



Harnessing the diversity of small-scale actors is key to the future of aquatic food systems

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Small-scale fisheries and aquaculture (SSFA) provide livelihoods for over 100 million people and sustenance for ~1 billion people, particularly in the Global South. Aquatic foods are distributed through diverse supply chains, with the potential to be highly adaptable to stresses and shocks, but face a growing range of threats and adaptive challenges. Contemporary governance assumes homogeneity in SSFA despite the diverse nature of this sector. Here we use SSFA actor profiles to capture the key dimensions and dynamism of SSFA diversity, reviewing contemporary threats and exploring opportunities for the SSFA sector. The heuristic framework can inform adaptive governance actions supporting the diversity and vital roles of SSFA in food systems, and in the health and livelihoods of nutritionally vulnerable people—supporting their viability through appropriate policies whilst fostering equitable and sustainable food systems.

Concerns that the global food system is failing to deliver safe, nutritious, sustainable and equitable diets have intensified over the past decade, leading to calls for food system transformation¹. At the same time, population growth and rising affluence are fuelling demand for more food and for resource-intensive diets. In this landscape of demand and need, visions of what constitutes progress towards a sustainable food system diverge. Agendas for change highlight challenges related to production efficiency, technological innovation, and equity and inclusion².

Recognizing the critical role that small-scale actors play in meeting these challenges requires a deeper understanding of their diverse characteristics and the contributions they make to sustainable and equitable food systems. In this article we draw on the livelihoods and social–ecological systems literature to define the diversity of small-scale fisheries and aquaculture (SSFA)—first, in terms of the suite of strategies used by actors throughout the value

chain to meet their objectives and spread economic, social and environmental risk, both across and within geographies and socio-environmental systems; and second, in terms of how SSFA diversity can impact production, distribution and benefits arising from aquatic food systems.

SSFA produce more than half of the global fish catch and two-thirds of aquatic foods for human consumption, and associated value chains support over 100 million full- and part-time jobs³. Nevertheless, the nature and importance of these contributions to food and nutrition security, livelihoods and sustainability remain inadequately recognized by development, food, environment and fisheries policies⁴. We argue one reason for this persistent neglect is that policymakers are challenged by the diversity and dynamism of the SSFA sector. Despite significant advances towards acknowledging SSFA diversity and contributions via efforts such as the FAO's Voluntary Guidelines for Securing Sustainable Small-scale

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Fisheries (SSF Guidelines)⁵, policies affecting the sector typically make unrealistic assumptions of homogeneity and stasis^{6,7}. In contrast, as highlighted by the COVID-19 pandemic, responses and adaptive capacity of small-scale actors are highly variable, reflecting their diversity^{8,9}.

Failure to address the diverse and dynamic nature of SSFA risks jeopardizing their persistence and the food systems of which they are part. While the viability of SSFA appears key for equitable and sustainable food systems¹⁰, 'blue economy' narratives^{11,12} grounded in expansion of capital-intensive fisheries, transnational investments and offshore mariculture have gained traction in national and international policy debates. These narratives tend to further homogenize SSFA as dysfunctional, vulnerable and/or marginal, and give preference to industrial over small-scale modes of production^{10,11}. Interactions between industrial fishing and aquaculture interests with SSFA are heterogeneous and can range from cooperation and interdependence¹³ to competing and undermining sustainability with immediate impacts on SSFA viability¹⁴. It is critical to remove subsidies to industrial concerns, rebalance access to capital and political influence and take steps to counteract simplistic characterizations of SSFA actors, their roles in food systems and how governance reforms may affect, enable or exclude them. As social-ecological systems and food sovereignty perspectives argue, SSFA are key to holistic blue food futures¹⁵, but policymakers need tools that can better incorporate and capitalize on their inherent diversity.

The diversity of SSFA is commonly overlooked, partly due to misrepresentation and contestation over what constitutes 'small-scale'¹⁶. Similar to discourses around smallholder agriculture¹⁷, most analyses of the aquatic sector agree that binary classifications of 'small' and 'large' are inadequate given high geographic and socioeconomic heterogeneity¹⁸. Rather than pursuing one definition of SSFA, consistent with the SSF Guidelines⁵, this paper aims to prime future analysis to be inclusive of SSFA diversity. We present an innovative heuristic that illustrates the diversity of SSFA actors to examine threats from climate, environmental, socioeconomic and political change, and opportunities to support SSFA viability for more sustainable and equitable food systems.

Results

We characterized SSFA actors from freshwater and marine fisheries and aquaculture based on 70 case profiles (Extended Data Tables 1 and 2), which span poor to richer or industrialized contexts, and a range of activities by women, men, youths and children. Profiles span value chains, from input procurement to production and harvesting, processing, distribution and trade (Fig. 1 and Extended Data Table 2).

We identified four key dimensions: inputs and assets; markets and demand; management and institutions; and specialization/diversification (Methods, Fig. 2 and Extended Data Fig. 1). An iterative, inductive process, including two coauthor workshops, was then used to explore diversity and examine case details (Fig. 2). A reductive process was subsequently employed to group characteristics into a manageable and representative core set of eight attributes (Fig. 3). Attributes were then used to describe individual cases (selected examples are presented in Fig. 3). Case profiles were also examined for the relevant threats and opportunities (environmental, economic, social, political) as overarching pressures or levers which alter or enhance an actor's attributes (Fig. 2 and Extended Data Table 3).

The eight attributes, nested within the four dimensions are: (1) level of investment; (2) human and social assets; (3) distance to consumer; (4) product value; (5) formality of institutions/governance; (6) exclusivity of access to the resource; (7) degree of pluriactivity; and (8) diversity of products (Fig. 3). Each attribute represents an intermediate level of abstraction and generalizability of the identified actor and contextual attributes. Attribute combinations provide

a way to assess different implications of actor profiles in terms of threats and opportunities, vulnerability or adaptability. In the following sections, we explore these attributes and their diversity, starting at the level of individual actors and activities and expanding to engagement with external actors, markets and influence of governance.

Inputs and assets. Levels of monetary investment and technology are heterogeneous across SSFA (see Table 1, row A for examples). Case profiles show assets ranging from modern processing plants using imported equipment to locally fabricated or home-made gear. The key common element of SSFA is that activities are controlled at a local level by individuals or groups of households. Production inputs also range from self-provisioned or gifted, to investments by other value-chain actors or purchased. Underpinning this variability is a wide range of credit arrangements, from no credit, to informal familial borrowing to formal bank or NGO-facilitated loans, to which access is often mediated by a combination of class, gender, ethnicity, education, age and economic development context. Formal and/or informal access to input provision, information, logistical support, savings, cash or credit helps actors at various points of supply chains to address, cope with or adapt to shocks, market failures and asset shortfalls¹⁸. Although structures and initiatives that seek to improve access to savings, credit and cash can build adaptive capacity, continued attention to equity, as well as other dimensions of adaptive capacity, remains critical¹⁹.

The human capital of SSFA actors is also highly variable (Table 1, row B), from basic technical skills adequate to support household food security²⁰, to professionalized SSFA producers, traders and processors with formal education or training meeting complex market specifications²¹. Acquiring skills has diverse trajectories from urban-based formal education to local/traditional ecological knowledge and skills employed across value chains. Additionally, case profiles show that the degree of collaboration between actors and across value-chain nodes differs. Some SSFA actors operate individually, while others collaborate through formal or informal agreements, including cooperatives operating in value chains across sectors²².

Specialization. SSFA actors specialize in terms of products, activities and engagement through value chains. The degree of specialization is often linked to the ecology of the resource base and the methods used to exploit it (Fig. 1). SSFA might target or cultivate a single species using specialized gear, or use a range of gear and techniques to harvest or cultivate a diversity of species. A focus on more than one species, gear, system, activity and/or product is driven by season, ecology, temporary abundance or market incentives (for example, Table 1, row C). Small-scale fish farmers often utilize polyculture, or engage in activities upstream (for example, trading inputs) or downstream (for example, processing). In much of Asia and sub-Saharan Africa, production of crops and livestock on very small landholdings produces insufficient income and necessitates pluriactivity; aquaculture has often emerged as a secondary activity. Ponds holding fish, doubling as on-farm irrigation water storage, act as a reserve to cover expenses such as school fees²³ whilst supporting associated horticulture²⁴.

SSFA actors engage in aquatic food value chains from year-round to seasonal, from full- to part-time, and trading-off roles within and outside supply chains depending on opportunity or necessity. Both specialization and pluriactivity characterize the livelihood portfolios of SSFA actors (for example, Table 1, row D). Activities may be part of mixed-livelihood portfolios, and involve paid labour or unpaid familial inputs. Age, gender, religion, education and ethnicity are critical factors in the dynamics of how actors may access, enhance and invest their own human capital in livelihoods based around SSFA, with highly variable outcomes for equity and food and nutrition security²⁵.



Fig. 1 | Profiles of 15 small-scale actors selected as examples from 70 case profiles representing producers from marine and freshwater fisheries and aquaculture, traders and processors across diverse geographies and demographics. a, Inland Canadian lake-fisher and retail entrepreneur channelling catch to domestic and US markets (Supplementary Table 2, #SSFA-8). **b,** Rural Chilean fisherwoman targeting multiple species, including benthic gastropods, in a collective territorial user rights system (#SSFA-10). **c,** Processing plant worker from a fishing cooperative in Baja California, Mexico (#SSFA-45). **d,** Monosex Nile pond tilapia farmer in Myanmar (#SSFA-53). **e,** Mangrove integrated organic shrimp farmer in Vietnam (#SSFA-65). **f,** Pluriactive Zambian crop farmer and fisher, who is also a new fish farmer (#SSFA-67). **g,** Middleman in Guangdong province, China (#SSFA-17). **h,** Chinese businesswoman buying a variety of species wholesale to sell to Shanghai residents (#SSFA-18). **i,** Feed producer for the commercial tilapia aquaculture sector in Kenya (#SSFA-32). **j,** Lobsterman, finfish and shark fisher from a cooperative in Mexico, geared towards the tourist-based commercial market (#SSFA-47). **k,** Child gleaners in Madagascar use handwoven baskets to collect freshwater shrimp, crabs and small fish (#SSFA-42). **l,** Indigenous i-Taukei (Fijian) fisherwomen collect mud crabs from mangroves (#SSFA-23). **m,** Women seaweed farmers using tubular net technology in Zanzibar, Tanzania (#SSFA-59). **n,** Market trader of dried fish in Myanmar's coastal Ayeyarwady region (#SSFA-52). **o,** Shellfish processor supplying yellow clams to the Uruguayan luxury restaurant market (#SSFA-60).

SSFA actors show important differences in the possibilities for diversification. In general, diversification can grant flexibility to an individual's operations, securing them against certain risks and enabling adaptability, as recently demonstrated by responses to the COVID-19 pandemic⁴⁹. Flexibility to move between occupations can also provide conditions that support adaptive responses²⁶. However, diversification is not always a positive characteristic; it may be an outcome of necessity rather than opportunity²⁷. Efficiency or consolidation may be effective in certain operations and contexts, such as processing of high-value resources or transportation logistics. Furthermore, diversification should not undermine the importance of value-chain coordination, much of which is informal within private-sector networks.

A continuum between capture fisheries and aquaculture case profiles highlights important differences between fisheries and aquaculture, particularly for producers. Whereas in some contexts,

only low-cost and superficial changes may be required in gear, timing and location of the activity to target a different species for a fisher, aquaculture producers demonstrate serial innovation and adaptation in what and how they farm and how the product gets to market^{28,29}.

Engagement with markets and demand. SSFA actors provide aquatic foods to consumers of diverse socioeconomic status, with high-end consumers accessing luxury products through global markets (for example, Table 1, row A), to poorer consumers accessing daily staples from their own harvest, exchange or local markets³⁰ (for example, Table 1, row E). High-value products can be accessed through short supply chains, particularly where freshness, water-to-plate or cultural value fetch a price premium (for example, associated with tourism)³¹. Luxury products are also exported after value addition (for example, smoking of sea cucumbers), enabling

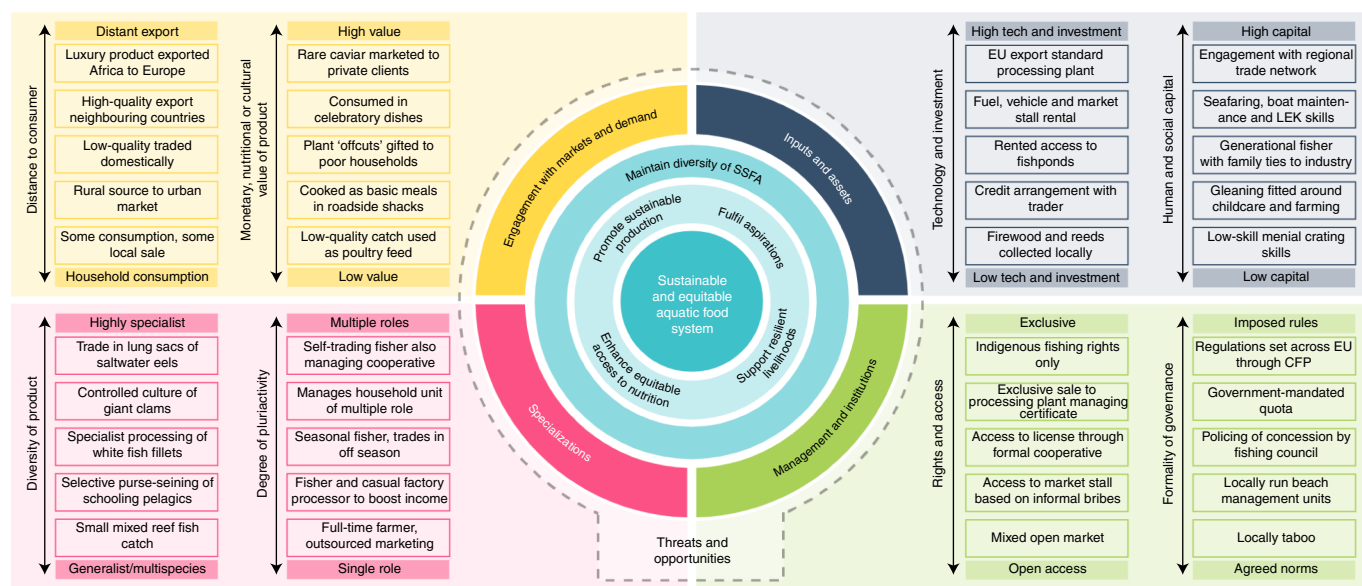


Fig. 2 | An exploration of diversity across SSFA actors and their contribution to a sustainable and equitable aquatic food supply. The key contributions of SSFA to a sustainable and equitable aquatic food supply are shown in the internal rings. The key underpinning dimensions of SSFA actors are shown in the outer ring, and their key attributes as determined by the reductive process are shown on the axes. Diversity within the SSFA sector is demonstrated by example details from case profiles (boxes). CFP, Common Fisheries Policy; LEK, local ecological knowledge.

SSFA actors to benefit from global value chains, although these benefits largely remain inequitably distributed²⁵. Lower-value products may also be traded over long distances to meet national and regional demand³⁰. Food security is supported directly through processing (drying, salting) and trading or gifting both primary products and by-products locally and indirectly, for example, as livestock feeds³².

Market dynamics often reflect local power relations and are commonly underpinned by access to credit. Informal arrangements for cash or provision of consumables by a local patron who also buys and markets the product, typically on a preferential basis, are common (for example, Table 1, row F). The specific dimensions of such patron–client relationships are culturally mediated³³, and dependence on such relationships is often directly related to the (lack of) availability of family-based credit and accessible, formal credit given by commercial, cooperative or government lenders.

Market dynamics are also sensitive to rapid change in the face of trends and shocks. The COVID-19 pandemic, for example, interrupted supply chains and livelihoods of some, especially those dependent on distant high-value markets³⁴. However, new markets and channels—such as online and direct sales—emerged or rapidly expanded to serve consumers in many regions of the world, often in response to faltering or disrupted value chains^{8,9}.

Supporting the development of market infrastructure has proven critical for SSFA actors in many contexts, especially where they reduce concentration of market power. Rapid growth of small-scale aquaculture in Asia has often been linked to improved market access, often through competitive intermediaries³⁵. Exploring the diversity in SSFA shows that those focused on self-provisioning, exchange and/or supplying local markets are likely to have different needs and challenges to those that target international or urban domestic markets. By linking proximity to consumers and the different modes of production, policymakers can more effectively address equity issues.

Case profiles show aquatic foods may have particular cultural importance that transcends their nutritional qualities, including for communities most nutritionally dependent on them, such as Indigenous and marginalized groups³⁶. Cultural attachment and the importance of food sovereignty is also evidenced by transfer of consumption preferences among fish-eating diaspora³⁷.

Management and institutions. SSFA actors and their activities are governed by management systems and institutions ranging from centralized government control to localized, culturally embedded arrangements (Fig. 2). In some countries and contexts, access and use rights are legally assigned to SSFA actors. In other contexts, local and cultural institutions dictate those rights, in isolation from (or in concert with) formal legal structures (for example, Table 1, row G)³⁸. All governance arrangements present opportunities and challenges to equity and inclusion along lines such as class, gender and ethnicity³⁸. Exclusive resource access or private ownership characterize some SSFA, while de facto open-access systems support others, with multiple intermediate forms of common access and use rights to land and water falling in between. Open-access regimes, however, can restrict investment, sustainable management and equity (for example, Table 1, row H). The agency and inclusion SSFA actors experience in governance arrangements present an important avenue through which to improve food system outcomes²². In contrast, imposed governance mechanisms can sometimes prove ineffective or counterproductive³⁹.

Cooperative arrangements were common in many case profiles, particularly for fisheries, enabling coordination and innovation through collective action⁴⁰. Similarly, market-based collective institutions, such as metric-based environmental and social standards, can be critical for SSFA actors to gain and retain access to markets⁴¹.

Any degree of exclusivity and formality in governance will be influenced by levels of enforcement and compliance, which remain extremely variable across SSFA, particularly as their unique characteristics are often underappreciated in risk–benefit assessments and interventions⁴². Some actors may operate in highly controlled systems of intense monitoring, others may be self-compliant or self-policed through commitment to collective action, and others may operate in wholly unmonitored systems. This diversity highlights the need to recognize and address the specific impacts of monitoring and enforcement on SSFA as a key component of designing inclusive, equitable solutions.

Discussion

Threats and opportunities for action. Based on the case profiles, here we present key threats from climate, environmental, political

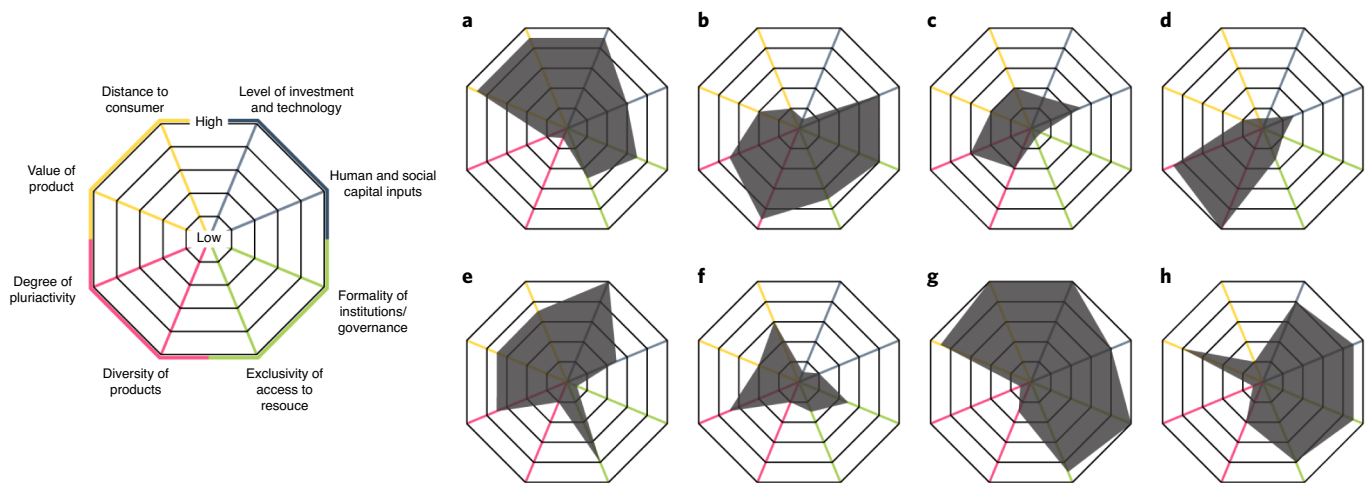


Fig. 3 | Framework of key SSFA attributes. A heuristic framework of key SSFA attributes critical to contextualized policy development is shown in the left-hand panel. **a–h**, Spider charts exemplifying how the framework may be used to assess SSFA actors in different contexts. Examples represent diverse actors drawn from case studies: high-input intensive tilapia farmer (**a**); cooperative-supported small-scale freshwater fisher (**b**); trader and roadside restaurant owner in rural village (**c**); opportunistic gleaner–agricultural farmer in rural reef fishery (**d**); trader middleman and creditor (unregulated) serving large urban markets and regional export (**e**); female part-time fish processor for rural to urban market (**f**); high-tech processing plant owner serving distant European markets, recently Marine Stewardship Council certified and aiming to commercialize/expand (**g**); small-scale Californian fisher targeting seasonal species (multi-gear) in community-supported scheme largely serving local, affluent, subscription-based customers (**h**).

and socioeconomic change, and opportunities for supporting SSFA viability and equity in the face of these major drivers. Governance failures, poor political representation and power, resource over-exploitation, habitat degradation, illegal activities, climate change and COVID-19 emerged as widespread challenges to the viability of SSFA. Dysfunctional institutions, including markets, inequitable access to resources and opportunities, and limited gender and social inclusion are also key threats. Efforts to address these issues can be viewed as investments in supporting sustainable and equitable food systems. Case profiles indicate that SSFA diversity may confer adaptive capacity in the face of threats and opportunities. Greater awareness of the diversity of SSFA actors, within and across social-ecological systems, is a prerequisite for appropriate policy development that can support viability in this highly dynamic sector.

Climate change and environmental impacts. Climate change and variability were identified as pervasive threats in case profiles of marine systems (see Extended Data Table 3 for more detail, highlighted by case studies), and in SSFA worldwide^{13,44}. In freshwater contexts, water quality, land degradation and loss to urbanization and farming, and changing precipitation also present significant environmental threats⁴⁵. For SSFA actors whose inputs and assets are threatened by climate change—for example, low-tech actors dependent on vulnerable systems (Fig. 3d)—technologies and investments in human and social capital, and in diversification and development of appropriate institutions, offer key opportunities to support their viability²⁶.

Shocks to food systems, both market and environmental, can limit local access to aquatic foods and restrict their nutritional contribution. They can also propagate through domestic and international trade networks, impacting prices and availability at multiple scales¹⁶. Multiple shocks can synergistically combine to affect SSFA actors across whole value chains. Sustainable intensification is a particular challenge for these actors⁴⁷ in increasingly commoditized value chains. Managing water quality to optimize productivity and avoid losses from disease and mass mortalities in the face of increasing climate extremes and uncertainty is a key challenge⁴⁸.

SSFA actors relying on high product diversity but low technology and investment (for example, Fig. 3b) tend to be closely linked to

the environment and so are particularly vulnerable to shocks and longer-term environmental change trends. However, our cases also demonstrate high adaptive capacity. For instance, tilapia farmers in northern Zambia, having no access to improved strains used by farmers further south, have based culture on diverse local species adapted to local climate variability. In doing so, local knowledge-exchange networks have evolved, resulting in improved efficiency and circumventing the direct competition of tilapia from southern farmers (Extended Data Table 3). Such adaptation requires agency, flexibility and learning capacities²⁶. The development of programmes and policies that remove barriers and provide incentives and resources for diversification, and emphasize inclusive and equitable outcomes, are key strategies for supporting climate adaptation in SSFA.

Some SSFA attributes incur high exposure and sensitivity to shocks. SSFA actors who fish for and sell high-market-value species are exposed to market, transport and infrastructure shocks (for example, Fig. 3g). In addition to addressing logistical or financial exposure, building adaptive capacity in these systems also requires support for social networks and collective learning³⁴. Policy developments that incorporate support for the design, implementation, monitoring and institutionalization of climate change adaptation programmes are needed. Supporting adaptive institutions under climate change should be based on a detailed understanding of formal and informal (including traditional) practices—and explicit recognition of previous governance failures. Climate uncertainty can undermine incentives for engaging in long-term planning and commitments to sustainability, or reduce investment in aquaculture development by poorer, more risk-averse actors⁴⁹. Established user-rights-based systems in Chile, Mexico and Uruguay (Fig. 2b,c,o) provide important lessons for what enabling conditions support adaptation to climate change⁵⁰.

Insurance, credit and market mechanisms can provide important protection against extreme events in the dimension of inputs and assets, but they are no substitute for broader adaptive capacity. They may offer little protection to human and social capital. Insurance schemes thus far have only been taken up by large-scale farming operations, through fisheries insurance schemes⁵¹. Although climate derivatives approaches, which are currently expanding in aquaculture⁵², have the potential to increase the resilience of aquatic food

Table 1 | Key examples drawn from case profiles to illustrate the diversity of actor characteristics or strategies across the identified SSFA attributes (Fig. 3)

Attribute	Example of diversity within small-scale sector
A Investment and technology	Case studies range from state-of-the-art processing plants with equipment supplying certified fresh yellow clams to Uruguayan restaurants, to home-made reed baskets by local traders in the Barotse floodplain of Zambia. Malawian tilapia farmers may use their agricultural waste as feed, whereas others in Hainan, China may receive subsidized inputs from large umbrella firms in exchange for exclusive trade agreements. Others, such as shark fishers in Madagascar or rural-to-urban traders, may need to externally purchase all fuel. The differential scale of middlemen in small-scale Kenyan systems demonstrates a dichotomy: low-investment 'Mchuuzis' provide credit in exchange for preferential catch, but high-investment 'Tajiris' may control boats, equipment and selling power of numerous fishers.
B Human and social capital input	Peer-to-peer asset/knowledge exchange between small-scale and commercial farms in Kerala, India, community-supported fisheries in the United States developing consumer subscription schemes and networks such as the African Women Fish Processors and Traders Network are examples of diverse social cooperation.
C Diversity of product	Abalone divers in Tasmania targeting a specific species with specialized gear and monoculture, monosex tilapia farming contrast with the reef fisheries of northeastern Madagascar, where net fishers target whatever they can and traders prioritize volume over specialism in hard-to-reach communities.
D Degree of pluriactivity	Actors engage to a widely variable degree with aquatic food production, from opportunistic mosquito net fishers fitting the activity around predominant farming and household duties, to full-time dedicated producers, traders and processors. Similarly, actors may engage with one or multiple nodes of the aquatic foods value chain; for example, Vietnamese shrimp farmers may circumvent low prices from processors by directly marketing on social media, branching out to trade, process and even own restaurants to sell organic shrimp.
E Proximity to consumer	The catch of subsistence mosquito net fishers in Mozambique may go no further than the household's plates, whereas women seaweed farmers in Tanzania have access to export markets, and cooperative-owned processing plants in Mexico may be geared towards EU import regulations.
F Monetary, nutritional and cultural value of product	Small-scale actors may deal in high-end luxury products such as caviar from sturgeon aquaculture in Uruguay, or in crabs gleaned from rice paddies in Madagascar with little monetary value that are eaten at home. Nutritional contributions are similarly variable. The provision of offcuts to local low-income families by a Kenyan small-scale tilapia-processing plant may constitute the only source of animal nutrition for such households, whereas trade of eel lung sacs for Chinese traditional medicine purposes may provide little to no nutritional value. Small-scale actors often serve cultural markets, seasonal celebrations and localized speciality preferences; for example, Seychellois trap fishers target multiple species to suit the local preference for variability, but also culturally important species, which will sell well.
G Formality of governance	The Comcaác indigenous community gains access to Mexico's fish through formal concessions based on indigenous rights alongside formal self-governance, in contrast to local customary laws and practices, which guide access to sea cucumbers in Palau. Enforcement may rely on relatively high-tech interventions such as phytosanitary testing in processing plants or electronic monitoring in the high-value Canadian sablefish fishery. Other institutional frameworks require self-policing; often the case in newly formed co-management efforts in northern Mozambique.
H Exclusivity of access	Usufruct access in Vietnam means mangrove concessions granted after the war support many small-scale shrimp farmers; rules on mangrove retention for timber limits expansion. Alternatively, expansion for women traders in the free markets of Kafr El Sheik, Egypt is limited not by governance, but by competition for space. Market access may be restricted or controlled in numerous ways; including parent-company-managed sustainability certifications tying-in many small tilapia farms in Hainan, China. Markets may also be open and largely unregulated, such as the many rural markets serving communities of sub-Saharan Africa.

systems to extreme weather events, it is critical that these schemes avoid perpetuating inequalities by favouring larger enterprises to the detriment of poorer or marginalized actors⁵¹.

Investments in environmental protection and restoration, done collaboratively with actor buy-in and understanding of the full dimensions in which they operate, can deliver significant win-wins. Escalating demand for natural resources, trade-offs with other sectors, and the increasing risks and uncertainties from overexploitation, declines in water quality and disease pose major challenges to effective environmental management for both fishers and farmers and for other value-chain actors. Supporting the diversification of products and activities, continued learning and enabling collective action are key strategies for viable and adaptive SSFA.

Economic shocks, changing demand and globalization impacts.

As consumption and demand for aquatic foods increase with rising purchasing power, some species historically produced, traded or consumed within SSFA may be diverted to high-value export markets or local tourism markets⁵³ (for example, Fig. 3e). Resulting increased incomes for SSFA actors can pose important trade-offs with local food and nutrition security. SSFA actors, particularly in the rural sector, have limited capacity to influence global market drivers and prevent negative outcomes. Rapidly growing international demand for marine products, for example, has led to industrial harvest of nutritious small pelagics that were previously targeted by artisanal fisheries for local direct human consumption in West Africa⁵⁴. Positive economic and social outcomes may be

achieved by combining export products with products of low economic value and high nutritional value for local consumption⁵⁵, but such opportunities need diverse targeted policy interventions and strategies⁴⁷ to maintain local food and nutrition security and, at the same time, withstand potential instability of global markets.

The COVID-19 pandemic has brought major disruption to fisheries and aquaculture throughout supply chains, exposing significant vulnerabilities and inequalities^{8,9,34} and highlighting the powerful influence of market dependence. Early in the pandemic, most exports were halted and the majority of domestic markets closed, with major impacts and losses for SSFA actors and supporting socioeconomic systems around the world³⁴. Where actors lacked political recognition they could also be excluded from supportive and enabling responses such as curfew exemptions⁵⁶. SSFA responses to the pandemic have been characterized by increased vulnerability but also high resilience. Mobilization of SSFA actors and networks to share information, monitor impacts and transform the crisis into an opportunity has occurred, as has a surge in direct producer to consumer sales (for example, Fig. 3h), e-commerce and local food sharing^{8,9}. Such adaptive short-term actions, involving both the products produced/traded and modes of engagement with consumers, have potential to evolve into longer-term adaptive strategies, with as yet uncertain distribution of benefits.

The pandemic has demonstrated the importance of SSFA diversity and recognition as a key element to build adaptive capacity to future economic shocks. Aquatic food systems experience considerable price volatility⁵⁷. Although aquaculture has some ability to schedule production, and thus can decrease price volatilities compared to fishing, such volatility also relates to species and production technology⁵⁷. Case studies signal that pluriactivity and linked fishery and aquaculture systems, such as those developed under territorial user right arrangements, can provide important niche innovations to deal with volatility and economic shocks⁴⁹.

Globalization of SSFA markets also generates competition with industrial operations, both on the water (in the case of fisheries) and in markets, where industrial operations reliably produce cheaper and often high-quality products as an effect of economies of scale throughout value chains. Luxury product, distant market case studies have highlighted the potential impacts of substitutions at a global scale (for example, Fig. 3a). Enhancing diversity in SSFA must consider the complexity of fisheries and aquaculture interactions and how strategies may disrupt long-standing cultural preferences and traditional practices.

Increased participation of SSFA actors in export markets can also mask issues of marginalization and exploitation. Ensuring both traceability and visibility of social impacts is challenging with increasing distance from the end consumer, although use of QR codes by retailers and food service providers show promise in bridging such divides⁵⁸. Supporting SSFA actors at the local scale can be key to ensuring affordable, sustainable and healthy diets. It is important to consider the significant role of women, who remain largely underappreciated drivers of nutritional security and are frequently excluded from land and resource tenure⁵⁹. There are opportunities to embrace 'alternative' systems based on short supply chains for products with strong local identities and local, decentralized approaches to production and processing (for example, Fig. 3c). Diversity, deeply embedded in these food systems, could be supported by policies mandating or incentivizing local retention of SSFA products to ensure food self-sufficiency—for example, the development or control of local markets and school feeding programs. Market-based approaches that encourage actors to increase the value of products through processing, marketing or certification (for example, Fig. 3g) need to carefully consider such trade-offs on economic, social, environmental and public health outcomes.

Future viability of SSFA. The future of SSFA in all their diverse forms demands that actors are recognized, continue to benefit and remain engaged. The persistence of the small-scale sector suggests that benefits do exist and need to be understood and supported in broader terms than economic value alone. Diversity is essential to SSFA viability and their ability to provide nutritional security; underpinned by individual needs surrounding human and social capital, gender equity and agency, which need to be respected and supported.

First and fundamentally, SSFA actors need to receive sufficient benefits (for example, economic, nutrition, cultural value) from SSFA. There are certain contexts for which being a SSFA actor is tied to poor outcomes with few opportunities to exit and where broader system transformation is necessary⁶⁰. Investments in alternative livelihoods have been largely inadequate and more fundamental structural shifts, such as changes to property rights, that recognize SSFA actors' unique roles and needs are required. Policies that support inclusive relationships with state and/or corporate actors in and beyond the food system may be a key element. Such policies must recognize traditional and indigenous rights, and access rights should support not undermine the rights of indigenous people.

Second, SSFA actors play a key role in food and nutrition security, with globalization often intensifying trade-offs between economic gains from supplying distant markets and the loss of nutritional benefits to local actors. Aquatic foods provide critical support in addressing the triple burden of malnutrition^{54,61}. Guidance toward more nutrition-sensitive fisheries governance and aquaculture approaches (for example, polyculture, ecosystem-based solutions) linked to integrative landscape approaches are required to ensure SSFA viability.

Third, human and social capital support the viability and adaptive capacity of SSFA. Our case profiles illustrate that many actors benefit from the economic, nutrition and cultural values delivered through SSFA, and that these attributes can be managed and maintained to align to equity and human well-being objectives of future food systems. Historically, agricultural models have focused on economic upgrading rather than social mobility and resilience²³. The focus on creating enabling conditions for SSFA actors to adapt and thrive²⁶, rather than provision of inputs, is essential for addressing actor-level threats and equity.

Fourth, a high diversity of actors is common within SSFA production systems and value chains and across other sectors. Such diversity may also manifest as pluriactivity and can indicate vulnerability because actors are in some cases forced to take on other functions to cope with variable and uncertain access to assets and opportunities. Maintaining and expanding this diversity and flexibility, and addressing its possible unintended consequences, is key to the viability of SSFA.

Fifth, gender and other aspects of identity are strong determinants of the experiences of different SSFA actors, their contributions to nutritional security and their ability to contribute to overcoming barriers and constraints to better food system outcomes. The roles of women in SSFA remain understudied and undervalued, and the structural disadvantages they face will need to be overcome to achieve equitable and sustainable food systems. The engagement of higher numbers of women in post-harvest and trading is a common phenomenon in aquatic food value chains in many parts of the world, alongside growing recognition of comparatively greater nutritional contributions at the household level⁵⁹. Improving food systems requires a gender lens so as not to perpetuate and exacerbate existing inequalities (for example, intensifying labour burdens⁶²), and to overcome persistent barriers to women's inclusion.

Conclusion

The case profiles demonstrate a multitude of benefits associated with greater awareness of and support for the diversity within and across SSFA systems. SSFA actors currently play key roles in families,

communities and nations. This paper presents a case for their critical centrality in viable aquatic food systems. There are trade-offs that policymakers have to navigate to maintain the benefits from continued engagement of SSFA actors. In particular, meeting the needs of global consumers through large-scale industry poses risks for the cultural integrity, equity, nutritional security and livelihoods provided by SSFA actors. Longer-term actions to redress broader power inequalities, constrain monopolies and support the diversity of SSFA capacities will be critical.

This heuristic framework provides a novel and scalable approach, which can be more fully elaborated subsequently, to specify the diverse and dynamic nature of SSFA in different policy contexts. This contribution aligns closely with the SSF Guidelines⁵, while adding a theoretically informed practical approach to recognize diversity and the suggestion that a similar lens is also relevant to small-scale aquaculture. An appropriate next step would be to extend the inferences enabled by Fig. 3 to other real-world examples. Future research can be deployed in a systematic manner to look at single-food systems, components of food systems, specific regions or countries or other food systems where small-scale actors are key. Deeper consideration of the diversity and characteristics of SSFA actors, through the attributes presented in this framework, will enable policymakers in local, national and global fora to ensure that SSFA maintain and expand their role in sustainable and equitable food systems.

Methods

We characterize SSFA actors from freshwater and marine fisheries and aquaculture based on 70 case profiles provided by this paper's 30 authors (Extended Data Tables 1 and 2). Experts were selected by lead authors, based on contributions to the literature and leadership in international initiatives in the SSFA space (for example, the FAO voluntary guidelines for securing sustainable small-scale fisheries⁵) to span diverse geographies and systems, across fisheries and aquaculture and value chains. Despite efforts to comprehensively represent actors, systems and geographies, some gaps remain. To minimize these gaps, we iteratively identified regions and sectors that were underrepresented in workshops, and filled these gaps through additional case studies. Each case profile provided a suite of descriptive variables that depict actors, their roles and contributions in aquatic food systems, as well as the main threats and opportunities they face. The profiles enabled us to explore the diverse roles SSFA actors play in food systems, identifying characteristics that drive their diversity and adaptability.

Analysis proceeded iteratively. Submitted profiles were initially assessed for consistency and completeness within and across cases through iterative discussions across the coauthor group. Any gaps identified were filled through direct requests to specific experts, and literature review. We then adopted a qualitative, empirically grounded and partly inductive approach to characterizing the diversity, threats and opportunities of SSFA.

We assessed and categorized case profiles drawing on archetype analysis approaches⁶³ (see Supplementary Text 1 for more details) and the Sustainable Rural Livelihoods Framework⁶⁴, building on this framework through discussion and vetting within the group. The resulting heuristic framework aims to bridge the gap between 'global narratives and local realities'⁶⁵ by supporting an intermediate level of abstraction and generalizability of identified actor and contextual attributes. By examining the factors and processes that underlie the diversity through the lens of actors, rather than food systems, the heuristic supports SSFA livelihoods and sustainability through future policy change that accounts for high diversity, rather than being stymied by it.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The minimum dataset generated during and/or analysed during the current study is available from the corresponding author on reasonable request. A summary table is provided in Supplementary Table 2.

Received: 9 March 2021; Accepted: 9 August 2021;
Published online: 15 September 2021

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Acknowledgements

This paper is part of the Blue Food Assessment (BFA) (<https://www.bluefood.earth/>), a comprehensive examination of the role of aquatic foods in building healthy, sustainable and equitable food systems. The BFA was supported financially by the Builders Initiative, the MAVA Foundation, the Oak Foundation and the Walton Family Foundation, and has benefited from the intellectual input of the wider group of scientists leading other components of the BFA. This work was also undertaken as part of the CGIAR Research Program (CRP) on Fish Agri Food Systems (FISH), led by WorldFish and contributing to the WorldFish 2030 Research and Innovation Strategy: Aquatic Foods for Healthy People and Planet and the One CGIAR. The programme is supported by contributors to the CGIAR Trust Fund. Other acknowledgements towards this collaboration go to: ANID-Iniciativa Científica Milenio ICN2019_015, ANID-PIA/Basal FB 0002 (for S.G.); the GAIN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 773330 (for D.C.L.); National Science Foundation DEB121244 and BioOce 1736830 (for F.M.); the Nippon Foundation Ocean Nexus Program, Earthlab, University of Washington (for E.H.A.); the Erling-Persson Family Foundation (for B.C.); the Inter-American Institute for Global Change Research (for O.D.); the National Science Foundation (CNH 1826668) and the John and Katie Hansen Family Foundation (for C.D.G.); the European Research Council (grant number 759457) (for C.H.); and the iFISH programme from China Blue Sustainability Institute (for W.Z.).

Author contributions

R.E.S., S.G., D.C.L. and F.M. were responsible for conceptualization, methodology, formal analysis, investigation, data curation, writing (original draft), writing (review and editing), visualization, project administration and supervision. L.H. was responsible for formal analysis, data curation, writing (review and editing), visualization and project administration. E.H.A., X.B., B.B., M.R., C.B., S.R.B., L.C., B.C., P.J.C., O.D., P.E., C.E.F., N.F., C.D.G., B.S.H., C.H., D.J., A.M.K., S.M., R.L.N., U.R.S., S.H.T., M.T., C.C.C.W. and W.Z. were responsible for conceptualization, investigation and writing (review and editing).

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s43016-021-00363-0>.

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Peer review information *Nature Food* thanks Gianluca Brunori, Tim Gray and Kristen Lowitt for their contribution to the peer review of this work.

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