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A blue transformation for global One Health

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Global per capita consumption of aquatic foods has never been higher, though significant differences between nations exist. The nutritional benefits of consuming aquatic foods, their wider role in food security, and the potentially lower food safety risks of consumption compared to other meats—combined with their lower environmental footprints—deliver One Health benefits as part of a so-called “blue transformation.” Whilst this is intuitive and correct, it can only be achieved by protecting and enhancing water quality in our rivers, seas, and oceans; by mitigating the negative impacts of climate change in locations where aquatic production occurs; and by ensuring that poor animal health does not catalyse overuse of antimicrobial agents, which subsequently threaten human, animal, and environmental health.

KEYWORDS

aquaculture, food security, food safety, seafood, One Health

Introduction

The Food and Agriculture Organization (FAO) of the United Nations has outlined an urgent need for transformation of the global food system, including changing the way we produce, process, trade, consume, and dispose of aquatic foods—a so-called “blue transformation” (BT). In this commentary, we propose that the recent publication of the One Health Joint Plan of Action by the quadripartite—comprising the FAO, the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the World Organisation for Animal Health (WOAH)—provides useful framing for a BT, the cumulative benefits (and costs) of which may be considered via a systems-level approach using the lens of One Health.

By pivoting to greater relative production and consumption of aquatic foods in the coming decades, we may not only elicit direct benefits for human health and wellbeing via more nutritious and safer diets but also decrease the impact of our food system on biodiversity and on greenhouse gas emissions driving climate change. Together, this requires critical focus on the value, protection, and restoration of aquatic habitats—and more broadly, on the quality and sustainable use of the global water system on which any BT will inevitably rely. In addition, recognising that animal health poses perhaps the most serious barrier to achieving a BT, simultaneous attention to maximising biosecurity and

minimising the use of antimicrobial treatments that can drive resistance in animal and human populations is essential (Stentiford et al., 2023).

Here, we consider current aquatic food consumption patterns at the multinational level, the role played by aquaculture in current and future provisioning, barriers to achieving BT, and the One Health benefits that may be accrued by catalysing a sustainable transition.

Why is blue food important?

Aquatic (blue) foods already provide essential fatty acids, nutrients, and protein to billions of people worldwide. Many of these nutrients—such as vitamin D, vitamin B12, iron, selenium, and zinc—are low in modern-day diets, whilst others, including the omega-3 fats eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are predominantly supplied by aquatic food sources.

In addition to human health benefits, increased consumption also leverages broader benefits for health and prosperity. In 2020, production (including of fish, molluscs, crustaceans, other animals, and algae) from fisheries and aquaculture combined to reach 223 million tonnes—employing almost 62 million people directly and indirectly supporting the livelihoods of another 600 million, creating trade products worth over US\$195 billion (FAO, 2024).

Rapid and sustained expansion of aquaculture since the 1960s contrasts with relatively flat supply from the global fishery—the former is responsible for a doubling in per capita consumption of aquatic foods over this period, to approximately 21 kg/person/year currently, and growing (FAO, 2024). Of course, this global average masks significant differences in per capita consumption at the national level. Data for 175 countries reveal five broad consumption patterns based on the volume and type of aquatic food consumed by citizens of each nation (Stentiford and Holt, 2022). Here, high-volume consumption nations exceeded the global average, with their citizens predominantly consuming marine fish and a wide variety of other aquatic food types. In other nations, citizens are known to consume much lower volumes (<2 kg/person/year), with consumption dominated by freshwater fish. Regional analyses revealed the lowest consumption patterns in Africa and the highest in the “large ocean states” of Oceania—some nations with negligible consumption (e.g., Sudan, <1 kg/person/year) and others far exceeding the global average (e.g., Maldives, >180 kg/person/year). Differences were due to the availability of suitable production sites, the wealth and cultural habits of citizens, and the dynamics in global trading of aquatic foods (Stentiford and Holt, 2022).

Whilst aquaculture now accounts for over half (51%) of all aquatic foods consumed by humans globally (Stentiford et al., 2023), adoption of aquaculture relative to the demand for aquatic foods varies greatly among different nations. In some nations (e.g., Norway, Vietnam), aquaculture production exceeds (>100%) the nominal per capita demand for aquatic foods by their citizens. Elsewhere, national aquaculture production comprises only a small proportion (<5%) of the aquatic foods demanded by its citizens (Stentiford and Holt, 2022). With global fishery output projected to remain stable or decline by 2050 (concomitant with global

population expansion to 10 billion), enhanced national-level adoption of aquaculture will therefore be a prerequisite for a sustainable BT (Stentiford and Holt, 2022; FAO, 2024).

The need for a blue transformation

Acknowledging the key role that blue foods could play in feeding the future global population, it is important to consider how such development can be achieved sustainably. Failure to develop and deploy appropriate aquaculture production systems is predicted to lead to significant supply chain gaps at national and regional levels, exacerbated by greater controls on supply from capture fisheries and inevitable changes in future transnational trading patterns in aquatic foods (Froehlich et al., [[NoYear]]). A BT aims to address these shortcomings by building a resilient and equitable global aquatic food sector, harnessing innovation in aquaculture and fisheries, and working in partnership with national and local governments, the private sector, and society to realise benefits.

One Health as a driver of transformation

One Health describes the interconnectedness of human, organismal, and environmental health. It directly addresses the dysfunction caused in food systems by failing to consider the sectors, the consumers, and the environment as an integrated whole. The recent FAO–WHO–WOAH–UNEP quadripartite One Health Joint Plan of Action outlines activities to strengthen partnership working across these UN agencies, national governments, and other actors to address cross-cutting health issues. As part of this, food systems and their component sectors are now recognised as a pivot around which One Health policies may be operationalised - with the aim of maximising human benefits from food systems whilst minimising their impact on nature and reducing emissions that drive climate change (Bremner et al., 2023).

One Health success metrics are already being considered in relation to aquaculture. Here, the research, evidence, policy, and legislative foundations needed to improve upon a diverse set of human- (e.g., gender equality), organismal- (e.g., reduced disease and higher welfare), and environmental- (e.g., protection of biodiversity) health outcomes, when grouped, define how One Health principles could be “designed in” to food sectors such as aquaculture (Stentiford et al., 2020). Taking such a systems-level approach serves to operationalise the concept of One Health into a tangible outcome (in this case, food produced from aquaculture) by designing and deploying a set of practical policies targeting different, interconnected components of the system. Whilst perhaps intuitive, the cross-cutting nature of the One Health approach nevertheless has high potential to be hampered by the discrete disciplinary and organisational silos that currently operate across this evidence and policy space. Overcoming such barriers by uniting around shared

outcomes (e.g., a sustainable BT) is now urgently required (Bremner et al., 2023). Whilst previous work demonstrates how One Health metrics may be “designed in” to improve the performance and sustainability of aquaculture *per se*, it is equally beneficial to consider how wider One Health outcomes may arise from the sector—effectively “designing outward” the tangible benefits for human, organismal, and environmental health from the BT and increased aquatic food production and consumption at national, regional, and global levels. Examples of potential positive One Health benefits of a BT are shown in Figure 1 and described for humans, nature, and the wider environment below.

Benefits for human health

The nutritional and dietary benefits of consuming aquatic foods have been well articulated by WHO, with intake of two portions of fish per week (one “oily”) linked to decreased premature mortality from non-communicable diseases (Jamiol-Milc et al., 2021). In low- and middle-income countries, specific benefits for pregnant and lactating women and their very young children are also reported—essential fatty acids and micronutrients enhancing health outcomes, particularly in the first 1,000 days of life (Bogard et al., 2015). High aquaculture production (and consumption) scenarios to 2030, supporting increased accessibility to and decreased price of aquatic foods, have the potential to deflect 166 million cases of nutrient and food insecurity by 2030 (Golden et al., 2021).

Zoonotic diseases arising in human populations in contact with and consuming mammalian and avian sources of meat, can cause significant health risks at individual, epidemic, and pandemic scales. Although pathogens (e.g., bacteria and parasites) with zoonotic potential can also occur in aquatic animals destined for human consumption (Stentiford et al., 2022), the cold-blooded nature of these hosts and their taxonomic distinction from mammals (including humans) supports a similarly distinct viral profile, with relatively few taxa likely to have zoonotic (or pandemic) potential. Figure 2 illustrates (1) the high correspondence between viruses infecting humans and other warm-blooded animals and zoonotic diseases; and (2) that the viral profiles of molluscs and crustaceans (and to a lesser extent, fish) are highly dissimilar from those of vertebrates. This broad analysis reveals very few examples of fish viruses being zoonotic, although fish may be a source of potential future zoonotics (for example, as has been suggested for influenza viruses [Orthomyxoviridae]) (Callaway, 2023), pointing to a category of potential future risk that should be considered as part of a BT. Scenarios for BT that involve greater proportional consumption of aquatic foods may therefore be intuitively expected to decrease zoonotic (and pandemic) potential of food systems at national and international levels—not only due to consumption of lower-risk food types but also by their potential to avert wider human–wildlife contact via reduced hunting, preparation, and consumption of bushmeat, such as bats (Olival et al., 2017).

It is important to note that this commentary does not consider the significant cultural and socio-economic barriers for this type of

transition to occur in practice. Rather, it acknowledges both the low aquatic food consumption patterns and low aquaculture production in many nations where reliance on bushmeat hunting and consumption is greatest [see (FAO, 2024) for context, and (Brashares et al., 2011; Friant et al., 2015)].

Production and consumption of aquatic foods are, of course, not without risk from exposure to other food-borne pathogens and hazards introduced during the supply chain. However, appropriate application of available risk control measures—particularly those focusing on water quality at harvest and refrigeration conditions post-harvest—can minimise the impact of some of these hazards on human health (Stentiford et al., 2022). Perhaps most significantly, the generation of antimicrobial-resistant (AMR) microbes due to (over)use of antimicrobial agents in aquaculture is both a significant threat not necessarily being appropriately controlled in national action plans (Caputo et al., 2023) and one that may be exacerbated by climate change, particularly in developing nations where aquaculture predominates (Reverter et al., 2020). Broader considerations on aligning policies that protect and enhance water quality, and reduce reliance on antimicrobial agents, with aspirations outlined in the BT, are thus critical and urgent (Stentiford et al., 2020; Stentiford et al., 2022; Stentiford et al., 2023). Examples of potential positive human health benefits of a BT are shown in Figure 1.

Benefits for the environment

The global food system has a major impact on terrestrial, aquatic, and atmospheric environments—accounting for 70% of freshwater extractions, the use of over half of all habitable land, and the production of more than a quarter of total global greenhouse gas emissions. In addition, land-based agriculture causes over 75% of all marine eutrophication due to the release of nutrients via wastewater and runoff (Ritchie et al., 2022).

Whilst a comprehensive analysis of the impacts (positive and negative) of a BT is not possible here, the broad-scale benefits to the environment, which align with the One Health paradigm, may include the potential for a significantly lower greenhouse gas emissions profile associated with a shift to cold-blooded animal production (Gephart et al., 2021) and a reduced spatial footprint allocated to land-based food production (with concomitant benefits for habitat restoration, reduced agricultural runoff, and subsequent aquatic eutrophication). Furthermore, BT has a positive role of “extractive” [non-fed] species (e.g., seaweeds and bivalve molluscs) in provisioning ecosystem services beyond food supply (e.g., nutrient removal and carbon capture); and can foster the creation of a socio-cultural pivot from “use of water for food production” to “production of food in water”.

The latter may bring collateral benefits including lower overall water use for global food production, increased utilisation of (relatively extensive) available marine space for food production, and prioritisation of policies aimed at improving freshwater quality and protection—including regulations that minimise waste disposal via aquatic systems. Examples of potential positive environmental health benefits of a BT are shown in Figure 1.

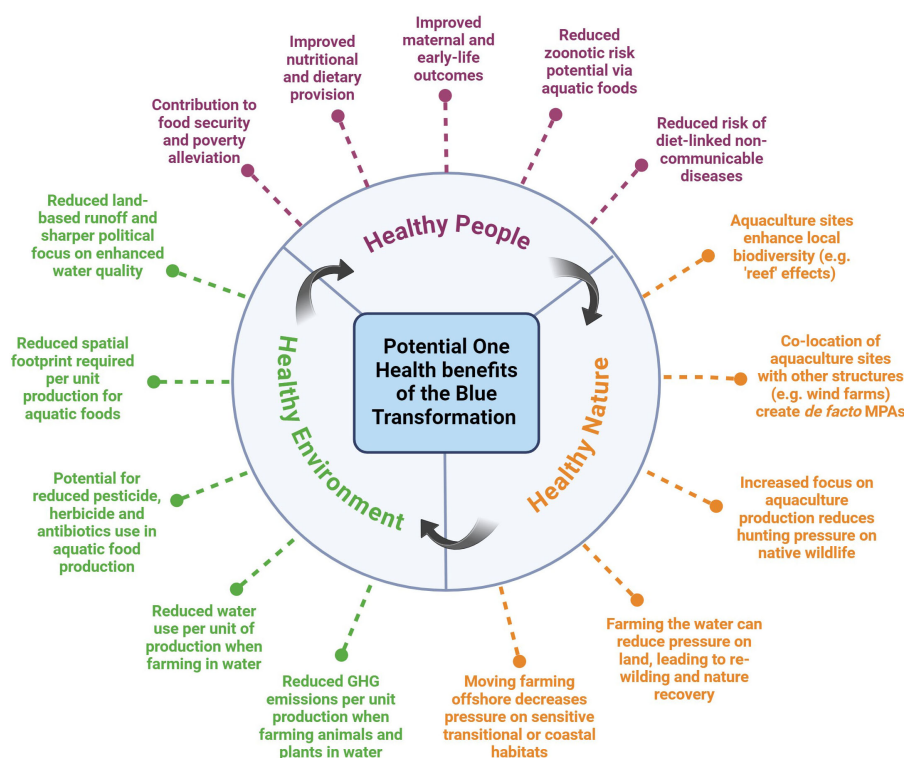


FIGURE 1
Potential One Health benefits of a sustainable blue transformation.

Benefits for nature

A sustainable BT has the potential to significantly benefit biodiversity on land and in water. Certain types of low-impact (e.g., bivalve molluscs) marine aquaculture have been shown to have significant restorative effects on the seabed at locations previously degraded by fishing pressure (Bridger et al., 2022), whilst farms can also serve as artificial reefs and fish-aggregating structures, enhancing native biodiversity and potentially supporting nearby commercial fishing and recreational angling sectors (Bridger et al., 2024).

The ability to co-locate marine aquaculture with other marine infrastructures (such as offshore wind turbines) may create *de facto* marine protected areas, with food and energy production occurring in concert with biodiversity protection, and leading to spillover into adjacent areas. A sustainable BT may also reduce pressure on land-based farming and on terrestrial habitats and biodiversity—allowing for enhanced rewilding and nature recovery.

Notwithstanding the cultural norms that challenge its occurrence, a potential pivot to aquatic food production and consumption by communities reliant on terrestrial wildlife hunting (i.e., bushmeat) not only reduces the risk of zoonotic pathogen transfer via this practice (see above), but may also directly protect mammalian and avian biodiversity—and their habitats—where this practice occurs. Examples of potential positive benefits to nature and biodiversity from a BT are shown in Figure 1.

Towards a blue transformation

Health, food security, and nature conservation are core functions of governments. Whilst industry and (ultimately) the consumer drive supply and demand relating to the sector, we propose that a sustainable BT can only be facilitated by concerted top-down policies and actions that support transition at the national level. Food systems rely on intact, functioning ecosystems but also have significant potential to directly impact the status of these systems. Previously, we have argued that food systems offer a tangible pivot around which to design and operationalise One Health policies (Stentiford et al., 2020; Stentiford et al., 2022; Bremner et al., 2023).

For BT at the national level, recognising that watercourses are a food production medium (like soil) rather than a convenient route for waste disposal is a fundamental first step. Once water (including marine) is considered through this lens, the more routine and practical benefits of farming cold-blooded animals—some of which do not require feeding—alongside algae and plants that can remove land-derived nutrients from their environment (thus further improving water quality), perhaps become self-evident. This underpins the potential for positive tipping points towards a BT ultimately driven by societal movements (Bremner et al., 2023).

Of course, it is incorrect to state that all forms of aquatic food production will offer the positive One Health benefits to humans, nature, and the wider environment proposed in this commentary.

	Molluscs	Crustacea	Fish	Humans	Primates	Non-primate mammals
Adenoviridae				◆◆◆◆	7	21
Adomaviridae						
Alloherpesviridae			■ ■ ■ ■			
Amnoonviridae			■ ■ ■ ■			
Arenaviridae				◆◆◆◆	1	23
Arteriviridae					1	3
Astroviridae					?	5
Bornaviridae					1	7
Caliciviridae						19
Coronaviridae				◆◆◆◆	3	15
Cremegaviridae						
Filoviridae				◆◆◆◆	4	6
Gresnaviridae						
Hantaviridae				◆◆◆◆	?	?
Hepadnaviridae					1	4
Hepeviridae					1	3
Kirkoviridae						
Kolmioviridae						
Matonaviridae						
Nanghoshaviridae						
Nanhypoviridae						
Olifoviridae						
Orthoherpesviridae					23	49
Papillomaviridae					1	15
Paramyxoviridae				◆◆◆◆	12	28
Pecoviridae						
Picornaviridae					6	14
Pistolviridae						
Pneumoviridae					4	5
Polyomaviridae						
Redondoviridae						
Retroviridae				◆◆◆◆	12	18
Sunviridae						
Tobamiviridae						
Tosoviridae						
Adamaviridae						
Adintoviridae					1	1
Anelloviridae						
Anicreviridae						
Asfarviridae						1
Bacilladnaviridae						
Belpaoviridae						
Birnaviridae	○ ○ ○ ○		■ ■ ■ ■			
Chuviridae						
Circoviridae						2
Draupnirviridae						
Flaviviridae				◆◆◆◆	13	74
Gandrviridae						
Genomoviridae						
Geplanaviridae						
Iridoviridae	○ ○ ○ ○	++++	■ ■ ■ ■			
Kanorauviridae						
Mahapunaviridae						
Metaviridae						
Nairoviridae				◆◆◆◆		?
Nodaviridae		++++	■ ■ ■ ■			
Nyamiviridae						
Orthomyxoviridae			■ ■ ■ ■	◆◆◆◆	2	10
Ouroboviridae						
Parvoviridae		++++			5	14
Peribunyaviridae				◆◆◆◆	6	136
Phenuiviridae				◆◆◆◆	?	
Poxviridae			■ ■ ■ ■	◆◆◆◆	3	26
Pseudototiviridae						
Rhabdoviridae		?	■ ■ ■ ■	◆◆◆◆	1	51
Sedoreoviridae					3	45
Smacoviridae						
Spinareoviridae			■ ■ ■ ■			
Togaviridae	○ ○ ○ ○		■ ■ ■ ■	◆◆◆◆	7	52
Totiviridae			■ ■ ■ ■			
Roniviridae		++++				
Dicistroviridae						
Iflaviridae						
Sarothroviridae						
Qinviridae						
Yueviridae						
Crullviridae						
Nudiviridae		++++				
Nimaviridae		++++				
Microviridae						
Permutotetraviridae						
Malacoherpesviridae	○ ○ ○ ○					
Arenaviridae						
Marseilleviridae						
Papovaviridae	○ ○ ○ ○					
Mininucleoviridae		++++				

FIGURE 2
Comparison of viruses infecting the main groups of aquatic food organisms (fishes, crustaceans, molluscs) with those infecting warm-blooded mammals. Out of c. 315 viral families, only 35 exclusively include viruses infecting vertebrates (light grey highlighted families in left-hand column); a further 35 families include both vertebrate- and invertebrate-infecting viruses (mid-grey highlighting). 16 families infect aquatic invertebrate hosts only (dark grey highlighting; white text). Coloured shading indicates viral species within families affecting the host group. Circles, pluses, and squares in the Mollusc, Crustacea, and Fish columns respectively indicate virus families containing the most significant viral pathogens of species in those groups with respect to food production. Diamonds in the Human column indicates virus families containing the most documented zoonotic viruses; darker shading indicates families containing multiple zoonotic viruses. Numbers in the Primates and Non-primate mammals indicate the number of virus species per family known to infect those host groups (data summarised from Olival et al. (2017). ?'s indicate uncertainty due to changes in viral nomenclature).

Practical considerations—including the appropriate trophic status of the species being farmed; their feed requirements (and where this feed is sourced, and who it impacts); who ultimately benefits from the food (and profit) generated; and wider societal perceptions of the health and welfare of the animals being farmed—are all important factors in the journey to a sustainable BT (Stentiford et al., 2020).

Climate change has the potential to significantly narrow the scope for a BT—the cold-blooded nature of aquatic animals makes them particularly prone to changes in their environment and, significantly, more susceptible to disease. Here, the selection of resilient production species, appropriate siting of farm locations, and maintenance of high biosecurity status are all critical in mitigating the impacts of climate change—and in averting overuse of antimicrobial agents applied to treat disease.

Nevertheless, despite these challenges, it is our opinion that the capacity for food production from water (and particularly from the sea) is great—offering significant One Health benefits through an aquacultural revolution alongside the sustainable harvesting of aquatic food from the global fishery.

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

GS: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. DB: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. JB: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration,

Resources, Software, Writing – original draft, Writing – review & editing.

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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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