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Social-ecological shifts, traps and collapses in small-scale fisheries: Envisioning a way forward to transformative changes

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ABSTRACT

Small-scale fisheries (SSF) are critical to food systems and livelihoods. However, the relation between fisheries resilience, outcomes of proximate and distal drivers and the potential space for transformative changes have been largely unexplored. Such knowledge is key to understanding how fishery resources, institutions and actors respond to, and learn from, diverse drivers of change and social-ecological crises, as well as to design policies aimed at building resilience in SSF. This paper provides a new heuristic model to analyze the factors that combined lead SSF to trajectories towards shifts, traps and collapses, including the opportunity to navigate sustainable transformations. We illustrate the proposed Heuristic with three case studies with different bio-physical and socio-cultural contexts and final outcomes: the Galician shellfisheries on foot (Spain), the Chilean king crab small-scale fishery (Chile), and the Galapagos sea cucumber small-scale fishery (Ecuador). The application of the Heuristic and a detailed description of model key elements for each case study provide practical examples and a valuable guide for fisheries scientists, practitioners and decision-makers to learn and/or respond in a flexible way to SSF social-ecological crises in the pursuit of fisheries sustainability and equity. Scholars are welcome to adopt our Heuristic to classify and bound SSF, order events, suggest hypotheses of linked drivers, pathways of change, potential trajectories, and outcomes, and envision potential space for transformative changes.

1. Introduction

Small-scale fisheries (SSF) are critical to food systems and livelihoods. Yet, their actual and perceived contributions to food security, poverty alleviation and human well-being are often undervalued. To meet an ever-growing demand for seafood and face the pressures arising from global change, SSF need to be considered as social-ecological systems (SES) [1], where the biophysical (biota and environment) and human (economic, cultural, ethical and sociopolitical aspects) subsystems interact through complex and interdependent relationships [2]. Therefore, their management and governance require considering a wide range of environmental and human processes acting concurrently with climatic and human-induced drivers, and understanding how fishers, and the SES they are embedded in, will respond.

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Proximate and distal drivers [3,4] acting simultaneously at multiple temporal and spatial scales [5,6] challenge the capacity of SSF to maintain seafood supply, secure livelihoods, and recover from stress or shocks, compromising their resilience. We refer to resilience in an operational and normative way [7] as the capacity of fishing communities and organizations (e.g., cooperatives, fishery agencies) to cope with, adapt to, and shape change to sustain a fishery system and human well-being within a desirable state [1,8].

Recently, the transition and transformation literature has addressed major changes in marine SES [9,10]. High-level initiatives (e.g., IPBES, IPCC, the UN 2030 Agenda) are explicitly seeking to understand and foster societal positive changes by using the transformation rhetoric [11]. Progress has also been made in embedding the transformation concept in policies and practice [12] and how transformative changes are linked with social (in)justice [13,14], socio-political systems [15], ocean governance [16] and SSF [17]. Yet, in the context of SSF, the relation between system resilience, outcomes of proximate and distal drivers and the potential room for transformative changes, have been seldom explored.

Several frameworks have been useful to conceptualize observed changes and to assess the type and extent of responses in SSF. For example, Basurto et al. [18] analyzed governance processes and outcomes in benthic SSF based on the general framework to diagnose sustainability of SES [19]; Bundy et al. [20] developed a decision support tool to react to impacts of global change, including those affecting SSF; and Freduah et al. [21] developed a framework for SSF to assess their adaptive capacity to multiple climatic and non-climatic stressors. Although a variety of analytical frameworks have emerged in recent years, there is still poor understanding about how SSF fall into and respond to different social-ecological changes [22] that could lead to shifts, traps, and collapses (see Section 2.4), and how these responses are shaped by past experiences, path dependency and context-specificities of the fishery and governing systems. Furthermore, how the aforementioned concepts are related to potential transformative pathways is not well understood. Such knowledge is critical to understand how fishery resources, institutions and actors learn and respond to diverse drivers of change, as well as to design policies aimed at building resilience in SSF [23,24].

To cover this gap, we provide a unifying Heuristic model that contributes to improving the current state of the art by analyzing the interactions between drivers, potential trajectories (shifts, traps, and collapses), and the influence of enabling and inhibiting conditions in determining possible outcomes, including the opportunity to navigate sustainable transformations in SSF.

2. The Heuristic model

The Heuristic developed herein provides the basis for a better understanding on how SSF can follow different pathways and how transformative changes are catalyzed over time (Fig. 1). Systematically assessing and comparing pathways that can lead to different potential trajectories over space and time will help policy makers, users and NGOs moving towards sustainable transformations pathways [11,17].

2.1. *Setting the scene: identification of small-scale fisheries boundaries and model basics*

Boundaries of SSF are defined case-by-case based on key social and ecological attributes, entities, and components [25]. Bounding SSF helps to solve scaling issues and to identify relevant drivers and feedbacks that are either endogenous or exogenous (Fig. S1). Often, SSF are bounded for management purposes based on operational criteria that may conflict with biophysical and social boundaries [25,26]. Therefore, there is a need to acknowledge interactions and feedbacks that transcend the selected scale but are still relevant.

SSF are dynamic SES, but for the sake of simplicity, we only focus on a single cycle of change in the model. Transition times and cycle length depend on several factors, such as drivers' intensity, frequency and

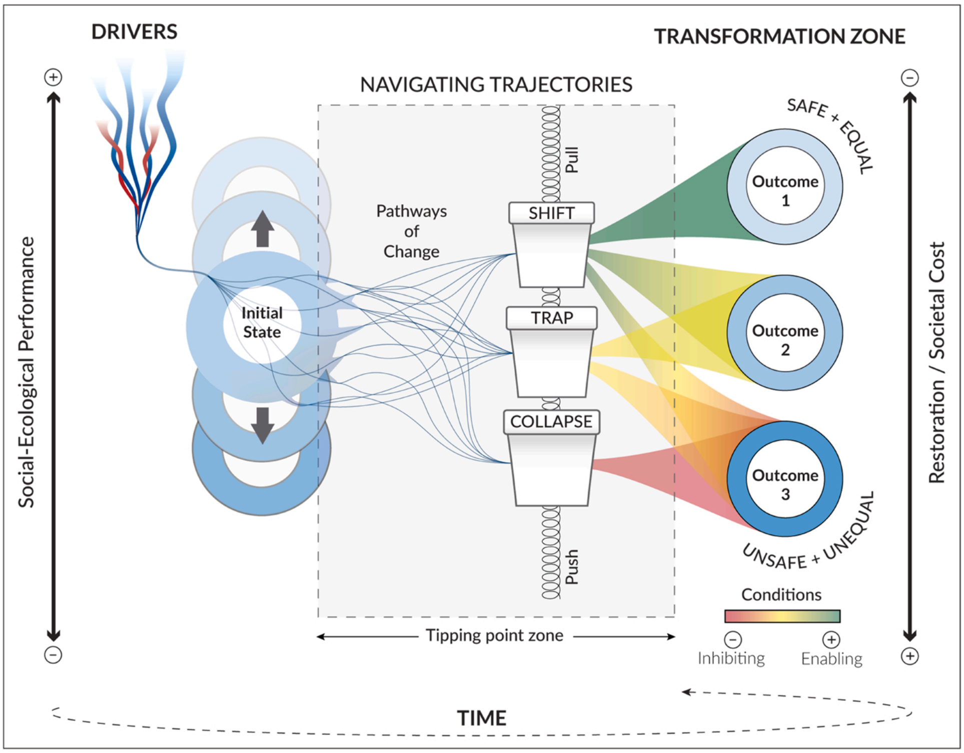

Fig. 1. Heuristic to organize components of plausible social-ecological changes in SSF. Drivers of change push SSF where pathways of change occur and tipping points are potentially crossed. Possible trajectories towards shifts, traps, collapses can lead to multiple SSF outcomes, including the opportunity to navigate sustainable transformations.

duration, response time of users and institutions, and species lifespan. Thus, time flows unevenly and is implicitly included as a cyclic unidirectional x-axis in the model (Fig. 1).

Given that transformations might have different points of departure, the Heuristic model includes a "transformation zone" which does not necessary imply positive and deliberate transformations, as they can be negative, unintended, or spontaneous. We also acknowledge the possibility of a "tipping point zone" composed by single or multiple ecological or social thresholds affecting the system [16–27]. It is still extremely difficult to know precisely how far a human or climatic driver can push SSF while remaining within the safe and equal operating space. However, fisheries management would be more effective when managing uncertainty rather than trying to remove it [28]. While tipping points have mainly been used to avoid critical thresholds with negative consequences, we also conceive tipping points that deliberately tip in a desirable direction [29].

We propose a gradient of social-ecological performance that posits a safe biophysical space in the upper region of Fig. 1, where an SSF can maintain its structure and function to provide sustainable and equitable societal benefits. In the lower region of Fig. 1, SSF performance is diminished, because it is in an unsafe biophysical space, where ecosystem services are disputed, unequally distributed among societal actors, or even disappeared (Fig. 1). Besides, the vulnerability to external drivers is increased as resilience is diminished, leading to lower cooperation and a growing uncertainty. In this case, societal and restoration costs are high and there is no guarantee to return to a biophysical safe space.

2.2. Drivers

Drivers of change in the SSF literature have been mostly addressed according to their type (e.g., climate-induced, ecological, economic, market, technological, institutional, social, cultural, shocks). Yet, drivers can also be understood based on their proximity (i.e., distal and proximate drivers and interactions [3,4]), their temporal scale (fast and slow variables [30,31]), and their nature (endogenous and exogenous drivers) [32]. Exogenous drivers (e.g., seafood demand [33]) can act solely or intertwined across temporal and spatial scales (Fig. S1, see [4]). While exogenous drivers are more commonly addressed in the SSF literature, endogenous drivers such as poverty [34], community failure [35], and inequity [36] have received less attention, despite their critical importance in undermining SSF resilience and modulating effects of exogenous drivers (Fig. S1). SSF can respond to drivers in two main ways: oscillating around an initial state or potentially crossing a tipping point and thus transiting towards a new outcome (Fig. 1). The extent and magnitude of impacts of single or multiple intertwined drivers depends on the buffering capacity (i.e., minimize or absorb) of the SSF. The amplitude of oscillations and the recovery rate of the system will be determined by its social-ecological resilience. When oscillating around the original SSF state (Initial state in Fig. 1), gradual changes can be observed. Still, they ultimately will be absorbed without modifying their structure or functioning in a meaningful timeframe.

2.3. Navigating trajectories

2.3.1. Pathways of change

Drivers can erode and weaken SSF resilience, and thus can either facilitate undesired (and potentially drastic) trajectories or create a new window of opportunity to navigate into a new state if such opportunity is capitalized. We conceptualize "pathways of change" (see oriented bundles of intertwined lines in Fig. 1) as the interacting processes at multiple levels (global, regional and local) between drivers of change, both exogenous and endogenous, and the local social-ecological responses of, and feedbacks within, a SSF. While pathways of change are often framed as patterns that led to negative outcomes [37], they can be also understood as value neutral. Their effect will depend on the social-cultural context of perceivers and underlying interests [37]. If a new trajectory is triggered (e.g., a tipping point is crossed), the direction and type of pathways of change will depend on the robustness of the SES that the SSF is embedded in, and the adaptive responses to deal with single or multiple intertwined drivers [38]. Pathways of change may deploy both rapidly or at a slow pace and can be easily noticed through signs or can go unnoticed as symptoms towards possible emerging trajectories. SSF sustainability can be described as the absence or the effective mitigation of these pathways.

2.3.2. Potential trajectories: shifts, traps and collapses

Depending on the social-ecological resilience and resistance (illustrated as push-pull dynamics, Figs. 1 and S2), an SSF could undergo the three trajectories more often documented in the SSF literature: shifts, traps and collapses. As a first trajectory, a social-ecological shift occurs as large, persistent changes in the structure and function of a SES, that impacts on human-centered benefits (e.g. revenues, employment, social capital) [39]. These shifts typically result from a combination of gradual changes in a driving variable (or set of variables) with an external shock or a fast variable (e.g., a tsunami, a hurricane, or a pandemic). Adaptive responses at multiple scales can compensate for losses when facing undesirable social-ecological shifts or can capitalize benefits when shifts represent a window of opportunity for desirable changes.

As a second trajectory, a social-ecological trap occurs when the SSF is highly resilient, i.e., when it can maintain its structure and function, but it is inefficient in providing benefits, leading to an undesirable state that may be difficult or impossible to reverse [40]. Key characteristics and feedbacks of a social-ecological trap could include interactions between poverty and resource use (e.g., poverty traps reinforced by unsustainable fishing practices) [40,41], the overlooked risks of focusing on a single high-priced fishery resource (i.e., gilded traps) [41,42], or the highly connectedness and inflexible institutions within a SSF (i.e., rigidity trap) [41,43]. SSF with these features may preclude adaptive change and deliberate transformations, or even worse, may facilitate a fishery collapse because they are locked into unsustainable pathways [30].

As a third trajectory, a social-ecological collapse occurs when [44]: (1) the identity of the SSF is lost: key actors or organizations, system components, and interactions disappeared; (2) loss of identity happens fast (loss of wealth, infrastructure, habitat, populations), relative to regeneration times and turnover rates of system components (species lifespan); (3) there are substantial losses of social-ecological capital; and (4) effects are lasting, persisting longer than the typical dynamics of the SES. In the Heuristic (push-pull dynamics), this trajectory is depicted as one of little resilience and resistance, rapidly triggered, and often unnoticed (i.e., unperceived symptoms and pathways of change) (Fig. 1 and Fig. S2).

2.4. Towards transformative changes

2.4.1. Inhibiting and enabling conditions

Inhibiting and enabling conditions modulate SSF outcomes, including the possibility to leverage on previous changes to foster place-based transformations (Fig. 1). These conditions include inherent properties of SSF subsystems (i.e., fishery resources, ecosystems, institutions, users) and their diversity and interactions [18,19,45]. Enabling conditions may be strengthened in co-governance systems compared to centralized governance structures [45,46], but the governability of SSF while navigating change is not guaranteed by co-management or community-based management arrangements [47]. Frequently, cognitive-related processes (e.g., awareness of change, social memory, acknowledging diversity of knowledge systems) [15,48], and agency-related features (e.g., power, leadership) [17,45] are the building blocks that support sustainable changes [49]. The pathway of a SSF to final outcomes will be largely dependent on institutional adaptive responses, the balance between inhibiting and enabling conditions, and the deliberative leadership actions developed by key actors [45]. By the latter, we refer to agencies, incentives, and power as important elements to create a space for experimentation, change or transformation [50].

2.4.2. Small-scale fisheries outcomes

If essential subsystems of an SSF (fish stocks, fishers and institutional arrangements) were affected by pathways of change and actors were able to capitalize and leverage on those changes, the SSF will be capable of moving towards a safe and more equitable operating trajectory (Outcome 1) (Fig. 1). This situation represents the normative idea of a transformative change understood as a deliberate and desirable SSF transformation. By contrast, trap-oriented pathways are characterized by high levels of inertia and path-dependency that often reproduce previous social-ecological traps (Outcome 2) or undermine system robustness, increasing the likelihood of social-ecological collapses (Outcome 3) (Fig. 1). This outcome would imply high intergenerational socio-economic (e.g., loss of revenues, jobs, cultural identity, and migration) [51] and ecological costs (e.g. overfishing, recruitment failure), which would ultimately find difficult -if not impossible- for policy makers to restore the system to a previous state [51,52], hampering future generations benefit from healthy SSF [53]. When the core components and functions of an SSF are highly disturbed, and the system is not able to develop a fast and effective adaptive response, it will move towards an unsafe trajectory involving social-ecological identity losses and suffering a transformation towards an irreversible state in a meaningful timeframe. Over longer time scales, the system may tend to reorder itself, and even if the people who suffered the collapse do not benefit from this restoration, but other generations do, then it has intergenerational equity implications. Alternatively, the SES can move from a collapse to a new state after pressing effects of drivers disappear [44].

3. Applying the Heuristic model

We empirically apply the proposed Heuristic to three case studies to illustrate the impacts of shifts, traps, and collapses, and possible SSF outcomes: the Galician shellfisheries (NW Spain), the Southern king crab (Chile), and the sea cucumber in Galapagos (Ecuador). Selected cases encompass different fisheries management systems and socio-cultural contexts, which help understand the role of different drivers, trajectories, and outcomes under different settings. We first provide a brief context of each case study, and then use these cases to highlight key elements of the proposed Heuristic (Table 1).

3.1. The shift of Galician shellfishing on foot

Galician shellfishing has historically been considered marginal, mainly as a complementary way to increase household incomes and performed without administrative control [54]. It was also characterized by technological backwardness, reflected in an aging workforce, scarce professional and technical training, and lack of investment, resulting in little commercialization, lack of internal cohesion and the overexploitation of most shellfish species [17]. During the 1960–80 s, fisheries regulations were vague or non-existent, and there was no control of compliance with regulations [55]. The transition from a traditional and non-formal activity to the development of a professional

Table 1
Key elements of the Heuristic identified for each of the case studies presented.

Initial state	Drivers	Pathways of change	Enabling (+) and inhibiting (-) conditions	Outcome
Case study 1: The shift of Galician shellfishing on foot				
• Open access (*de facto*) • Overexploitation • Fishing overcapacity • Lack of control and non-compliance • Marginal activity	• Governance (decentralization process and subsequent implementation of co-management) • Market demand (deliberate introduction of non-native species)	The creation of Autonomous Communities set the basis for co-management between fishing guilds (*Cofradías*) and the Galician government. Within *Cofradías*, fishers created Shellfishing Associations mostly composed of women. This triggered a higher internal cohesion, fishers' compliance, and a progressive improvement of women's income. While social conditions improved, native clams' abundance decreased, and non-native species became more abundant.	• Social capital (+) • Market integration (+) • Technical Assistants (+) • Fishers' empowerment (+) • Gentrification (-) • Fishers aging (-) • Illegal fishing (-)	Equal (societal) but possibly unsafe (biophysical). Shellfishing professionalization and increase in social cohesion and fishers' revenues. Clams harvesting is heading to a quasi-monoculture of an introduced species.
Case study 2: The "illegality trap" of the Chilean king crab small-scale fishery				
• Open access • Poverty driven migration • Lack of control	• Governance (weak governability and unenforceable regulations) • Market demand (international)	Institutional misalignment and strict but unenforceable rules increased fishers' resistance, non-compliance and illegal fishing. Lack of information on stock status and weak control impeded stock accountability and, therefore, management effectiveness.	• Geographical remoteness (-) • Power asymmetries (-) • Poverty (-)	Unequal (societal) and potentially unsafe (biophysical). High restoration and societal costs if the resource is overexploited.
Case study 3: The collapse of sea cucumber small-scale fishery in the Galapagos				
• Open access • Unregulated fishery expansion • Social conflicts • Ecological degradation	• Governance (shift towards co-management but poor implementation, enforcement, and compliance with management regulations) • Market demand (international trade and illegal fishing promoted by roving bandits)	The creation of a multiple-use MPA intended to regulate local fisheries and alleviate social tensions. High demand from Asian markets encouraged illegal fishing and poor compliance. Several management tools were unable to improve governance. As abundance becomes scarcer, the willingness of external agents to pay higher prices for sea cucumbers increased exponentially, leading to fishing intensification, and eventually to fishery collapse.	• Illegal fishing (-) • Sea cucumbers' scarcity increased their price (-) • Lack of social capital for collective action (-) • Power asymmetries (-)	Unequal (societal) and unsafe (biophysical). High societal costs due to long-term fishery closures and subsequent unemployment and labor diversification. High societal costs from monitoring, control, and surveillance activities.

sector encountered several obstacles, e.g., high poaching levels, social conflicts and women exclusion. As a result, most shellfish resources were overfished until the late 1980 s [17,55,56] (see Table 1: Initial state).

In the early 1980 s, Spain initiated a decentralization process that created Autonomous Communities. In 1993, the Galician Government generated a fundamental shift of these SSF through the promotion of a co-management system between Fisheries Guilds ("*Cofradías*") and the fisheries administration, advised by scientists, based on the allocation of Territorial Use Right for Fisheries (TURFs) [17,55,56] (see Table 1: Drivers) (Fig. 2). This co-management system allowed an increase in catch volumes, a higher internal cohesion, and a progressive improvement of women's income and social conditions due to the creation of Shellfishing Associations and the key figure of Technical Assistants within *Cofradías*, moving away from an uncontrolled and marginalized activity to professional shellfishing [56] (see Table 1: Pathways of change). Although this fundamental change was highly positive for the Galician shellfisheries, the increasing market pressure due to the high national and international seafood demand is driving shellfishers to harvest mostly Japanese carpet shell (*Ruditapes philippinarum*) (see Table 1: Drivers), a non-native species deliberately introduced in the 1980 s in Galician bays [57], which is more resistant to environmental changes and become economically more profitable than native species over time based on a more regular provision and an increasing trend in its price. Concentrating most landings in a single species can be risky and eventually lead to a social-ecological trap, particularly in a fast-changing environment (see Table 1: Outcome).

3.2. The "illegality trap" of the Chilean king crab small-scale fishery

Historically, fishing in Chile was ruled by the principle of historical occupation rights. However, neoliberalism reforms promulgated by the dictatorship government (1973–1989) redefined the SSF economy and culture in southern regions, moving from traditional practices to a radical extractivism fostered by international seafood demand [58] (see Table 1: Initial state).

In 1991, during the democratic government, a new Fisheries Law was enacted, introducing access restrictions for fishers' movements between regions. Local actors resisted the new institutional setting, arguing a high level of centralism and the lack of recognition of historical, cultural and context-specificities of local SSF. These factors, along with a strong international market demand (see Table 1: Drivers), led to a series of multi-actor autonomous processes that promoted the emergence of a path-dependent social-ecological trap, the "illegality trap" of the Chilean king (*Lithodes santolla*) crab SSF [58,59] (Fig. 3). The constituents elements of the trap include: (1) high number of fishers and fishing effort exerted, explained by poverty-driven migration during the 1960–1980 s to southern Chile; (2) implementation of institutions not legitimized by fishers to restrict access and, therefore, low levels of compliance; and (3) stricter sanctions imposed by the government, which in turn prompted further resistance and enhanced non-compliance and illegal captures, creating long-lasting feedbacks that characterize the trap (see Table 1: Pathways of change). Lack of information on stock status and weak control impedes stock accountability and, therefore, management effectiveness (Fig. 3).

Illegal fishing is a relational phenomenon involving fishers, intermediaries, processors, and consumers, and characterized by marked inequities among the post-harvest sector. As such, it is highly resilient since changes depend on deep transformations of intertwined practices of all actors across the value chain (see Table 1: Inhibiting conditions). At present, illegal fishing is locally justified as livelihood-driven misconduct motivated by international demand and prices or sociopolitical-driven transgressions moved by disillusionment with the sociopolitical context [58]. It is also accepted as a strategy for material prosperity, based on the increase of pecuniary benefits associated with a commercial opportunity (see Table 1:Outcome).

3.3. The collapse of sea cucumber fishery in the Galapagos

The sea cucumber *Isostichopus fuscus* is the most valuable small-scale shellfishery in the Galapagos (Fig. 4). The unregulated expansion of this fishery in the mid-1990 s caused social conflicts and ecological degradation, leading to the creation of the Galapagos Marine Reserve in 1998 [60] (see Table 1: Initial state). Several fishery management measures were implemented between 1998 and 2002, including the institutional shift from a hierarchical (top-down) to a co-management regime [61]. However, co-management implementation was unable to prevent the collapse of the fishery: catch per unit of effort decreased 43% after co-management implementation, concurrently with a significant decrease in landings and abundance, and an exponential rise in unit price (see Table 1: Pathways of change).

Several factors are responsible for this failure [61,62], including: (1) weak leadership, lack of social cohesion and poor organization of the local fishing sector; (2) lack of long-term strategic planning and mechanisms for precautionary and adaptive management; (3) incapacity of the rights-based management system (i.e., licenses and fishing permits) to mitigate over-exploitative fishing practices; and (4) poor implementation, enforcement and compliance with management regulations. As resource abundance becomes scarcer, the willingness of external agents to pay higher prices for sea cucumbers increased exponentially. In this context, the co-management regime was unable to break down the pervasive partnership created between "roving bandits" (sensu [63]) and local fishers since 1992 (see Table 1: Drivers), which led to the intensification of illegal fishing and to the collapse of the fishery [37,47,64]. Despite the implementation of several fishery closures since 2006,

Fig. 2. **(A)** Shellfishing on foot in the Galician "rías". Women use a fishing gear set consisting of "ganchas" and "raños" (rake-like fishing gear), buckets and a rubber float; **(B)** The shellfish landings consist of three species of clams (two native and one introduced) and one species of cockle (photo). © María José Rey.

Fig. 3 (A). The king crab artisanal fleet in the Magallanes region; (B) Crabs landed and transported to processing plants. The number of traps per vessel is not regulated and can vary from 400 to 1000 traps in larger vessels. © Laura Nahuelhual.

Fig. 4 (A). Fresh sea cucumbers in the Galapagos; (B) Sea cucumbers in brine drying in the sun; © for (A) Mauricio Castrejón, (b) Boris Enrique Novoa Ruiz.

the sea cucumber stock represents nowadays only 33% of its virgin abundance, and the fishery would not reach the maximum sustainable yield even if it is closed until 2030 [65]. This fishery has remained closed since 1992 in continental Ecuador (see Table 1: Outcome).

4. Concluding remarks

Our contribution goes beyond the current state-of-the-art by unraveling the crucial importance of analyzing interdependencies between drivers, trajectories (shifts, traps, and collapses) and possible solutions within the interdisciplinary research on SSF. By retrospectively analyzing trajectories of SSF through the Heuristic, it is possible to reconstruct the social-ecological memory of SSF and to identify social-ecological shifts, traps, or collapses. Considerable local and global management efforts to reverse such changes are usually made, but most of them are highly expensive in terms of intergenerational equity, since they are taken after the shifts, traps or collapses take place, with potential irreversible ecological and socioeconomic costs. We propose the use of the Heuristic to identify typologies of combination of drivers, pathways of change, observed social-ecological responses and deliberate actions to envision commonalities across SSF trajectories. Drawing recurring patterns and lessons from previous successful experiences could help create new windows of opportunities to reverse undesired outcomes. Our Heuristic model is not only flexible to different socio-cultural contexts but also useful to identify pathways of change as early warnings before social-ecological crises materialize.

Top-down policies or fisheries management strategies that apply fixed rules for achieving constant yields without considering existing social-ecological interactions and potential drivers, usually lead SSF to lose resilience over time. SSF will respond and/or adapt to drivers of change, regardless of organization levels of the governance regime in place. Often, responses will be reactive and individual when governance is weak and organizational capacities are low (Chilean case). In contrast, participatory governance regimes, such as co-management (Galician case), are more prone to develop deliberate and collective adaptive responses, although this is not always the case when social capital within fishing communities is undermined (Galapagos case). Adaptive responses can take place through a reorganization of fishing and commercialization strategies to mitigate the impact on fishers' livelihoods, or even through livelihood diversification within and outside the fisheries sector. A major challenge consists in transforming driver-induced crises and maladaptive practices in opportunities for change, considering that management of SSF is mostly sectorized and often lacks social-ecological memory to respond proactively to change, based on lessons learned from previous experiences. SSF management needs to be flexible, adaptive, and experimental at scales compatible with the scales of ecosystem functions and drivers' influence. Only when SSF are governed and managed as complex SES, uncertainty, changes, and positive tipping points would create opportunities that enable deliberate desirable transformations.

Our Heuristic is by no means intended to be prescriptive or capable of exploring all future possibilities; we hope it will serve to expand desired futures and help to foresee unintended consequences. We encourage the adoption of our Heuristic by scholars to classify and bound SSF, order events, suggest hypotheses of linked drivers, pathways of change, potential trajectories, and outcomes, and visualize the potential space for transformative changes. The application of the Heuristic, along with illustrative examples of SSF under different contexts and with contrasting outcomes, could provide valuable guidance for fisheries scientists, practitioners, and decision-makers to be able to respond in a flexible way to social-ecological shocks of SSF in the pursuit of fisheries sustainability in an increasingly uncertain world.

CRediT authorship contribution statement

Sebastian Villasante, Ignacio Gianelli, Leonardo Ortega, Omar Defeo: Conceptualization. **Sebastian Villasante, Ignacio Gianelli, Mauricio Castrejón, Laura Nahuelhual, Leonardo Ortega, Omar Defeo, U. Rashid Sumaila**: Methodology. **Sebastian Villasante, Ignacio Gianelli, Mauricio Castrejón, Laura Nahuelhual, Leonardo Ortega, Omar Defeo:** Investigation. **Sebastian Villasante, Ignacio Gianelli, Mauricio Castrejón, Laura Nahuelhual, Leonardo Ortega, Omar Defeo, U. Rashid Sumaila:** Writing – review & editing. **Sebastian Villasante, Laura Nahuelhual, Omar Defeo:** Funding acquisition.

Competing interests

The authors declare no competing interests.

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Appendix A. Supporting information

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