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Seasonal and gendered patterns in subsistence fishing and shellfish gathering: insights from Mfumbwi (Zanzibar) for archaeological interpretation and contemporary fisheries management

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The village of Mfumbwi (Jambiani, Zanzibar Island) is home to maritime fishers and shellfish gatherers who use traditional methods to harvest marine fauna for subsistence. This study examines the extent to which seasonality and gendered patterns of behavior affect the marine subsistence record of Mfumbwi using an extensive ethnographic maritime subsistence dataset (MS-1819) collected between June 2018 and June 2019. As we show, seasonality driven by the wet-dry monsoonal climatic regime of Zanzibar intersected with local gender ideologies in interesting and significant ways, affecting men and women differently. Further, the roster of marine species harvested varied between men and women, most likely reflecting different ecozones frequented by each gender. However, the seasonal availability or accessibility of specific taxa harvested by either men or women may also be influenced by the behavior of individual taxa, which may or may not be climatically driven. Further, various biological and cultural variables affecting maritime subsistence patterns in Mfumbwi may have skewed the MS-1819 data as they were collected. This study lays the foundation for future studies using modern socio-ecological datasets that holds significance not just for current conservation and cultural heritage management efforts, but also for archaeological studies of maritime subsistence on the Swahili coast and other regions of the Indian Ocean World, highlighting as it does some of the varied and intersecting factors affecting subsistence activities.

KEYWORDS

ethnoarchaeology, gendered labor, Indian Ocean monsoon, marine resource exploitation, maritime subsistence, seasonality, Swahili coast, Zanzibar

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1 Introduction

Jambiani is a group of villages located on the southeast coast of the island of Zanzibar, known locally as Unguja (see Figure 1). In 2012, the population of Jambiani stood at roughly 7,000 inhabitants (2012 Population and Housing Census, 2013) but the region has seen heavy population growth since. Like many Zanzibari communities nowadays, Jambiani and its constituent villages are characterized by both maritime subsistence activities and employment in the island's tourism sector. The inhabitants of Mfumbwi, one of the villages that comprise Jambiani and where the data for this project was collected, have historically been fishers and shellfish gatherers who practiced some small-scale cultivation and raised livestock. This settlement was chosen as the site of data collection due to the personal connections established between Sarathi and its inhabitants and the potential to capture signals of preindustrial patterns of maritime subsistence practices. The resulting dataset (titled the MS-1819 Dataset) offers valuable insight into the marine subsistence behavior of a small-scale East African maritime community but must be used with some caution when employed as the basis of fisheries policy or to interpret the zooarchaeological record.

While the nature of the MS-1819 Dataset allows for a multiplicity of questions to be considered concerning marine subsistence behavior, we here focus on the intersection between seasonality and gender. As described below, the high resolution of the data comprising the MS-1819 Dataset revealed unforeseen connections between variables that were initially assumed to be independent of each other—in this case, gender and seasonality. As we show below, the seasonality of marine faunal exploitation at Mfumbwi was strongly skewed by gender. The MS-1819 data were collected primarily with a view to understanding the East African archaeological record, but the intersection between seasonality of marine exploitation and gender ideologies currently prevalent in Mfumbwi cautions us against wholesale and simplistic comparisons between past and present exploitation of marine fauna on the East African coast. Intangible, mutable, and contingent cultural forces play a key role in faunal exploitation, perhaps to an extent underappreciated by archaeologists.

Further, as we note below, while the MS-1819 Dataset certainly captures preindustrial modes of subsistence, various complicating factors affected the data collection process, and these will need to be taken into consideration when applying the MS-1819 Dataset to the archaeological record and when deploying this dataset for

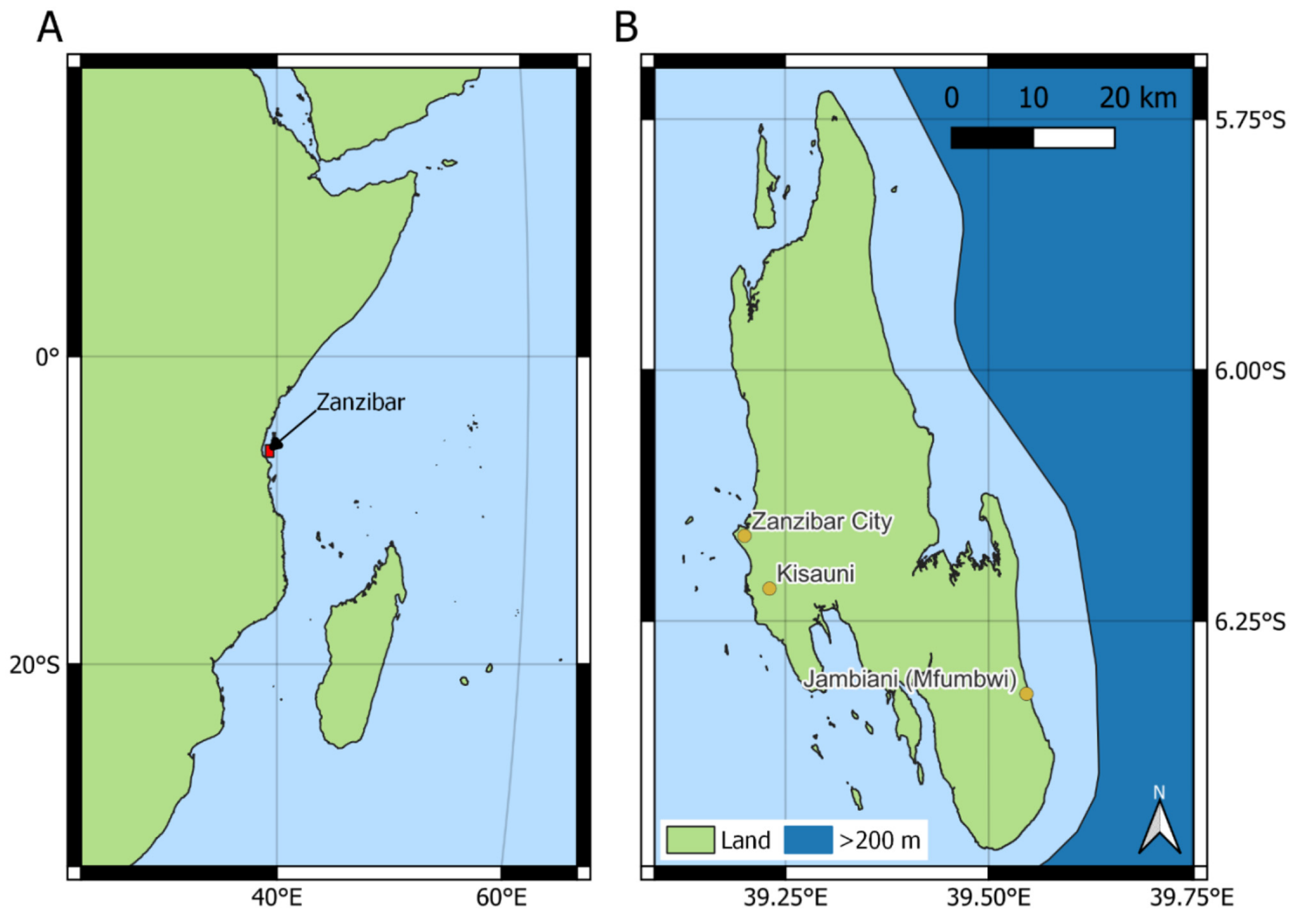

FIGURE 1
Location of Zanzibar on the East African coast **(A)**; map of Zanzibar (Unguja) Island with key locations marked **(B)**.

other purposes. While we do not believe that these factors in any way affect the validity of this study and the interpretations we draw from it, these factors should be considered in future studies either of the MS-1819 dataset itself or applying insights derived from it to interpret the archaeofaunal record. Therefore, we suggest deep consideration of the complex factors that influence human social behavior before using the MS-1819 dataset to interpret archaeofaunal data. On the whole, however, the MS-1819 Dataset reveals the complexity inherent in maritime subsistence activities in preindustrial contexts and the interplay between environmental forces and cultural ideologies in the determination of subsistence activities at any given place and time.

2 Background

2.1 Modern socio-ecological research

The fisheries and marine subsistence systems of Zanzibar represent a dynamic interplay of ecological, cultural, and economic processes shaped by both long-standing traditions and contemporary pressures. Artisanal fishers and shellfish harvesters rely on non-mechanized, small-scale technologies embedded in deep reservoirs of traditional ecological knowledge passed down across generations (Jiddawi, 2012). Yet as discussed below, these practices are increasingly situated within an environment of ecological degradation, a burgeoning tourism industry, shifting consumer demands, gendered divisions of labor, and broader climatic uncertainties. The antecedent literature on Zanzibar's fisheries and shellfish beds provides critical insights into how these factors intersect, revealing a complex subsistence mosaic where adaptability and vulnerability coexist. This review organizes the literature into thematic sections, allowing for both an assessment of discrete factors and a synthesis of their cumulative implications for understanding Zanzibar's marine subsistence systems.

2.1.1 Gear, technology, and transport

Fishing in Zanzibar is characterized by the persistence of preindustrial gear (handlines, nets of various kinds, traps, and spears) that has been considered to be versatile and accessible, but also non-selective (Jiddawi, 2012). Different gear captures a wide range of taxa, creating ecological pressures across species and habitats. For example, longlines are particularly efficient at capturing elasmobranchs, while gillnets and handlines often ensnare them incidentally (Barrowclift et al., 2017). In this way, gear not only mediates which taxa are harvested but also determines levels of incidental bycatch. Historical accounts reinforce the durability of traditional gear. In 1924, Ingrams documented the use of fish traps (*dema*, pl. *madema*) in Zanzibar and Pemba, both single- and double-wayed designs (Ingrams, 1924). These traps remain in use today, demonstrating technological continuity across a century. Yet, gear choice is not neutral: it reflects ecological knowledge and economic strategies. Traps, for instance, are often associated with sedentary, reef-based fishing, while longlines and gillnets connect fishers to more mobile and offshore practices (Jiddawi, 2012).

Transport modes also structure fishing strategies. Canoes and foot-based harvesting restrict fishers to nearshore habitats, whereas more durable vessels allow longer journeys offshore, often exceeding 10 km (Silas et al., 2020). This distinction is particularly important in a context of climate change and habitat degradation, where nearshore resources are increasingly scarce. Mobility thus becomes a determiner of inequality, differentiating those with the capital to invest in vessels from those dependent on shrinking productivity in coastal ecosystems. The very act of traveling farther offshore represents an adaptation to ecological stress but also exposes fishers to higher risks and costs.

2.1.2 Markets, consumers, and trophic pressures

The demand side of Zanzibar's fisheries plays as significant a role as the supply side. Differential consumer preferences exert uneven pressure across trophic levels, ensuring that no category of fish escapes exploitation. Hotels and town markets prefer large, mature, higher-trophic fish, while local consumers and small-scale traders purchase and consume smaller, lower-trophic species (Thyresson et al., 2013). This layered demand creates what might be called a "pressure gradient," where both apex predators and forage fish are simultaneously extracted, destabilizing ecological balances. Elasmobranch fisheries illustrate this interplay vividly. Their catches fluctuate according to consumer demand as well as ecological and technological variables. In settlements like Kizimkazi-Dimbani, fishers report that season, weather, gear type, and even bait availability determine whether elasmobranchs are caught in significant numbers (Barrowclift et al., 2017). When consumer demand spikes, longlines are deployed more intensively, amplifying fishing pressure on already vulnerable populations. The trophic consequences of such market differentiation extend beyond individual taxa. By targeting both high- and low-level species, fishers inadvertently erode the structural redundancy of the ecosystem. The removal of apex predators disrupts predation dynamics, while the depletion of forage fish undermines the food base for larger species. Thus, markets and consumption preferences are not peripheral economic concerns but central drivers of more recent ecological change.

2.1.3 Gender and access

Gender is one of the most persistent structuring principles in Zanzibar's fisheries and shellfish harvesting practices. Access to marine spaces, rights to particular species, and knowledge of harvesting techniques are all mediated through gendered divisions of labor that have both ecological and cultural consequences. Women's labor has historically been concentrated in nearshore and intertidal environments (mudflats, mangrove edges, and shallow reefs) where they fish and collect mollusks, crustaceans, sea cucumbers, and other invertebrates. Men, by contrast, have historically dominated finfish capture, particularly offshore and pelagic species that require boats, capital-intensive gear, and greater physical mobility (Fröcklin et al., 2014). This division is not simply an ecological accommodation; it reflects cultural norms and expectations about appropriate labor roles. Women's shellfish harvesting is often embedded in household provisioning and childcare responsibilities, as these activities can be coordinated with other domestic work and are less time- and capital-intensive. Men's fishing activities, by contrast, are associated with market-oriented production, prestige, and the risks of seafaring. In this sense, gender structures the scale and visibility of different kinds of marine exploitation: men's labor is often more visible in markets and statistics, while women's contributions are more hidden yet vital for household nutrition.

The encroachment of men into traditionally women-dominated spaces illustrates how ecological decline reshapes gendered landscapes. As Fröcklin et al. (2014) documented in Chwaka Bay, the depletion of high-value invertebrates led men to increasingly harvest species in habitats once primarily exploited by women. This reconfiguration had ripple effects: women lost access to important income streams, household provisioning strategies were disrupted, and the symbolic meanings of gendered labor divisions shifted. In this way, environmental degradation produces not only ecological but also social dislocations. It is a reminder that sustainability is not only about biomass and catch statistics but also about maintaining socially embedded systems of resource access. Folkeryd's (2020) ethnography of single mothers in Paje (on Zanzibar's east coast) underscores the compounded vulnerabilities faced by women in coastal communities. During the rainy season, these women found their livelihoods disrupted, not because fish or shellfish were necessarily unavailable, but because their broader economic activities (e.g., seaweed farming, rope-making, basketry) became untenable in heavy rains. This shows how women's livelihoods are precariously diversified across multiple sectors, each of which is seasonally vulnerable. The intersection of gender and seasonality thus shapes not only who fishes what but also who bears the brunt of environmental variability.

From a broader anthropological perspective, these dynamics resonate with feminist political ecology, which highlights how gender mediates access to resources and how environmental change disproportionately impacts women. In Zanzibar, women's marginalization in marine management systems (where decision-making authority is often held by male elders or government officials) means that their knowledge of intertidal ecosystems and their vulnerabilities are frequently overlooked in policy frameworks. Yet women's expertise in shellfish harvesting provides critical ecological data, often more granular and seasonally attuned than the broad patterns captured by fisheries statistics. Comparative ethnographies reinforce the significance of these findings. In Mozambique and Madagascar, for example, women's harvesting of mangrove cockles and sea cucumbers has been central to household economies, yet declines in stocks have led to similar men's incursions into intertidal zones, often pushing women out of their traditional niches (de la Torre-Castro et al., 2022). These parallels highlight that gendered transformations in access are not unique to Zanzibar but reflect a wider pattern across Western Indian Ocean fisheries where ecological decline reshapes social boundaries. Recognizing these dynamics is crucial not only for ecological sustainability but also for ensuring equitable participation in resource management.

2.1.4 Seasonality and monsoons

Seasonality, driven by the shifting Inter-Tropical Convergence Zone (ITCZ), is one of the defining features of Zanzibar's marine environment. The resulting bimodal monsoon system—the southeast monsoon (March–May) and the northeast monsoon (October–December)—shapes wind patterns, currents, primary maritime productivity, and thus the abundance and availability of marine fauna. Yet, while the monsoons provide an overarching environmental rhythm, their influence is highly uneven, producing species-specific, habitat-specific, and socially mediated outcomes. Ecological studies reveal a striking diversity of seasonal effects. Small pelagic fish such as anchovies and sardines fluctuate with upwelling-driven productivity cycles, with catches often peaking during monsoon periods (Sekadende et al., 2020). Tuna and prawns are more abundant during the southeast monsoon (Silas et al., 2020; Silas, 2022), while sharks peak during the dry season, declining sharply when rains arrive (Schaeffer, 2004). Zooplankton, which form the base of the pelagic food web, also show seasonal peaks between January and March, yet with considerable spatial variation (Sekadende et al., 2020). This mosaic underscores that "seasonality" cannot be reduced to a simple binary of productive vs. unproductive periods. Instead, it interacts with species life cycles, habitat preferences, and local ecological contexts.

Chwaka Bay offers a case in point, however this area appears distinct from other parts of Zanzibar. While Zanzibar's west coast fisheries peak during the northeast monsoon, Chwaka Bay fishers report higher catches during the southeast monsoon (Jiddawi, 2012). de la Torre-Castro et al. (2014) corroborate this, finding that per-fisher catch rates were higher during both monsoon seasons than during the dry season, but with marked differences in gear effectiveness—basket traps, for instance, yielded four times more during the northeast monsoon than in other periods. In contrast, fishing follows the Arabic calendar and exhibits clear bimodal rhythms on Mafia Island to the south. During the northeast monsoon, calm seas permit access to outer reefs, while the southeast monsoon restricts activity to nearshore areas (Gaspare et al., 2015). Seasonal differences in gear use were evident, though grouper landings showed no seasonal variation, illustrating a divergence between ecological data and local ecological knowledge. This demonstrates that gear, habitat, and seasonality form an intertwined triad shaping actual catches.

Historical and archaeological perspectives reinforce the importance of seasonality. The prey choice model applied by Bird et al. (2004) suggests that seasonal variations in availability strongly influence what taxa appear in middens, providing insights into past subsistence strategies. Pretelli et al. (2022) show that certain shellfish (*panga*) are more abundant in the dry season, due to seasonal mortality from exposure, illustrating how intertidal taxa can exhibit strong seasonal dynamics that are archaeologically visible. Elsewhere, in mangrove and mud/sand flat habitats, Lugendo et al. (2007) observed declines in density and species richness during the southeast monsoon, suggesting salinity and visibility were more influential than rainfall alone. In the Pemba Channel, Kizenga et al. (2021) and Kyewalyanga (2022) reached different conclusions about when mackerel catches peak, illustrating spatial heterogeneity even within a single channel.

Even archival fisheries data, such as Losse's (1966) study of the Zanzibar Channel, show distinct seasonal abundance patterns among specific taxa, demonstrating the long-standing recognition of monsoon cycles in shaping fisheries.

From an anthropological perspective, seasonality highlights the entanglement of ecological cycles with human temporalities. Fishing calendars, market rhythms, and household labor portfolios are structured around the monsoons, embedding ecological seasonality into cultural and social life. Seasonality is thus not only an environmental determinant but also a cultural framework through which people organize time, labor, and meaning. Finally, climate change complicates the predictability of seasonality. Changes in monsoon onset, intensity, and reliability are already being reported across the western Indian Ocean, raising questions about the continued viability of knowledge systems and practices that rely on relatively stable seasonal cycles. Thus, previous research suggests that for Zanzibar's fishers and shellfish gatherers, the erosion of seasonal predictability represents not only ecological disruption but also a cultural rupture, undermining the calendars, expectations, and rhythms that structure daily life.

2.1.5 Human impact, climate change and environmental stressors

Climate change and environmental degradation pose escalating challenges for Zanzibar's fisheries. Rising sea surface temperatures, ocean acidification, sea level rise, and sand accumulation all threaten shellfish populations (Ali and Zuberi, 2022). Although methodological limitations complicate the strength of these findings, they align with broader global patterns where climate change disproportionately affects intertidal and shallow-water species. Overfishing represents another critical stressor. Multiple studies document declining stocks and the disappearance of key species from local ecosystems (Mkenda and Folmer, 2001; Jiddawi, 2012). Research in Chwaka Bay reveals stark evidence of overexploitation. Mohammed (2004) documents how generations of fishing and mangrove cutting have degraded both fish populations and forest cover. Jiddawi (2012) reports that annual fish production in the bay declined from 950 tons in 1990 to just 370 tons by 2007, with octopus and sardines disappearing altogether. These figures highlight both the intensity of exploitation and the fragility of nearshore ecosystems. Habitat destruction compounds these pressures, particularly in mangroves and seagrass beds that serve as nurseries for many taxa. The loss of these habitats reduces resilience, making ecosystems less able to recover from climatic shocks. The relationship between seaweed farming and fisheries illustrates the difficulty of predicting environmental interactions. Globally, seaweed farming is associated with increased siganid catches, as in Southeast Asia. Yet in Zanzibar, no such correlation exists, likely due to the small scale and sporadic nature of local farming (Hehre and Meeuwig, 2016). This discrepancy demonstrates the dangers of assuming uniform outcomes from similar practices across contexts.

Despite mounting challenges, Zanzibari fishers and harvesters exhibit notable adaptive strategies. Facing declining landings, fishers report shifting fishing grounds, experimenting with new gear, and investing in vessels capable of traveling farther offshore (Silas et al., 2020). These strategies exemplify resilience but also reflect growing costs, both material and ecological. Offshore fishing requires capital investment, while nearshore intensification risks further habitat degradation. Migration represents another adaptation. Seasonal itinerancy allows fishers to exploit areas with temporarily greater productivity, but it also concentrates pressure in particular zones at specific times (Jiddawi and Öhman, 2002; Wanyoni et al., 2016; Sekadende et al., 2020; Seme et al., 2022). Such mobility strategies are highly responsive but risk redistributing rather than alleviating pressure. The possibility that some species migrate to deeper, cooler waters during dry seasons (Moshy et al., 2015) adds further uncertainty. Fishers must constantly recalibrate strategies in response to shifting ecological baselines. In this sense, adaptation is less about solving problems than about managing an ongoing condition of instability.

2.2 Synthesizing antecedent scholarship

The antecedent literature on Zanzibar's fisheries paints a picture of a system at once resilient and precarious. Traditional gears, gendered divisions of labor, and monsoon-driven seasonality provide continuity and adaptability. Yet market demand, overfishing, climate change, and habitat degradation are eroding ecological and social buffers, with fisher strategies (mobility, gear change, investment) represent adaptive responses but often redistribute rather than resolve pressures. Ultimately, Zanzibar's fisheries embody a tension between persistence and transformation. Traditional practices endure, but they are being reshaped by ecological decline, market demands, and climatic volatility. Understanding this dynamic requires a holistic approach that integrates ecological, social, and historical dimensions.

That said, certain gaps exist in the literature published thus far on Zanzibar's fisheries and the factors influencing patterns of exploitation of specific taxa. Most studies focus disproportionately on finfish, especially economically important pelagic and reef taxa. Shellfish, invertebrates, and other marine fauna are understudied, both in general and especially in relation to seasonal availability or harvesting patterns. Few studies address gendered patterns of exploitation or explicitly ethnoarchaeological questions (despite clear relevance). The patterns observed in Mfumbwi thus both mirror and complicate these antecedent studies. Like the communities of Chwaka Bay and Mafia Island, Mfumbwi's fishers and shellfish gatherers structure their activities around monsoonal rhythms, yet the ethnographic data show that these rhythms are refracted through local gender ideologies in ways not fully captured in previous literature.

3 Materials and methods

3.1 Ethnoarchaeological research and the creation of the MS-1819 dataset

The MS-1819 Dataset was collected between June 2018 and July 2019 by Sarathi with the express purpose of creating an ethnoarchaeological baseline against which East African zooarchaeological data could be compared. The use of quantitative ethnographic subsistence data to interpret the archaeological record has a venerable history in scholarship. Sarathi based the MS-1819 Dataset and its collection process on the work of Henry Bunn, whose work with the Hadza foragers of Tanzania played a key role in the interpretation of sites like Olduvai Gorge (Bunn, 1981, 2007; Bunn et al., 1986; Bunn and Ezzo, 1993; Bunn and Gurtov, 2014). Bunn's comparison of the taxonomic, age, and skeletal element patterning of Hadza hunting with the zooarchaeological dataset at the site of FLK Zinj (Olduvai Gorge) was the foundation of his argument for ambush-based hunting by early *Homo* (Bunn and Gurtov, 2014). The MS-1819 Dataset was collected with a similar and yet more expansive aim—to assess the factors that determine marine faunal exploitation by traditional East African maritime communities today and to build as detailed a dataset as a possible to serve as a high-resolution ethnoarchaeological baseline to better understand the archaeological record of marine faunal subsistence on the East African coast.

Sarathi initially contacted 20 women and 20 men of Mfumbwi to request their assistance in the creation of the dataset. While most of the women participated in the project for the entirety of its duration, many of the men contributed for a more restricted period of time. Some women and men also joined the project once it had begun. Therefore, the MS-1819 Dataset is woman-skewed, but not to the extent of invalidating gender-based comparisons. Each participant was asked to specify when they went to the ocean and when they returned, whether they used a canoe, and what tools/equipment they used. Participants were requested to bring their catch straight to Sarathi without processing or modifying it in any way for counting, identification, weighing, and measuring. All specimens were identified taxonomically and counted, the only exception with taxonomic identification being the *dagaa* fish category. *Dagaa* is an aggregate ethno-category comprising a number of small pelagic fish species that are often not easily identified. Acting effectively as a species complex, the *dagaa* fish category is currently important for food security in the region and given that it is viewed as different in terms of fishing activity relative to other, more easily identifiable taxa (Fujimoto, 2018; Trägårdh, 2023), we have retained this ethno-category within the analyses. Shellfish and crustaceans were only weighed while fish, cephalopods, and the few turtles recorded were measured for their length as well. This daily record of a part of the catch of the fishers and shellfish harvesters of Mfumbwi was then combined with climatic data for 2018–2019 gathered at a meteorological station at Kisauni, which lies about 37 km in a straight-line distance from Mfumbwi. No other meteorological station was located closer to the research site. The resulting dataset thus covers an entire year of marine subsistence activities that should allow for an examination of the influence of climate, season, mode of transport, specific gear, and time of day. Importantly, the intersection of these subsistence-influencing factors with gender were also able to be analyzed based on the methods used in data collection.

3.2 Statistical methods

To understand the basic structure of foraging and fishing over the course of the year, we use two measures of diversity common to ecological and archaeological analyses. Taxonomic richness (or NTAXA) refers to the number of species within a given sample, and as such is a measure of sample richness. It requires tallying all the non-overlapping taxonomic categories to ensure that taxa are not potentially counted multiple times, such as, where taxa are identified to species levels as well as to higher taxonomic levels (genus or family) in an assemblage. In such cases the higher taxonomic level data would need to be excluded and only species counted, or alternatively the species level data combined to genus and counted only once (Grayson, 1984; Lyman, 2008; Faith and Lyman, 2019). The Shannon index (H') is a measure of taxonomic diversity that combines species richness (measured by NTAXA) and evenness (factoring in variation between species and their abundance). The value of this measure generally ranges between 1.5 and 3.5 for living communities, with a higher index value indicating a greater degree of diversity in that sample (Magurran, 2004; Faith and Lyman, 2019). Both NTAXA and Shannon H' are affected by differences in sample size, so we use rarefaction analysis to compare these two measures at the smallest equivalent sample size. In other words, rather than providing true richness or diversity, rarefaction estimates the NTAXA and Shannon index values if the number of individuals were the same (Gifford-Gonzalez, 2018; Faith and Du, 2022), thereby normalizing data where there are substantial differences between samples. Calculation of the diversity indices and the rarefaction analyses were undertaken using the PAST Paleontological Statistics Package Version 4.13 (Hammer et al., 2001).

Principal components analysis (PCA) is an ordination method that finds those components that account for as much of the variability within a dataset as possible. It allows for the visualization of similarity or dissimilarity within/between samples by reducing a complex dataset to two variables (i.e., the first two components), effectively summarizing a complex set of inter-relationships in one scatterplot (Hammer et al., 2001; Drennan, 2009). Although PCA is suitable for abundance data, it assumes that there is a linear relationship between taxa and environmental gradients (e.g., from multiple sites following Faith and Lyman, 2019), this is less of an issue for the seasonality data being analyzed here as it derives from a single location over the course of a year. We use the proportional abundance of individual taxa over the 13 months of data collection rather than absolute abundance to account for any differences in sample size per species. These abundance data were summed and converted to percentages per taxon according to season, defined as the Hot Dry (January–February), Long Rain (March–June), Cool Dry (July–October), and Short Rain (November–December) following a scheme similar to that outlined by Alonso Aller et al. (2017). PCA biplots also show a projection of the seasonal variables, allowing for evaluation of the relationship between groups or clusters of taxa and season of capture/harvest. The number of clusters have been defined via visualization of dendrograms produced by hierarchical cluster analyses (Hammer et al., 2001). The PCA analyses were undertaken using the PAST Paleontological Statistics Package Version 4.13 (Hammer et al., 2001) and the hierarchical cluster analyses by jamovi 2.4 (The Jamovi Project, 2025) using the snowCluster multivariate analysis 7.2.7 module (Seol, 2023).

4 Results

4.1 Taxonomic category abundance and diversity

Some differences across the year are apparent when viewing the proportional contribution of each faunal category to individual monthly totals (Figure 2). Fish dominate from September to December and again in February and March, with bivalves peaking in June (2018) and July, and the gastropods demonstrating a higher proportional representation in August and across April to June (2019). Fish contributes less than the mollusks in June–August 2018 and April–June 2019, with the cephalopods providing a relatively low proportion to the overall catch throughout the year, with minor peaks in September and February/March. The crustacea (which are not depicted on this figure) do not contribute more than 1.1% throughout the year, although there are minor peaks in their distribution mirroring that seen with the cephalopods (September–November and February–March).

Plotting the rarefied NTAXA (Figure 3A) and Shannon H' (Figure 3B) values illustrate variability in species richness and diversity across the year, although here we focus on the nature of the fluctuations in each distribution rather than the absolute values of each measure. Fish NTAXA and H' show similar trends, with a peak in June/July 2018, a major decrease in August followed by a more gradual increase into the early months of 2019. There is another steep decrease in NTAXA and H' in May, again followed by an increase in June 2019 to levels similar to that recorded in June of the previous year. For the bivalves and gastropods, NTAXA follows relatively similar trends over the course of the year, with distinct peaks representing an increasing number of species harvested in June 2018, September/October, and February 2019. Species diversity for these categories is also broadly similar, with comparatively higher H' values in September/October and in February followed by a gradual decrease in diversity to June 2019. Gastropods show greater diversity than the bivalves in June/July 2018, with higher bivalve diversity in January. The cephalopods exhibit low NTAXA and H' values throughout the year, with minor peaks in both measures in June (2018 and 2019) and in December. The crustaceans (again not depicted in Figures 3A, B for consistency) present similarly low values for NTAXA and H' as seen with the cephalopods, but interestingly follow an inverse pattern, where there is a slight increase in crustacean values as the cephalopod values decrease and vice versa.

Breaking these data down by gender to examine the proportional contribution of each taxonomic category to the monthly catch totals shows clear differences in the way men and women broadly fish and forage throughout the year (Figures 4A, B). For women, cephalopods form a consistent yet minor resource (at 1.3% or less), whereas for men they contribute between 2 and 16% of the monthly totals, with more cephalopods caught between January and March. Women harvest mollusks and catch fish throughout the year, with distinct peaks and troughs in the contribution of these categories. Fish dominate from September to December and February/March, gastropods in August and April to June (2019), and bivalves in June/July 2018. For men, fish are the primary resource extracted from marine environments throughout the year barring August, where gastropods increase substantially, although these species and the bivalves were only harvested between June and August 2018.

Fish species richness and diversity for women's harvests (Figures 5A, B) remain relatively consistent throughout the year

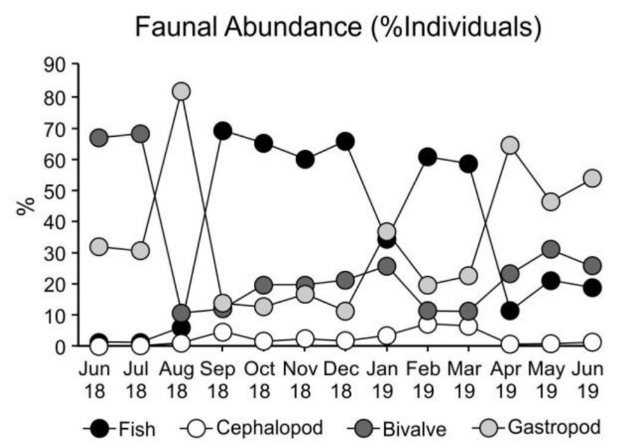

FIGURE 2
Proportional abundance of major faunal categories at Mfumbwi by month.

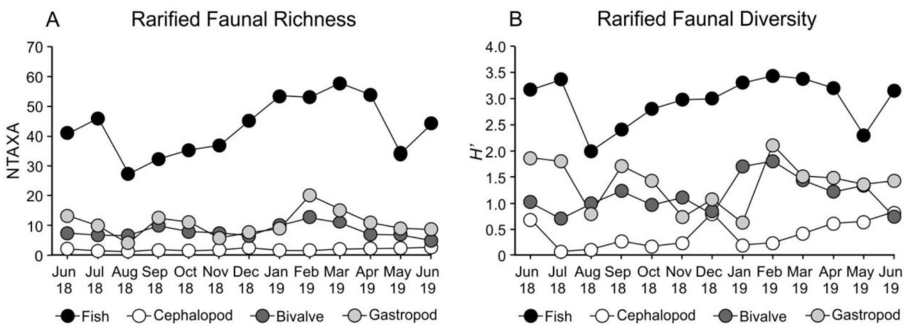

FIGURE 3
Rarified faunal richness (NTAXA) by month **(A)**; rarified faunal diversity (H') by month **(B)**.

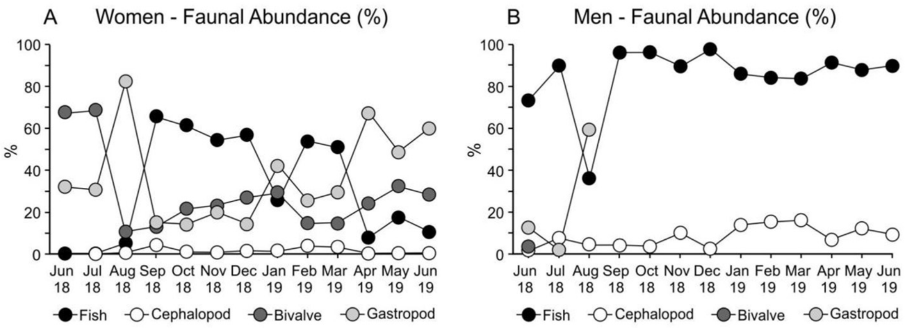

FIGURE 4
Proportional faunal abundance for women **(A)** and men **(B)**.

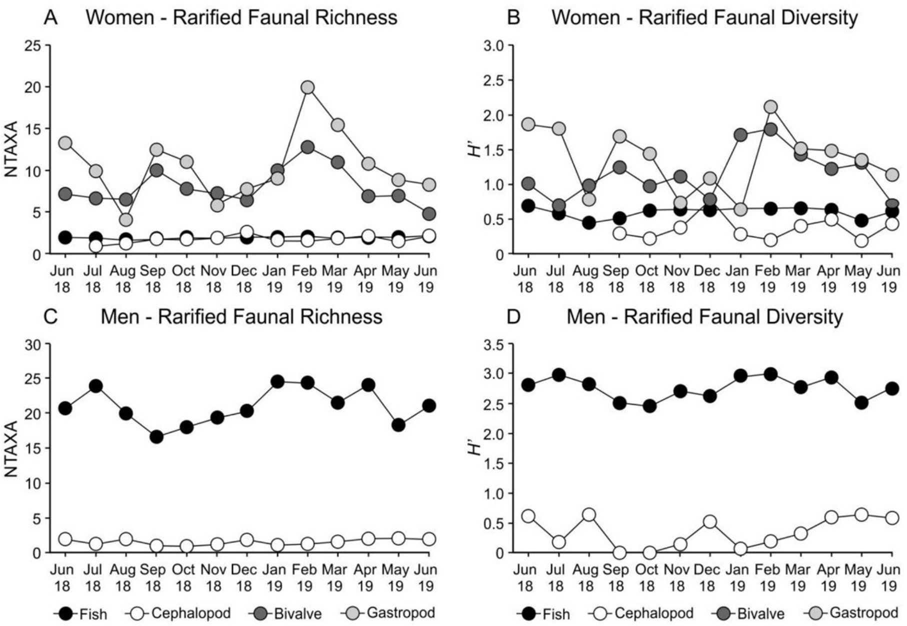

FIGURE 5
Rarified faunal richness **(A)** and rarified faunal diversity **(B)** for women, and rarified faunal richness **(C)** and rarified faunal diversity **(D)** for men.

based on the rarefied data. The cephalopods show only minor fluctuations by month in richness, with the major peaks in diversity occurring in December 2018, April and June 2019. The trends in mollusk harvesting are similar in many respects, only differing by the order of magnitude in the shifts in richness and diversity. The major peaks and troughs in species richness and diversity for both the gastropods and bivalves run in parallel for much of the year, peaking in June/July (2018), September/October and February/March for the gastropods, with bivalves represented by relatively lower values in June and July 2018 being the major difference.

For men, only the rarefied fish and cephalopod NTAXA and Shannon H' data can be plotted by month (Figures 5C, D) due to the small sample size and restricted monthly distribution of gastropods and bivalves. The cephalopods show a minor increase in the number of species and diversity of species acquired in June (2018), August, December and through April to June 2019. The fish NTAXA and Shannon H' values also parallel each other, with higher fish species richness in July, January/February and April, lower values in September and May, with gradual transitions between these peaks and troughs.

4.2 Seasonality

To further investigate seasonality influences in marine resource use, the fishing data for men and women, and the gastropod and bivalve shellfish harvesting data for women are considered in more detail below. These data provide a more robust sample from across the year sampled at Mfumbwi in comparison with the smaller sample of seasonally restricted cephalopod, crustacean and men's shellfish harvesting data.

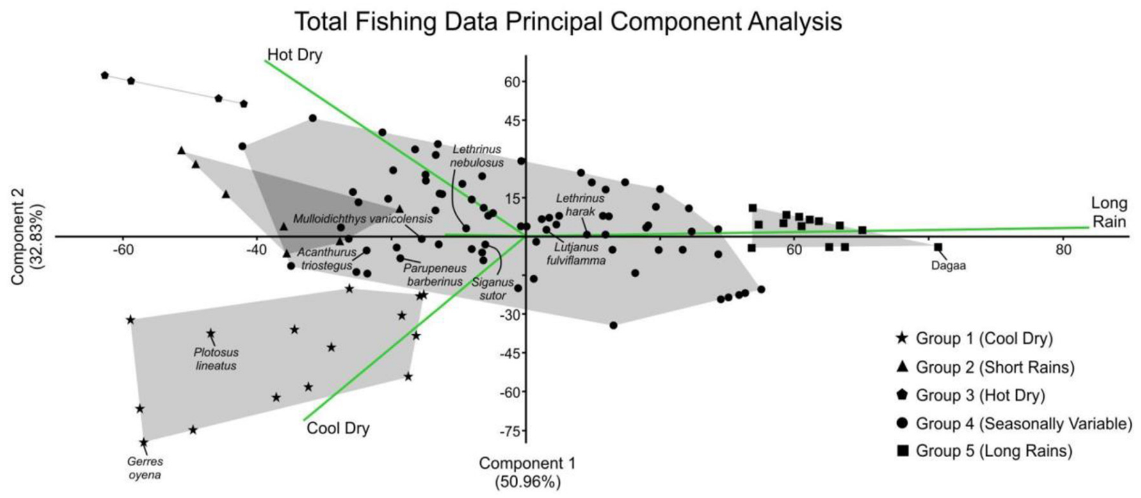

FIGURE 6
Principal Component Analysis biplot of total fishing data and seasonal groups.

Five clusters are apparent in the combined fishing PCA (Figure 6). This figure also shows the 10 dominant fish taxa, which together comprises 64.0% of the total dataset. Group 1 comprises 25 species caught largely during the cool dry season. Of these species, 11 were caught only during the cool dry, with the remaining 14 species characterized by a dominant cool dry occurrence with minor to moderate seasonal dispersion. This group includes *Gerres oyena* (n = 1,919, 17.5% total) and *Plotosus lineatus* (n = 365, 3.3% total). Group 2 contains 11 species that were caught primarily during the short rainy season, with five species occurring during that season only. The remaining six species also display variable degrees of seasonal dispersion outside of the dominant short rain season, largely during the hot dry. Group 3 is largely restricted to the hot dry season, with 11 of the 15 species in this group only occurring during that season. The remaining four species show a minor occurrence in the long rainy season, proportionally ranging between 3 and 17%. The largest of the clusters situated in the center of the PCA plot, Group 4 contains 81 fish species that show variable seasonal distributions. None of these species fall easily within the other four groupings and their dominant seasons (although there is overlap with Group 2), having been caught over multiple seasons with at least two of these seasons exhibiting a more even proportional distribution in comparison with the other groups. Group 4 includes *Lutjanus fulviflamma* (n = 1,085, 9.9% total), *Siganus sutor* (n = 1,044, 9.5% total), *Lethrinus harak* (n = 558, 5.1% total), *Parupeneus barberinus* (n = 414, 3.8% total), *Mulloidichthys vanicolensis* (n = 299, 2.7% total), *Lethrinus nebulosus* (n = 291, 2.6% total), and *Acanthurus triostegus* (n = 241, 2.2% total). Containing 44 species, Group 5 largely occurs during the long rainy season, with 31 of these species only occurring during that season. The other 10 species show a minor to moderate dispersion into the hot dry and short rain seasons, with only one of these species having been caught during the cool dry. This group is dominated by *dagaa* (n = 815, 7.4% total).

Separating out the fishing data by men and women highlights some differences in seasonal exploitation. Five groups have been identified relative to women's fishing, with there being some overlap between several of these groups (Figure 7A). Here the dominant 10 fish taxa are labeled, comprising 67.4% of the catch of women. Group 1 contains 19 species that were predominantly caught during the cool dry, with 10 species extending into other seasons at lower proportional abundance. *Gerres oyena* (n = 1,550, 20.1%) and *Plotosus lineatus* (n = 286, 3.7%) fall within Group 1. The 18 species within Group 2 were primarily caught in the short rain season, with 12 of these species extending into other seasons. There is substantial overlap with the species in Group 4, illustrating the degree of variability in seasonal influence within and between these two groups. Group 3 contains 12 species that represent catch during the hot dry, with only one species also caught during the long rainy season. Group 4, the largest with 56 species, shows a broader (and somewhat more even) seasonal distribution in comparison with the other groups, encompassing the hot dry, long rain and cool dry seasons in terms of abundance, although 40 of these species were caught across all four seasons. Group 4 contains *Lutjanus fulviflamma* (n = 751, 9.7%), *Siganus sutor* (n = 701, 9.1%), *Lethrinus harak* (n = 330, 4.3%), *Parupeneus barberinus* (n = 243, 3.2%), *Acanthurus triostegus* (n = 187, 2.4%), *Pardachirus marmoratus* (n = 167, 2.2%), and *Mulloidichthys vanicolensis* (n = 165, 2.1%). Group 5 contains 48 species, including *dagaa* (n = 815, 10.6%), with exploitation concentrated in the long rainy season. Twenty-one of these species occur in lower proportional abundance in one or more other seasons, albeit less so within the short rains with only five species.

The men's fishing PCA biplot shows a different pattern to that described for the data for women above, with 6 groups identified (Figure 7B) and the ten dominant taxa comprising 60.1% of men's catch. Containing two species, Group 1 is largely confined to the cool dry season, with one of these species also having been caught during the long rains. Group 2 represents four species that were only caught during the short rainy season. Group 3 comprises 18 species that were primarily caught during the hot dry season, with minimal occurrence in other seasons (only six species). Group 4

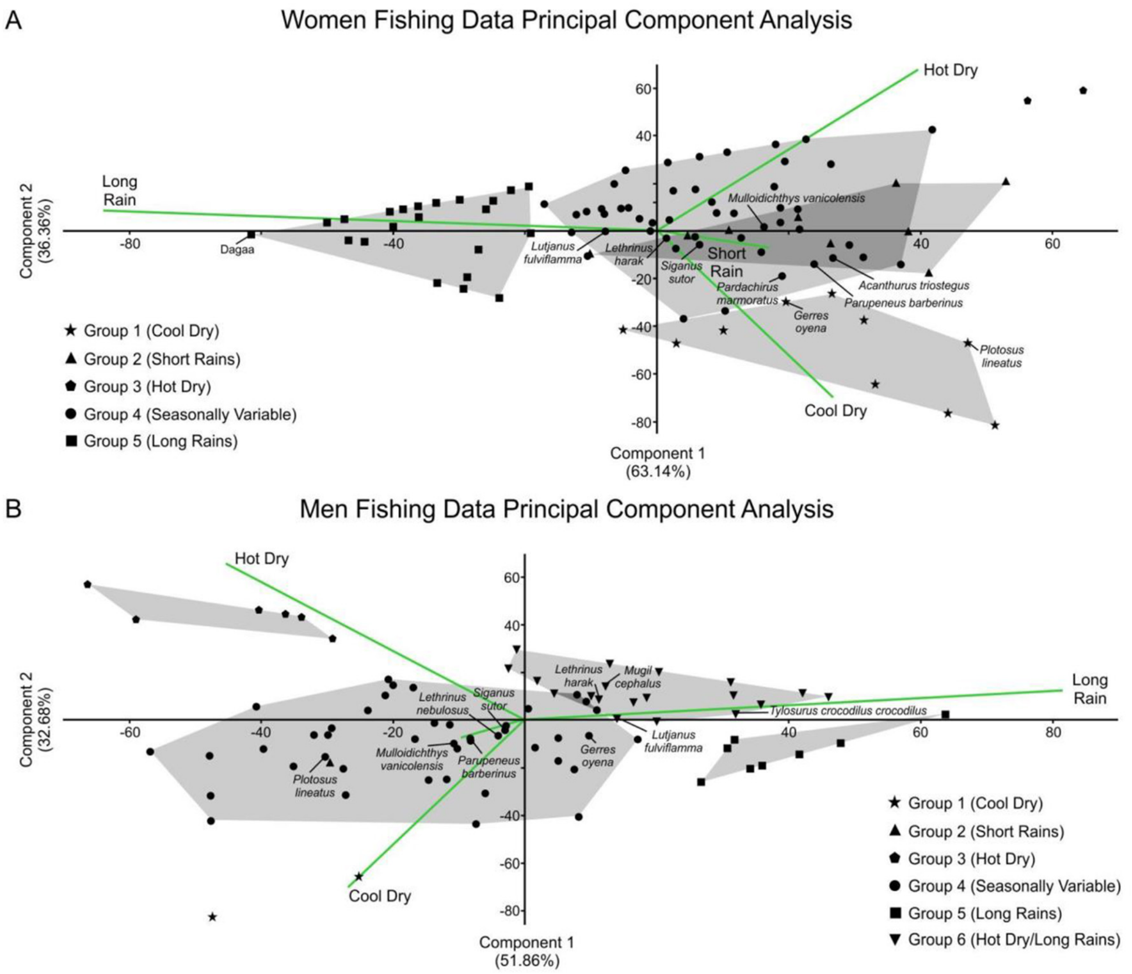

FIGURE 7
Principal Component Analysis biplot of women's **(A)** and men's **(B)** fishing data and seasonal groups.

contains 44 species, showing a more even seasonal distribution in comparison with the other men's fishing species groups, distributed across all seasons in terms of primary abundance. This group is similar in many respects to the women's Group 4 described above. Group 2 contains *Gerres oyena* ($n = 369$, 11.3%), *Siganus sutor* ($n = 343$, 10.5%), *Parupeneus barberinus* ($n = 171$, 5.2%), *Mulloidichthys vanicolensis* ($n = 134$, 4.1%), *Lethrinus nebulosus* ($n = 133$, 4.1%), and *Plotosus lineatus* ($n = 79$, 2.4%). Group 5 contains 33 species that are largely confined to the long rainy season, with seven of these species also having been caught during the cool dry in lower numbers. The 28 species falling within Group 6 were primarily exploited during the hot dry and long rainy seasons, with 11 of these species extending into the other two seasons at lower proportional abundances. Within Group 5 are *Lutjanus fulviflamma* ($n = 334$, 10.2%), *Lethrinus harak* ($n = 228$, 7.0%), *Tylosurus crocodilus crocodilus* ($n = 107$, 3.3%), and *Mugil cephalus* ($n = 70$, 2.1%).

Interestingly, there are 59 fish species that do not occur in the fishing datasets for both men and women, 37 of which were caught by women only, and 22 by men only. For women fishers, these taxa generally range in number for the year from one to seven (0.01%−0.09% of the yearly total), with higher numbers recorded for *Caesio caerulaurea* ($n = 13$, 0.17%), *Decapterus russelli* ($n = 16$, 0.21%), and the *dagaa* ($n = 815$, 10.6%). For male fishers, the number of individuals per taxon ranges from one to eight, comprising 0.03 to 0.24% of the yearly men's catch, respectively. While there is some overlap in the clusters shown in the PCA plots above, for these species there are much clearer seasonal differences. Twenty-seven species were primarily caught during the long rains (18 by women, nine by men), 15 species primarily during the hot dry with some overlap into the long rain (seven by women, eight by men), 11 species caught during the cool dry (seven by women, four by men), and six species in the short rains (five by women, one by men). A further 59 fish species were caught by both women and men. Although these taxa show slightly different proportional distributions across the four seasons (Figure 8), the majority of fish taxa caught by both women and men largely fall within the same respective seasonal groupings. This is illustrated by the 12 fish taxa highlighted on Figure 8 that were identified above as being the dominant taxa overall and/or by women or men. The majority of these taxa fall close together seasonally, and all were caught across all four seasons. For example, *Acanthurus triostegus*, *Lethrinus harak*, *Lethrinus nebulosus*, *Lutjanus fulviflamma*,

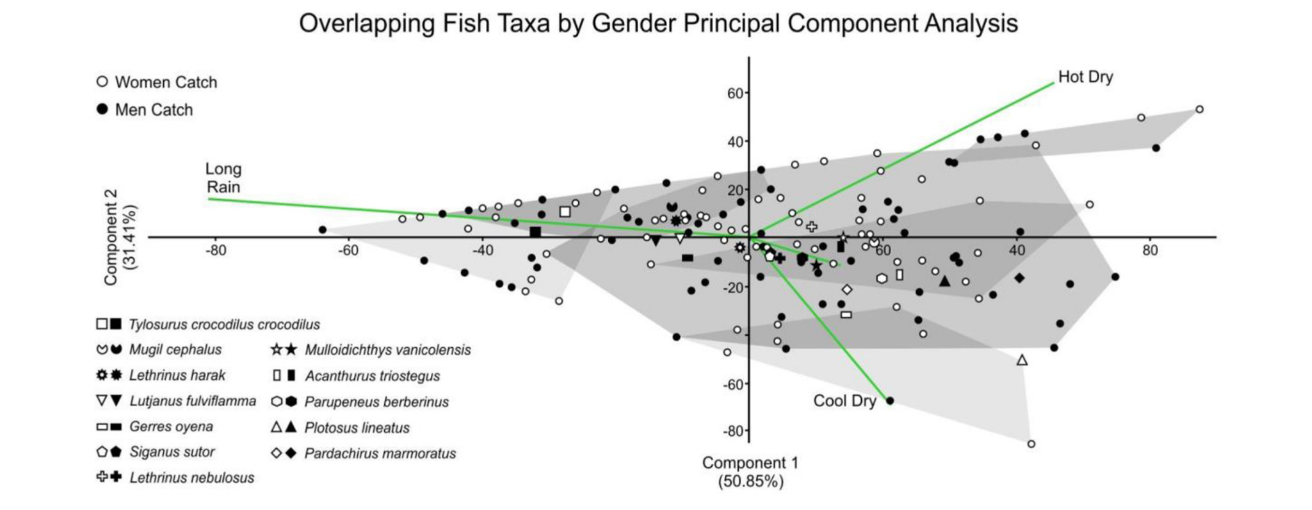

FIGURE 8
Principal Component Analysis biplot of overlapping fish taxa caught by women and men.

Mulloidichthys vanicolensis, *Parupeneus berberinus*, *Siganus sutor*, and *Tylosurus crocodilus crocodilus* show similar patterns of seasonal exploitation by women and men with only minor proportional seasonal differences. In comparison, *Gerres oyena*, *Mugil cephalus*, *Pardachirus marmoratus*, and *Plotosus lineatus* are also caught across four seasons, however there are proportional differences relative to the main season in which these taxa were caught by women and men. This degree of seasonal overlap in catch by women and men is common in the fishing data from Mfumbwi. Although represented by small numbers of individuals each (ranging between two and 11), only eight taxa were caught by women and men in different seasons, these being: *Abudefduf saxatilis* (F = Cool Dry, M = Hot Dry); *Chaetodon bennetti* (F = Long Rain, M = Short Rain); *Epinephelus polyphekadion* (F = Long and Short Rain, M = Cool Dry); *Heniochus acuminatus* and *Platax teira* (F = Short Rain, M = Hot Dry and Long Rain); *Scorpaenopsis venosa*, *Thunnus albacares*, and *Zanclus cornutus* (F = Hot Dry, M = Long Rain).

Women's shellfish harvesting also demonstrates clear seasonal differences within and between bivalve and gastropod taxa. The PCA blot of bivalves harvested by women shows a set of five clearly distinguished species groups (Figure 9A), with the 10 dominant taxa comprising 98.2% of the bivalves collected by women over the course of the year. Group 1 is a cluster of five bivalve species, *Gafrarium pectinatum* (*n* = 28,088, 65.9%), *Anadara antiquata* (*n* = 6,803, 16.0%), *Mactrotoma ovalina* (*n* = 417, 1.0%), *Anodontia edentulina* (*n* = 242, 0.6%), and *Modiolus auriculatus* (*n* = 162, 0.4%), largely characterized by harvesting during the long rain and cool dry seasons, with three of these species also showing a minor occurrence during the hot dry season (between 3 and 5%). Group 2 is the largest of the bivalve groups, containing 17 species that were predominantly harvested during the long rainy season. This Group includes *Pinna muricata* (*n* = 4,122, 9.7%) and *Meropesta nicobarica* (*n* = 150, 0.4%). Ten of these species show a minor to moderate dispersion into one or more seasons outside of the long rains, with two of these species having been harvested throughout the year, albeit in much lower proportions. The five species within Group 3 demonstrate a more even seasonal distribution, including *Donax incarnatus* (*n* = 1,431, 3.4%), with three of these species occurring across all four seasons. As such these species do not exhibit as strong a seasonal influence as the other four groups. Group 4 contains seven species, five of which were harvested during the hot dry season only, with the other two species also present in proportionally lower abundances in the long rain and cool dry seasons. Group 4 contains *Barbatia decussata* (*n* = 225, 0.5%) and *Semele radiata* (*n* = 225, 0.5%). Group 5 contains a single species that occurs only during the short rain season.

Similar to the data of women's harvesting of bivalves, the PCA plot of gastropods harvested by women shows seasonal separation, in this case into four groups of species (Figure 9B). Also depicted are the 10 dominant taxa that together comprise 89.4% of the gastropods harvested by women. Group 1 contains 11 species that were primarily harvested during the cool dry, with six of these species also occurring in one or more of the other seasons, albeit at much lower proportional abundances. This group contains *Conomurex decorus* (*n* = 4,104, 11.3%), *Vasum rhinoceros* (*n* = 1,520, 4.2%), *Lentigo lentiginosus* (*n* = 1,143, 3.1%), *Cassis cornuta* (*n* = 579, 1.6%), *Nassarius echinatus* (*n* = 682, 1.9%), and *Nassarius arcularia* (*n* = 267, 0.7%). Twenty-three species occur within Group 2, including *Semiricinula konkanensis* (*n* = 384, 1.1%). These gastropods were largely harvested during the long rainy season, although seven species also occur during the hot or cool dry seasons leading into and out of the long rains, respectively (but not both). The largest of the gastropod species clusters, Group 3 is comprised of 27 species that are variably distributed across the hot dry, long rain and cool dry seasons, thereby showing comparatively less of a seasonal influence on harvesting than the other groups described here. Within this group there was minimal harvesting during the short rains (only five species with proportional abundance between <1 and 5%). Gastropod taxa in this Group includes *Gibberulus gibberulus* (*n* = 15,153, 41.7%), *Volema pyrum* (*n* = 7,449, 20.5%), and *Nassarius*

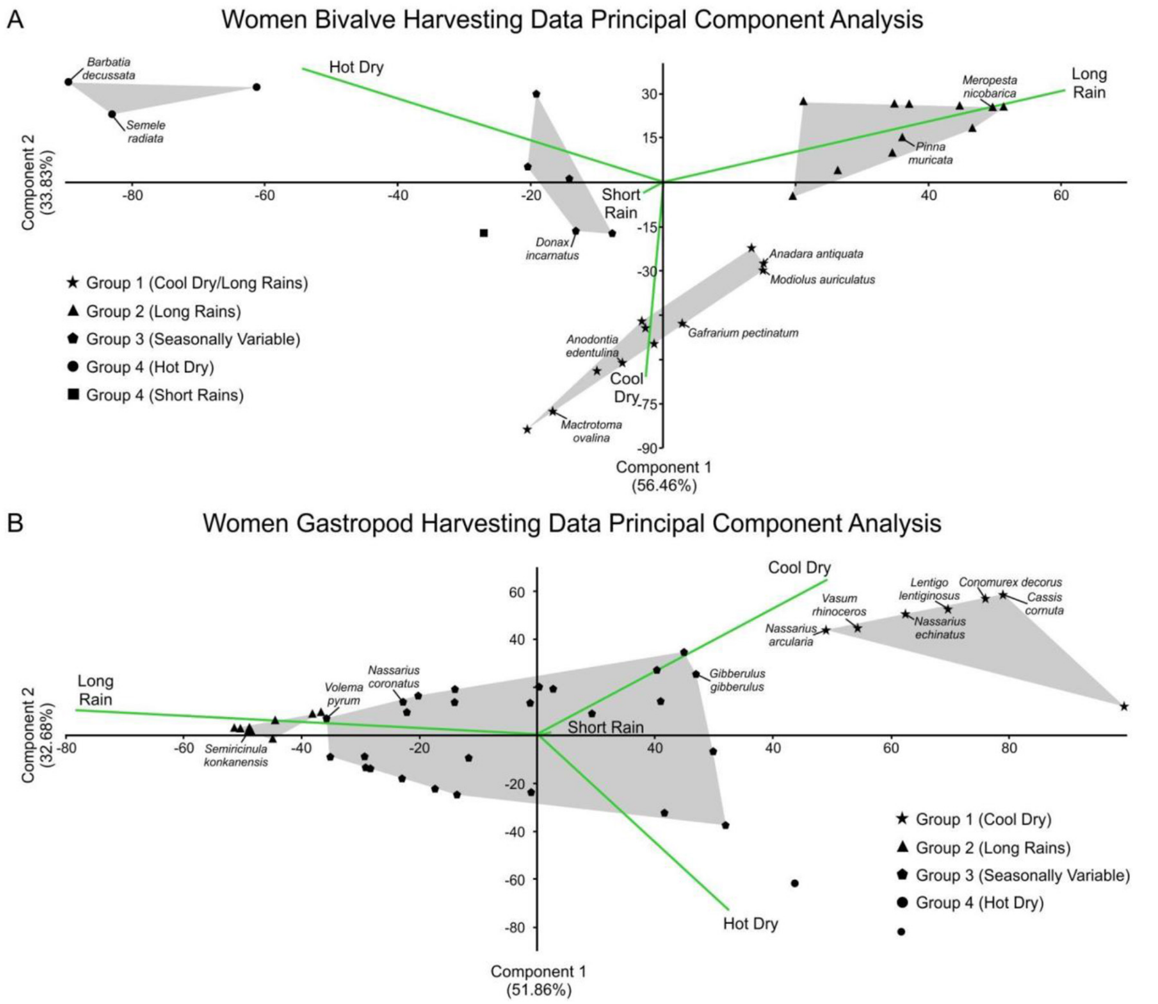

FIGURE 9
Principal Component Analysis biplot of women-harvested bivalve **(A)** and gastropod **(B)** data and seasonal groups.

coronatus (n = 3,434, 9.5%). Group 4 contains eight species that were harvested during the hot dry season. Only one species in this group was harvested outside of that dominant season, also occurring within the long rain and cool dry seasons at 17 and 4%, respectively.

5 Discussion

5.1 Key findings

Although all marine resources were available and acquired throughout the year, there are substantial differences in the major taxonomic groups in terms of their proportional contribution, richness and diversity per month. Importantly there is no simple direct or inverse relationship between the faunal categories by month in any of these values, with each category appearing to track relatively independently over the year (possibly with the exception of the fish and gastropod proportional abundance). These trends are largely replicated in the fishing and shellfish foraging proportional faunal data of women by month. The men's data indicate a greater emphasis on fishing, with foraging being a very minor component with harvest of mollusks in only three months of the year. As such richness and diversity for the women's data is much more variable, particularly for mollusk foraging, with rarified richness and diversity for both men and women being comparatively more stable across the year. However, this could be an artifact of men's patchy participation in the data collection process.

The fish seasonality data indicates that the majority of taxa are available and were caught across multiple seasons (67.04% of taxa). Although there is a seasonal influence apparent to greater or lesser degrees, the dominant category of fish taxa by season of capture is characterized as being more consistent with less of a specific seasonal influence. This is also a hallmark of the seasonal fish distribution by gender, although there are some often subtle differences in the season of catch between men and women for the same taxa, with marked seasonal differentiation by gender for a small number of taxa. Patterns of seasonal availability and harvest in the women's bivalve and gastropod foraging data are different to that seen in the fishing data. For the gastropods there is a comparatively lower proportion of taxa harvested across multiple seasons (54.42% of taxa), with the bivalves having a higher proportional distribution across multiple seasons (82.86% of taxa). Importantly, even where there may have been a primary season of catch/harvest, the majority of the dominant fish (falling between 60.1 and 67.4% depending on whether the total in the catch data for either men or women are considered), bivalve and gastropod taxa (at 98.2 and 89.4%, respectively) have relatively broad seasonal distributions.

These findings reinforce the perspectives prevalent in the ethnographic literature about the diversity of subsistence resources acquired from marine habitats, and the differential distribution of these resources between men and women. In warmer, less seasonal regions, men will forage to a greater degree than seen in temperate areas, with women fishing for more reliable species in terms of their returns, creating a comparatively greater overlap with the activities undertaken by women, thereby decreasing the sexual division of economic behavior (Bird, 2007; Marlowe, 2007; Jones, 2011). With women being the primary producers of resources acquired from nearshore habitats, our data emphasizes the broad overlap in fishing activity between men and women, with greater separation apparent in foraging activity.

These key findings provide the baseline trends for understanding differential resource acquisition and seasonality at Mfumbwi, something that is required to establish the foundation for further analyses and comparison with contemporary and past datasets, however what is not yet factored into the analyses presented above is a consideration of what may be driving the patterns observed. These are complex issues that are, as yet, unable to be addressed, however they form part of the discussion around future research in the region below.

5.2 Ethnographic significance

The MS-1819 dataset offers a high-resolution window onto how people, places, seasons, and species are intertwined in everyday maritime life at Mfumbwi. Several ethnographic insights emerge from our analysis of this dataset:

1. Gendered ecologies and labor portfolios: women's harvesting and men's fishing are not simply different activities; they map onto different ecozones, mobilities, and time budgets. Women's stronger engagement with intertidal molluscs reflects work that can be interleaved with childcare and household responsibilities, while men's emphasis on finfish and cephalopods is tied to higher mobility, risk, and market visibility (Jochim, 1988; Venkataraman et al., 2024). The dataset therefore documents how gender is a primary factor determining access to species and ecozones, and why women's contributions remain undercounted when only market landings are considered. These patterned differences are visible in the proportional abundances and rarefied diversity measures by gender, as well as in the PCA clustering that separates men's and women's seasonal catch profiles.
2. Seasonality as a cultural rhythm as much as an environmental driver: the seasonal signals noted here are clearly refracted through gendered lenses that determine what is captured, when, and by whom. The PCA groupings make explicit that "seasonality" is rarely a simple on/off switch (see also Silas et al., 2023); instead it produces mosaics of practice that are legible only when read alongside gendered access, transport, gear, and daily routines.
3. Technology, markets, and tourism as determining factors in subsistence: adoption of spearguns, synthetic lines, and refrigeration/freezing has altered when and how resources are acquired, stored, and traded, thereby changing the social pathways that leave archaeological traces. Tourism reshapes men's schedules and repurposes vessels; women report altered beach access and safety concerns. These entanglements help explain why some taxa rise or fall in particular months independent of purely ecological cues. This is explored in further detail below.
4. Diversity, redundancy, and household security: women's shellfish collecting and men's fishing constitute a complementary portfolio that spreads risk across habitats and taxa. The dataset shows broad seasonal distributions for dominant taxa, suggesting that people maintain dietary and economic buffers by switching gears, grounds, or targets rather than relying on narrow seasonal peaks. This redundancy is a hallmark of small-scale subsistence systems and underpins food security.
5. Community knowledge as management-relevant evidence: because the MS-1819 Dataset records who went, where, with what, and what returned, it translates fine-grained, lived knowledge into a format that can inform local management. The observed gender-season intersections caution against one-size-fits-all rules (e.g., closures that unintentionally displace women's intertidal harvesting) and argue for co-management that recognizes differentiated access, risks, and knowledge.

Taken together, these findings frame Mfumbwi not as a residual "traditional" system but as an adaptive, information-rich social ecology in which gender, season, and technology co-produce subsistence outcomes. Whereas earlier research emphasizes seasonality as a broad environmental determinant, the MS-1819 dataset demonstrates that gendered divisions of labor mediate how seasonality is experienced and enacted. This seasonal skew by gender parallels but also makes more nuanced Fröcklin et al.'s (2014) findings of gendered spatial segregation in Chwaka Bay, suggesting that environmental variability alone cannot explain labor differentiation without attention to social constraints and domestic schedules determined by prevalent ideologies. Moreover, the relative taxonomic stability observed across seasons in the Mfumbwi dataset—where most dominant taxa occur year-round—echoes the ecological redundancy and opportunistic flexibility described by Jiddawi (2012) and Silas et al. (2020), but the ethnographic data clarify that such continuity results from deliberate behavioral buffering rather than uniform species availability. The interplay of gendered mobility, access to gear, and the demands of the tourist economy thus introduces new interpretive dimensions to the antecedent literature: rather than treating Zanzibar's small-scale fisheries as environmentally constrained systems, the Mfumbwi evidence highlights them as socially differentiated, risk-managed ecologies whose rhythms arise as much from cultural negotiation as from monsoon cycles.

5.3 Archaeological interpretation

The MS-1819 dataset was designed as an ethnoarchaeological baseline, and the results have direct implications for how we read marine fauna in archaeological contexts and in reconstructing East African historical ecology.

1. Seasonality is not a proxy you can assume from presence: because most dominant taxa occur across multiple seasons, the presence of a given fish or shellfish taxon in an assemblage cannot be taken as a direct indicator of a single season of site use. The PCA clusters show primary seasonal tendencies, but the wide distributions in the rarefied NTAXA and Shannon H' curves demonstrate substantial overlap. However, most taxa are able to be caught or harvested across multiple seasons. Seasonality in the archaeofaunal record therefore requires independent lines of evidence (e.g., shell growth increments, otolith microstructure, isotopes) to corroborate inferences (see Kwiecien et al., 2022 for a discussion on the complexities of understanding seasonality in the archaeological record).
2. Gendered access creates structured sampling of the habitat mosaic: if women and men harvest different ecozones with different frequencies and gears, then the archaeological signature of a household, neighborhood, or site will reflect who contributed which remains and when—at least in theory. Intertidal mollusks with women's collection signatures may co-occur with finfish obtained during men's offshore trips, producing mixed signals in single deposits. This helps explain why richness and diversity trends do not track inversely between categories and why equifinality is a persistent interpretive risk (Bailey, 2007). Furthermore, archaeologists deal with palimpsests and contexts created by multiple depositional events (both short-term and long-term) and by multiple agents (e.g., men and women, and often even non-human actors). We may not be able to identify gendered differences in discard archaeologically, given the often communal and haphazard nature of garbage dumping, but we must at least attempt to make out gendered patterns of discard.
3. Social practices precede discard and shape visibility: the dataset documents pre-discard processes—capture, processing, sharing, storage, and trade—that act as social filters on what ultimately enters refuse contexts. Refrigeration/freezing and motorized redistribution can disarticulate catch location from discard location; tourism labor can shift harvest to odd hours or reduce it altogether; gear changes can alter size profiles and skeletal part representation. These processes are archaeological in effect even though they are ethnographic in description.
4. Linking quantitative patterns to analytical strategies: observed differences in gendered taxa rosters and seasonal clusters suggest specific analytical payoffs:

    a. Shell sclerochronology and isotopic profiling to test whether archaeological valves record the broad seasonal envelopes seen ethnographically rather than narrow peaks.
    b. Otolith microchemistry and size-frequency analyses to distinguish nearshore vs. offshore contributions that plausibly track gendered access and transport regimes.
    c. Element and cut-mark patterning to evaluate gear shifts that would change size spectra and butchery signatures (e.g., spearing vs. netting).
    d. Multiproxy community composition metrics (NTAXA, rarefied H') applied to stratified deposits to detect shifts in redundancy vs. specialization through time (Giovas, 2021).

5. Caution against simplistic analogical reasoning and presentism: because present-day practices incorporate modern materials, market/tourism effects, and current gender ideologies, analogies must be framed as structured comparisons rather than direct mappings. The value of MS-1819 is not in asserting that "the past looked like this," but in providing falsifiable expectations about how gender, seasonality, technology, etc., interact to generate assemblage properties under known conditions. Archaeological tests can then assess whether similar interaction patterns operated in earlier periods. This allows for the evaluation of both similarity and difference across time and space (taking into account various locally-relevant factors), the establishment of contextually-based relevance, and the evaluation of the strength and robustness of analogical relationships between the present and the past (Wylie, 1985; Wolverton and Lyman, 2000; Ravn, 2011).
6. Site formation expectations for Swahili coastal contexts: where assemblages derive from locales integrating intertidal and reef-edge use, we should expect: mixed seasonal signals within single contexts; co-occurrence of broad-season taxa; uneven representation of cephalopods relative to finfish and mollusks (if they preserve archaeologically at all); and deposit-to-deposit variability tracking household composition or taskscape differences. These expectations are consistent with the observed proportional abundance swings and the strong woman-skewed shellfish signal in MS-1819.

In sum, MS-1819 encourages archaeologists to replace single-cause seasonal and habitat inferences with models that foreground intersecting social filters—especially gendered access and technology—prior to discard. It thus repositions "taphonomy" to begin at capture and provisioning rather than at the midden, offering concrete proxies and tests for sites across the Swahili coast.

5.4 Implications for marine ecosystem management

The MS-1819 dataset translates everyday subsistence decisions into ecosystem-management-ready evidence. Because it links people (who), practices (how), places (where), times (when), and taxa (what), it can inform management in some concrete, scalable ways. The creation of baselines for ecosystem management must take into account humans and their activities (past and present) by integrating the long archaeological record into modern socio-ecological contexts and contemporary datasets (see for instance Salomon and McKechnie, 2025).

1. Gender-aware co-management: women's intertidal harvesting and men's offshore/reef fishing contribute differently to

household nutrition and income. Regulations and support programs should be co-designed with both groups to avoid unintended burdens (e.g., closures that disproportionately affect women's gleaning). Practical actions include issuing intertidal harvesting permits in women's names, recognizing women's leadership in beach committees, and scheduling consultations at times compatible with caregiving.

2. Habitat-specific rules, not one-size-fits-all: because gear, access, and risk vary by habitat (intertidal, reef edge, nearshore/offshore), rules should be habitat-tuned:

    a. Intertidal: rotating micro-closures on heavily used flats, temporary no-take zones for key mollusks during peak reproductive windows, and minimum harvest sizes that are actually measurable in the field.
    b. Reef/nearshore: seasonal effort caps that track sea-state rather than fixed calendar months; area-based limits where tourism vessel traffic displaces small boats.
    c. Offshore: by-gear effort controls (trip limits or soak-time caps) instead of blanket species bans that are hard to enforce.

3. Effort (not just catch) monitoring: MS-1819 shows that availability signals are filtered through labor, sea conditions, and tourism work. Management should monitor and manage effort (trips, hours, gears, crew size) alongside landings. Simple, low-burden logbooks or phone-based tally sheets (designed with fishers and shellfish harvesters) can extend this dataset into a routine monitoring system.
4. Size spectra and gear selectivity as health indicators: observed shifts in size composition and target species across different types of gear offer quick diagnostics of fishing pressure. Managers can adopt size-based indices (median and interquartile size by gear) as early-warning indicators and adjust gear-specific rules (mesh sizes, spear use near nursery habitats) before biomass declines are visible in catch totals.
5. Redundancy and portfolio management: households buffer risk by switching habitats, gear, and taxa. Management should protect this "portfolio effect" by avoiding policies that force narrow specialization (e.g., licensing tied to a single gear). Supporting gear repair funds, fuel cooperatives for small boats, and safe access paths to beaches sustains switching capacity and food security.
6. Spatial planning that preserves access corridors: women's reports of beach access constraints and men's reallocation of boats for tourism suggest that infrastructure and tourism zoning affect who can reach which grounds. Use participatory mapping to identify harvesting corridors, launch points, and conflict zones; then encode them in local marine spatial plans (e.g., time-sharing of boat ramps; buffer rules around hotel seawalls).
7. Nutrition-sensitive management metrics: because shellfish and small fish contribute substantially to everyday diets, track nutrient-dense taxa (iron, zinc, omega-3 proxies via species lists and size classes) rather than only revenue species. Management success should include stable access to these foods, not just biomass or export value.

In short, MS-1819 is not just a description of "what people catch." It is a management-ready template that links social practice to ecological outcomes. By centering gendered access, habitat-specific effort, and lived seasonality, it supports co-management that is more equitable, more enforceable, and more likely to protect both livelihoods and stocks.

5.5 Future research directions

The MS-1819 dataset captures a detailed snapshot of how environmental, social, and technological variables intersect to shape maritime subsistence at Mfumbwi. Yet these findings also point toward several promising lines of future research that could refine both archaeological interpretation and fisheries management. Rather than treating biological, climatic, and cultural variation as confounding factors, future work should explore them as productive lenses through which to understand the dynamism of coastal livelihoods and their archaeological legacies.

5.5.1 Biological processes and ecological rhythms

The biological structure of the marine environment around Mfumbwi (e.g., short-lived taxa, rapid reproductive cycles, and habitat-linked ontogeny) introduces variability that remains only partially understood. Future research could examine how spawning aggregations, larval dispersal, and predator–prey mobility shape not only availability but also the temporal clustering visible in daily or monthly catches. Linking ecological monitoring to ongoing ethnoarchaeological sampling would clarify whether fluctuations in abundance reflect biological pulses or socially mediated scheduling decisions. Likewise, systematic studies of gear selectivity (especially the interaction between mesh aperture, fish size, and cohort turnover) could reveal how specific technologies amplify or filter ecological signals. Such work would improve our capacity to interpret temporal patterning in both ethnographic and zooarchaeological assemblages.

5.5.2 Climatic variability and local environmental knowledge

Because the MS-1819 climatic data derive from Kisauni rather than from Mfumbwi itself, future studies should prioritize site-specific environmental monitoring. Deploying local weather sensors and combining them with fisher and gatherer observations could produce a fine-grained record of how tides, wind, rainfall, and sea temperature structure access to different ecozones. This would enable researchers to separate environmental forcing from social or cultural scheduling effects and to test how seasonal predictability (and its erosion due to climate change) shapes both labor allocation and resource resilience. Long-term monitoring that aligns environmental and subsistence data could also serve as a model for integrating indigenous temporal frameworks and instrumental climate records, reinforcing the MS-1819 project's commitment to collaborative, community-based research.

5.5.3 Cultural, technological, and economic transformations

Perhaps the most promising direction for future work lies in tracing how technological and economic change reconfigures subsistence practice. The introduction of rubber-powered spearguns, synthetic lines, and metal hooks represents a shift from locally produced to market-mediated and industrially produced implements, with likely consequences for species composition, size profiles, and skeletal element representation. Experimental replication and comparative studies could quantify these effects, helping archaeologists distinguish between technological and environmental causes of variability in faunal assemblages. The growing accessibility of refrigeration and motorized transport has likewise altered how catches circulate and are consumed, decoupling capture from discard. Research tracking how freezing, storage, and inter-village trade redistribute marine fauna could clarify how modern infrastructure obscures taphonomic signatures that were once tightly linked to daily subsistence.

Tourism, too, reshapes Mfumbwi's maritime landscape. Men increasingly adjust fishing schedules or repurpose vessels for tourism work, while women report changes in access, safety, and comfort along the reef flats. These observations suggest that future ethnographic and archaeological research must treat tourism as part of the evolving "social taphonomy" of the coast—a process that reorganizes labor, redefines beachscapes, and transforms how and where marine resources are handled (see Schiffer, 1983). Parallel attention should also be given to household meat production (e.g., ducks, chickens, goats, and cattle) which intersects with marine resource use and may modulate dietary signals over the annual cycle.

In sum, the MS-1819 dataset underscores that subsistence at Mfumbwi (and by extension, on the Swahili coast) is best understood as a moving system rather than a static analog. Future research that links biological monitoring, climatic recording, and ethnographic observation will not only refine archaeological interpretation but also strengthen community-based management of coastal resources. By following these lines of inquiry, subsequent work can transform the MS-1819 dataset from a descriptive baseline into a comparative framework for understanding the social ecologies of maritime subsistence across the Indian Ocean world. Taken together, these prospective avenues return us to the central argument of this study: that seasonality, gender, and technology operate not as isolated variables but as co-produced dimensions of social taphonomy. By treating the biological, climatic, and cultural dynamics outlined above as ongoing processes rather than background conditions, future research can extend the MS-1819 framework beyond Mfumbwi—testing how everyday choices about when, where, and how to harvest marine fauna become the patterned traces that archaeologists recover. In this way, the study of Mfumbwi becomes not an endpoint but a generative model for integrating ethnography, ecology, and archaeology along the Swahili coast and across the wider Indian Ocean world.

6 Conclusion

The ethnographic record from Mfumbwi, alongside the modern socio-ecological literature summarized above (Section 2.2), illustrates that maritime subsistence along the Swahili coast is an "ecocultural act" in which gender, technology, and seasonality are entangled dimensions rather than discrete variables. The MS-1819 dataset shows that men and women engage overlapping yet distinct spatial and temporal regimes of exploitation, shaped as much by seasonality and gender ideology as by the availability of various marine taxa. These intersecting influences produce an ethnographic landscape where ecological and cultural variability cannot be neatly separated. The apparent stability in species richness and diversity across seasons, for example, reflects not environmental uniformity but the capacity of households to buffer uncertainty through diversified, gendered labor. This finding challenges models that treat subsistence seasonality as an environmental constraint and instead situates it as a social rhythm embedded in everyday life.

From an archaeological perspective, these results demonstrate that cultural and technological processes (capture, sharing, preservation, and discard) should be regarded as taphonomic events in their own right. The formation of the faunal record begins long before bones and shells reach the ground. The MS-1819 dataset offers empirical traction on this principle: gendered access, technological mediation, and infrastructural change all shape what is ultimately preserved, transported, or consumed. By foregrounding these pre-discard processes, this study contributes to an expanded taphonomy that repositions the social and the ecological as co-constitutive forces in assemblage formation. In this sense, Mfumbwi provides not simply an ethnographic analog but a methodological framework for reinterpreting faunal variability in coastal archaeological contexts—one in which human behavior is recognized as both patterned and dynamic, structured by ideology as well as by environment.

Finally, the implications of this study extend beyond archaeology. The same attributes that make Mfumbwi's subsistence system archaeologically legible—its redundancy, adaptability, and gendered labor portfolios—also define its resilience under contemporary ecological and economic stress. Integrating ethnographic evidence such as the MS-1819 dataset into management frameworks can ensure that conservation strategies remain sensitive to the differentiated realities of local communities. In emphasizing the complementarity of men's and women's work, the coupling of environmental and social seasonality, and the enduring interplay of tradition and innovation, this research underscores the need for co-management approaches that protect both livelihoods and ecosystems. Future papers will detail multifarious applications of the MS-1819 Dataset in multiple contexts to better understand the archaeology and historical ecology of the East African coast, for instance. Ultimately, the study of Mfumbwi affirms that the archaeology of the Indian Ocean world is inseparable from the living knowledge of those who continue to shape its shores 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 humans were approved by Institutional Review Board, University of Wisconsin-Madison. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AS: Writing – original draft, Writing – review & editing. PF: Writing – original draft, Writing – review & editing. BL: Writing – original draft, Writing – review & editing. AA: Writing – original draft, Writing – review & editing. HO: Writing – original draft, Writing – review & editing. AU: Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work 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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The author(s) declared that generative AI was not used in the creation of this manuscript.

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