium vitis-idaea* showed prevalence as fallback foods in the 1930s and are still used today in all current studies in Hutsulshschyna (both Romania and Ukraine). *Chenopodium album* as well as *Rumex acetosa* are still used in soups in all studies. Unique to our study, young shoots are noted to be fried with onion. *Ribes* spp. (including *R. nigrum* and *R. rubrum*) are used in the fermentation of cucumbers, as well as in various recreational drinks (juice, tea, and wine), jam and marmalade. Additionally, both species have medicinal value (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2020). *Thymus* spp. (specifically *Thymus serpyllum*) are used as seasoning in soups and traditional foods as well as medicine for cold-related ailments like coughing.

Tussilago farfara is primarily used medicinally today in syrups, tinctures, and teas to treat colds, bronchitis, and coughs. Interestingly, it was also noted to be used only during famine times as traditional food in cabbage rolls (*holubtsi*)

TABLE 3 Percentages by use category.

Use category	Percent
Medicinal	30.8%
Food	30.6%
- Tea	13.9%
- Fruit	6.6%
- Vegetable/Mushrooms	3.1%
- Recreational beverages	2.8%
- Seasoning	2.6%
- Alcoholic beverages	1.6%
Ecological	23.7%
Symbolic	9.7%
Toxic	2.3%
Economic	1.8%
Veterinary	0.4%
Textile	0.4%
Repellant	0.3%

Use category percentages of cultivated and wild plants, lichens, and mushrooms. Some species have multiple uses, falling into more than one category. Grey denotation indicates food use category and subcategories.

TABLE 4 Species noted as economically important in Hutsulshchyna.

Species (Most commonly cited first) [CI index ranking]	Part sold	Uses	Seasons sold	Preparation
Arnica montana [4]	Roots	MED, ECO	All	Dried
				Fresh
	Flowers	MED	All	Dried
**Gentiana lutea* [7]	Roots	MED, ECO	All	Dried
***Boletus edulis* [42]**	Mushroom	FOOD	All	Dried
				Marinated
				Fresh
***Vaccinium myrtillus* [2]**	Berries	FOOD, MED	Summer, Fall	Fresh
***Cantharellus ciborius* [69]**	Mushroom	FOOD	All	Dried
				Fresh
**Rhodiola rosea* [11]	Roots	MED, ECO	All	Dried
Cetraria islandica [14]	Moss	MED, ECO	Summer, Fall	Fresh
Rubus caesius [10]	Berries	FOOD	Summer	Fresh
Rubus idaeus [3]	Berries	FOOD, MED	Summer	Fresh

Data derived from collaboration with the Hutsulshchyna National Park.
Listed as endangered species.
Uses—Med, Medicinal use; Eco, Ecologic use; Food, Food use; Econ, Economic use.
Bold—Species with a food use.

TABLE 5 Comparative uses of fallback foods as noted by Adam Fischer questionnaires in Hutsulshchyna and current studies.

Noted species used in Hutsulshchyna according to Fischer (1939)	Uses noted from recent studies Sõukand and Pieroni (2016)* Pieroni and Sõukand (2017)** Mattalia et al. (2020)*** Stryamets et al. (2022a)****	Our Study
Allium ursinum	Food (*Allium* spp.)—soups and omelets (*; **)	CI index: 0.625 Food—raw, salads Medicine—tincture (cholesterol) Veterinary—snake bites (Noted: endangered)
Carlina acaulis	X	CI index: 0.125 Food—humans, cows (Noted: people used to gather it more)
Chenopodium album −42 people (leaves boiled/fried as greens/soup)	Food—boiled and eaten in soup (**); Eaten with sour cream (*; ***)	Infrequently mentioned (3 people and therefore not included in the CI index calculation) Food—Used to cook soup (grandmothers made this)
Cirsium oleraceum	X	X
Crataegus spp.	Food—fruit (tea) —good for heart (***) Medicine—flowers (tincture) —good for blood pressure (***)	CI index: 0.575 Food—fruit (tea)—good for heart Medicine—flowers (tincture) —regulates blood pressure
Fagus sylvatica (leaves, bark pulp as bread ingredient)	Used for smoking pork meat by Romanian Hutsuls (***)	Infrequently mentioned (not included in the CI index calculation) Food—inner part of the part of young trees, roasted seeds (Mentioned use during time of famine/food shortage)
Lamium spp.	Medicine (*Lamium album*) —tea (used for heart problems) (*) Medicine (*Lamium album*) —tea (blood pressure, heart, nerves (***)	X
Malus domestica	Medicine—fruits boiled with onion (cough) (***)	*Malus* spp. CI index: 0.525 Food—recreational drinks (uzvar, compote) Medicine—good for teeth
Oxalis spp.	Food (*Oxalis acetosella*) —snack, salad (**; ***)	X
Pyrus sp.	Medicine—tea and tincture (salt in joints) (***)	CI index: 0.275 Food—compote, fresh fruit, jam, compote, jam, marmalade Medicine—Vitamin C, nerves
Ribes sp.	*Ribes nigrum* Food—added to lacto-fermented cucumbers; leaves—recreational tea; (**) Medicine—fruits (high blood pressure) (*; **) tea (cough), juice (blood pressure), jam (food for hemoglobin), jam (eyes), raw (blood pressure) (***) *Ribes rubrum* Medicine—raw (kidney stones), tea (fever, flu) (***)	CI index: 0.175 *Ribes nigrum, Ribes rubrum* Food—Fruit, jam, wine; recreational drink (juice); seasoning (fermenting of cucumbers and added to *kulesh* (traditional food)
Rumex spp. (14 people)—both raw and cooked in soup	*Rumex acetosa* Food—Soup—borshch (leaves—fresh/dried) (*); Green borshch but only a few people use it; salad (**); Ingredient in soups/leaves (soup, snack, salad) (***)	CI index: 0.150 Food—Soup in spring, cooked with *Urtica dioica*, cooked with eggs, snack (fresh leaves)
Thymus pulegiodes/*Thymus* spp.—exchanged for parsley	*Thymus serpyllum* Food—seasoning for soups (*); recorded as used in the past as seasoning for soups (**) Medicine—tea (cough/cold) (*;**) tea (stomach aches) (**) *Thymus serpyllum, Thymus vulgaris* Medicine—tea (cough, stomach, lung, alcoholism) seasoning; syrup and tea (cough) (***)	*Thymus serpyllum* CI index: 1.275 Food—added to *holubtsi* (*Holubtsi* are a traditional food consisting of cabbage rolls), soup, tea Medicine—tea (cough/colds, digestion, inflammatory processes, traditional rites)

(Continued)

TABLE 5 (Continued)

Noted species used in Hutsulshchyna according to Fischer (1939)	Uses noted from recent studies Sõukand and Pieroni (2016)* Pieroni and Sõukand (2017)** Mattalia et al. (2020)*** Stryamets et al. (2022a)****	Our Study
Tussilago farfara −14 people, wraps for cabbage rolls/soup	Food—*holubtsi* (*); only during famine times—cabbage rolls (holubtsi); —in the past (**) Medicine—flowers (tincture) for rheumatic pains (*); tea (cough) (*; **; ***); syrup (throat), whole plant boiled (cough) (***)	CI index: 0.425 Food—*holubtsi* (traditional food—cabbage rolls) Medicine—syrup (colds/bronchitis/respiratory system)
Urtica dioica −18 people, leaves (fried/cooked)	Food—soup (borshch), tea (*; **; ***), snacks (**), salad, seasoning (***) Medicine—washing hair (shine) (*; ***), fever (*; **); soup (blood cleansing), tea (blood pressure, good for heart, stomach, and others) (***)	Infrequently mentioned (not included in the CI index calculation) Eaten in conjunction in soups with *Chenopodium album*
Vaccinium vitis-idaea	Food—fruit (*), jam, juice (*; **; ***); recreational tea (**; ***), kvass, compote, syrup, snack (***) Medicine—juice (diarrhea, high blood pressure), tea (high blood pressure, heart problems) (*), diabetes (*; **; ***), eye diseases, stomachache (**) juice (kidney problems) (*; ***), fruit (blood pressure), tea (panacea) (***)	CI index: 1.075 Food—berries, recreational drinks (juice, kvass), tea Medicine—tincture (blood pressure, liver)
Armoracia rusticana	Food (*Armoracia* spp.)—leaves: seasoning (fermented cucumbers), sauerkraut (*; **; ***), fermented tomatoes (**; ***), roots (salads), whole plant (seasoning) (***) Medicine—topical application (toothaches) (*; **); topical application (joint pain and rheumatic pains) (***)	Infrequently mentioned (not included in the CI index calculation) Food—fermented foods (Used during time of famine), horseradish eaten with beets during holidays (traditional food)
Mushrooms growing on beech as well as other mushrooms not specifically identified	Ethnomycological study (****)	9 species of mushrooms (food and medicine)

X—No uses noted; The * symbols indicate specific study noted in table heading.

(Pieroni and Sõukand, 2017), like Fischer's observations in 1934. However, in our study, coltsfoot is still occasionally used today to make *holubtsi*. This plant's use in foods could have been reserved to times of scarcity since it can exhibit latent liver toxicity (Chen et al., 2020). Typically eaten as a berry, *Vaccinium vitis-idaea* is used as a food in jam, juice, tea, and medicine to treat blood pressure. These wild species are not simply reserved for times of scarcity; they are culturally important species of active importance, prevalence and use in traditional foods and medicine.

Other species mentioned in Fischer's study that continue to exhibit cultural importance today include *Vaccinium vitis-idaea* (CI index: 1.075), *Allium ursinum* (CI index: 0.625), *Crataegus* spp. (CI index: 0.575), *Tussilago farfara* (CI index: 0.425), and *Rumex* spp. (CI index: 0.150). These species exhibit a diversity of uses in addition to serving as nutrient-dense foods during times of scarcity. Unique to our study, knowledge holders also mentioned many additional common and prolific species including *Elytrigia repens, Typha latifolia, Elymus repens, Fagus sylvatica, Quercus robur, Orchis mascula, Plantanthera bifolia, Rhodiola rosea, Plantago major, Trifolium pratense, Carduus nutans, Carduus natuns, Armoracia rusticana* (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017), and *Urtica dioica* (Sõukand and Pieroni, 2016; Pieroni and Sõukand, 2017; Mattalia et al., 2020). Most importantly is the continual reliance of berries including Vaccinium species (*V. myrtillus, V. Vitis-idaea*), Rubus species (*R. idaeus, R. caesius*), Ribes species (*R. nigrum, R. uva-crispa*), *Fragaria vesca, Sambucus nigra, Aronia melanocarpa, Sorbus aucuparia*, and mushroom species (particularly *Boletus edulis* and *Cantharellus cibarius*) (Stryamets et al., 2022a). Mushrooms, specifically within the family of Boletacea, contain proportionally high amounts of protein (Turner et al., 2011). The importance of wild berries and mushrooms in Hutsul traditional foods, while not specifically mentioned by interviewees (unless asked), is an integral part of culture and survival.

Regional environmental changes and their impacts on gathering

In interviews surrounding species use, ample discussion of regional environmental change and its impact arose. Ecosystem, climatic and cultural changes are testing local and

regional resilience; there are specific factors impacting culturally important species in the region (Table 6) as stated by local Hutsul community members. Colonial legacies documented from the 1700s up until 1991 have impacted the landscape, including grass and forest communities and with it culturally important medicinal species. Commercial harvesting, a more recent development, threatens accessibility for local gathering of medicinal species such as *Vaccinium myrtillus*, *Arnica montana*, *Cetratria islandica,* and *Gentiana lutea*. Additionally, erosion and accompanying flooding have increased in frequency and severity because of extensive sanitary logging practices. Lastly, the continuing impacts of climate change have caused more dysregulation of phenological plant cycles as well an increased the uptick of pest infestation.

Discussion

Culturally important species in the historical heart of Hutsulshchyna include a total of 108 species (including plants, fungi, and lichens) from 79 genera and 48 families commonly found in a total of 10 different habitats. Many highly ranked culturally important food species are noted for their medicinal qualities [with medicinal use being ranked first in use category (30.8%)]. Food use (30.6%) is the second highest use category cited by Hutsul community members. Culturally important species are found in a variety of habitats, with different degrees of human interaction, providing accessibility during times of need or disturbance. Transformative uses of fallback foods provide an additional layer of resilience. Various regional changes, including lasting reverberations of colonial policies, commercial harvesting, illegal logging, and climate change are impacting the landscape with its effects cascading down to culturally important species, which also have economic importance (*Arnica montana, Gentiana lutea, Rhodiola rosea, Cetraria islandica*).

Comparing ethnographic data to our findings on a species-by-species basis of noted fallback foods of the past show that many fallback foods have maintained cultural importance in the day-to-day lives of Hutsul community members; these species exhibit a diversity of uses, while also serving as nutrient-dense foods in times of scarcity, uncertainty, and regional disturbance (even seen today with Russia's current, and ongoing invasion of Ukraine).

It is this deep emergent response to disturbances, resultant of years of tumult seen through world wars, food shortages, shifting borders, colonialism, that drives resilience-thinking and action. A resilience-based approach includes mitigating disturbances by strengthening and encouraging the self-healing capacity of ecosystems. Resilience looks directly into the face of change, crisis and uncertainty, as embedded parts of life. Ecosystems continually adapt to disturbances at various scales and cannot be managed formulaically to maintain optimal levels of functioning (Bottom et al., 2009). It is the coupling and intertwining of both spheres, social and ecological, that elicits the complexity in understanding the dynamics of resilience in the region.

In our discussion, we frame the analyzed ethnobotanical knowledge shared in the results as part of a broader knowledge base known as traditional ecological knowledge (TEK). TEK, by its very nature is resilient in its iterative, dynamic, time-tested, generational process of knowledge gathering and implementation. In response to regional challenges, we explore both coping mechanisms and adaptive strategies that are informed by TEK in Hutsulshchyna. The stewardship and management practices embedded in local TEK support the presence of traditional foods and are a testament to this resilient food sovereign system.

Traditional ecological knowledge: Language, practice, holidays

TEK is a dynamic empirical knowledge base gained through generational observation of the environment which is revisited, reinterpreted, and re-evaluated (Molnár et al., 2008; Berkes, 2012); it serves as the groundwork for maintaining resilience in communities. As noted in the methods, interviews were conducted in Ukrainian, while participants responded in Ukrainian and Hutsul. Language is a critical part of memory formation and knowledge retention; culturally distinctive values, knowledge, meanings, and worldviews transit and emerge through language (Simpson, 2008). How do Hutsul names relate to the environment? In Table 7, we highlight a few names that allude to plant phenology, habitat, physical characteristics, medicinal qualities, gathering cues, taste, stories of colonial invasions, and historical land uses. For example, during Mongol invasions of the 1200s, plants such as *Acorus calamus* and *Orchis mascula* (endangered), which are considered culturally important plants, were brought to Hutsulshchyna. The local, Hutsul name for *Acorus calamus*, Татарске зілля (Tatarske zillia) translates to "Tatar potion/herb", illuminating the ecological, medicinal, and historical relevance of this plant in Hutsulshchyna.

Other local species' names are connected to landscapes that are prevalent in Hutsul lifeways, including "tolokнianka/толокнянка" (*Arctostaphylos uva-ursi*) and "polonynskyi hran/полонинський грань" (*Cetraria islandica*). In our study, these species display "ecological use", since their names address specific culturally important landscapes. These plants are found, respectively, on *tolokas* and *polonynas*; culturally and biologically managed habitats for centuries. As described in Table 1, *tolokas* are traditionally held pastures located typically on a nearby hillside from the home, and passed down from one generation to the next, ensuring both connection and access to land. *Polonynas* are summer alpine meadows, providing grazing for communal livestock, which

TABLE 6 Community observations of factors impacting culturally important species in Hutsulshchyna.

Factors impacting culturally important species	Community observations	Predicted effects
Socio-ecological consequences of historical colonial policies	• Soviet policies (1939–1991) - Mass aerial fertilizing of land changed structure of grass cover (*Trifolium pratens* dominates) (3) • Austrian-Hungarian empire (1772–1918) - Excessively logging of culturally and ecologically important, endangered species (*Pinus cembra*) (1) - Planting of monoculture pine species (E)	• Slow recovery of grass plant communities (Example: *Thymus serpyllum* has recovered; *Matricaria chamomila* still recovering) (E) • Impacts cultural use of species (weddings) (1) • Limits ecosystem functioning of forests (2) • *Pinus cembra* stays endangered status/reaches extinction (1) • Increase in pine dieback (*Pinus sylvestris*) due to pine bark beetles (1)
Commercial harvesting	• Improper harvesting techniques (*Arnica montana*) (1) - Not leaving root behind (E) - Gather flower before seed release • Mass harvesting (*Cetraria islandica*) (2) - No recovery growth of slow-growing lichen (4)	• Culturally important plants become rarer; less accessible to local Hutsul populations (1)
Logging	• Legal/illegal logging practices on mountainsides (1)	• Impacts succession of species (berries and mushrooms) (1) • Increase of regional flooding (1)
Climate change	• First mowing of hayfields occurring earlier in the season (2) - Plants of importance are being cut down before reseeding occurs (*Carum carvi*, *Centaurium erythraea*) (E) • Elevation shifts of plant habitats (*Arnica montana, Rhodiola rosea, Veratrum album*) (1) • Extreme weather conditions (shortened time frames between flooding events) (1)	• Dysregulated phenological cycles of plant communities (1) • Stay at endangered status (*Gentiana* spp., *Allium ursinum, Orchis mascula, Platanthera bifolia*)(1) • Increased incidence of pests (*Leptinotarsa decemlineata*) on cultivated crops (1) • Increase in pine dieback (*Pinus sylvestris*) due to pine bark beetles (1)

Observation rankings: 1 = widely shared (many observations and expert generalizations across villages), 2 = place specific (well-accepted within a particular community), 3 = somewhat common (various participants), 4 = less common (one or a few local experts), E = observation mainly reported by elders.

produce culturally important dairy products. All livelihoods of Carpathian highland people are somehow tethered culturally or economically to the maintenance of *polonynas* (Geyer et al., 2011). For example, ecocultural memories, forming TEK, are reinforced through language and practiced through maintenance of *polonynas*. Language, specifically names, provide critical insights into understanding species' natural history, medicinal use, gathering cues, and importance in day-to-day life.

Hutsul communities in the Carpathian Mountains have maintained and passed down many ecocultural memories and practices, embodied in traditional ecological knowledge. TEK is embedded not only in the spoken language or words that are used to describe culturally important species or landscapes; it is practiced as a part of daily life starting from childhood. In forest-dependent communities, human interdependence with the land is nurtured and recognized daily—whether it is gathering specific medicinal species on the way to milk cows on the communal hillside (*toloka*), gathering mushrooms with a grandparent in neighboring conifer forests for a meal or taking a basket filled with forest foods for blessing. This continual interaction with the landscape is a type of biomonitoring, enabling communities to make decisions about harvesting, mobility, and land use, especially when environmental stressors are detected.

Holidays, songs, traditional foods, embroidery, and dance keep this knowledge alive through practice. Observation of specific Holy days typically includes blessing of culturally

TABLE 7 Ecocultural meanings of 9 Hutsul, local names.

Names	Hutsul names—Translation	Ecological context	Cultural context
Common Name: Sweet flag Scientific name: *Acorus calamus* Hutsul name: татарске зілля; аїр болотний Standard Ukrainian name: Аїр тростиновий	"Татарске зілля"—Tatar potion/herb (Tatarske zillia)	Tatars, a Turkic ethnic group, relied on sweet flag to purify water and for this reason was carried on their conquests. Current research explores sweet flag's purification properties.	The story behind the introduction of this marsh plant in this region coincides with Tatar invasion of Ukraine, beginning in 1200s. It is used in tinctures, and helpful for treating stomach issues.
	"Аїр болотний"—marsh plant (Ayir bolotnyi)	Sweet flag grows in marshy areas.	
Common name: Bearberry Scientific name: *Arctostaphylos uva-ursi* Hutsul name: толокнянка Standard Ukrainian name: ведмежі вушка; мучниця звичайна; вапянка	"Толокнянка" —little toloka (Tolokniankа)	*Toloka* has two definitions: (1) a pasture for livestock near a home (2) collective mutual assistance within the community. This plant can be found on the toloka.	Toloka is rapid voluntary work done by community members on a toloka (pasture). In addition to having economic value, it is commonly used in tinctures to treat kidney problems.
Common name: Fireweed Scientific name: *Chamaenerion angustifolium* Hutsul name: іван чай, чайок, димник	"Іван чай"/"Чайок"—John's tea (Ivan chai/Chaiok)	There is convergence of the feast day of a St. John the Baptist with the phenological timing of fireweed blooming.	Fireweed is prepared as a medicinal tea and exceedingly more so in recent years due to its popularity on the internet.
Standard Ukrainian name: хаменерій вузьколисти	"Димник"—little smoke (*diminuitive*) (Dymnyk)	This refers to the blooming characteristics of fireweed - "When it blooms, it comes up like smoke - so quickly and it spreads!" as stated by an elder in 2018.	Since it is a pioneer species, Hutsuls note that fireweed grows were there was recent logging. This provides a gathering cue.
Common name: Icelandic moss Scientific name: *Cetraria islandica* Standard Ukrainian name: ісланских мох Hutsul name: полонинський грань, золотинь мох, гарячий камінь, вананец, баранчики	"Полонинський грань"—on the face of polonynas (Polonynskyi hran)	Icelandic moss is found on the face of alpine pastures (called *polonynas*) and when the sun hits it, the moss is blinding. This quality is used as a sensory cue to find gathering places.	*Polonynas* are an important place in the Hutsul landscape. This species is considered a natural antibiotic and has great economic value.
	"Гарячий камінь"—hot stone (Hariachyi kamin)	This name alludes to growing conditions. This lichen grows on exposed (hot) rocks.	It also refers to its medicinal quality—treating fevers. It is used to make tea and helps with bronchitis.
Common name: Reindeer lichen Scientific name: *Cladonia rangiferina* Standard Ukrainian name: ягель Hutsul name: кашлянек, оленячий мох, баранець	"Кашлянек"—coughs (Kashlianek)	Name alludes to helping heal coughing fits.	This lichen is a source of medicinal tea which facilitates coughing.
	"Оленячий мох"—deer moss (Oleniachyi mokh)	Deer eat this lichen as a source of nutrition.	
Common name: Horsetail Scientific name: *Equisetum arvense* Standard Ukrainian name: хвощ полевой Hutsul name: падиволос	"Падиволос"—hair falls off (Padyvolos)	This name refers the plant's anatomical characteristics. The leaves of the plant come off like hairs.	Culturally it is gathered and medicinally, it is used externally for the treatment of boils and sepsis.

(Continued)

TABLE 7 (Continued)

Names	Hutsul names—Translation	Ecological context	Cultural context
Common name: Alpine avens Scientific name: *Geum montanum* Standard Ukrainian name: сиверсія гірська Hutsul name: підойма, вівсик	"Підойма"—to uplift the spirits (Pidoima)	There is a specific story that highlights the timing of gathering, as well as preparation of tea.	Medicinally, alpine avens is uplifting, relieving tired muscles (inflammation).
Common name: Early-purple orchid Scientific name: *Orchis mascula* Standard Ukrainian name: зозулинець Hutsul name: люби мене, не покинь	"Люби мене, не покинь"—Love me, don't leave me (Liuby mene, ne pokyn)	–	This name addresses its medicinal use entirely. Its romantic connotation aligns with its usage as an aphrodisiac for men.
Common name: Wild pear Scientific name: *Pyrus pyraster* Standard Ukrainian name: дика грушка Hutsul name: дичка; гнилички	"Дичка"—little wild one (diminutive) (Dychka) "Гниличка"—little rotten one" (diminutive) (Hnylychka)	Wild pear species is hardy—disease and frost resistant. Wild pears are the tastiest (sweetest) when they become overripe/rotten.	The wild species is valued over the cultivated species, hence its diminutive name—"little wild one". The relationship joining gathering time with taste preference is shown in the name—little rotten one.

important species (Stryamets et al., 2021b). For example, August is a particularly important month for the blessing of healing herbs, plants, flowers, and grain, which coincides with the time where many summer herbs, flowers, stems, leaves, and roots are collected (Figure 2). Among many observed holy days, there are four holy days that occur in the summer that integrate plant use into Christian church calendar (August 9, August 14, August 19, and August 28). The importance of the environment in daily nourishment is seen through community gatherings on church holy days. In the face of dynamic regional challenges, TEK helps maintain a food system that culturally ties people, health, and land; it is the thread that unites ecosystem health and resilience to create a food sovereign system.

Short-term coping mechanisms

In the face of regional environmental changes highlighted (Table 6), there are two distinctive responses to mitigate disturbances and maintain resilience: short-term response (coping mechanisms) and long-term responses (adaptive strategies). TEK informs these varied, time-tested responses. In Hutsulshchyna, two important coping mechanisms are present: (1) modifying subsistence activity patterns (changing how, where, and when to gather culturally important plants), and (2) gathering species across various habitats at varying intensities These are adaptive, immediate responses based environmental changes such as shifts in climate patterns and logging practices, compounded by land degradation seen continuously through erosion (57.5% of territory), pollution (20% of territory), and flooding (12% of territory) (Dovbenko, 2014).

Modifying subsistence patterns: Changing how, when, and where to gather

Increased seasonal variability and logging have caused local Hutsul communities to adjust the timing of their seasonal gathering and garden planting. Phenological shifts in flowering, and extended rainy seasons as described by local experts have resulted in shifts in gathering practices of culturally important plants. Waiting has become a common coping strategy for community members as they inform one another on the status of flowering or fruiting of economically important species. Another response has been following plant communities, especially medicinal species, as they shift to higher elevations. For example, due to climatic shifts, community members now to hike to higher elevations to gather species like *Arnica montana*. The question of community accessibility arises in response to climatic shifts; it impacts distance and time needed for community members to gather cultural important medicinal species.

In addition to climatic changes, illegal logging remains a significant regional challenge, causing increased flooding and erosion in the last decade (Geyer et al., 2010; Soloviy et al., 2011). WWF Ukraine World Wildlife Fund, 2018 has determined that 44% of the timber harvested from the Carpathian Mountains

and exported to the EU is illegal, reinforcing the fact that sanctions for committing forest crimes remain unenforced. The use of multi-time satellite images, DNA and isotope analyses of wood, and local activism has recently helped combat illegal logging in the region (Associação Natureza Portugal, 2020). In a recent study in Northern Bukovina of Ukraine, Hutsul knowledge holders stated that exploitation of forest resources is driven by immediate economic return, with logging companies harvesting timber year-round (Mattalia et al., 2021b). In our study, the impacts of illegal logging, as stated by Hutsul locals, encourages succession of species such as *Rubus idaeus, Rubus caesius, Vaccinium myrtillus, Chamaenerion angustifolium, Orchis mascula*, and *Aronia melanocarpa*. These culturally important species are gathered and used for personal use and sold fairly frequently. However, community members note that species such as *Rubus caesius* can hinder forest growth and regeneration, and that gathering this species helps manage forest health. Illegal logging also weakens mushroom growth and nutrient cycling, impacting gathering of mushrooms. By modifying and continually adapting to both climate change and logging impacts within the region, coping mechanisms arise such as waiting, communicating with other community members, and shifting gathering practices to higher elevations.

Diversity of species use, intensity of use, and habitat use

Another coping mechanism, informed by TEK, includes varying the intensity of habitat use (temporally) as well as gathering culturally important species in various habitats (spatially). Communities are reliant on a diversity of habitats for their nutritional and medicinal needs, spatially radiating from their homes to gardens (whereby agroforestry techniques are employed), pastures, fields, *tolokas* (where grazing promotes plant diversity), meadows, woodlands, forests, alpine areas, as well as *polonynas* (which provide communal grazing and medicinal root plants), and more recently the incorporation of local, grocery stores. These radiating layers of habitats nest spatially and vary in use intensity temporally. Some landscape levels (like gardens, pastures, woodlands, alpine areas, meadows, *tolokas*, fields, and *polonynas*) are used more intensely during specific seasons, ensuring time for regeneration and growth. Other levels (like forests and small markets) are used at a constant low intensity and require accounting of time and distance to resource. Each of these nested habitats provides a layer of redundancy, ensuring a societal effort to live sustainably within the limits of the environment, while actively monitoring habitat changes from season to season. Additionally, most culturally important species are found in a range of habitats with varying levels of human structuring, ensuring availability to communities (Figure 5). Diversification is a well-known risk-spreading strategy used to mitigate unexpected events and uncertainty (Kelly and Adger, 2000; Berkes and Jolly, 2001), by increasing system complexity (Sterk et al., 2017). By identifying potential food and medicinal resource redundancies and spreading out use intensities in a variety of habitats, a coping mechanism emerges, helping to secure both ecosystem and community survival.

Among the diversity of habitats relied upon, community members mentioned cultivated plants and their gardens. Gardens typically contain a variety of trees including sweet cherry, cherry, plum, apricot, apple, pear, nut trees along with perennial bushes including strawberry, raspberry, currant, gooseberry, and grape. In the Carpathian Mountains, home gardens provide a source of food and medicine. In some cases, elders mention transplanting wild plant species into their own home gardens including *Fragaria vesca* and medicinal root species such as *Rhodiola rosea* and *Arnica montana*. These agroecosystems create another function and layer of resilience in a larger ecosystem; they act as centers of experimentation, introduction, and crop improvement.

Reliance on local forests, *tolokas*, fields, gardens, meadows, woodlands, and pastures requires observation of conditions and vegetative states of preferred plants. If family pastures are maintained (*tolokas*), grazing and milking of livestock requires interactions with landscape and monitoring of ecological and weather changes. Dialogue between locals and their surrounding ecosystems occurs during gathering seasons and ritualistically, during holidays, when sharing traditional foods (made from culturally important species). These coping mechanisms are crucial for maintaining resilience within food systems, with communities adapting to a variety of convergent environmental stressors.

Long-term adaptive strategies

While coping mechanisms play an immediate, responsive role in maintaining resilience, Hutsul communities have also integrated long-term adaptive strategies. Adaptive strategies emerge at larger spatial scales. In their work in Arctic communities, scholars Krupnik and Jolly (2002) among others present two adaptive strategies including 3) inter-community trade as well as 4) social networks to provide mutual support (Krupnik, 1993; Freeman, 1996; Berkes and Jolly, 2001; Galappaththi et al., 2019). In the context of this study, the adaptive strategy of intercommunity trade is expressed through the economy of gathering; another adaptive strategy includes the transformative use of fallback foods.

An economy of gathering and impacts of commercial harvesting

The act of gathering plants and mushrooms for personal use in Ukraine is embedded in seasonal and holiday rhythms, with harvesting carried out mainly from spring until fall. In the forests of Ukraine, 25 tons of birch juice are harvested annually, 150 tons of commercial honey, more than 7,000 tons of dried mushrooms, 7,000 tons of wild fruits and berries, as well as 5,000 tons of medicinal plants (FAO, 2008). Hutsulshchyna is considered one of the most economically depressed regions of Ukraine; gathering and selling of medicinal roots and berries is common. Gathering and selling of wild species has intensified since the dissolution of the Soviet Union in 1991 (Stryamets et al., 2015). Additionally, with current high unemployment rates in the region exacerbated by the pandemic (Yarmosky, 2020) and now Russia's invasion of Ukraine, locals continue to rely on gathering and selling wild food species. More than half of local Hutsuls in interviews described the economic and cultural value of gathering plants through an *economy of gathering*. While the local *economy of gathering* provides a local flow of income through the gathering of economically important species, as mentioned in the results, there is an external force in the region—commercial harvesting (Table 6). Locals noted a rise of commercial berry (*Vaccinium myrtillus*) and medicinal plant harvesting in the Carpathian Mountain region.

Species that are culturally, nutritionally, and economically valued can be split into the following categories: mushrooms, lichens, berries, and roots. Many of these species are found on *polonynas*, alpine meadows and forests. The more remote a village is from roadsides and grocery stores, the more gathering for personal use (medicinal and food purposes) is practiced. Often these species are also collected for further sale. There is an understanding that each year's harvests will be variable and subject to change based on impacts of externalities (weather, commercial harvesting, pests, phenology, etc.) Forest species are used primarily for filling cyclical income gaps. In terms of providing supplemental income, the sale of all these species helps subsidize costs to buying other food items, agriculture equipment, school supplies, clothing, and household cleaning supplies. In a recent study analyzing Hutsul forest use in Northern Bukovina (Ukraine) vs. Southern Bukovina (Romania), Hutsuls in Ukraine expressed more dependence on forests, stating that selling berries and mushrooms was a primary source of income (Mattalia et al., 2021b). In our collaborative study, the *economy of gathering,* as an adaptive strategy, also highlights Hutsul forest dependence, promotes trade and social support between communities, and allows for the supplementation of income while also recognizing the variability of local markets based on seasonal cycles of harvest and resource use.

An *economy of gathering*, as an adaptive strategy, faces the pressure of commercial berry and medicinal plant harvesting. *Arnica montana*, a plant prevalent in local markets, is also noted to have suffered a population decline due to the over-harvesting. In addition, there has been a rise of commercial harvesting of endangered plants such as *Rhodiola rosea* and *Gentiana lutea*. *Rhodiola rosea* has been greatly impacted due to industrial production, with tinctures being very popular. However, as noted by elders, *Rhodiola rosea* roots need 3–4 years to mature and, because of early harvesting, local plant populations have diminished. In addition, international medicinal plant companies have shown a growing interest in harvesting medicinal plants in the Carpathians and target vulnerable plant species. To address the demand for medicinal plants, various national parks have integrated the development of medicinal plant plantations to offset the endangered status of native medicinal plants such as *Arnica montana* and *Rhodiola rosea*. As stated by a local park authority, these plants are grown in controlled outdoor environments and, for tinctures to be as effective, proportions need to be amplified by 20–30% to be just as effective as wild plant harvests. External commercial harvesting of culturally relevant and economically profitable plants such as *Arnica montana, Rhodiola rosea* and *Gentiana lutea* in Hutsulshchyna, in addition to regional impacts of illegal logging and climate change present layers of complexity in retaining resilience.

There is a tension between local economies (an *economy of gathering*) and external economies (including but not limited to commercial harvesting). As explained by numerous elders in various ways, "once gathering becomes a business, there [also] appears a consumer and corporate interest". Most elders in the region adamantly oppose putting medicinal plants in the rank of industrial production due to accompanying habitat destruction. Intensive commercial harvesting in the region began 20–30 years ago and has impacted the region and endemic plant populations. There is a local saying, "After me, [there will be] a flood", reflecting the business-driven aspect of over-harvesting. It implies that environmental destruction is an inevitable result of corporate presence. Both logging and increased mean temperatures increase erosion, causing an uptick of hydrological events such as flooding in the region (Farley et al., 2009; Geyer et al., 2011). In terms of maintaining resilience, the local economy of gathering is based on a centuries-long practice of gathering a range of species inhabiting diverse environments both temporally and spatially, inviting constant dialogue between communities and the landscape. Additionally, local gathering is based upon gathering methods that are selective and species-specific. Yearly harvests of locally gathered species are variable and reflective of the current state of ecosystem functioning. This knowledge is embedded within the local communities and serves as a participatory method of resource monitoring. Local, place-based economies are resilient

by nature, while extractive economies tend to be divorced of the immediate needs, values, and ecocultural memories of locals reliant on those landscapes.

Fallback foods: Transformative uses of culturally important species

Another adaptive long-term strategy informed by TEK is the incorporation of fallback foods. During the famines of the nineteenth and twentieth centuries, gathering of wild species provided a source of medicine and food for Ukraine (Komendar, 1971). Fallback foods mostly consist of plant and mushroom species that serve as nutritional support during times of restricted movement [war, crop failure, weather (flood), and disease]. Many of these species remain culturally important and provide a variety of functions in the nested habitats in the Carpathian Mountains for at least the last century. In our analysis, there is little distinction between specific fallback foods used only during times of scarcity and those used today. Instead, these critical fallback species are nested within everyday cultural uses of medicine, seasoning and food, thereby ensuring a long-term adaptive strategy.

Hutsulshchyna has experienced battles due to invasions from Tartar hordes (1000s), the Polish regime (1340), and the Austrian-Hungarian Empire (1780s—1918). In the interwar period, Hutsulshchyna was divided at the borders with the central part belonging to Poland, the southern and eastern part under Romania, and the western part under Czechoslovakia (Figlus, 2009). The part of Hutsulshchyna in this study was occupied by Poland (1919–1939), followed by Germany (1939–1943) and then the Soviet Union (1943–1991). Political boundaries running through the territory have had less effect on Hutsul unity since it is the mountains that form the natural boundary among states, not the artificial lines drawn through it (Domashevsky, 1985). The geography of the Carpathian Mountains served as a buffer up until late 1930s against political terrors, war, genocide, and violence waged in Ukraine by German Nazis, Soviet Communists and Russian czars. The Austrian-Hungarian colonization of Hutsulshchyna meant that this region was spared from the Holodomor (meaning "death by starvation") of 1932–1933, a Soviet-Russian orchestrated genocide in Central and Eastern Ukraine (Klid and Motyl, 2012; Bezo and Maggi, 2015). However, in interviews, elders mentioned that another Soviet famine of 1946–1947 affecting Ukraine, Moldova, Russia, and Belarus (Gráda, 2015), causing an influx of Moldovans to migrate to the Carpathian Mountains. These demographic shifts of refugees caused more reliance on neighboring ecologies and species' usage. Currently, due to Russia's invasion of Ukraine, the Carpathian Mountains are again serving as a refuge, with an estimated 65,000 internally displaced people within Ukraine fleeing from the east of the country (Frankfurt Zoological Society, 2022).

While literature highlights a deep history of berry and mushroom reliance during times of scarcity in Ukraine, finding information on other fallback foods in Hutsulshchyna is both scattered and primarily written in Polish. Hutsulshchyna, along with Western Ukraine, was under Polish Republic rule from 1918 to 1939. Books by Ukrainian authors were censored (Gráda, 2015) and scholarly ethnographic works were mainly published in Polish. In the postwar years, literature surrounding Hutsulshchyna was written but there is practically no focus on foods. It is important to note that this type of knowledge is generally passed down orally, generationally, and infrequently documented in written form. Lastly, this rich knowledge is embedded in the daily rhythms of Hutsul life which cannot be fully captured in an extensive literature review or interviews; knowledge of fallback foods has survived and thrived in the face of colonization, famine, and war.

Many of the species mentioned as fallback foods by Polish ethnographers in the early twentieth century are still used today in diverse ways (Table 5). In Hutsulshchyna, during times of scarcity, species use transitions from a medicine or seasoning to a food. Knowledge of plant use transformation is embedded in TEK. Here is an example of resilience, which is the combined result of coping, adaptive and transformative capacities leading to transformative response. Interestingly, according to Lukasz' analysis of Polish ethnographer Adam Fischer's work, as early as 1934, memory of wild plants used in times of shortage was fading, and most respondents in non-Hutsul counties spoke about using fallback foods in both past and present tenses (2008). However, in Hutsul counties of 1934, the people talked about fallback foods being used presently in 94% of places. Many of these same plants including *Chenopodium album, Ribes* spp., *Rumex acetosa, Thymus* spp., *Tussilago farfara,* and *Vaccinium vitis-idaea* are still used today. Past uses inform present formation and retention of ecocultural memories forming TEK, thus propelling and ensuring future sustainability and community resilience.

The presence of traditional foods: An expression of food sovereignty

In rural Hutsulshchyna, households produce most of their own food with relatively low expenses on food compared to the total amount of expenses. In Ivano-Frankivsk province, which encompasses the area of Hutsulshchyna in this study, 42.8% of average monthly monetary expenditure is spent on food and non-alcoholic drinks, which is one of the lowest monthly expenditures documented in the country (Babych and Kovalenko, 2018). (Comparatively, in the Dnipropetrovsk region, the average monthly monetary expenditure spent on food is 59.3%; these statistics have drastically changed since the time of the study due to the impacts of war.) In our study, we

found that 55% percent of economically significant species are food; 55% of culturally important species exhibit a food use, while 49% of species serve as food uses either as their primary or secondary use. The highest use category was medicinal use (30.8%), followed by food use (30.6%), with the convergent importance of "food is medicine". In addition to gathering wild and cultivated species from a range of multi-functional landscapes, livelihood is also composed of community-derived resources including agricultural animals (primarily cattle, cows, pigs, goats, and chickens), which supply both dairy and meat. Rivers and ponds provide fish. Beekeeping is a common activity, with the endemic Carpathian bee (*Apis mellifera carnica*) providing honey.

Short-term responses (coping mechanisms) and long-term responses (adaptive strategies) result in the presence and maintenance of culturally important species used in traditional foods in the region. Many commonly gathered berry species are traditional foods including Vaccinium species (*V. myrtillus, V. Vitis-idaea*), Rubus species (*R. idaeus, R. caesius*), Ribes species (*R. nigrum, R. uva-crispa*), *Fragaria vesca, Sambucus nigra, Aronia melanocarpa*, and *Sorbus aucuparia.* As noted earlier, berries are considered a fallback food and contribute to the local economy. Berries are eaten fresh, frozen, and dried, or cooked into jams, jellies, fillings for traditional dumplings, syrups, and sauces, or used in recreational drinks including fermented kvass, as well as juice, uzvar (a compote), and wine. The culturally important bilberry (*Vaccinium myrtillus*) is used in *varenyky* (dumplings), and as a flavoring in alcoholic tinctures, fruits, and juice. In terms of health benefits, there are diverse phytochemicals present in berries, specifically wild berries of the *Vaccinium* genus, which are seasonally harvested. Wild *Vaccininum* berry species are renowned for their high concentrations of phenolic and polyphenolic compounds that interact to improve human health (Grace et al., 2014). In addition to berries providing a source of vitamins and medicine, they also infuse an array of flavor to teas, recreational drinks, jams, and jellies. Raspberries are consumed recreationally, and their leaves, stem, and berries used as a medicinal tea. Wild raspberries have slightly better medicinal properties, taste, and aroma than garden raspberries. Chokeberry (*Aronia melanocarpa*) has a wide range of uses including consumption as a fruit, tea, kvass, wine and as a medicinal tincture. As noted many times, a diversity of berries serve as important staples in Hutsulshchyna.

Hutsul traditional foods incorporate an important dairy product from *polonynas*, a cheese made from Carpathian cows or sheep (*polonynska bryndza*), and as well as many mushroom species (particularly *Boletus edulis* and *Cantharellus ciborius*). Mushrooms are used traditionally in cooking of holiday meals (Figure 2). Most people and families go out and gather mushrooms in summer and fall, a recreational and intergenerational, seasonal activity. For example, one elder mentioned, "I take my grandson and we go together to pick mushrooms. I show him the place where mushrooms grow." [Mykola (L.)] Mushrooms are very popular during winter holidays, where large quantities of marinated mushrooms, and mushroom dishes are eaten. During specific Christian holidays, fasting is a practice and "it is important for people to stock with dried mushrooms" [Katya (K).]. They are added to traditional dishes including *banosh* and *kulesha*. The main components of *banosh* and *kulesha* are corn flour (*Zea mays*) and *polonynska bryndza* (cheese made from *polonyna*) (Figure 2). Both traditional dishes serve as a base to add either berries or mushrooms, depending on the holiday. Forest mushroom soup is also a very common first course and has long been a part of the Hutsul, traditional diet. Overall, mushroom hunting is embedded in Ukrainian culture overall (seen in traditional foods) but even more so in the Carpathian forests, where these species thrive.

The presence of traditional food in Hutsulshchyna is an expression of food sovereignty, as "healthy and culturally appropriate food", which is "produced through ecologically sound and sustainable methods", as seen through coping mechanisms (modifying subsistence activity patterns, and relying on a diversity of species, intensity of use, and diversity of landscape use). Lastly, we see "the right to define their own food and agriculture systems" (Declaration of Nyéléni, 2007) through the economy of gathering and fallback foods, as adaptive strategies (Figure 2). Not only does gathering provide food and medicine, but it is also a cultural activity that upholds personal and community wellbeing and relationship-building through religious holidays, harvesting, and processing (Lynn et al., 2013) as seen in Figure 2. Direct reliance on ecosystems confirms the necessity of maintaining regional biodiversity, while culturally-informed economies drive regional economic stability. Nested in TEK, these types of community-based food systems not only provide medicinal and nutritional needs, but also present an active opportunity to connect with the land, which in turn allows community members to, quite literally, nourish one another.

Polonynas: The tie between landscape and traditional food

The role of *polonynas* (transhumance) in Hutsul landscape is intertwined with traditional foods, specifically in the making of sheep's cheese (Figure 2). *Polonynska bryndza* is made during the summer months (June through September) and obtained from milk of local Carpathian sheep or cows. The process of making bryndza is at least a 600-year-old tradition and is deeply intertwined with traditional food and the *polonyna* landscape (at least 700 m above sea level). This tradition, passed down from generation to generation, preserves ecocultural memories tied to culturally important plant species found on *polonynas* as well the process of making *polonynska bryndza*.

The decline of *polonynas* is linked to cattle population decline after the collapse of the Soviet Union, when keeping cattle became economically difficult and expensive. Due to this decline, it began to synergistically change the landscape and its biodiversity, leading to overgrowth. Without grazers and active management of the land, this biocultural reservoir faces loss. The decline of livestock numbers and *polonyna* pasture use is directly related to intergenerational decline of interest and low economic competitiveness, as well as the time constraints on working populations (Bitter and Bomba, 2008). This has rippled down to demographic shifts and work migration seen Hutsulshchyna. Migration was observed in many of the villages visited, where residents migrate seasonally to work in Poland, Russia or Western Europe with predominant sectors being seasonal agricultural work, construction, and service (Zhyla et al., 2014). Government subsidies to uphold Hutsul pastoral traditions are non-existent in Ukraine. One recent positive development in 2020 that works to preserve *bryndza*, and by proxy, *polonynas*, is the European Union's incorporation of *bryndza* as a geographical indicator. The EU states use a system of protected geographical indicators, which include names that are applied to products made within a specific area (like "champagne" in Champagne, France) (Druzhuk, 2020). It is the ecological processes within the landscape, climate, and soil that ensures the tradition, and its perpetuation of local economy within the region and unique taste. This is the first product in Ukraine with this geographical indication mark, ensuring its authenticity, promotion on the economic market, and guaranteeing its quality.

Traditional foods in Hutsulshchyna are tethered to the landscape and the various habitats that species are found. *Polonynas*, as a critical and culturally significant habitat in Hutsulshchyna, are concretely linked to the traditional food of *bryndza*, as well as many other culturally important plants (Figure 2); their survivals interlinked. The significance of the EU's incorporation of *bryndza* as a geographical indicator provides a layer of resilience in maintaining these practices and thus providing a step to ensuring regional food sovereignty.

Conclusion

Attributes of socio-ecological resilience include adaptive capacity, which consists of both short-term, immediate responses (called coping strategies) and long-term, culturally valued responses (called adaptive strategies). TEK is an environmental knowledge base upheld by language, gathering practices, holidays, song, and culture; it ultimately sustains the adaptive capacity of Hutsul communities to survive wars, food shortages, shifting borders, long-lasting impacts of colonialism as well as competing environmental challenges such as illegal logging, commercial harvesting, and climate change. While Hutsulshchyna along with the entirety of Ukraine face many socio-ecological impacts due to Russia's invasion of Ukraine, resilient communities continue to survive, thrive, and adapt. Ecocultural memories thread together to form a dynamic knowledge base called TEK, which provides a continual opportunity for knowledge sharing within communities. It can be seen as a time-tested, repeated, readjusted knowledge base resulting in resilience. Coping strategies include gathering a diversity of foods (culturally important species) from a diversity of habitats, mitigating the possibility of food scarcity by redistributing reliance on any one habitat type or food source. Another coping strategy includes modifying and continually adapting harvesting of where, when, and how of culturally important species are gathered, dependent on disturbances and climatic changes. Adaptive strategies include an *economy of gathering,* which provides a diversified way of supplementing income and personal needs, while providing trade and social connectivity between communities. Additionally, fallback foods used in the early twentieth century are still used today, with uses transforming from medicine or seasoning to food, under times of stress. Fallback foods provide a transformative capacity to overcome future adversities. It is the integration of coping mechanisms and adaptive strategies that provide the pathway to maintaining traditional foods in the region, which explicitly connect people to land through sustainable gathering practices, religious holidays, meal sharing, and customs. Food sovereignty is an emergent characteristic of community-driven, sustainably maintained ecosystems that provide culturally relevant sustenance, nurturing both community and landscape especially critical today.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by International Review Board (IRB). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

NF devised the study project, the main conceptual ideas, goals, research, field work, data analysis, review of bibliography, analysis of results, writing of the manuscript, and manuscript revision. MP and OP contributed to goals, research, field work, analysis of

results, writing of the manuscript, and manuscript revision. All authors contributed to the article and approved the submitted version.

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Dedication

We dedicate this paper to all the people in Ukraine who are bravely standing resiliently in community with one another and fighting for their freedom.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.720757/full#supplementary-material

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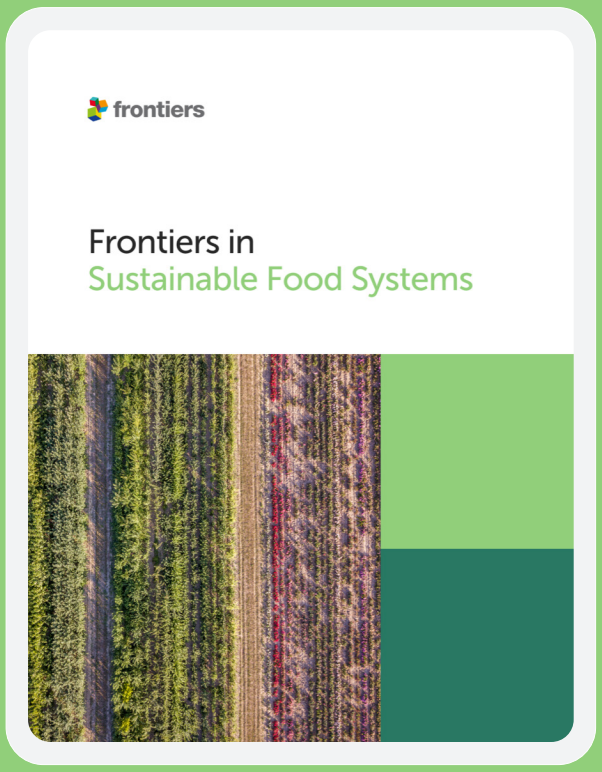
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