



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 heterogeneity⁷. 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 pandemic^{4,9}. 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

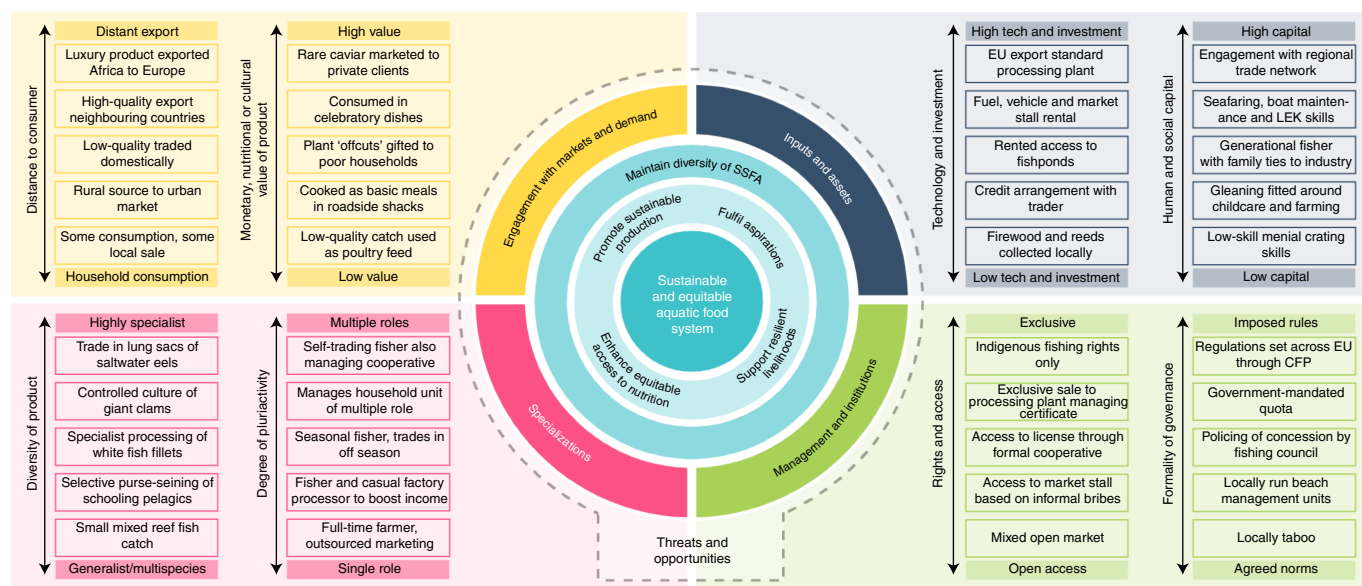


Fig. 2 | An exploration of diversity across SSFA actors and their contribution to a sustainable and equitable aquatic food supply. The key contributions of SSFA to a sustainable and equitable aquatic food supply are shown in the internal rings. The key underpinning dimensions of SSFA actors are shown 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

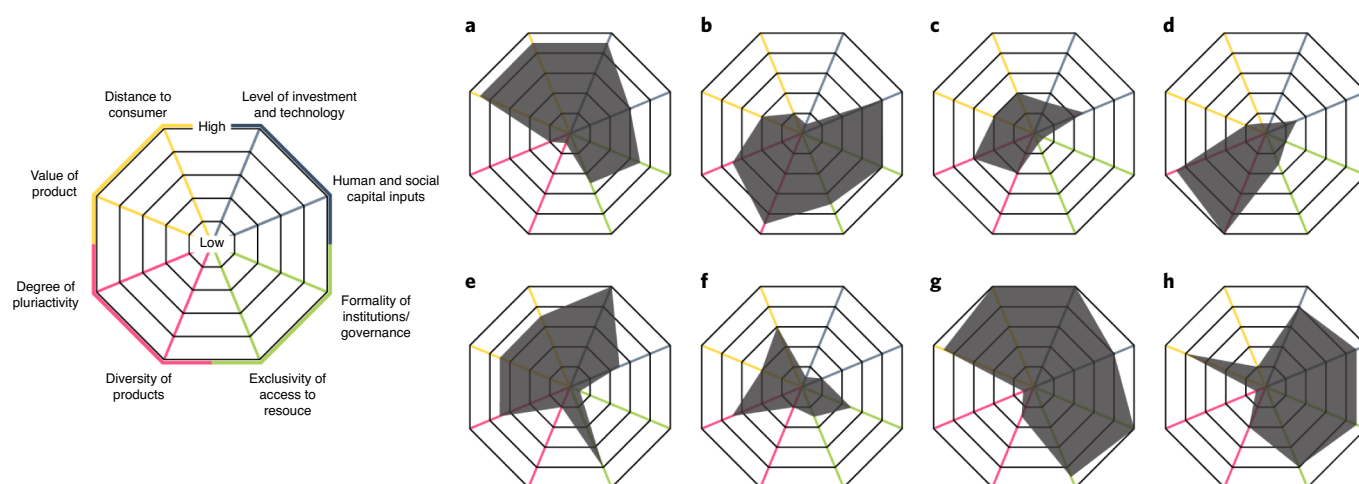


Fig. 3 | Framework of key SSFA attributes. A heuristic framework of key SSFA attributes critical to contextualized policy development is shown in the left-hand panel. **a–h**, Spider charts exemplifying how the framework may be used to assess SSFA actors in different contexts. Examples represent diverse 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^{43,44}. 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 scales⁴⁶. 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 Comcáac 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.

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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

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Study description	This is a perspective piece, though it draws on case studies these are produced by the study authors and no external data collection or people were involved
Research sample	75 case studies
Sampling strategy	Expert knowledge elicitation
Data collection	Electronic template circulated to authors
Timing	16/07/2020 - 20/10/2020
Data exclusions	3 cases were excluded due to being related to governance groups rather than actors, which was the focus of the study
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Supplementary information

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

In the format provided by the
authors and unedited

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

Supplementary information

Table S1 - List of experts consulted for case profiles and subsequent expert knowledge elicitation

Name	Submission affiliation & address
Fiorenza Micheli	Stanford Center for Ocean Solutions, and Hopkins Marine Station, Stanford University, USA
David Little	Institute of Aquaculture, University of Stirling, UK
Stefan Gelcich	Instituto Milenio en Socio-Ecología Costera, Pontificia Universidad Católica de Chile, Chile.
Rebecca Short	Stockholm Resilience Centre, Stockholm University, Sweden
Michelle Tigchelaar	Center for Ocean Solutions, Stanford University, USA
Eddie Allison	WorldFish, Malaysia
Xavier Basurto	Duke University, USA
Ben Belton	WorldFish, Malaysia; Department of Agricultural, Food and Resource Economics, Michigan State University, USA
Melba Bondad-Reantás	Fisheries Division, Food and Agriculture Organization of the United Nations (FAO), Italy
Cecile Brugere	Soulfish Research & Consultancy, York, United Kingdom
Simon Bush	Environmental Policy Group, Wageningen University and Research
Ling Cao	School of Oceanography, Shanghai Jiao Tong University
Beatrice Crona	Stockholm Resilience Centre, Stockholm University, Sweden
Pippa Cohen	WorldFish, Malaysia; ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia
Omar Defeo	Facultad de Ciencias, Montevideo, Uruguay
Peter Edwards	School of Environment, Resources and Development, Asian Institute of Technology, Thailand
Caroline Ferguson	School of Earth, Energy, and Environmental Sciences, Stanford University
Nicole Franz	Fisheries Division, Food and Agriculture Organization of the United Nations (FAO), Italy
Christopher Golden	Dept. of Nutrition, Harvard T.H. Chan School of Public Health, Boston, USA
Ben Halpern	National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, USA; Bren School of Environmental Science and Management, University of California, USA
Lucie Hazen	Center for Ocean Solutions, Stanford University, USA
Christina Hicks	Lancaster Environment Centre, Lancaster University, UK
Derek Johnson	Department of Anthropology, University of Manitoba, Canada
Alexander Kaminski	Institute of Aquaculture, University of Stirling, UK
Sangeeta Mangubhai	Wildlife Conservation Society, Fiji Country Program, Fiji
Roz Naylor	Department of Earth System Science and Center on Food Security and the Environment, Stanford University, USA

Rashid Sumaila	Institute for the Oceans and Fisheries, University of British Columbia, Canada
Shakuntala Thilsted	WorldFish, Malaysia
Colette Wabnitz	Stanford Center for Ocean Solutions, Stanford, Ca, USA and Institute for the Oceans and Fisheries, University of British Columbia, Canada
Wenbo Zhang	College of Fisheries and Life Science, Shanghai Ocean University

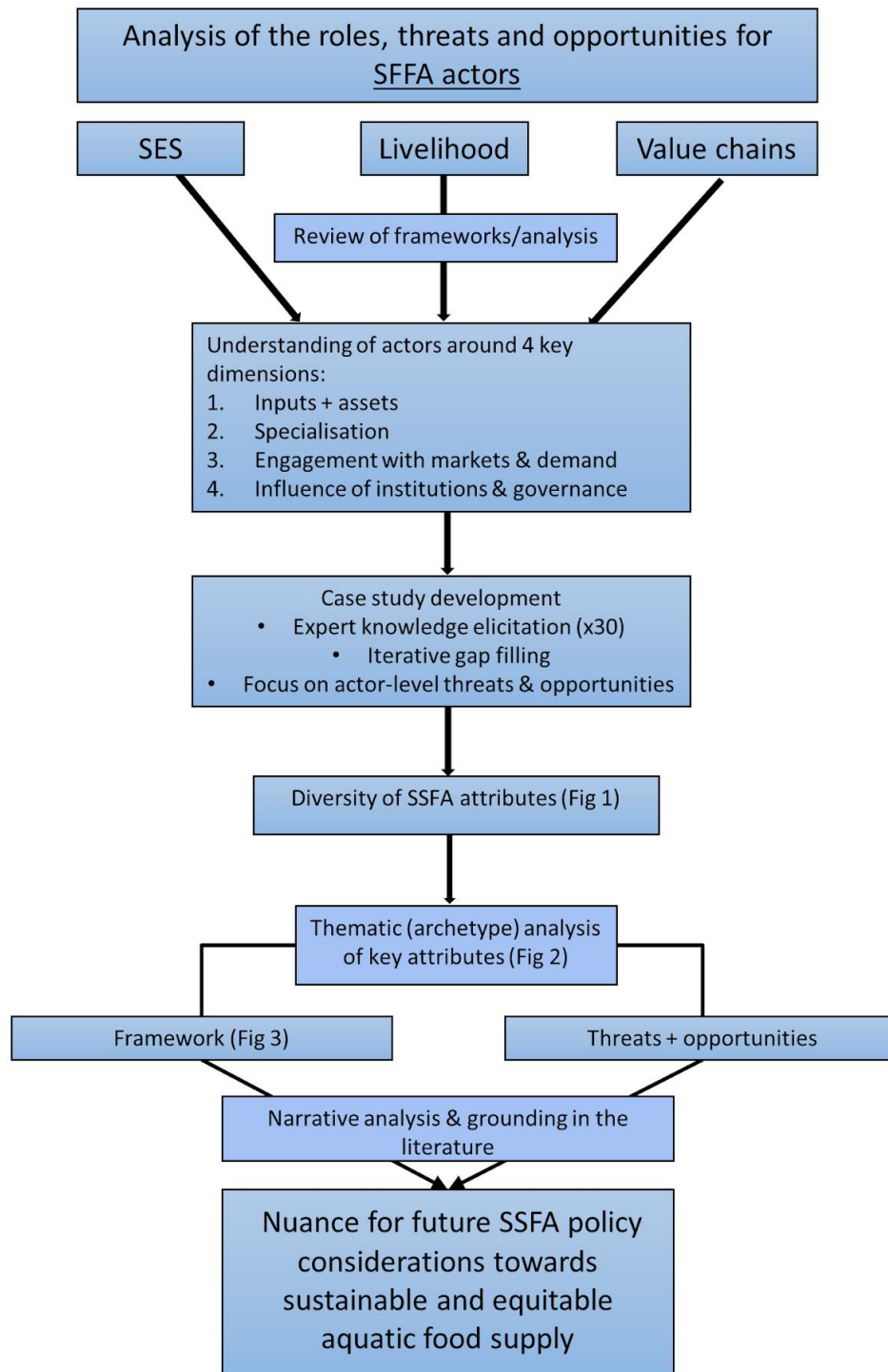


Figure S1 - Process flow diagram

Supplementary text S1:

Expert knowledge elicitation was used to collect small-scale fisheries and aquaculture typical actor profiles from 30 experts (Table S1) across 27 institutions globally in July 2020. Profiles which experts were familiar with were requested across the value chain (production, processing, trading, multiple), with no geographical restrictions and where the expert defined the actor as small-scale as academic definitions vary and no globally comparable metric exists. A template was circulated in order to structure profiles around the four dimensions of: 1) inputs and assets, 2) specialization, 3) engagement with markets and demand, and 4) institutions and governance. Dimensions were decided upon following review of key frameworks e.g. Ostrom's social-ecological framework (Ostrom, 2009) and the sustainable livelihoods framework (Carney, 1998). The lead authors workshoped the dimensions of most relevance at the level of the actor and to the goals of the analysis. In addition, experts were instructed to include current and future threats and opportunities specific to the profiled actor and their engagement with the aquatic food sector. In the first instance, experts were asked to provide two diverging profiles, adding additional profiles of perceived importance thereafter. After initial submissions were received, the lead author team reviewed submissions and made select follow-up requests to attempt to fill key gaps such as geographical representation, value chain nodes, production systems/resource types and gender.

Seventy profiles were analyzed (Table S2), with methods drawn from archetypes analysis, in an inductive process to categorize each of the narrative profile dimensions into a set of attributes representing diversity of actor characteristics along given spectra (Fig S2). These attributes were presented for feedback from the expert team in a set of three workshops in September 2020. These workshops aimed to further reduce the attributes, identify redundancy and explore gaps in representation of diversity across the dimensions. Following these workshops, a framework was developed based on a continued reductive process, identifying key representative attributes (Fig S2 – boxes). In addition, associated threats and opportunities were categorized in a similar process and cross-referenced for association with given attributes. Cross-cutting threats and opportunities were identified for further discussion and to provide focus for the narrative analysis within the paper. The framework, threats and opportunities, and key questions arising were again presented to the expert group in a second set of workshops in November 2020. These second workshops were intended to refine the framework and structure the discussion around use and presentation of this framework. Additionally, following the workshops a validation step was undertaken with each expert independently applying the framework to one of their submitted profiles, further clarifying any issues or gaps in representation.

Experts had input throughout the drafting of the paper's narrative and a collaborative effort was therefore applied to a grounding of the framework, threats and opportunities in the current literature.

Supplementary text S2 - Template for case profile collection as circulated to expert co-authors

Submitted by: [Name]

How would you title this actor? Please provide a photograph if possible for context (these will not be used further without appropriate permissions)	
Please provide short description of this actor 'type'	Relevant aspects may include nationality/region, age, ethnicity, gender, socio-economic profile, education, residency, primary/secondary/other livelihoods etc.
Please provide detail on how this actor may fit with/engage within the domains of SFFAs below:	
1. Inputs/assets	We would like to think beyond production-based inputs or necessary assets and may include: • Time investment, physical effort, trade-offs/strategies • Knowledge/skill requirements • Social capital requirements • Capital investment inc. strategies e.g. credit agreements • Spatial requirements • Biological inputs e.g. feed • Degree of intensity • Technological inputs • Where is product sourced?
2. Position in value chain	Where along the value chain does this actor sit? E.g.: • Production • Processing • Trade • Marketing • Consumption • Multiple (please list)
3. Engagement with markets and influence of demand	• Who and where are their end consumers? • Where do they source their product? • Scale (e.g. feeds commercial markets, remains local) • Degree of specialization/diversity of product • Product use e.g. human consumption, non-human consumption (feed, fertilizer?), luxury, staple, medicinal, ornamental

4. Degree of regulation/formality of governance	Description of structures relevant to actor e.g.: • Top down (e.g. quotas) or bottom up (e.g. collectives) • Access • Quality control • Related costs • Independent/state regulation?
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swOT

5. Threats	Please outline any long and short term exogenous threats to the food security outputs of these actors. Outputs which may be threatened by external change may include: • Volume produced/traded/processed • Nutritional quality of product • Diversity of product • Access, affordability, and fair trade particularly where end consumers are vulnerable • Sustainability/longevity of production • Relevance to food sovereignty, agency and autonomy • Known trade-offs e.g. high nutrition, low volume foods sold for low nutrition, high volume staples.
6. Opportunities	Please outline any opportunities for preserving or enhancing these food security outputs for this actor, in the context of both contemporary systems/governance and future transformative policy change.

Directions:

This first development stage will be to ask you all to submit a set of **2-5 examples** of SFFA actor ideal types that you are particularly familiar with or have conducted research involving, using the attached template. The focus here is on **the actors and how they engage with the broader food system**, rather than a focus on the food system itself. These can be actors at any stage of the value chain and may be an individual, group or company/organisation. As a minimum we would really like you to describe **two actors who you view as quite different from one another**, in order to really capture heterogeneity in the system.

As such, we want you to first ask yourself the question ‘who is this actor?’ and to provide **a photo and short description** you feel encapsulates this person/group, if you have one. These photos will not be used beyond the group without further express permission, however the BFA has an open data sharing agreement across the teams of authors, so your submissions more generally may be made available to other team members in future.

Once the context of the actor is envisioned, we would like you to frame some detail on these ideal types around a set of **4 dimensions**, informed by prior work on ideal types and your feedback so far;

1. Input/assets
2. Position in value chain
3. Engagement with markets and influence of demand
4. Degree of regulation/formality of governance

These dimensions are laid out in more detail in the attached template, and some example ideal types are also attached as prompts. Lastly, we would like you to feed into the start of the swOT analysis by explicitly considering some of the **threats and opportunities** which may apply to the **food security-specific** outputs of a given actor, also detailed in the template.

Whilst we want to be clear on the exercise, and the detail we are looking for, we are also conscious that we do not want to lead you all too rigidly in defining how these ideal types should be shaped. This is deliberate as we believe the greatest strength of this approach is you, the experts, leading on how SFFA actors can be better understood towards effective policy. As such the content of the template and the examples given are not intended to be exhaustive or present an inductive categorisation, but a sufficient prompt to start the thought process off.

However, please do let us know if anything is unclear, or you have any questions.

We would really like to have a first set of submissions **by the end of July** to start stage two. Please also find a rough timeline for the next phases of paper development outlined below this e-mail, and do let us know in advance if any of these timings are likely to be problematic for you.

Hopefully this all makes sense and we will send a couple of reminders out as the month progresses, if you could all send your sets of ideal types to Rebecca in the first instance (rebecca.short@su.se), then we will get back to you to organize some further discussions going forward. This is an exemplary group of authors and we are excited to get to work with you all on what we hope will be a key point of further development for the blue foods narrative.

Table S2 - Case profiles from expert knowledge elicitation

SSFA #	Author	Country	Aquaculture/ Fisheries	Brief Description	Gender	Value Chain Position(s)
1	Franz	Antigua and Barbuda	f	Small-scale fisher, SSF spokesperson	m	Producer
2	Wabnitz	Australia	f	Commercial abalone dive fisher	m	Producer
3	Little	Bangladesh	f	Throw net fisher	m	Producer, Seller, Consumer
4	Johnson	Bangladesh	f	Net repair engineer	m	Supporting role
5	Belton	Bangladesh	a	Commercial catfish farmer	m	Producer
6	Johnson	Bangladesh	a, f	Generational fisher	m	Producer, Seller
7	Wabnitz	Canada	f	Small-scale boat-based fisher	m	Producer, Seller, Processor, Consumer
8	Johnson	Canada	f	Freshwater fisher and retailer	m	Producer, Processor, Seller
9	Wabnitz	Canada	f	Commercial trap sablefish fisher	m	Producer
10	Gelcich	Chile	f	Benthic hookah fisher	f	Producer, Seller, Consumer
11	Gelcich	Chile	a	Small to mid-scale mussel aquaculture	m	Producer
12	Naylor	China	a	Tilapia pond sharecropper	m	Producer, Seller, Consumer
13	W Zhang	China	a	Small-scale carp farmer	f	Producer
14	W Zhang	China	a	Small-scale crucian carp fingerling farmer	m	Producer
15	W Zhang	China	a	Small-scale mitten crab farmer	m	Producer
16	W Zhang	China	f	Small-scale tilapia farmer	m	Producer
17	W Zhang	China	f	Shrimp middleman	m	Middleman/Trader
18	W Zhang	China	f	Small-scale fishmonger	f	Trader/Seller

19	Cao	China	f	Unspecialized fisherwomen	f	Producers, Processors, Consumers
20	Cao	China	f	New migrant fishers	m	Producers
21	Little	Egypt	f	Fish market vendor	f	Trader/Seller
22	Mangubhai	Fiji	f	Small-scale fishers	m	Producer, Seller
23	Mangubhai	Fiji	f	Small-scale fisherwomen	f	Producer, Seller
24	Mangubhai	Fiji	f	Indigenous freshwater fisherwomen	f	Producer
25	Brugere	France	a	Small-scale oyster farmers	f, m	Producer, Processor, Seller/Trader
26	Wabnitz	French Polynesia	f	Small-scale spear and boat-based fisher	m	Producer, Seller, Processor, Consumer
27	Wabnitz	French Polynesia	f	Small-scale giant clam fisher	m	Producer, Processor, Seller, Consumer
28	Johnson	India	f	Manager of household fishing operation	f	Producer, Processor, Seller
29	Brugere	India	a	Small-scale carp farmers	m	Producer
30	Naylor	Kenya	a	Small-scale tilapia producer	f	Producer, Seller, Consumer
31	Naylor	Kenya	a, f	Fish market vendor	f	Seller/Trader
32	Naylor	Kenya	a	Aquaculture feed producer	m	Producer, Processor, Seller
33	Naylor	Kenya	a, f	Fish processing employee	f	Processor
34	Crona	Kenya	f	Large-scale trader	m, f	Trader/Middleman
35	Crona	Kenya	f	Small-scale trader	m	Trader/Middleman
36	Hicks	Kenya	f	Small-scale fish trader	f	Processor, Trader
37	Little	Kenya	a	Tilapia cook and trader	f	Processor, Trader
38	Golden	Madagascar	f	Motorized net fisher	m	Producer, Seller, Consumer
39	Golden	Madagascar	f	Informal fish trader	f	Trader/Seller

40	Golden	Madagascar	f	Commercial eel byproduct trader	m	Trader/Seller
41	Golden	Madagascar	f	Net fisher	m	Producer, Seller
42	Golden	Madagascar	f	Child mosquito net fishers	f, m	Producers, Traders, Consumers
43	Golden	Madagascar	f	Child gleaners	f, m	Producers, Consumers
44	Short	Madagascar	f	Shark Jarifa net fisher	m	Producer, Processor
45	Micheli	Mexico	f	Processing plant worker	f	Processor
46	Micheli	Mexico	f	Benthic hookah fisher	m	Producer
47	Basurto	Mexico	f	Lobster, shark and finfish fisher	m	Producer
48	Basurto	Mexico	f	Pen shell diver	m	Producer, Processor, Trader, Consumer
49	Basurto	Mexico	f	Small-scale trader	m	Trader/Middleman
50	Short	Mozambique	f	Mosquito net fishers	f	Producer, Consumer
51	Short	Mozambique	f	Mosquito net fishers	m	Producer, Processor, Consumer
52	Belton	Myanmar	f	Dried fish trader	m	Trader
53	Edwards	Myanmar	a	Small-scale tilapia farmer	f	Producer, Seller
54	Ferguson	Palau	f	Commercial sea cucumber gleaner	m	Producer, Processor, Seller, Consumer
55	Ferguson	Palau	f	Recreational gleaner	f	Producer, Processor, Consumer
56	Ferguson	Palau	f	Sea cucumber trader	f	Trader/Seller
57	Ferguson	Palau	f	Sea cucumber gleaner	f	Producer, Processor, Seller, Consumer
58	Hicks	Seychelles	f	Traditional trap fisher	m	Producer, Seller
59	Brugere	Tanzania	a	Tubular net seaweed farmers	f	Producers
60	Defeo	Uruguay	f	Shellfish processing plant owners	f, m	Processor, Trader

61	Defeo	Uruguay	f	Shellfish harvesters	f, m	Producer, Seller
62	Defeo	Uruguay	a	Sturgeon aquaculture business	m	Producer, Processor, Seller
63	Defeo	Uruguay	f	Freshwater cooperative fishers	m	Producers
64	Halpern	USA	f	Community Supported Fisheries (CSF) fishers	m	Producers
65	Bush	Vietnam	a	Small-scale mangrove integrated shrimp farmer	m	Producer
66	Bush	Vietnam	a	Small-scale shrimp farmer	m	Producer, Seller
67	Kaminski	Zambia	a	Small-scale tilapia fish farmer	m	Producer, Seller
68	Kaminski	Zambia	a	Small-scale tilapia farmer	m	Producer
69	Kaminski	Zambia	f	Fish processor and trader	f	Processor, Trader
70	Kaminski	Zambia	f	Fish trader	f	Trader

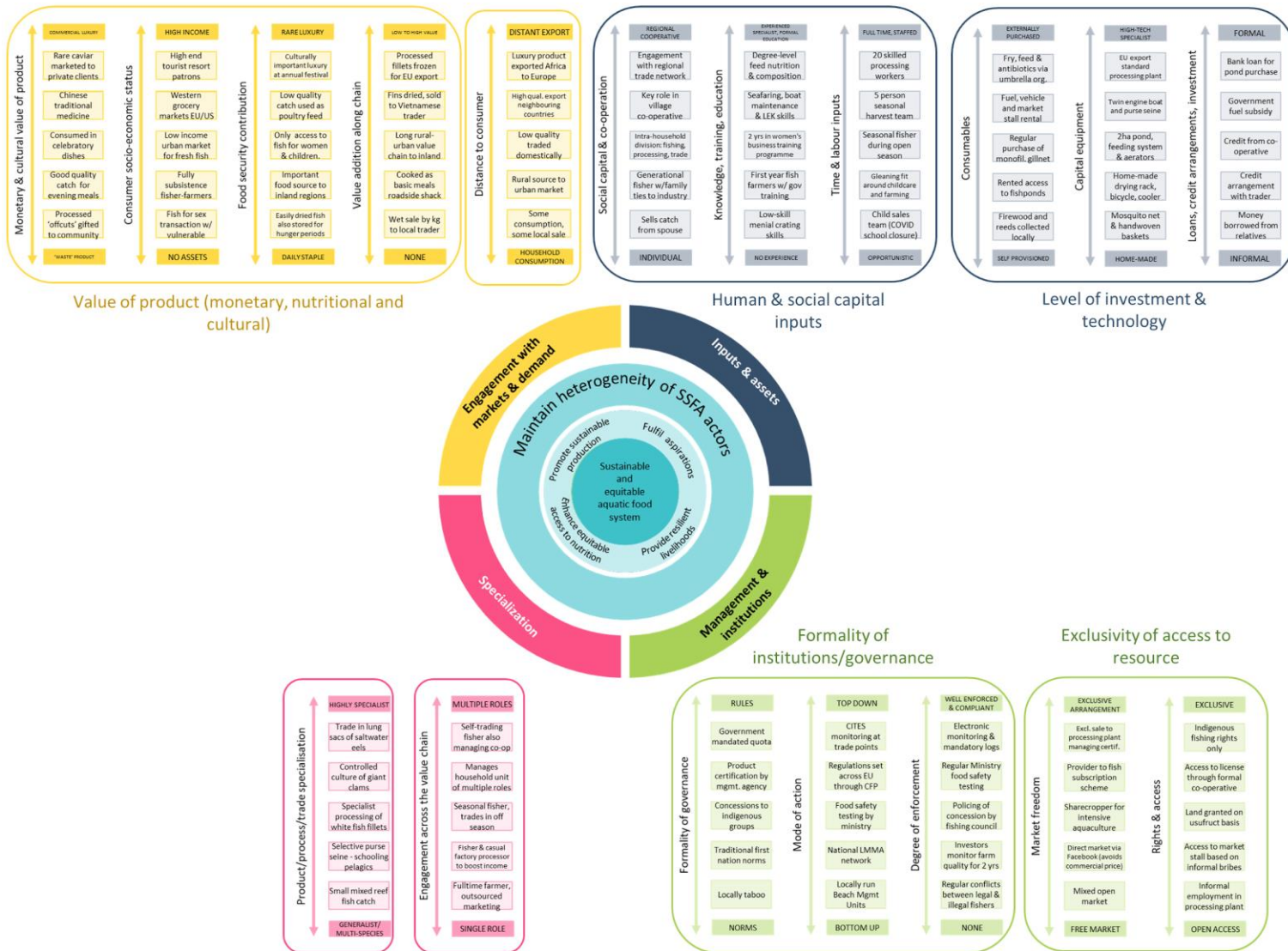


Figure S2 - All SSFA attributes associated with each of the four dimensions and groupings representing reductive analysis.

Table S3 - Categorized threats and opportunities drawn from case profiles and select examples from individual actors.

Threats		Examples from case studies			
Climate change	<i>Severe weather events</i>	Cyclones in Fiji reduce fishers abilities to target grouper aggregations			
	<i>Warming</i>	Tatakoto and Reao, two atolls in the Tuamotu archipelago, French Polynesia were hit by severe bleaching mortality during the 2015-2016 El-Nino event, which also harmed small-scale clam aquaculture and also lead to a ban on clam exports to protect wild populations.	Declining seagrass beds due to ocean warming have reduced sea cucumber catches in Palau leading to a ban on exports and severe price drops for gleaners		
	<i>Sea level rise</i>	The ongoing viability of small Vietnamese farming systems in Ca Mau province are threatened by sea level rise as a low-lying and vulnerable coastal region.			
	<i>Altered water flows</i>	Large amounts of low-lying Twantay District, Myanmar are now populated by small-scale tilapia ponds which are prone to frequent flooding with associated loss of stock.	There is continuing and increasing degradation of watersheds in Fiji due to poor land-use practices, and this is likely to impact many species targeted by women.		
Overexploitation of resources	<i>Overfishing</i>	Marketisation and commodification of sea cucumbers in Palau in 2011 led to rapid overexploitation for export and a ban by 2012, leaving small-scale gleaners serving local markets (important for food sovereignty) with a reduced resource.			

Habitat degradation	<i>Pollution</i>	Harmful algal blooms and prolonged hypoxia in Mexico mean less seasonal work for abalone processing workers and declines in personal catch for households.			
	<i>Invasive species</i>	Increased introduction of non-native species by farmers in the south of Zambia struggling to make their farms viable may mean an increased tendency for successful northern farms to follow, posing a threat to sensitive ecosystems in this region.			
	<i>Benthic damage/al teration</i>	Illegal infilling of urban water bodies for development in Dhaka, Bangladesh means loss of fishing grounds for throw net fishers			
	<i>Land degradation and poor pond manageme nt/abandonment</i>	Loss of mangroves in Fiji impacts women fishers who sell mud crabs to the tourism market			
Disease	<i>Die-offs and reduced efficiency</i>	Artificial pond production of carp in Hubei province is heavily impacted by disease. Government restrictions on wastewater may help slow the spread, but require significant investment in new technology which may force out small-scale farmers.	French small-scale oyster farms dependent on a single species are prone to disease. Alongside seasonality of demand this can often mean that women, 'assisting spouses', may be forced to find alternative incomes whilst their husbands continue to farm.		
	<i>Reduced community bonds</i>	Chilean salmon farmers have distanced themselves from the community by increasingly hiring contract divers from other regions/countries as farms increase in size/become more mechanized			

	<i>Conflicts at the local level</i>	Social tensions in Kenya between tilapia farmers and communities have been caused by local preference shift to cheaper, imported tilapia from China	Pond waste from Chinese tilapia farms flowing into Hainan's public waterways is threatening the tourism industry and creating conflicts		
Inequity	<i>Gender inequality</i>	Gujarati families who may collectively provide different 'parts of the plate' towards a meal may not equally benefit from this, with girls eating last and often denied fish or other nutritionally rich foods by the time they eat.	Women mosquito net fishers, who fish closer to shore than men and therefore are more visible, are more likely to be fined or have their nets confiscated by fishing councils or government officials.	Efforts to encourage small-scale seaweed farming amongst women in Tanzania are threatened by the increasing profitability of this activity, meaning men are moving into farming spaces more and forcing women out.	
	<i>Cultural marginalization</i>	Indo-Fijians are not recognized as having access to Fijian fishing grounds and are required to gain written permission for a license, despite being the second largest ethnic group. Their contributions remain unrecognized and unquantified with no access to government support.			
	<i>Lack of access to education and training</i>	Lack of access to basic vocational training in small-scale Zambian farms means pond management skills are severely lacking and investment risks are extremely high.			
	<i>Elite capture</i>	Public 'Blue growth' investments are being used to increase marine space allocation to large scale aquaculture, tourism and foreign fisheries across Africa	The urban market where women traders sell their fish in Shanghai will soon be luxury flats. A new, improved market is to be built but stall rents are already too high and these will only go to the wealthiest traders.	Although the fisheries policy of Bangladesh states that inland fisheries resources will only be leased to fishers, government-owned fisheries water bodies are leased by the local elite and influential people of the ruling political party.	

	<i>Lack of access to financial resources/infrastructure</i>	Loss of government subsidies for tilapia farmers in Kenya would decrease viability and enable Chinese products to flood the market, in turn there is the threat of a Chinese processing plant which would outcompete existing Kenyan plants	A concentration of government and donor support in the north of Zambia has meant inconsistent access to feed and fry for those in the south, leading to the abandonment of production systems as they do not prove viable.	A lack of ice and cold storage infrastructure for fisher in Rio Negro, Uruguay precludes commercialization of products with high-added value, and intermediaries take advantage of limitations in local cooperative infrastructure.	The Californian tourism sector over the years has taken over various infrastructure facilities (dry boat storage space and harbor slips), which has narrowed availability for fishing community needs.
	<i>Loss/under performance of collective action mechanism</i>	Vietnamese shrimp farming families in an organized co-op are wholly dependent on the organic shrimp market for a living, meaning whilst safer from disease they have few alternatives for marketing their shrimp in times of volatility and are unable to take advantage of changes in market price.			
	<i>Poor/unsafe working conditions</i>	As the Myanmar raft fishery expands and catches decrease, viability of the fishery is maintained through exploitative labor practices, with mistreatment causing injury and death of many workers on rafts each year.			
	<i>Illness and lack of access to healthcare</i>	The fish-for-sex phenomenon is thought to be a contributing factor to the high prevalence of HIV/Aids in fishing communities and fish trading networks in Zambia.			
	<i>Disease and illness</i>	COVID19 shocks have reduced demand for Pangasius in Bangladesh as households switch to hardship expenditure (rice and staples) which is leading to delayed harvesting, restocking and even temporary withdrawals of farms with associated compromises to nutritional capabilities	Covid-19 exposed the vulnerability of a Community Supported Fishery in Canada that did not provide door-to-door services, with their customers unable to collect their product.	Covid-19 illustrated the vulnerability to external markets for walleye and whitefish in Canada with export markets for walleye in the US slowly closed down meaning small-scale fishers on Lake Winnipeg could not go out to fish.	

Markets and competition	<i>Access to resource (capacity, space)</i>	Women in Mozambique have been gleaning and mosquito net fishing in shallow water sand and seagrass beds for many years, but recent co-management efforts to expand closed zones and shallow oyster mariculture have failed to successfully integrate these women, meaning they are forced out of their traditional fishing grounds.	Kenyan Mama karangas often buy undersized species which are considered trash fish that they are able to repurpose as nutritious and available food for the community, but which are caught using illegal gears. If and when regulations are tightened up they will lose access to this catch, their livelihoods and this nutritional contribution.	Local aquaculture projects in British Columbia supported by the Canadian government are considered a threat to sablefish as the facilities are located in inlets providing important habitat for young sablefish and may undermine the economic viability of the wild capture fishery.	
	<i>Competition from commercial/industrial actors</i>	Small-scale lobster fishers in Mexico are being out-competed by industrial shrimp boats which are able to harvest multiple species at a time.	Small-scale Zambian tilapia farmers struggle to compete with commercial companies, three of whom dominate the market, set the price and largely govern the value chain.	The Seychellois inshore trap fishery is fairly diverse and resilient, however the offshore semi-industrial fisheries are open access with recent large increases in efforts to boost incomes but declines in catches. These fishers may move inshore threatening the trap fishing grounds.	
	<i>Competition from alternative/cheaper products</i>	Mass mortality of yellow clams in Uruguay due to ocean warming with limited recovery has meant severe loss of income for processing plant owners, leaving unmet demand in local markets which is rapidly being filled by cheaper imported clams.	All Zambian tilapia production is threatened by the introduction of cheaper Asian tilapia, however this product provides affordable fish for some experiencing food insecurity.	Production of seaweed by women in Zanzibar is threatened by competition from cheaper products from Indonesia	
	<i>Volatility and changing demand</i>	Traders from Angola, Namibia and DRC are beginning to come to Zambia as domestic demand can no longer be met, as value increases may be higher in these markets, alongside unfavorable exchange rates, these traders have more buying power than the women's network traditionally controlling local distribution.	Middlemen in Kenya can operate on hugely differing scales. Smaller-scale middlemen with much of their capital tied up in credit arrangements may be quickly forced out during periods of volatile pricing by larger, more stable middlemen financing their own boats.		
Food security and nutrition	<i>Reduced local availability/affordability</i>	Small dried fish from West Africa are an important, affordable source of essential nutrients for local communities but increasingly being bought up at higher prices for fish meal production in industrial-scale			

		plants.			
	<i>Increased availability of nutritionally poor imports</i>	Intergenerational knowledge loss and changing food preferences for convenient and cheap high-calorie foods have led to declining herring consumption and increasing health problems amongst Comox First Nation fishing communities in Canada.			
	<i>IUU</i>	Illegal itinerant divers may take oysters and lobsters from traditional concessions in Punta Lobos, Mexico, reducing the catch of local fishers			
	<i>Banned gear/methods</i>	Mosquito net fishing is viewed as a growing threat to coral reef fishers of Mozambique, but is an important source of food and income for marginalized people unable to access the fishery with formal gears.			
Opportunities		Examples from case studies			
Investments/technologies	<i>Better shared resources and infrastructure</i>	The commercial sector and infrastructure for tilapia farming in Zambia have vastly improved in the last 10 years, the benefits of which should be better shared with small-scale farmers by building relations so that they can be inclusively integrated into the value chain.	Agreements between Californian community supported fisheries and other port and coastal users could be fostered to better enable shared infrastructure needs (space is very limited). For example, new partnerships are being explored for fishers to work with other sectors that could be complementary such as aquaculture and the ocean energy industry.		

	<i>Access to credit and business expansion</i>	Greater access to loans and credit for small-scale carp farmers in India would facilitate expansion within already highly suitable environments by enabling investment in high quality feeds and achieving economies of scale.	Replacing informal loan shark arrangements with formal co-operative bank loans to start revolving funds cuts interest rates and permits more borrowing over time has enabled expansion for small-scale carp farmers in Myanmar.	Village savings and loans associations (VSLAs) provide community-supported access to credit for women mosquito net fishers in Northern Mozambique, meaning the income from this illegal but informally tolerated activity can be invested in alternative small-businesses and lifestyle improvements such as education and housing.	
	<i>Access to technology and equipment (increased efficiency, quality)</i>	Opportunity to increase productivity of the tilapia aquaculture in Kenya through high-quality, locally produced feeds that are affordable to a growing number of producers, additionally bolstering small-scale agriculture.	Tubular nets for seaweed farming in Tanzania offer opportunities to mitigate impacts of climate change and empower women to be more competitive through higher-value products.	While the majority of members own fishing equipment, the number of equipment items per person is very low. This indicates that there may be scope for more investment and the opportunity to enhance the overall productivity of members, particularly in the inland fishery.	
	<i>Increased storage & transport capacity</i>	Improved availability of cool storage boxes, ice, and credit support for things like transport costs have increased the purchase and selling power of female fish traders in Kafr el Sheik, Egypt.			
Markets	<i>Increasing demand for product</i>	In Kisumu, Kenya there is an opportunity to meet growing demand for animal protein (fish) and micronutrients in the province and in the country through targeting school lunches, additionally providing better nutrition for children's physical and cognitive development.			
	<i>Diversification (new resources and demand)</i>	Diversifying Madagascar's relatively well-equipped shark fishers away from this boom and bust fishery to more productive species serving domestic markets, through efforts like gear exchanges for smaller gillnets, may provide a more stable	A range of species exist in Zambia which could diversify aquaculture production and lessen the temptation to illegally stock invasive species.		

		income and contribute more to domestic food supply.			
	<i>Access to e-commerce</i>	Mitten crab is very suitable as a fresh food e-commerce product for farmers in Jiangsu Province, China, as crab can survive several days long distance transport using simple ice boxes. The online sales of mitten crab have increased rapidly as market demand has diversified.			
	<i>Value addition</i>	Opportunity for small-scale Chinese tilapia farmers to expand to simple processing as tastes change and demand for fillets in urban areas increases, but control of processing activities by large parent companies over sharecroppers needs addressing.			
	<i>Improved market access/connectivity</i>	Uruguayan clam processing plants may be certified by DINARA, which provides strict inspections of the product stored at the processing plant (testing concentration of toxins and organoleptic quality) to authorize its sale to wider markets.	Enabling Mozambican mosquito net fishers to dry fish with basic equipment would improve access to sporadic rural traders who will pay a premium for dried fish for more distant domestic markets and boost incomes even in the rainy season.		
Improved rights, access and equity	<i>Gender mainstreaming & inclusion</i>	Efforts have been made in Mexico to enhance the role of female processing plant workers, via fishing cooperatives, into new roles in administration, technical staff positions, and production, primarily in aquaculture and mariculture which is consequently expanding.	Legal recognition of the status of 'assisting spouse' is considered a significant step for women in fisheries and aquaculture in France, giving women the right to represent the company, participate in related representative organizations, and access to vocational training.	There is a unique opportunity to work with rural freshwater fisherwomen in Fiji to improve handling and hygiene standards, and the product that gets to market, connect them better to markets and provide education to better understand how changing land-use practices are impacting their resources.	

	<i>Increased inclusion in governance (see below)</i>	Immigrant fishers are rarely if ever included in management decision-making in Palau. There are opportunities to include a more diverse set of stakeholders in discussions about the sea cucumber fishery's recovery, and new funds for aquaculture could be expanded to include immigrants and women.			
	<i>Access to collective action groups</i>	Collective action among Egyptian female fish traders has aimed to improve their bargaining power and market access through support from international projects and advocacy.	The Caribbean Network of Fisherfolk Organizations is part of an enabling regional framework and mechanism that can facilitate support to small-scale production systems. The challenge is – as in many cases, the insufficient application and operationalization.	Under institutionalized co-governance in Uruguay, fishers and intermediaries of Rio Negro put back into operation the icemaker and cold storage room for fish. Moreover, illegal fishing was mitigated with 10,000 m of illegal nets replaced after agreements with fishers.	
	<i>Social development (healthcare, sanitation, water, literacy)</i>	To date, the Machhiyara communities of Gujarat, India, have been completely ignored in governance regimes. A basic income supplement, provision of basic but reliable health care, sanitation, and drinking water, and literacy training are some of the many interventions that are needed to ensure their fishing activities remain viable.			
	<i>Economic development (increasing incomes)</i>	Moaming is a major tilapia producing area of China, but as farms for other species such as crucian carp and pangasius enter the region there is increasing demand for semi-skilled workers whose wages have increased rapidly, doubling in 10 years.			

Improved governance	<i>Enabling governance structures</i>	There are increased efforts in Fiji and the Pacific region to better consider gender and social inclusion in small-scale/coastal fisheries. Advocacy by NGOs has helped support draft national management plans for key fisheries and influence national level policy for better enabling governance for marginalized fishers.	Institutionalized co-governance and clear access rights in Uruguay improved the transparency, accountability and legitimacy of fisheries management, and has empowered the local community of Barra del Chuy, whose members are proud to be clam gatherers (“almejeros”).	The political will to establish aquaculture in Zambia is much higher than in neighboring countries and Zambia has tremendous potential for small-scale producers.	CSFs provide a viable model that, although limited, might provide inspiration and opportunities for adaptation for the industry, government, regulations and further interest from consumers in other geographies, socio-economic realities.
	<i>Improved management capacity</i>	MSC certification, fisheries improvement projects (finfish), voluntary marine reserves and ecological restoration projects have resulted in increased government support through infrastructure (roads, electricity) and awards, as well as philanthropic support for improvement projects in Baja, Mexico.	The Tasmania abalone fishery is one of the most valuable fisheries in the world and as such is well regulated. Amendments in Total Allowable Commercial Catch have led to improvements in some areas and such precautionary measures are likely to support the fishery into the future.		
	<i>Improved environmental management</i>	Exclusive access rights, local infrastructure and social capital has enabled Chilean hookah fishers to maintain stocks and quality of resources. Ideas for voluntary marine reserves and restoration projects are now underway to maintain and enhance this success.	Increased understanding of flood protection value of urban water bodies by city planners in Dhaka, Bangladesh may better protect urban fishing grounds for local throw net fishers.	Efforts are now underway to monitor, manage, and farm sea cucumbers in Palau. “Transplanting” sea cucumbers from abundant areas to over harvested areas has been practiced in Palau for decades, possibly centuries.	
	<i>Improved socio-economic management</i>	Popular and well-tested local management tools in Palau include ‘bul’, or temporary restrictions on harvest - especially area-based restrictions, and the prohibition on marketing/selling.			
Alternative livelihoods	<i>Capacity building, education, training</i>	Opportunities for training and education in shellfish farming exist in France, particularly of interest for women who currently have the status of ‘assisting spouse’, enabling them to manage their own farms or take on management roles.			

	<i>Support for new businesses</i>	Female co-operative efforts to pool resources from mosquito net fisheries in Mozambique have been successful in becoming competitive, access to additional credit or savings schemes would provide next steps to development of small businesses outside the fishery, reducing this illegal activity.			
	<i>Knowledge exchange</i>	There may be opportunities to create greater connections between gleaners marginalized for gender or ethnicity reasons and those who have knowledge of traditional practices for sustainable harvesting (mainly older Palauan women).	Enhanced peer-to-peer knowledge sharing about fish farming practices (rather than top down from the Fisheries Department) would provide Indian carp farmers in Kerala with more consistent support and ability to expand.		
	<i>Increasing local job provision/diversification</i>	The K'ómoks in Canada have been resourceful and entrepreneurial, diversifying their income sources. A number increasingly cater to tourism by hosting individuals and running trips, providing an opportunity to learn about the rich history of the community.	Development of "pesca-tourism" as a diversification opportunity related to shellfish farming in France has presented alternative livelihoods for 'assisting spouses' of oyster farmers; welcoming groups to the farm, presenting their product for tasting and hosting tours.		
	<i>Maintain social identity of actors</i>	The Barotse floodplain is a lifeline for thousands of Zambian people. The entire Lozi culture, history and traditions is associated with the floodplain and preservation of this fishery and the associated livelihoods is critical and there is great potential for effective buy-in to co-management which focuses on this.			

	<i>Better recognise food & nutrition security contributions (alongside rents)</i>	An effort to transition perceptions of Yellow clams away from “bait” towards “high-quality seafood product” for human consumption improved the economic situation of the local community in Uruguay, evidenced in the marked increase of unit price and the societal valuation of the product.	Dried fish traders play an important intermediary role, aggregating dried fish and ensuring its distribution throughout the country, often overlooked in assessments of food security contributions. As Myanmar’s food system modernizes further, enabling these traders to adapt to demand for improvements in quality, food safety, packaging and traceability will be a key opportunity.	Very small-scale women traders of the Giriama in Kenya who sell cheap, small fish to local people, often the most poor, provide an irreplaceable service for food security. Such actors who are extremely vulnerable to shocks and who may buy only from illegal gears (what they can access culturally) need support and inclusion to make sure this service is not lost	
	<i>Re-focus on supporting adaptive capacity (social & environmental stressors)</i>	Pre-existing experience in adaptation to environmental stressors in Chilean mussel mariculture is now being supported by a willingness to invest in early warning systems for harmful algal blooms.	Exclusive access rights, extensive infrastructure and financial and social capital has enabled the Mexican benthic hookah fishers of Baja's cooperatives to adapt and face climate and market shocks.		