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

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Abstract

Small-scale fisheries and aquaculture (SSFA) provide livelihoods for over 100 million 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 can assume homogeneity in SSFA despite being diverse in nature. 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.

Introduction

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 transformation[1]. At the same time, population growth and rising affluence are fueling demand for more food, and 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 inclusion[2].

Recognizing the critical role that small-scale actors play in meeting these challenges requires a deeper understanding of their diverse characteristics and contributions to sustainable and equitable food systems. Herein, 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. 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 jobs[3]. Yet, the nature and importance of these contributions to food and nutrition security, livelihoods, and sustainability remain inadequately recognized by development, food, environment and fisheries policies[4]. We argue one reason for this persistent neglect is that policy makers are challenged by the diversity and dynamism of SSFA. Despite significant advances towards acknowledging SSFA diversity and contributions via efforts such as the FAO Voluntary Guidelines for Securing Sustainable Small-scale 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 systems[10], '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 interdependence[13] to competing and undermining sustainability with immediate impacts on SSFA viability[14]. It is critical to remove subsidies to industrial concerns, rebalance

87 access to capital and political influence and take steps to counteract simplistic characterizations of SSFA
88 actors, their roles in food systems, and how governance reforms may affect, enable or exclude them. As
89 social-ecological systems and food sovereignty perspectives argue, SSFA are key to holistic blue food
90 futures[15], but policy-makers need tools that can better incorporate and capitalize on their inherent
91 diversity.

92 The diversity of SSFA is commonly overlooked partly due to misrepresentation and contestation over
93 what 'small-scale' constitutes[16]. Similar to discourses around smallholder agriculture[17], most analyses of
94 the aquatic sector agree that binary classifications of 'small' and 'large' are inadequate given high
95 geographic and socio-economic heterogeneity[7]. Rather than pursuing one definition of SSFA, consistent
96 with the SSF Guidelines [5], this paper aims to prime future analysis to be inclusive of SSFA diversity. We
97 present an innovative framework that illustrates the diversity of SSFA actors to examine threats from
98 climate, environmental, socioeconomic and political change, and opportunities to support SSFA viability
99 for more sustainable and equitable food systems.

100 Results

101 We characterized SSFA actors from freshwater and marine fisheries and aquaculture based on 70 case
102 profiles (Extended data Table S1 and S2), which span poor to richer or industrialized contexts, and a
103 range of activities by women, men, youth and children. Profiles span value chains, from input
104 procurement to production and harvesting, processing, distribution and trade (Figure 1, and Extended
105 data Table 2).

106 We identified four key *dimensions*: inputs and assets; markets and demand; management and
107 institutions; and specialization/diversification (Methods; Figure 2; Extended data Figure S1). An iterative,
108 inductive process, including two co-author workshops, was then used to explore diversity and examine

109 case details (Figure 2). A reductive process was subsequently employed to group characteristics into a
110 manageable and representative core set of eight attributes (Figure 3). Attributes were then used to
111 describe individual cases (selected examples are presented in Figure 3). Case profiles were also
112 examined for the relevant threats and opportunities (environmental, economic, social, political) as
113 overarching pressures or levers which alter or enhance an actor's attributes (Figure 2; Extended data
114 Table S3).

115 The eight attributes, nested within the four dimensions are: (1) level of investment; (2) human and
116 social assets; (3) distance to consumer; (4) product value; (5) formality of institutions/governance; (6)
117 exclusivity of access to the resource; (7) degree of pluriactivity; and (8) diversity of products (Figure 3).
118 Each attribute represents an intermediate level of abstraction and generalizability of identified actor and
119 contextual attributes. Attribute combinations provide a way to assess different implications of actor
120 profiles in terms of threats and opportunities, vulnerability or adaptability. In the following sections, we
121 explore these attributes and their diversity, starting at the level of individual actors and activities and
122 expanding to engagement with external actors, markets and influence of governance.

123 *Inputs and assets*

124 Levels of monetary investment and technology are heterogeneous across SSFA (see Table 1 - A for
125 examples). Case profiles show assets ranging from modern processing plants using imported equipment
126 to locally fabricated or homemade gears. The key common element of SSFA is that activities are
127 controlled at a local level by individuals or groups of households at a local level. Production inputs also
128 range from self-provisioned or gifted, to investments by other value chain actors or purchased.
129 Underpinning this variability is a wide range of credit arrangements, from no credit, to informal familial
130 borrowing to formal bank or NGO-facilitated loans, to which access is often mediated by a combination

of class, gender, ethnicity, education and age, as well as 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 shortfalls[18]. Whilst 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 critical[19].

The human capital of SSFA actors is also highly variable (Table 1 - B), from basic technical skills adequate to support household food security[20], to professionalized SSFA producers, traders and processors with formal education or training meeting complex market specifications[21]. 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 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 sectors[22].

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 methods used to exploit it (Figure 1). SSFA might target or cultivate a single species using specialized gear, or use multiple gears 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 (e.g. Table 1 - C). Small-scale fish farmers often utilize polyculture, or engage in activities upstream (e.g. trading inputs) or downstream (e.g. processing). In much of Asia and sub-Saharan Africa, production of

153 crops and livestock on very small landholdings produces insufficient income and necessitates
154 pluriactivity; aquaculture has often emerged as a secondary activity. Ponds holding fish, doubling as on-
155 farm irrigation water storage, act as a reserve to cover expenses such as school fees[23] whilst supporting
156 associated horticulture[24].

157 SSFA actors engage in aquatic food value chains from year-round to seasonal, from full- to part-time,
158 and trading-off roles within and outside supply chains depending on opportunity or necessity. Both
159 specialization and pluriactivity characterize the livelihood portfolios of SSFA actors (e.g. Table 1 - D).
160 Activities may be part of mixed livelihoods portfolios, and involve paid labor or unpaid familial inputs.
161 Age, gender, religion, education and ethnicity are critical factors in the dynamics of how actors may
162 access, enhance and invest their own human capital in livelihoods based around SSFA, with highly
163 variable outcomes for equity and food and nutrition security[25].

164 SSFA actors show important differences in the possibilities for diversification. In general, diversification
165 can grant flexibility to an individual's operations, securing them against certain risks and enabling
166 adaptability, as recently demonstrated by responses to the COVID-19 pandemic[4,9]. Flexibility to move
167 between occupations can also provide conditions that support adaptive responses[26]. However,
168 diversification is not always a positive characteristic; it may be an outcome of necessity rather than
169 opportunity[27]. Efficiency or consolidation may be effective in certain operations and contexts, such as
170 processing of high value resources or transportation logistics. Furthermore, diversification should not
171 undermine the importance of value chain coordination, much of which is informal within private sector
172 networks.

173 A continuum between capture fisheries and aquaculture case profiles highlights important differences
174 between fisheries and aquaculture, particularly for producers. Whereas in some contexts, only low cost
175 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 socio-economic status, with high-end consumers accessing luxury products through global markets (e.g. Table 1 - A) to poorer consumers accessing daily staples from their own harvest, exchange or local markets[30] (e.g. Table 1 - E). High value products can be accessed through short supply chains, particularly where freshness, water-to-plate or cultural value fetch a price premium (e.g. associated with tourism)[31]. Luxury products are also exported after value addition (e.g. smoking of sea cucumbers) enabling SSFA actors to benefit from global value chains, though these benefits largely remain inequitably distributed[25]. Lower value products may also be traded over long distances to meet national and regional demand [30]. Food security is supported directly through processing (drying, salting) and trading or gifting both primary products and byproducts locally and indirectly, for example as livestock feeds[32].

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 (e.g. Table 1 - F). The specific dimensions of such patron-client relationships are culturally mediated[33], 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 markets[34]. However, new markets and channels - such as online and direct sales -

198 emerged or rapidly expanded to serve consumers in many regions of the world, often in response to
199 faltering or disrupted value chains[8,9].

200 Supporting the development of market infrastructure has proven critical for SSFA actors in many
201 contexts, especially where they reduce concentration of market power. Rapid growth of small-scale
202 aquaculture in Asia has often been linked to improved market access, often through competitive
203 intermediaries[35]. Exploring the diversity in SSFA shows that those focused on self-provisioning, exchange
204 and/or supplying local markets are likely to have different needs and challenges to those that target
205 international or urban domestic markets. By linking proximity to consumers and the different modes of
206 production, policy makers can more effectively address equity issues.

207 Case profiles show aquatic foods may have particular cultural importance that transcends their
208 nutritional qualities, including for communities most nutritionally dependent on them, such as
209 Indigenous and marginalized groups[36]. Cultural attachment and the importance of food sovereignty is
210 also evidenced by transfer of consumption preferences among fish-eating diaspora[37].

211 *Management and institutions*

212 SSFA actors and their activities are governed by management systems and institutions ranging from
213 centralized government control, to localized culturally embedded arrangements (Figure 2). In some
214 countries and contexts, access and use rights are legally assigned to SSFA actors. In other contexts, local
215 and cultural institutions dictate those rights, in isolation from (or in concert with) formal legal structures
216 (e.g. Table 1 - G)[38]. All governance arrangements present opportunities and challenges to equity and
217 inclusion along lines such as class, gender, and ethnicity[38]. Exclusive resource access or private
218 ownership characterize some SSFA, while *de facto* open access systems support others, with multiple
219 intermediate forms of common access and use rights to land and water falling in between. Open access

220 regimes, however, can restrict investment, sustainable management and equity (e.g. Table 1 - H). The
221 agency and inclusion SSFA actors experience in governance arrangements present an important avenue
222 through which to improve food system outcomes[22]. In contrast, imposed governance mechanisms can
223 sometimes prove ineffective or counterproductive[39].

224 Cooperative arrangements were common in many case profiles, particularly for fisheries, enabling
225 coordination and innovation through collective action[40]. Similarly, market-based collective institutions
226 such as metric-based environmental and social standards can be critical for SSFA actors to gain and
227 retain access to markets[41].

228 Any degree of exclusivity and formality in governance will be influenced by levels of enforcement and
229 compliance, which remain extremely variable across SSFA, particularly as their unique characteristics are
230 often under-appreciated in risk-benefit assessments and interventions[42]. Some actors may operate in
231 highly controlled systems of intense monitoring, others may be self-compliant or self-policed through
232 commitment to collective action, and others may operate in wholly unmonitored systems. This diversity
233 highlights the need to recognize and address the specific impacts of monitoring and enforcement on
234 SSFA as a key component of designing inclusive, equitable solutions.

235 Discussion

236 *Threats and opportunities for action*

237 Based on the case profiles, here we present key threats from climate, environmental, political and socio-
238 economic change, and opportunities for supporting SSFA viability and equity in the face of these major
239 drivers. Governance failures, poor political representation and power, resource overexploitation, habitat
240 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 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 (here and thereafter see Extended data Table S3 for more detail highlighted by case studies), and in SSFA worldwide[43,44]. In freshwater contexts, changes in rainfall, water quality, land degradation and loss to urbanization and farming, and changing precipitation also present significant environmental threats[45]. For SSFA actors whose inputs and assets are threatened by climate change, for example low-tech actors dependent on vulnerable systems (Fig. 3 - d), technologies and investments in human and social capital, as well as in diversification and development of appropriate institutions offer key opportunities to support their viability[26].

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 scales[46]. Multiple shocks can synergistically combine to affect SSFA actors across whole value chains. Sustainable intensification is a particular challenge for these actors[47] 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 challenge[48].

263 SSFA actors relying on high product diversity but low technology and investment (e.g. Fig. 3 - b) tend to
264 be closely linked to the environment and so are particularly vulnerable to shocks and longer-term
265 environmental change trends. However, our cases also demonstrate high adaptive capacity. For
266 instance, tilapia farmers in Northern Zambia, having no access to improved strains used by farmers
267 further south, have based culture on diverse local species adapted to local climate variability. In doing
268 so, local knowledge exchange networks have evolved, resulting in improved efficiency and
269 circumventing the direct competition of tilapia from southern farmers (Extended data Table S3). Such
270 adaptation requires agency, flexibility and learning capacities[26]. The development of programs and
271 policies that remove barriers and provide incentives and resources for diversification, and emphasize
272 inclusive and equitable outcomes, are key strategies for supporting climate adaptation in SSFA.

273 Some SSFA attributes incur high exposure and sensitivity to shocks. SSFA actors who fish for and sell
274 high market value species are exposed to market, transport and infrastructure shocks (e.g. Fig. 3 - g). In
275 addition to addressing logistical or financial exposure, building adaptive capacity in these systems also
276 requires support for social networks and collective learning[34]. Policy developments that incorporate
277 support for the design, implementation, monitoring, and institutionalization of climate change
278 adaptation programs are needed. Supporting adaptive institutions under climate change should be
279 based on a detailed understanding of formal and informal (including traditional) practices--and explicit
280 recognition of previous governance failures. Climate uncertainty can undermine incentives for engaging
281 in long-term planning and commitments to sustainability, or reduce investment in aquaculture
282 development by poorer, more risk-averse actors[57]. Established user rights-based systems in Chile,
283 Mexico, and Uruguay (Fig. 2 - b, c, o) provide important lessons for what enabling conditions support
284 adaptation to climate change[49].

285 Insurance, credit, and market mechanisms can provide important protection against extreme events in
286 the dimension of inputs and assets, but they are no substitute for broader adaptive capacity. However,
287 they may offer little protection to human and social capital. Insurance schemes thus far have only been
288 taken up by large-scale farming operations, through fisheries insurance schemes[50] Although climate
289 derivatives approaches, which are currently expanding in aquaculture[51], have the potential to increase
290 the resilience of aquatic food systems to extreme weather events, it is critical that these schemes avoid
291 perpetuating inequalities by favoring larger enterprises to the detriment of poorer or marginalized
292 actors[50].

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

300 *Economic shocks, changing demand and globalization impacts*

301 As consumption and demand for aquatic foods increase with rising purchasing power, some species
302 historically produced, traded or consumed within SSFA may be diverted to high value export markets or
303 local tourism markets[52] (e.g. Fig 3 - e). Resulting increased incomes for SSFA actors can pose important
304 trade-offs with local food and nutrition security. SSFA actors, particularly in the rural sector, have limited
305 capacity to influence global market drivers and prevent negative outcomes. Rapidly growing
306 international demand for marine products, for example, has led to industrial harvest of nutritious small
307 pelagics that were previously targeted by artisanal fisheries for local direct human consumption in West

308 Africa[53]. Positive economic and social outcomes may be achieved by combining export products with
309 low economic value and high nutritional value products for local consumption[54], but such opportunities
310 need diverse targeted policy interventions and strategies[47] to maintain local food and nutrition security
311 and, at the same time, withstand potential instability of global markets.

312 The COVID-19 pandemic has brought major disruption to fisheries and aquaculture throughout supply
313 chains, exposing significant vulnerabilities and inequalities[8,9,34] and highlighting the powerful influence of
314 market dependence. Early in the pandemic, most exports were halted and the majority of domestic
315 markets closed, with major impacts and losses for SSFA actors and supporting socio-economic systems
316 around the world[34]. Where actors lacked political recognition they could also be excluded from
317 supportive and enabling responses such as curfew exemptions[55]. SSFA responses to the pandemic have
318 spanned increased vulnerability to high resilience. Mobilization of SSFA actors and networks to share
319 information, monitor impacts, and transform the crisis into an opportunity has occurred, as has a surge
320 in direct producer to consumer sales (e.g. Fig 3. - h), e-commerce, and local food sharing[8,9]. Such
321 adaptive short-term actions, involving both the products produced/traded and modes of engagement
322 with consumers, have potential to evolve into longer-term adaptive strategies, with as yet uncertain
323 distribution of benefits.

324 The pandemic has demonstrated the importance of SSFA diversity and recognition as a key element to
325 build adaptive capacity to future economic shocks. Aquatic food systems experience considerable price
326 volatility[56]. Although aquaculture has some ability to schedule production, and thus can decrease price
327 volatilities compared to fishing, such volatility also relates to species and production technology[56]. Case
328 studies signal that pluriactivity and linked fishery and aquaculture systems, such as those developed
329 under territorial user right arrangements, can provide important niche innovations to deal with volatility
330 and economic shocks[57].

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 (e.g. on Fig. 3 - a). Enhancing diversity in SSFA must consider the complexity of fisheries and aquaculture interactions and how strategies may disrupt longstanding 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 are challenging with increasing distance from the end consumer, although use of QR codes by retailers and food service providers show promise in bridging such divides[58]. 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 tenure[59]. 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 (e.g. Fig. 3 - c). 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 (e.g. Fig. 3 - g) 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

354 understood and supported in broader terms than economic value alone. Diversity is essential to SSFA
355 viability and their ability to provide nutritional security; underpinned by individual needs surrounding
356 human and social capital, gender equity and agency, which need to be respected and supported.

357 First and fundamentally, SSFA actors need to receive ***sufficient benefits*** (e.g. economic, nutrition,
358 cultural value) from SSFA. There are certain contexts for which being a SSFA actor is tied to poor
359 outcomes with few opportunities to exit and where broader system transformation is necessary[60].
360 Investments in alternative livelihoods have been largely inadequate and more fundamental structural
361 shifts, such as changes to property rights, which recognize SSFA actors' unique roles and needs are
362 required. Policies that support inclusive relationships with state and/or corporate actors in and beyond
363 the food system may be a key element. Such policies must recognize traditional and indigenous rights,
364 and access rights should support not undermine the rights of indigenous people.

365 Second, SSFA actors play a key role in food and ***nutrition security***, with globalization often intensifying
366 trade-offs between economic gains from supplying distant markets and the loss of nutritional benefits to
367 local actors. Aquatic foods provide critical support in addressing the triple burden of malnutrition[53,61].
368 Guidance toward more nutrition-sensitive fisheries governance and aquaculture approaches (e.g.,
369 polyculture, ecosystem-based solutions) linked to integrative landscape approaches are required to
370 ensure SSFA viability.

371 Third, ***human and social capital*** support the viability and adaptive capacity of SSFA. Our case profiles
372 illustrate that many actors benefit from the economic, nutrition and cultural values delivered through
373 SSFA, and that these attributes can be managed and maintained to align to equity and human wellbeing
374 objectives of future food systems. Historically, agricultural models have focused on economic upgrading
375 rather than social mobility and resilience[23]. The focus on creating enabling conditions for SSFA actors to

adapt and thrive[26], rather than provision of inputs or incentives, is essential for addressing actor-level threats and equity.

Fourth, ***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, as 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 level[59]. Improving food systems requires a gender lens, so as not to perpetuate and exacerbate existing inequalities (e.g., intensifying labor burdens[62]), 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 policy makers have to navigate to maintain the benefits from

399 continued engagement of SSFA actors. In particular, meeting the needs of global consumers through
400 large-scale industry poses risks for the cultural integrity, equity, nutritional security and livelihoods
401 provided by SSFA actors. Longer term actions to redress broader power inequalities, constrain
402 monopolies and support the diversity of SSFA capacities will be critical.
403
404 Our heuristic framework provides a novel and scalable approach, that can be more fully elaborated
405 subsequently, to specify the diverse and dynamic nature of SSFA in different policy contexts. This
406 contribution aligns closely with the SSF Guidelines[5], while adding a theoretically informed practical
407 approach to recognize diversity and the suggestion that a similar lens is also relevant to small-scale
408 aquaculture. An appropriate next step would be to extend the inferences enabled by Figure 3 to other
409 real-world examples. Future research can be deployed in a systematic manner to look at single food
410 systems, components of food systems, specific regions or countries or other food systems where small-
411 scale actors are key. Deeper consideration of the diversity and characteristics of SSFA actors, through
412 the attributes presented in this framework, will enable policy-makers in local, national and global fora to
413 ensure SSFA maintain and expand their role in sustainable and equitable food systems.

414 Methods

415 We characterize SSFA actors from freshwater and marine fisheries and aquaculture based on 70 case
416 profiles provided by the paper's 30 authors (Extended data Table S1 and S2). Experts were selected by
417 lead authors, based on contributions to the literature and leadership in international initiatives in the
418 SSFA space (e.g., the FAO voluntary guidelines for securing sustainable small-scale fisheries[5]) to span
419 diverse geographies and systems, across fisheries and aquaculture and value chains. Despite efforts to
420 comprehensively represent actors, systems and geographies, some gaps remain. To minimize these

gaps, we iteratively identified regions and sectors that were under-represented 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 co-author 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 approaches[63] (please see supplementary text S1 for more details) and the Sustainable Rural Livelihoods Framework[64]; 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"[63] 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.

Data availability

The minimum dataset generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. A summary table is provided in Supplementary Information, Table S2.

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467 Author Contributions

468 Rebecca E. Short, Stefan Gelcich, David C. Little, Fiorenza Micheli:
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470 Writing (review and editing), Visualization, Project administration, Supervision
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483 Supplementary Information is available for this paper.

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486 The datasets generated during and/or analyzed during the current study are available from the

487 corresponding author on reasonable request.

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489 Tables

490 Table 1. Key examples drawn from case profiles to illustrate the diversity of actor characteristics or strategies

491 across the identified SSFA attributes (Figure 3).

Ref.	Attribute	Example of diversity within small-scale sector
A	Investment & 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, where 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; where 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 & social capital input	- Peer-to-peer asset/knowledge exchange between small-scale and commercial farms in Kerala, India, community-supported fisheries in the US 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 e.g. 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 European Union import regulations.

F	Monetary, nutritional and cultural value of product	- Small-scale actors may deal in high-end luxury products such as luxury 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 e.g. 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 gain 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.

Figure legends

Figure 1. Selection of 15 example small-scale actor profiles selected 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 channeling catch to domestic and U.S. markets. (see SI 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 fishing cooperative of Baja California, Mexico (#SSFA-45); D. Mono-sex 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 of 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).

Figure 2 - Key contributions of SSFA to a sustainable and equitable aquatic food supply (internal rings), key underpinning dimensions of SSFA actors (outer ring) and their key attributes (axes) as determined by the reductive

process; diversity within the SSFA sector is demonstrated by example details from case profiles (boxes). LEK = Local ecological knowledge; CFP = Common Fisheries Policy; Excl. Exclusive

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

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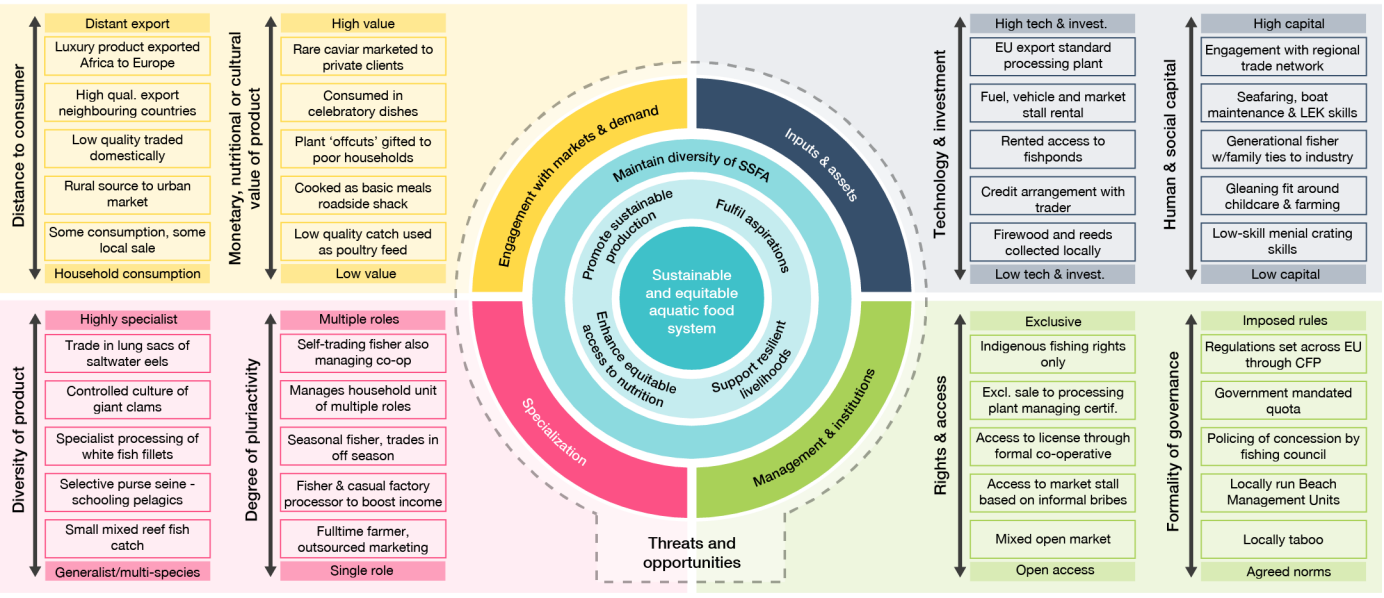
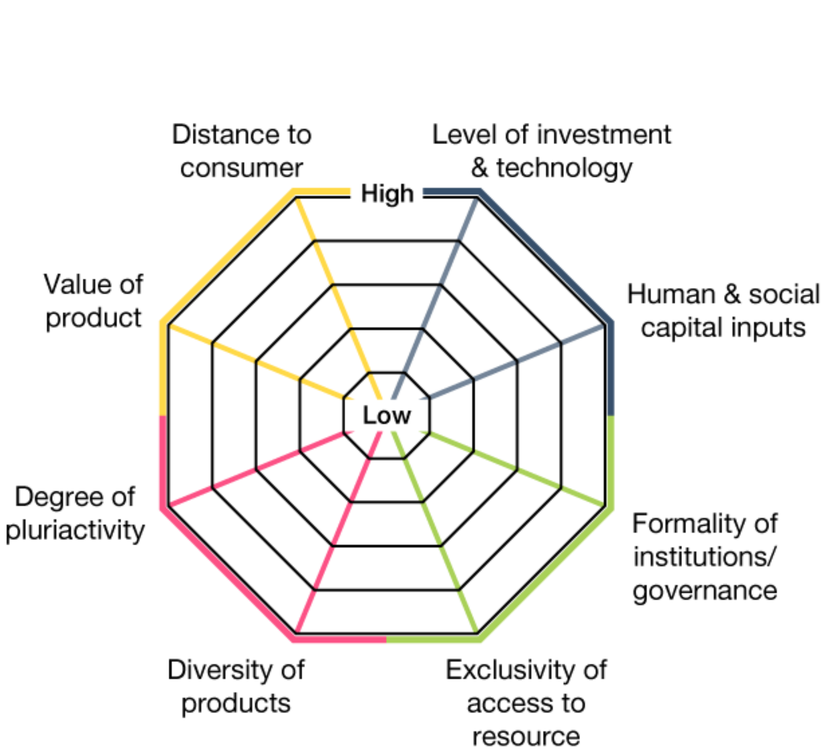
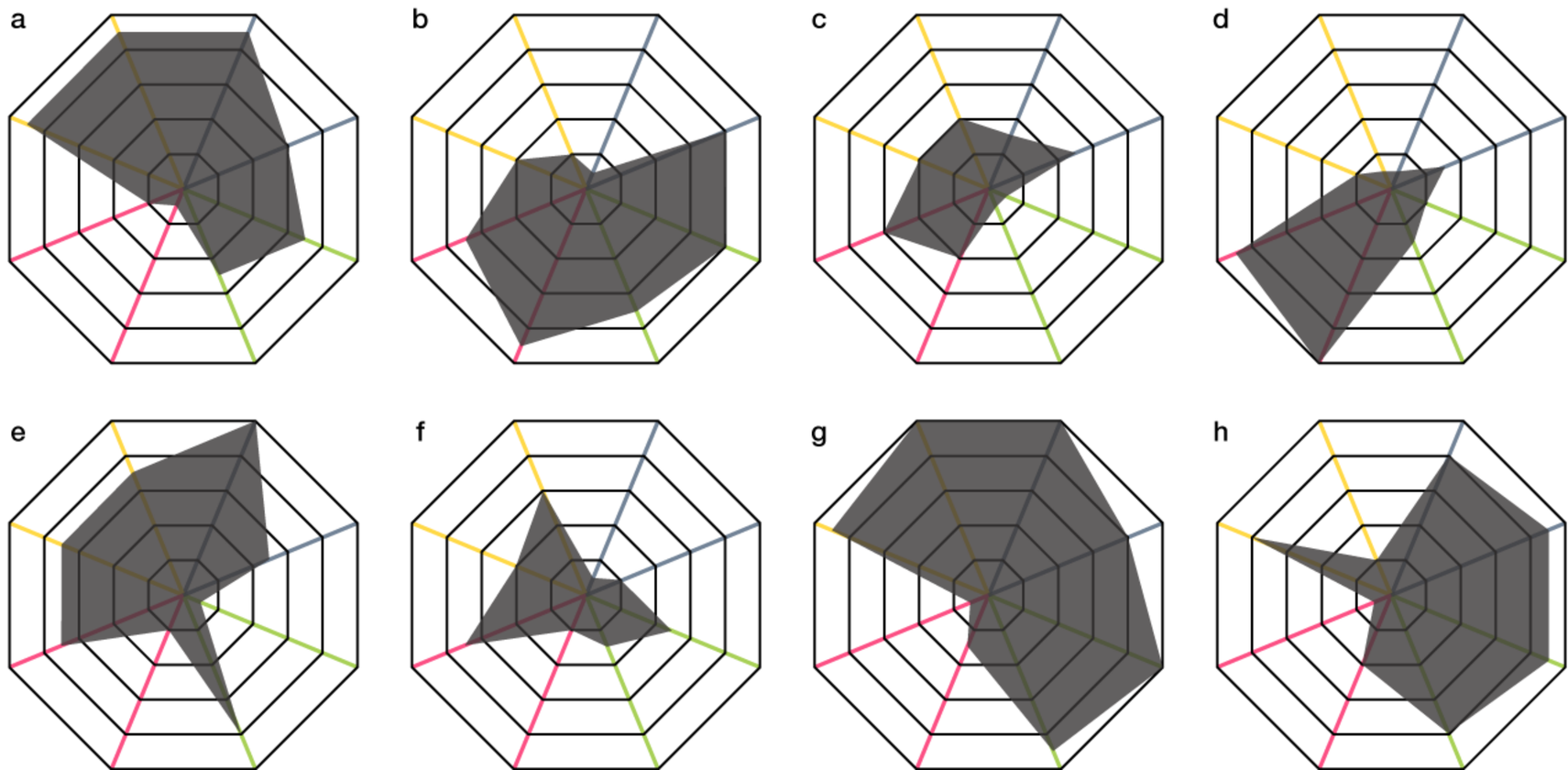

Distance to consumer
Distant export
Luxury product exported Africa to Europe
High qual. export neighbouring countries
Low quality traded domestically
Rural source to urban market
Some consumption, some local sale
Household consumption
Monetary, nutritional or cultural value of product
High value
Rare caviar marketed to private clients
Consumed in celebratory dishes
Plant 'offcuts' gifted to poor households
Cooked as basic meals roadside shack
Low quality catch used as poultry feed
Low value
Technology & investment
High tech & invest.
EU export standard processing plant
Fuel, vehicle and market stall rental
Rented access to fishponds
Credit arrangement with trader
Firewood and reeds collected locally
Low tech & invest.
Human & social capital
High capital
Engagement with regional trade network
Seafaring, boat maintenance & LEK skills
Generational fisher w/family ties to industry
Gleaning fit around childcare & farming
Low-skill menial crating skills
Low capital
Diversity of product
Highly specialist
Trade in lung sacs of saltwater eels
Controlled culture of giant clams
Specialist processing of white fish fillets
Selective purse seine - schooling pelagics
Small mixed reef fish catch
Generalist/multi-species
Degree of pluriactivity
Multiple roles
Self-trading fisher also managing co-op
Manages household unit of multiple roles
Seasonal fisher, trades in off season
Fisher & casual factory processor to boost income
Fulltime farmer, outsourced marketing
Single role
Engagement with markets & demand
Inputs & assets
Specialization
Management & institutions
Maintain diversity of SSFA
Promote sustainable production
Fulfil aspirations
Enhance equitable access to nutrition
Support resilient livelihoods
Sustainable and equitable aquatic food system
Threats and opportunities
Rights & access
Exclusive
Indigenous fishing rights only
Excl. sale to processing plant managing certif.
Access to license through formal co-operative
Access to market stall based on informal bribes
Mixed open market
Open access
Formality of governance
Imposed rules
Regulations set across EU through CFP
Government mandated quota
Policing of concession by fishing council
Locally run Beach Management Units
Locally taboo
Agreed norms


Distance to consumer
Level of investment & technology
High
Value of product
Human & social capital inputs
Low
Degree of pluriactivity
Formality of institutions/ governance
Diversity of products
Exclusivity of access to resource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