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Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries

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Small-scale fisheries (SSF) account for most of the livelihoods associated with fisheries worldwide and support food security for millions globally, yet face critical challenges from local threats and global pressures. Here, we describe how emerging concepts from social-ecological systems thinking can illuminate potential solutions to challenges facing SSF management, with real-world examples of three key themes: (1) external drivers of change; (2) social-ecological traps; and (3) diagnostic approaches and multiple outcomes in SSF. The purpose of this article is to aid practitioners by moving a step closer toward making these theoretical concepts operational and to stimulate thinking on how these linkages can inform a transition toward sustainability in small-scale fisheries.

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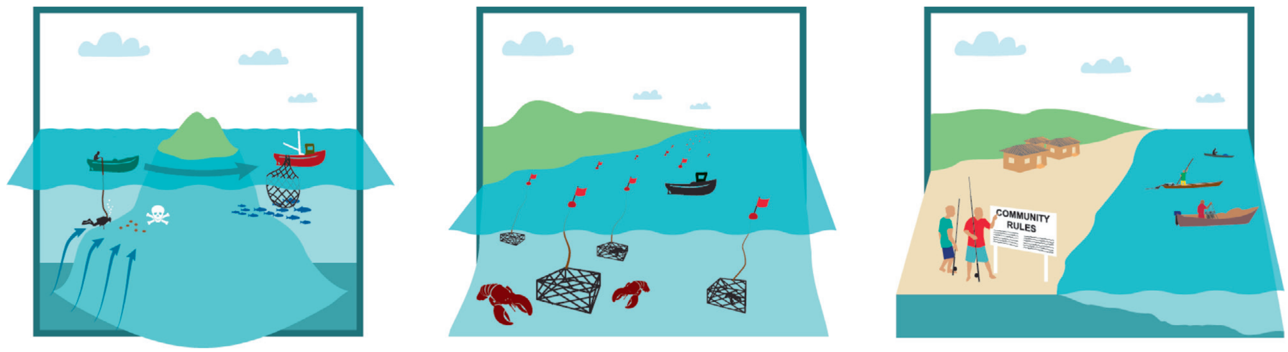
Introduction

Globally, small-scale fisheries (SSF) support food security for many millions [1,2], employ more than 90% of the world's capture fishers [3], and by some estimates account for more than half of global landings [4]. SSF are generally multi-gear and multi-species, play a large role in supporting household and community livelihoods, and contribute significantly to local and global trade in fish products [5,6].

SSF worldwide are increasingly affected by both local threats as well as external pressures, and vulnerability to these pressures threatens coastal communities and ecosystems. For example, emerging global markets incentivize the harvest of valuable species for export [7•], resulting in increased vulnerability of SSF to drastic price changes driven by international market dynamics [8•,9,10]. Additionally, global climate change may profoundly affect the distribution and abundance of key fishery species [11], altering socioeconomic and political dynamics of fisheries. At the local scale, threats such as overexploitation and land-based pollution can affect fisheries resources and habitats, placing at risk the livelihoods, food security, and cultural practices associated with fisheries.

To better meet these challenges, researchers and practitioners are focusing on understanding linkages between social and ecological dynamics — often referred to as linked or coupled social-ecological systems [12,13] — and how these dynamics affect the potential for sustainability [14••]. Social-ecological systems thinking is based on the recognition that the delineation between resource systems and associated social systems is arbitrary; they are

Figure 1



Theme 1: External Drivers of Change
Episodic upwelling of hypoxic waters in coastal Baja, Mexico result in mortality among targeted species and drive shifts in fishing effort and targeted species

Theme 2: Social-Ecological Traps
Historical overfishing of apex predators and active management has led to a hyperabundance of lobsters, reducing diversity in the fishery and creating a 'gilded trap'

Theme 3: Diagnostic Approaches and Multiple Outcomes in SSF
Community-based marine resource management systems have been implemented in SSF across the Pacific, with a diversity of social and ecological outcomes

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Visual vignettes of social-ecological linkages in small-scale fisheries, drawing on real-world case studies. Theme 1 describes the effects of episodic upwelling events in coastal Baja that bring hypoxic waters into nearshore fishery zones, affecting local ecosystems and the social dynamics of fisheries [23]. Theme 2 describes how a hyper-abundance of lobsters in the Gulf of Maine has created a 'gilded trap,' whereby a lucrative fishery is highly vulnerable to social or ecological disruptions [31•]. Theme 3 describes the proliferation of community-based marine resource systems in the Pacific region, which incorporate aspects of local culture and ecological context, often for utilitarian goals, and which exhibit a range of social and ecological outcomes [45•].

instead intricately connected [12,13]. Accounting for social-ecological linkages may help illuminate potential solutions to the challenges facing SSF management. However, it is often difficult for fishery managers, decision-makers, and non-governmental organizations (hereafter 'practitioners') to operationalize social-ecological thinking (i.e. design and implement management measures).

The purpose of this article is to move a step closer toward making social-ecological systems research operational through the synthesis of three emerging research frontiers described through real world examples from case studies. Our overarching goal is to stimulate thinking on how understanding key social-ecological linkages can inform a transition toward sustainability in SSF. Below, we provide an overview of three emerging frontiers: (1) external drivers of change; (2) social-ecological traps; and (3) diagnostic approaches and multiple outcomes in SSF (Figure 1). We conclude with recommendations about ways to advance these concepts from the academic realm to on-the-ground action for SSF management and sustainability.

Theme 1: External drivers of change

In an increasingly globalized world, external drivers of change present significant challenges to local resource users and fisheries managers, as such drivers typically are outside practitioners' realm of influence [15]. External drivers include trends, events, and policies that affect human behavior and local ecological processes in SSF through acute episodic effects or prolonged, chronic influences. Distinguishing external drivers from local processes depends largely on the scale at which the local social-ecological system is defined [16]. External drivers can be social or biophysical (or both) and act on SSF directly or indirectly, with important consequences for the sustainability of these resource systems [17,18•].

Researchers have described the important role of these external drivers (e.g. [19]), and recent work in SSF extends this research, highlighting the complex interdependencies among social and ecological systems in novel ways, with implications for different policy approaches [9,10]. While fishers and practitioners have long recognized that external drivers affect their SSF, coupled social-ecological research identifies management practices that either enhance or jeopardize the sustainability of SSF in the face of these pressures. For example, climate-driven shoaling of oxygen-poor water onto the continental shelf creates regional hypoxia events [20,21], with devastating implications for some benthic SSF [22]. In Baja, Mexico, for example, these events cause mortality in marine species with limited mobility, resulting in declines in stocks targeted by SSF, which, in turn, may cause small-scale fishers to move or switch fishing effort and gears toward less-affected species [23] (Figure 1). Alternatively, mobile species can concentrate in spatial refugia from hypoxia, increasing their susceptibility to overexploitation [24,25]. Social vulnerability to these events increases when management restricts the

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ability of a SSF to relocate or switch gears to access fisheries less impacted by hypoxia, or fails to respond to potential overexploitation with temporary restrictions on catch limits.

Socioeconomic factors such as external market demands can also alter local-scale dynamics in SSF. For example, expansion of globalized markets for fisheries species increases capitalization or specialization for particular local stocks, increasing their susceptibility to overexploitation and reducing the capacity of fishers to shift to alternatives when stocks experience declines [7•]. Alternatively, as external market prices fluctuate, local fishers may shift their strategies, gear types, fishing effort, or target species [26], but management institutions may not be prepared to accommodate (i.e. regulate) these sudden shifts. These direct and indirect changes can also increase conflict among small-scale fishers if market expansion results in increased fisher mobility and relocation into other fishers' territories [27,28].

Theme 2: Social-ecological traps

Researchers have also characterized social and environmental factors that can give rise to 'social-ecological' traps. Social-ecological traps are defined as 'situations when feedbacks between social and ecological systems lead toward an undesirable state that may be difficult or impossible to reverse' [29•] (p. 835). The critical distinction between social-ecological traps and other types of traps prevalent in the literature is the reinforcing nature of feedbacks between social processes and ecological dynamics, which may amplify the initial conditions causing the problems. Understanding these social-ecological traps can help illuminate some of the key features that are amenable to management and policy interventions to break destructive cycles.

Recent research on communities in the Western Indian Ocean highlights interactions between the dynamics of poverty and fishing practices in coral reef SSF [30]. Fishers entrenched in poverty are more likely to use destructive fishing gear that destroys habitat, captures a higher proportion of juvenile fishes, and targets functionally important species that promote ecosystem integrity. These practices also compete with other gear types, leading to lower catch and profits, and increased vulnerability of fishers. The absence of strong governmental institutions is also a critical social factor contributing to the trap. In places where institutions are either weak or missing, intensified fishing effort can cause resource declines with corresponding negative social outcomes [29•]. This combination of negative outcomes ultimately makes fishers poorer, reinforcing continued use of destructive gear with ecological impacts. Critically, poorer fishers are less likely to feel that they can consider alternatives (e.g. investing in different fishing gear), exacerbating the reinforcing nature of the trap [30]. The lack of strong governmental institutions in this region constrains the types of management interventions that may be employed. For fisheries interventions to be effective, they may have to be coupled with well-designed poverty alleviation and development aid projects.

Another example describes the vulnerability of the lobster fishery in the Gulf of Maine, in what is referred to as a 'gilded trap' [31•] (Figure 1). In this system, severe depletion of cod and other apex predators that were historically overharvested has released lobsters from predation and competition. Combined with effective fisheries regulations on size limits and protection of spawning females, this has led to a hyperabundance (1–2 per m^2) of commercially valuable lobsters, which comprise a benthic monoculture in this system. High abundances and yields of extremely valuable products now provide great economic benefits to local communities, but have simultaneously reduced the economic diversity of New England fisheries, providing fewer alternatives and increased risk to perturbations, such as climatic events or increased susceptibility of lobster populations to diseases. In this region, strategies designed to diversify marine resource harvesting may help decrease the vulnerability of this system to shocks, such as disease-mediated population collapse or sudden price fluctuations.

Theme 3: Diagnostic approaches and multiple outcomes in SSF

Increasingly, diagnostic approaches are being used to more rigorously characterize the social-ecological attributes of SSF and the multiple outcomes that can arise from the interaction of different system attributes. Such approaches stem from the recognition that simplistic cause-consequence relationships often fail to explain the complexity of social-ecological interactions [32] and that outcomes can take multiple forms (both social and ecological) as a result of different drivers [33].

Diagnostic approaches often rely on integrative research frameworks, such as Ostrom's framework for analyzing social-ecological systems [34••], the ecosystem services framework [35], livelihoods approaches [36], and others, which have recently been applied to SSF [37••,38]. Diagnostic approaches draw on a long history of social science research on the contextual factors and conditions that enable cooperation in human societies and the potential outcomes of these on natural resources (e.g. [39,40]). However, new applications of such approaches allow researchers to tease apart what makes each resource use problem unique or generalizable by understanding critical interplays between social, institutional, and ecological factors and the multiple outcomes that can arise from these interactions.

Diagnostic approaches help characterize key system attributes that derive from structural or social characteristics

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of the area (including institutional, economic, attitudinal and behavioral aspects) or biophysical dimensions of the ecosystem, including resource condition [41]. In SSF, important social attributes include resource dependence, livelihood strategies, and features of economic markets [37••,41]. Ecological attributes include condition or biogeographic distribution of resources and habitats, resource mobility, and the vulnerability of a species to exploitation [42,43].

Emerging research in this area helps explain how key ecological, social, and institutional factors interact to create incentives to overexploit or sustainably use resources, with a range of social and ecological outcomes. For example, recent research focuses on the social, ecological, and institutional conditions under which community-based fishery management arrangements succeed [44]. In Pacific SSF, for example, a proliferation of community-based initiatives has created space for the inclusion of customary approaches that better reflect local social-ecological contexts [45•] (Figure 1). Diagnostic approaches can help identify which key factors are associated with different outcomes in community-based initiatives. In successful cases, community-based management arrangements often better align with local social and ecological conditions, conferring social benefits, such as increased collaboration and learning among partners, integration of scientific and local knowledge systems, community empowerment, and high levels of compliance [8•,46•,47] (Figure 1). Ecological benefits include increases in standing biomass of fisheries stocks in co-managed areas compared with open-access areas [37••,48,49]. However, community-based management arrangements do not always guarantee successful outcomes; like other governance systems they are susceptible to poor implementation and resulting unintended consequences such as inequitable benefit allocation, social inequalities, lack of public accountability, and illegal behavior [50].

Conclusion and ways forward

The three themes highlighted here encompass a set of frontiers emerging from research on coupled social-ecological systems that have potential to improve the sustainability of SSF worldwide. Operationalizing these concepts requires careful consideration of how they translate into policy mechanisms and management strategies. Various policy prescriptions have been advanced to enhance the sustainability of SSF, including rights-based approaches, gear restrictions, economic incentives, and marine reserves [51–54]. However, emerging insights from social-ecological research show that successful policy approaches need to be tailored to the specific social-ecological context of a given fishery. For policies to be effective, they must be based on a deep understanding of social context, institutional capacity, ecological dynamics, and potential external drivers, all of which may present challenges to successful implementation [55••,56•]. Ignoring these critical social-ecological linkages can result in unintended consequences that are too significant to ignore [14••].

Integrating emerging insights from research into management strategies can be challenging due to real-world constraints on practitioners, which understandably may result in risk aversion to making significant shifts in practice based on new research. Such constraints include inadequate resources, rapid political shifts, conflicting management goals, and immediate demands that crowd out time needed for collaborative analysis and planning. These practical realities highlight the importance of participatory research approaches to help develop and support deep and enduring knowledge-to-action partnerships and use-inspired research. Evidence from emerging research suggests that collaborative and participatory approaches are effective in developing innovative ways to transfer new knowledge into actionable strategies [57–64]. Such approaches provide learning platforms that integrate different knowledge systems, develop trust among key stakeholders through co-production of new knowledge, and enable conditions for the institutionalization of collaboratively designed policy [65–67,68•]. Successful examples demonstrate the importance of partnerships that transcend disciplines and involve stakeholders across research, resource user, and management communities to work collaboratively toward sustainable strategies.

In conclusion, social-ecological thinking has much potential to inform approaches for sustainable resource management, yet translating these concepts from knowledge to action requires on-the-ground engagement with diverse partners to initiate positive change. More participatory fact-finding and management design processes are needed to develop the deep understanding and social capital necessary for designing and implementing measures based on social-ecological systems thinking. In particular, there is an urgent need to identify and build on existing 'bright spots,' where successful applications have resulted in better social and ecological outcomes, particularly given the importance of SSF and the high stakes for resource dependent communities globally.

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• Discusses the importance of agency, institutions, and innovation in navigating shifts and large-scale transformations toward global sustainability.

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