i. Title: Generalizability of Adaptive Responses in Small-Scale Fisheries: Insights from Latin America

ii. Running title: Generalizability Adaptation

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Abstract

Small-scale fisheries are crucial to the livelihoods and nutrition of hundreds of millions of people around the world. Fishers continuously adapt to changes in their social-ecological systems, and understanding whether adaptive responses can be generalized across different domains (e.g. environmental, market, social, institutional) or social-ecological systems is essential for designing policies to support adaptation. Here, we introduce and test a new approach to studying adaptation in small-scale fisheries by focusing on adaptive responses as the units of observation. Our proposed framework locates each adaptive response at the intersection of the stressor's domain and the affected social-ecological system, allowing systematic comparison of how, where, and why responses emerge. Drawing on 29 Latin-American case studies, we classified ten recurrent response types and scored their occurrence across domains and systems. Two strategies—forming collective-action platforms and adjusting fishing practices—proved highly generalizable, appearing in three of the four domains considered, and across all regions examined. Other responses, such as mariculture adoption or creation of no-take zones, were more context-specific. Overlaying governance attributes onto the framework revealed four enabling conditions that consistently accompany broadly applicable responses: collaboration across jurisdictions, evidence-based decision-making, recognition of local or Indigenous governance, and sustainable financing. By connecting stressors, responses, and governance conditions in a single analytical space, the framework provides a useful tool for studying adaptation in social-ecological systems, can help identify generalizable adaptive responses, and may help inform policies that enable adaptive responses.

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1. Introduction

Small-scale fisheries (SSFs) are essential sources of food security, nutrition, livelihood, and cultural heritage for hundreds of millions of people worldwide (Basurto et al., 2025; Cinner et al., 2018; FAO, 2024; Franz et al., 2023). As any social-ecological system (SES), SSFs confront challenges across environmental, social, institutional, and economic domains. Common challenges in these domains include climate variability and extremes (Ilosvay et al., 2022; Micheli et al., 2024; Villaseñor-Derbez et al., 2024), incursion of drug cartels into fisheries (Belhabib et al., 2020), resource overexploitation (Costello et al., 2012), and market and social change (Bennett et al., 2020; Castilla et al., 2016), all of which threaten the sustainability and well-being of the communities they support (Basurto et al., 2025; Short et al., 2021). In response to these challenges, fishers may adjust their practices or behaviors in ways that allow the system to adapt to change (*i.e.,* adaptive actions *sensu* (Barnes et al., 2020)), or fundamentally alter the main drivers of the SES, creating a new system (i.e., transformative actions *sensu* (Barnes et al., 2020). These two types of actions are often referred to as “adaptive responses[1]”.

Previous research has examined adaptive responses, including the type of stressors that trigger the adaptive action (Cline et al., 2017; Fisher et al., 2021; Galappaththi et al., 2022; Holland et al., 2017), the drivers of adaptive capacity (Cinner et al., 2018; Cinner & Barnes, 2019; Green et al., 2021; Mason et al., 2022), how local contexts and experiences shape responses (Ilosvay et al., 2022), and their outcomes (Bennett et al., 2020; Fisher et al., 2021). This rich body of literature has found that agency, property rights, governance, capacity, leadership, flexibility, and learning are key for successful adaptation, which enhances resilience to changes in a SES (Cinner et al.,

[1]It is important to note that the term “adaptive” does not necessarily imply a successful, beneficial or positive outcome. Rather, the term simply refers to actions taken in response to stressors in the SES, regardless of the outcome or effectiveness of the adaptation.

2018). However, less attention has been devoted to determining whether adaptive responses themselves can be *generalized* across or within SESs or domains.

Examining whether adaptive responses are deployed in response to stressors from different domains is relevant for addressing generic and specific vulnerabilities (Thiault et al., 2019). Further examining whether these responses emerge in multiple SES may allow us to assess the potential for transfer of adaptive responses–and the lessons they provide–across different contexts. Documenting the generalizability of adaptive responses is therefore a critical first step in guiding policy that supports the adaptation of fishing communities to different stressors in SSFs (Cinner et al., 2020).

The concept of "generalizability" of adaptive responses is the central focus of this paper and requires a detailed explanation. **Figure 1** provides a diagram to illustrate this concept including the domains from which stressors originate (environmental, social, institutional, or market) the SESs, and the adaptive responses being generalized across domains and SESs. That is, a circle represents an adaptive response implemented in a system to address changes in a particular domain. For the purpose of our work, we consider three ways in which generalizability may arise: 1) the same type of response is applied by a SES to adapt to changes in more than one domain, either simultaneously or at different times (i.e., horizontal movement represented in red); 2) the same type of adaptive response is applied in different SESs, but in the same domain (i.e., vertical movement represented in blue); and 3) the same type of adaptive response is observed across different systems and domains (i.e., diagonal movement represented in green).

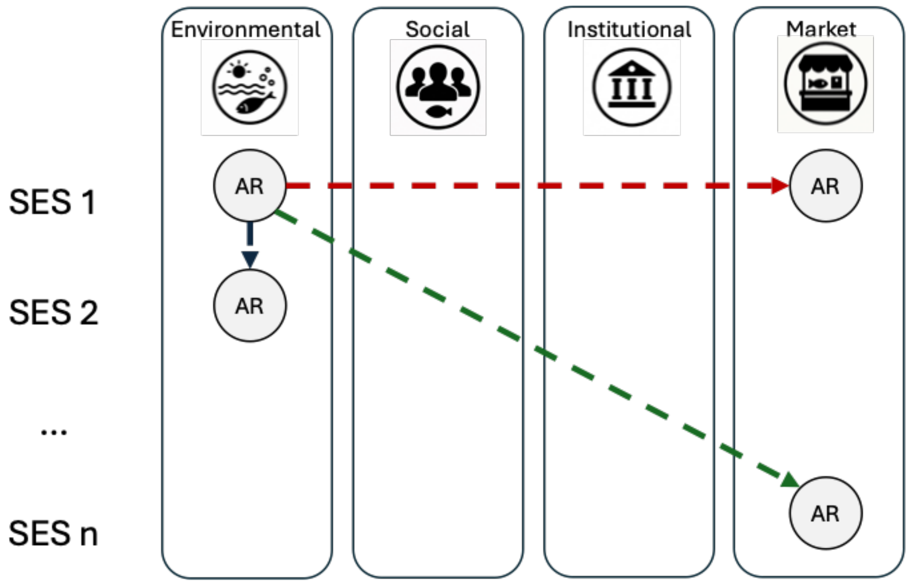


Figure 1 - Conceptual diagram of generalizability of adaptive responses. Each column represents a domain, and each row represents a social-ecological system (SES). The adaptive response (AR) being generalized is shown as a gray circle that moves across domains and SESs. The colored dashed lines represent the three main ways in which an adaptive response is considered generalizable (across domains, represented in red; across systems, represented in dark blue; or both in green).

Considering how we conceptualize generalizability, our goal is to develop a simple framework that allows us to think about adaptive responses as the unit of observation, and to investigate whether similar adaptive responses are observed across different SES and in response to stressors from different domains (see Box 1 for examples). We also aim to identify common factors that may facilitate or hinder the design and implementation of generalizable adaptive responses in SSFs. Therefore, we ask: 1) are adaptive responses generalizable in SSFs?; and 2) what are the conditions within the SES that are associated with this generalizability?

Our analysis focuses on SSFs in Latin America (**Fig. 2**), a region characterized by high diversity of its SSFs, and where the development of adaptive responses has been extensively studied. This paper builds upon a rich body of knowledge generated by numerous case studies spanning various geographical, ecological, and socio-cultural contexts (Castilla et al., 2016; Castrejón & Charles, 2020; Defeo et al., 2016; Gelcich, Edwards-Jones, et al., 2005; Gelcich, Edwards-jones, et al., 2005; Gelcich et al., 2019; Gianelli et al., 2015; McCay et al., 2014; Micheli et al., 2024; Nakandakari et al., 2017; Solano et al., 2021; Villasante, Gianelli, et al., 2022).

2. Methods

2.1 Data collection

We used an iterative approach to combine decades of cumulative collective knowledge, experience, and expertise of all authors to identify case studies across Latin America. We began with a series of group meetings and exploratory conversations and then developed a standardized data collection process that gathered place-based, system-specific information from experts in Argentina, Chile, Colombia, Ecuador, Mexico, Peru, and Uruguay on SSFs (**Fig. 2**). The first stage included five whole-team hybrid meetings, followed by 1:1 phone calls and video-conferences between the lead author and researchers in the co-author group that had specific expertise and experience with SSFs in their country or region. These calls were meant to generate a preliminary list of the types of adaptive responses they had witnessed (**Table 1**), and to identify other potential collaborators. This process helped inform our data collection approach, which was designed to standardize the collection of *our* collective experiences. We note that this is not a systematic review of adaptive responses in SSFs.

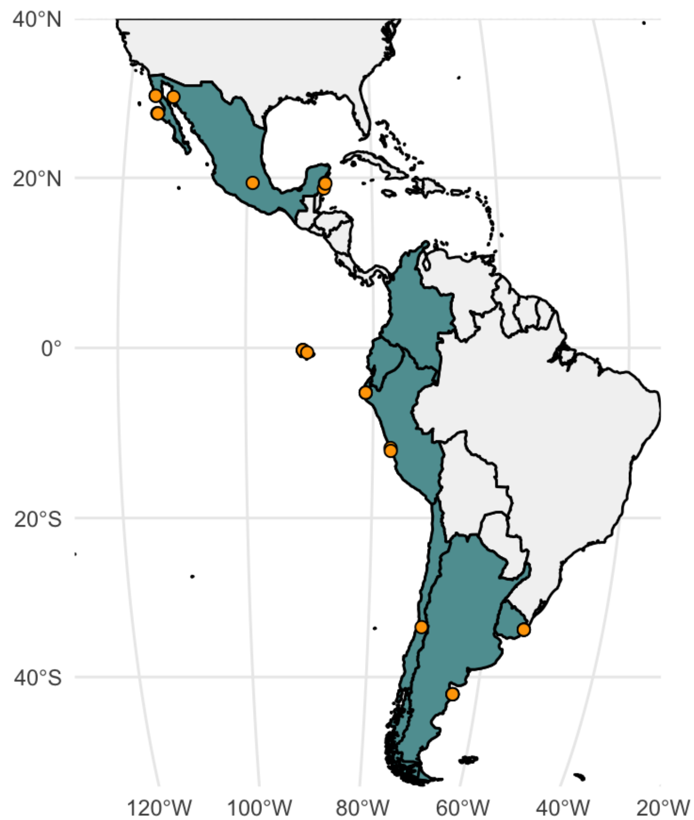


Figure 2 - Geographic distribution of the social-ecological systems covered by the study. Countries highlighted correspond to locations of author expertise and nationality, while points show the specific location of cases reported in our analysis.

The insights gathered from expert conversations informed the development of a standardized collection form (**Figure S2**) to capture the main categories of adaptive responses initially discussed and the broad domains (See **Box 1**). The categories group adaptive responses (AR), based on specific actions or activities as follows: Spatial relocation of resources or organisms (AR1), modifying fishing activity (AR2); increasing inclusion and representation (AR3); establishing no-take zones (AR4); developing platforms and institutions that facilitate collective action (AR5); shortening supply chains (AR6); engaging in aquaculture/mariculture (AR7); livelihood diversification beyond seafood production (AR8); developing saving and financing mechanisms (AR9); and changing marketing strategies (AR10) (**Table 1**). More details on each adaptive response are provided in the supplementary materials (**Appendix A1**).

The lead author initially completed the forms based on expert conversations and a review of relevant literature specific to each SES and/or adaptive response. The forms were then reviewed by the experts, who refined and supplemented the data to ensure that the full story of each adaptive response was captured, or contributed additional cases. Once completed, the data collection forms were used to develop the narrative of the adaptive responses for analysis, including details relevant to the theoretical frameworks employed [(Ostrom 2009; Grorud-Colvert et al. 2021); See Data analysis section below for details]. Each narrative was assigned a unique identifier to organize the adaptive responses based on the 10 types outlined above (**Table 1**) and they were systematically coded using the ten adaptive response types.

Table 1: Types of adaptive responses: Adaptive response (AR) categories used to code each case, while also providing one example of what the AR may look like in practice.

Adaptive Response (AR)	Examples
AR1	Spatial relocation of resources or organisms -*Fishers in El Rosario (Mexico) collected sea urchins from areas with low algal cover and relocated them to areas with higher algal cover to enhance their growth and commercial value*
AR2	Modifying fishing activity - *In Ecuador, faced with reduced demand due to COVID-19 market disruptions, fishers self-organized to limit the frequency and duration of individual fishing trips, promoting equitable income distribution.*
AR3	Increasing inclusion and representation - *Fishers throughout Mexico began listing women in their enterprise when applying for subsidies and permits*
AR4	Establishing no-take zones - *Following environmentally-driven mass mortality events in coastal Mexico, fishers implemented two community-based marine reserves designed to protect reproductive stock.*
AR5	Developing platforms and institutions that facilitate collective action - *Fishers in Peninsula Valdes, Argentina, formed an association and won recognition of their fishing rights within a newly created marine protected area.*
AR6	Shortening supply chains - *In Uruguay's yellow clam fishery, which faced an environmental regime shift and overexploitation, fishers shortened the supply chain by building a local processing plant and directly transporting and selling their product to restaurants at seaside resorts.*
AR7	Engaging in aquaculture/mariculture - *In Chilean territorial use rights for fisheries (TURFs), income was volatile due to international market fluctuations, so small-scale aquaculture systems were introduced within TURFs as a means to increase revenue and build resilience.*
AR8	Livelihood diversification beyond seafood production - *Argentinian fishers struggled to find buyers for their products or local prices were too low. They decided to open their own restaurants and food trucks.*
AR9	Developing savings and financing mechanisms - *Fishers in Peru faced high and unexpected costs, and had difficulty accessing government programs efficiently and fairly.They responded by creating collective insurance funds, administered by the OSPAs (artisanal fishing organizations).*
AR10	Changing marketing strategies - *Fishers in Ecuador were impacted by the 2008 financial crisis; they shifted their marketing away from lobster tails to whole lobsters.*

Box 1 - Examples of domains and stressors affecting social-ecological systems

The Environmental, Social, Institutional, and Market domains are examined to capture and categorize the wide variety of stressors that can be experienced by SESs. The Environmental domain encompasses the physical and ecological conditions of the ecosystem. Stressors in this domain include changes in dissolved oxygen levels (Low et al., 2021; Micheli et al., 2012), or marine heatwaves (Villaseñor-Derbez et al., 2024). The Social domain may undergo changes related to, e.g., urbanization (Wintergalen et al., 2022, 2024), or recruitment by drug cartels (Belhabib et al., 2020). The Institutional domain relates to governance structures, laws, regulations, and policies that govern resource use and management, which can be altered by the rollout of policies like a Marine Protected Area (MPA) (Saenz-Arroyo & Camacho-Valdez, 2022) or new subsidy laws (Lopez-Ercilla et al., 2021; Revollo-Fernández et al., 2024). Finally, the Market domain refers to the economic forces and mechanisms that affect the demand and supply of products and inputs within SESs. Stressors in this domain include trade restrictions (Williams et al., 2016), price fluctuations, and disruptions in global supply chains due to telecoupling with substitute products (Castilla et al., 2016), or market shutdowns such as those reported during the COVID-19 pandemic (Bennett et al., 2020; Lopez-Ercilla et al., 2021; Mangubhai et al., 2024). Note, however, that these domains often interact, and stressors may originate in one domain while manifesting in another.

2.2 Data analysis

Following the collection of the narrative of each adaptive response, we coded them according to the SES framework (Ostrom, 2009) which provides a structured way to analyze the interactions between resource units, resource systems, governance systems, and the users in the system. We supplemented with additional inductive codes that emerged during the analysis. Using NVivo v14.23.0 (13) (QSR International Pty Ltd., 2020), each response was categorized under Ostrom's four core subsystems: Resource Units (RU), Resource Systems (RS), Governance Systems (GS), and Users (U). Within each of these subsystems, adaptive responses were coded to capture detailed information across examples (Supplementary Figure S3). While the core subsystems were established deductively following the SES framework (Ostrom, 2009), the descriptive codes within each subsystem were developed inductively and iteratively. We analyzed each narrative, assigned a descriptive code under each subsystem, and repeated this process across the entire dataset to ensure comprehensive coverage and accurate representation of the adaptive responses. Additionally, other codes were developed during this process to identify patterns in the stressors, triggers, and responses across adaptive responses.

We characterized conditions favoring effective governance following the framework established by (Grorud-Colvert et al., 2021) to identify "enabling conditions for effective marine protected areas (MPAs)". While these conditions were developed specifically for MPAs, they are relevant for our analysis because they offer a useful perspective for understanding how effective marine governance and resource management relate to adaptive responses. We coded each adaptive response for the presence of 12 enabling conditions for effective governance: a clearly defined vision, collaboration across jurisdictions, conflict resolution mechanisms, coordination with governance institutions, evidence-based decision-making, knowledge integration, long-term political will, public participation with fairness, recognition of local or indigenous governance, sustainable financing, transparency and communication, and up-and-down accountability (Grorud-Colvert et al., 2021).

The four core SES subsystems (Supplementary Figure S3) were identified for each case, along with the presence of each condition for effective governance. After coding, we summarized the distribution of adaptive response typologies across geographies, SES subsystems, and conditions for good governance. Adaptive responses were then explained through meta-narratives that synthesized the data collected across cases and regions. These meta-narratives concisely document the key elements of the cases, demonstrating the adaptive response and their alignment with the theoretical frameworks (See supplementary materials).

3. Results

3.1 Summary of case studies

We compiled 29 cases of adaptive responses implemented in SSFs from six Latin American countries (Argentina, Chile, Ecuador, Mexico, Peru, and Uruguay). Our case studies reported adaptive responses triggered most commonly by changes in the Environmental domain (n = 11; 38%), followed by the Institutional domain (n = 8; 27.5%), the Market domain (n = 8; 27.5%), and the Social domain (n = 2; 7%). We recorded at least one case of adaptive responses for all 10 types of adaptive responses, with most responses recorded for AR5 (Developing platforms and institutions that facilitate collective action; N = 7; 24%), AR2 (Modifying fishing activity; N = 7; 24%); AR7 (Engaging in aquaculture; N = 3; 10%), and AR10 (Changing market strategies; N = 3; 10%). Only two cases were identified for each of AR1, AR6 and AR9, and only one case was identified for AR3, AR4, and AR8. Finally, the majority of cases were identified in Mexico (n = 10; 34.5%) and Peru (n = 6; 20.7%), with Ecuador (n = 5; 17.2%), Uruguay (n = 4; 13.8%), Argentina (n= 3; 10.3%) and Chile (n = 1; 3.4%) contributing the remaining responses. Note that geographic provenance is provided as a summary of our data collection efforts and not as a result. These numbers reflect the composition and expertise of our research group rather than any specific geographic pattern in adaptation.

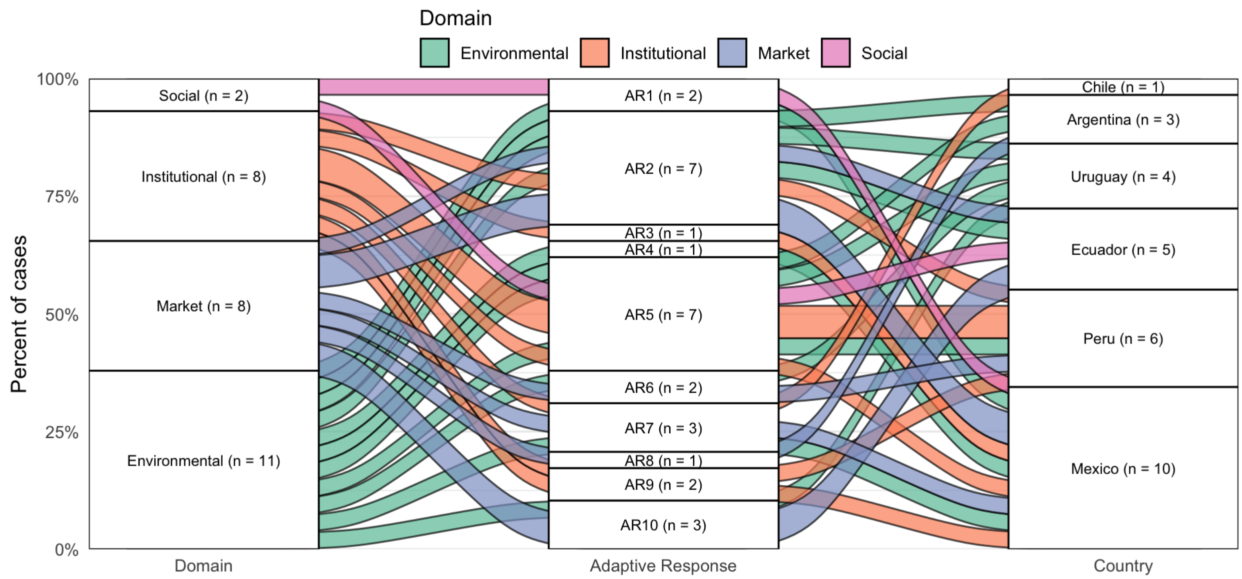
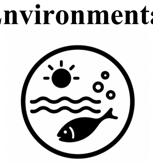
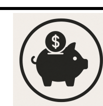
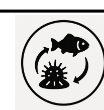
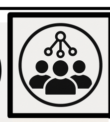
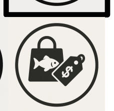


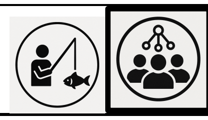
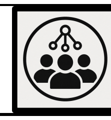
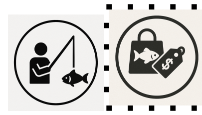
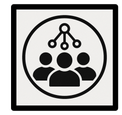
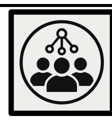
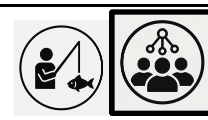
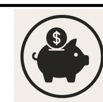
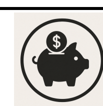
Figure 3 - Generalizability of adaptive responses across domains and geographies. The alluvial diagram shows the relationship between the four domains (left column), types of adaptive responses (AR, center column), and country names (right column). The width of the flow lines and the height of the blocks in each column are proportional to the number of responses. The adaptive responses are coded as follows: AR1: Spatial relocation of resources; AR2: Modify fishing activity; AR3: Increase inclusion and representation; AR4: No-take zones; AR5: Collective action; AR6: Shortening supply chain; AR7: Engage in Aquaculture / Mariculture; AR8: Livelihood diversification beyond seafood production; AR9: Saving and financing mechanism; AR10: Changes to marketing strategies.

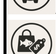
3.2 Generalizability of adaptive responses

No type of adaptive response was applied to stressors from all four domains, but some response types exhibited generalizability across three of the four domains (**Table 2**). The development of platforms and institutions to facilitate collective action (AR5) was observed in seven cases, in response to stressors from social, institutional, and environmental domains. Modifications to fishing activity (AR2) were also recorded seven times, and used in response to stressors from the social, market, and environmental domains. Three adaptive response types (AR1, AR6, AR10) were identified in response to two domains (AR1: social and environmental; AR6 and AR10: market, environmental). Increasing inclusion and representation (AR3) and the creation of new savings and financing mechanisms (AR9) emerged, in this dataset, only in response to institutional stressors. Similarly, no-take zones (AR4) were exclusively established in response to environmental stressors.

Table 2 - Summary of adaptive responses (AR) identified for each social-ecological system and domain. The SES are broadly defined by the combination of resource system and resource unit. The most frequently recorded adaptive response (AR5) is shown with a thick outline to highlight its presence across SESs and domains. Note that AR5 exhibits horizontal, vertical, and diagonal generalizability, based on our conceptual diagram (**Fig 1**). Responses with dashed outlines indicate two cases occur at the intersection of an SES and a domain. An asterisk (*) indicates these are not case-specific and were observed across many non-specific locations in the country.

	Domain			
Social-Ecological System	**Environmental** 	**Market** 	**Institutional** 	**Social** 
El Rosario (MEX)				
Banco Chinchorro (MEX)				
Rocha (URY)	   			

Península de Valdés (ARG)				
Galapagos (ECU)				
Maria Elena (MEX)				
Punta Herrero (MEX)				
La Islilla (PER)				
Mexico*				
Isla Natividad (MEX)				
Puerto Libertad (MEX)				
Ancon (PER)				
Chile*				
Peru*				

Legend	
 AR1: Spatial relocation of resources  AR2: Modify fishing activity  AR3: Increase inclusion and representation  AR4: No-take zones  AR5: Collective action	 AR6: Shortening supply chain  AR7: Engage in Aquaculture / Mariculture  AR8: Livelihood diversification beyond seafood production  AR9: Saving and financing mechanism  AR10: Changes to marketing strategies

The greatest number and diversity of adaptive responses were recorded for changes in the Environmental domain, with 11 responses across seven types (AR1, AR2, AR4, AR5, AR6, AR7, AR10). Five types of adaptive responses emerged from the Market (AR2, AR6, AR7, AR8, AR10) and Institutional domains (AR2, AR3, AR5, AR7, AR9), while the Social domain produced two types (AR1, AR5). Most adaptive responses were observed across multiple geographies. The most generalizable response types, AR2 and AR5, were found in all five countries included in our study. Most other response types were observed in two of the five countries, with the exception of AR3 and AR4, which were unique to SES in Mexico. These numbers indicate that generalizable responses were identified in multiple SES and countries, but likely reflect the geographic distribution of author expertise rather than systematic patterns in national-level adaptation.

Among the adaptive responses documented, AR2, AR5, and AR10 stand out for their application across a broader array of SES, as characterized using Ostrom's framework subsystems (**Table 3**). The modification of fishing activities (AR2) was observed in SESs involving various types of resource units, including benthic, pelagic, and multispecies fisheries. These SES were governed by a variety of collective and organizational institutional arrangements, such as fishing cooperatives, artisanal fishers' associations (OSPAs), Territorial Use-rights for Fisheries (TURFs), co-management bodies, and fishing permits. The users engaged included fishers, divers, boat owners, and processors, while the resource systems encompass diverse environments such as archipelagos, points, sandy beaches, among others.

The development of platforms and institutions that facilitate collective action (AR5) was applied across varied SESs, including benthic, demersal, pelagic, and generalist fisheries. These SES were typically governed through community-based or co-managed governance systems, involving management measures such as no-take zones and fishing gear control, and primarily engaging small-scale fishers. The resource systems in these cases included environments such as archipelagos, sandy beaches, and other coastal areas. Notably, platforms developed in response to one stressor were later leveraged against other types of stressors (e.g., in Península de Valdés, Argentina).

Changes to marketing strategies (AR10), though reported less frequently than AR2 and AR5, were also widespread across various SES. These strategies involved diverse resource units such as clams, lobsters and multispecies fisheries, and were implemented through governance systems extending from cooperatives to government management. The users included SSFs and their networks, encompassing diverse resource systems including a sandy beach, an island, and an archipelago. Shortening the supply chain (AR6) was observed in two distinct SESs involving benthic and multi-species fisheries, within a sandy beach and a coastal town. The governance systems included co-management and fisher organizations, with users primarily consisting of small-scale fishers and their networks.

The remaining responses (AR1, AR3, AR4, AR7, and AR9) were more context-specific. For example, although engaging in aquaculture/mariculture (AR7) was mentioned in three cases, it was limited to benthic resources within contained resource systems, managed by small-scale fishers in TURFs. The spatial relocation of resources (AR1) is limited to SES with benthic resources managed under TURFs-Coop by small-scale fishers. Finally, AR3, and AR4 were each described in only one SES, suggesting narrower current application.

Table 3 - Adaptive responses within the Social-Ecological Systems Framework. The first column is the type of adaptive response (AR), the second column is the domain, and the third column is the code for each country. The following columns correspond to one of the components outlined in Ostrom's Social-

Ecological systems framework. The adaptive responses are coded as follows: 1: Spatial relocation of resources; 2: Modify fishing activity; 3: Increase inclusion and representation; 4: No-take zones; 5: Collective action; 6: Shortening supply chain; 7: Engage in Aquaculture / Mariculture**;** 8: Livelihood diversification beyond seafood production; 9: Saving and financing mechanism; 10: Changes to marketing strategies. Domains are abbreviated as follows: Env: Environmental; Mkt: Market; Inst: Institutional; and Soc: Social. SSF (Small-scale fisheries), Co-Ops (Fishing cooperatives), OSPA (“Organizaciones Sociales de Pescadores Artesanales”: Social Organization of Artisanal Fishers), TURF (Territorial Use-rights for Fisheries).

AR	***Domain***	***Country***	***Resource Units***	***Resource System***	***Governance System***	***Users***
1	Env	MEX	Sea urchin	El Rosario	TURF and Coop	SSFs from cooperatives
1	Soc	MEX	Queen conch	Banco Chinchorro	TURF (1) and Coops (3)	SSFs from cooperatives
2	Env	URY	Yellow clam	Sandy Beach	Co-managed SSFs	SSF clam fishers’ network
2	Env	ARG	Benthic invertebrates and seaweeds	Península Valdés	Managed by provincial government with consultation	Commercial divers and and coastal gatherers
2	Env	ECU	Spiny lobster	Galapagos Islands	Managed Fishery (generalist permit)	Generalist fishers (freediving and hookah)
2	Mkt	ECU	Multispecies fisheries	Galapagos Islands	Co-managed rotational fisheries	SSFs and boat owners from co-ops
2	Mkt	MEX	Spiny lobster	Maria Elena	TURF and Coop	Lobster fishers
2	Mkt	MEX	Spiny lobster	Punta Herrero	TURF and Coop	Lobster fishers
2	Inst	PER	Squid	La Islilla	OSPA	Fishers and Processors
3	Inst	MEX	Multispecies fisheries	Mexico	Federal Agency	Women Fishers
4	Env	MEX	Benthic invertebrates	Isla Natividad	TURF and Coop	SSFs from cooperatives
5	Env	PER	Demersal finfish	La Islilla	OSPA	SSFs
5	Env	URY	Yellow clam	Sandy Beach	Co-managed SSFs	SSF clam fishers’

						network
5	Env	ARG	Benthic invertebrates and seaweeds	Península Valdés	Provincial government	SSFs
5	Inst	MEX	Bivalves/Finfish /Elasmobranchs	Puerto Libertad	Community-based management	SSFs
5	Inst	PER	Multispecies fisheries	La Islilla	OSPAs & voluntary patrols	SSFs
5	Inst	PER	Multispecies fisheries	La Islilla	OSPAs & spatial gear control	SSFs
5	Soc	ECU	Brown sea cucumber	Galapagos Islands	Co-managed no-take reserves	SSFs
6	Env	URY	Yellow clam	Sandy Beach	Co-managed SSFs	SSF clam fishers' network
6	Mkt	PER	Multispecies fisheries	Ancon	OSPAs	SSFs
7	Env	MEX	Benthic invertebrates	Isla Natividad	TURF and Coop	SSFs from cooperatives
7	Mkt	MEX	Benthic invertebrates	El Rosario	TURF and Coop	SSFs from cooperatives
7	Inst	CHL	Tunicates/Bivalves/Macroalgae	Small-scale aquaculture	TURFs	SSFs
2	Mkt	ARG	Benthic invertebrates	Península de Valdés	Co-managed SSFs	SSFs
9	Inst	MEX	Multispecies fisheries	Baja California	TURFs and Coops	SSFs
9	Inst	PER	Multispecies fisheries	Peruvian fishing communities	OSPA	SSFs
10	Env	URY	Yellow clam	Sandy Beach	Co-managed SSFs	SSF clam fishers' network
10	Mkt	ECU	Spiny lobster	Galapagos Islands	Government-managed reserve	SSFs
10	Mkt	ECU	Multispecies fisheries	Santa Cruz Island	Fishing coops and trade associations	SSFs

3.3 Enabling conditions for effective governance associated with adaptive responses

Different AR typologies were linked to specific governance enabling conditions, indicating that certain response types may require particular governance contexts in order to emerge (**Fig. 4**). Despite the variety of enabling conditions associated with each AR typology, certain conditions—such as collaboration across jurisdictions, evidence-based decision-making, recognition of local or indigenous governance, and sustainable financing—were consistently linked to the generalizability of several response types. For instance, in the case of spatial resource reallocation (AR1), the only enabling conditions present in both documented cases were collaboration across jurisdictions and recognition of local or indigenous governance. Evidence-based decision-making was consistently observed in all cases of modifications to fishing activities (AR2). Additionally, collaboration across jurisdictions was found in three out of seven AR2 cases.

Increased inclusion and representation (AR3) was documented in a single case, which involved coordination with government institutions, fair public participation, sustainable financing, transparency and communication, and up-and-down accountability. Similarly, establishment of no-take zones (AR4) occurred in only one case, where collaboration across jurisdictions, evidence-based decision-making, knowledge integration, and recognition of local or indigenous governance were key governance conditions.

In the development of collective action platforms (AR5), conflict resolution mechanisms and evidence-based decision-making were the most frequently observed governance conditions. In both cases of supply chain shortening (AR6), sustainable financing and collaboration across jurisdictions were present. For engagement in marine aquaculture or mariculture (AR7), collaboration across jurisdictions, evidence-based decision-making, recognition of local or indigenous governance, and up-and-down accountability were observed in two of the three documented cases. Sustainable financing was present in all documented cases of AR9 (saving and financing mechanism), and in two of three AR10 cases (changes to marketing strategies), suggesting a link to their generalizability.

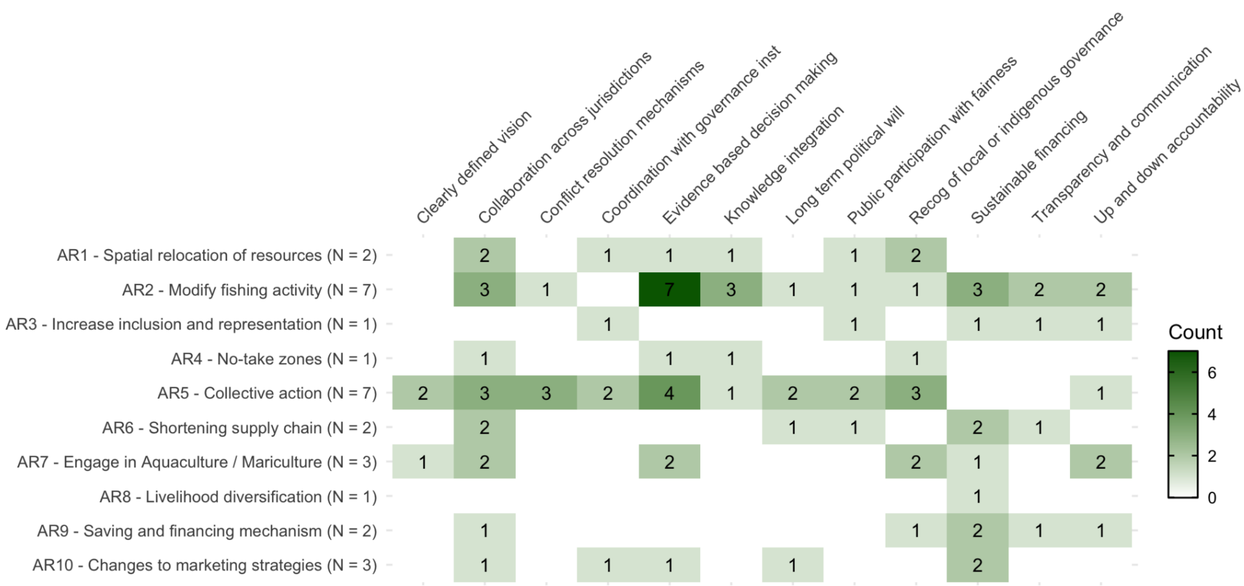


Figure 4 - Distribution of enabling conditions across adaptive responses. Counts in the matrix represent the number of instances where each enabling condition was identified across the adaptive response cases. Counts in parentheses indicate the number of cases implementing each response.

All adaptive response typologies demonstrated multiple enabling conditions for effective governance, though some exhibited more than others (**Fig. 5**). Notably, modifications to fishing activity (AR2) showed the highest diversity of governance conditions, with 10 out of 12 conditions present across seven cases. On average, each AR2 case demonstrated 3.4 governance conditions, ranging from one to six. Spatial relocation of resources (AR1) also exhibited a relatively high number of governance conditions per case (mean = 4; min = 2, max = 6).

Development of platforms and institutions to facilitate collective action (AR5) also stood out, cumulatively showing seven of the 12 governance conditions across cases. However, on average, AR5 responses demonstrated fewer conditions per case (mean = 2.4), highlighting variability in their implementation. These findings suggest that some adaptive responses, particularly AR2 and AR5, are consistently linked to a wider array of enabling governance conditions, emphasizing their broader applicability across different contexts. A detailed domain- and country-level analysis is available in the supplementary materials (**Figure S1**).

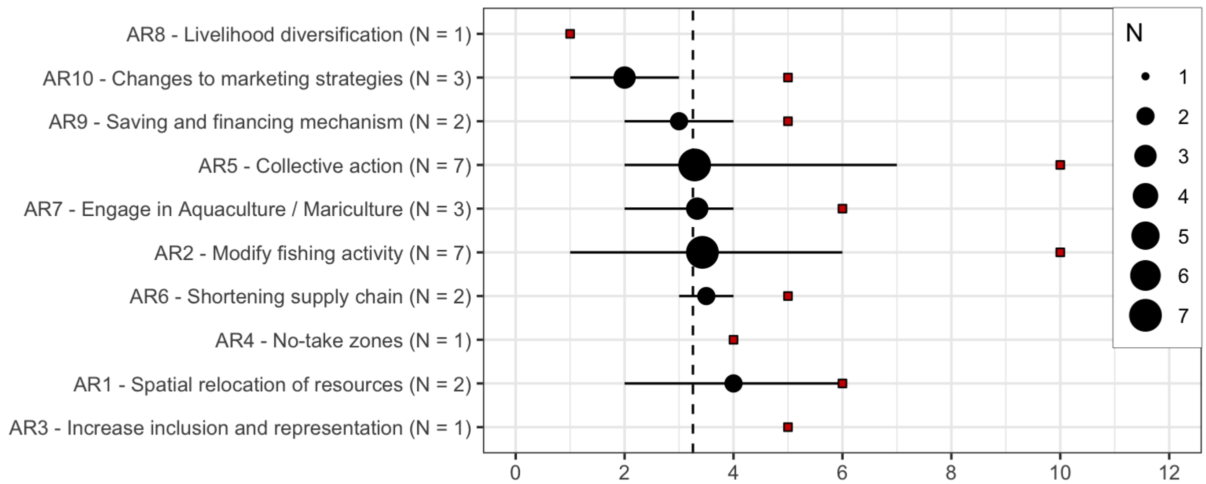


Figure 5 - Effective governance condition scores for type of adaptive response. Points and error bars represent the mean, minimum and maximum number of enabling governance conditions observed per response type. Point sizes represent the number of adaptive responses contained in each score. Red squares indicate the number of unique effective governance conditions observed across all cases within each group, from a total of 12. The dashed vertical line indicates the mean across all groups. Adaptive responses are ordered in ascending order based on their mean scores. Counts in parentheses indicate the number of cases implementing each response.

4. Discussion

Our examination of adaptive response in 29 cases of SSFs across Latin America suggests that similar strategies can emerge in response to stressors from different domains and across varying SES. Thus, we provide new evidence for the generalizability of adaptive responses in coastal SSFs, and a new framework for assessing the generalizability of adaptive responses, applicable across diverse SES. Our findings emphasize the importance of examining the relationship between robust governance and institutions, and the success of adaptive responses. A common trait of successful adaptive responses was the presence of multiple conditions enabling effective adaptation. While some conditions were more prevalent than others, the overarching theme was their diversity, suggesting that having multiple enabling conditions may be essential for supporting generalizable adaptive responses. Taken together, these insights highlight opportunities and approaches for broadly supporting and enabling adaptive capacity of SSFs across domains and SES.

By employing an inductive approach and leveraging the collective experience of SSF scholars in Latin America, we were able to characterize the responses of small-scale fishers and fisheries to environmental, social, institutional and market challenges, their enabling conditions/factors and the contexts in which they arise. This methodology has guided us in identifying key directions for future research on the transferability of adaptive responses and the lessons they offer across different SES and domains. While we found evidence supporting the generalizability of adaptive responses, our analysis also revealed variations in this generalizability, with some responses emerging less frequently and in more limited contexts. This pattern highlights the need to further investigate the conditions that make specific adaptive responses viable and effective in different contexts, and how they address general or specific vulnerabilities in SSFs.

The development of platforms and institutions for collective action was the most frequently recorded adaptive response. Although collective action is widely recognized as key for adaptive capacity (Cinner et al., 2018), previous assessments of adaptive responses rarely highlight the broad emergence of collective action platforms and institutions as key adaptive strategies (Green et al., 2021; Ilosvay et al., 2022; Miller et al., 2018). Nonetheless, given the crucial role that collective action plays in the sustainable functioning of SES (Ostrom, 2009), it is likely that actors in SSFs increasingly seek to strengthen and mobilize collective action in response to external change. Our analysis of detailed narratives revealed that this response emerged across various domains and SES, particularly where conflict resolution mechanisms and evidence-based decision-making were present. The broad applicability of this response suggests its potential for transferability, where collective action platforms established to address stressors in one domain can also be used to tackle challenges and strengthen adaptive capacity in other domains (Gianelli et al., 2021). Furthermore, new collective action platforms can drive adaptation and transformation (Ojea et al., 2020). Given their observed generalizability, there is a clear need to better understand how to support and harness these platforms to promote effective adaptation and resilience in SSF.

Adaptive responses involving the modification of fishing activities were also frequently documented among the studied cases. These adaptive responses include input and output control rules, changes in fishing effort, and switching gear and targeted species, all of which have been widely documented in the literature (Cline et al., 2017; Fisher et al., 2021; Ilosvay et al., 2022; Liu et al., 2023; Villasante, Macho, et al., 2022). Our analysis shows that these modifications to fishing activities were generalized across most domains and geographies, appearing in diverse SES. SSFs are known for their low specialization and flexibility, often utilizing multiple gears, fishing grounds, and targeting a variety of species (Short et al., 2021). Therefore, it is not surprising that when faced with changes, small-scale fishers frequently adopt these strategies. Some of these adaptations are at risk of becoming maladaptive (Cinner, 2011; Ojea et al., 2020). For instance, an increase in effort might provide short-term economic benefits but result in negative long-term economic and ecological impacts. Importantly, all cases of modification of fishing activities documented in our study exhibited evidence-based decision-making, and some demonstrated collaboration across jurisdictions, which may help to mitigate the risk of maladaptation. Additionally, we found instances where fishers self-organized to reduce fishing effort and achieve more equitable profits. These findings highlight the complex trade-offs involved in modifying fishing activities as adaptive responses to stressors. Given the prevalence of these responses, and the limited number of case studies in our study, future research is needed to better understand the drivers and outcomes of these adaptations in different settings.

Two instances of supply chain shortening (AR6) and three instances of changes in marketing strategies (AR10) were reported, illustrating how SSF actors leverage commercialization activities to mitigate the impacts of change. Although these responses emerged in reaction to environmental and market stressors, they were generalizable across different SES with relatively few effective governance conditions. Notably, all but one case involved sustainable financing. Credit and savings are known to enhance fishers' adaptive capacity by providing the capital needed to switch gears, target different resources, or increase fishing effort (Cinner et al., 2018). Our findings suggest that sustainable financing also supports adaptation through adjustments in commercialization activities. However, credit and savings are often limited in SSFs, particularly in Latin America (Salas et al., 2007; Short et al., 2021). This limitation highlights the importance of developing financing and saving mechanisms, as documented in two different SES that involved sustainable financing.

These responses play a crucial role in enhancing the capacity of SSF to adapt to various stressors. Spatial relocation of resources and the development of mariculture and aquaculture were observed in fewer SES compared to other similarly frequent adaptive responses. This again suggests differences in the generalizability of adaptive responses. For example, spatial relocation of resources and the development of mariculture and aquaculture were typically found in settings involving the management of sessile benthic resources through TURFs and fishers' associations. Most documented cases of these two response types also featured collaboration across jurisdictions and recognition of local or indigenous governance. This pattern may reflect how territoriality, collective action, and low resource mobility contribute to securing the benefits of these costly adaptive responses (Ostrom, 1990, 2009).

These observations highlight the need for caution when seeking universal solutions to support the resilience of coastal communities, as certain adaptations may require specific conditions. For example, while mariculture is often seen as a way to improve the resilience of small-scale fishers, our findings suggest it may not succeed in all contexts. This aligns with recent research emphasizing the need to consider local capacities, social capital, culture, and history when promoting such adaptive strategies in SSFs (Mansfield et al., 2024; Sepúlveda et al., 2019; Sierra Castillo et al., 2024).

Increasing representation and inclusion and the implementation of no-take zones were each reported in only one instance. While this prevents us from drawing conclusions about the generalizability of these responses, it suggests that they may arise under more specific circumstances than other responses. These two cases exhibited a higher-than-average number of effective governance conditions, indicating that these may be more specialized responses. These patterns highlight the need for further exploration into the specific conditions under which small-scale fishers might establish no-take zones and increase inclusion and representation, both of which are often promoted as pathways to enhance the resilience of SSFs (Ojea et al., 2020; Roberts et al., 2017).

Our analysis revealed specific governance conditions that support different types of adaptive responses. Evidence-based decision-making, collaboration across jurisdictions, and recognition of local and indigenous governance were key factors in the generalization of various response types, suggesting their role in enabling these adaptive responses to develop in different contexts and circumstances. Although certain governance conditions are linked to specific adaptive responses, the responses we studied emerged across a wide range of effective governance conditions. Our results further suggest that when fewer than 3-5 effective governance conditions are present, the ability of adaptive responses to occur may be limited. SES that meet multiple enabling conditions for sustainable SSF governance are more likely to adapt effectively to diverse stressors. Therefore, having a diversity of enabling conditions may be a critical factor in supporting the generalizability of adaptive responses.

5. Conclusions

Our examination of adaptive responses in SSFs to stressors across environmental, social, institutional, and market domains identified a diverse suite of adaptive responses. Importantly, we found that these adaptive responses generally apply across diverse domains, geographies, and SES, thereby providing evidence of generalizable adaptation. However, we also found context-specific differences in generalizability, which highlight several areas for further investigation, including: (1) the potential transferability of collective action platforms and institutions across different stressors, domains, and SES; (2) the need for a more nuanced characterization of adaptive responses involving modifications to fishing activities to anticipate maladaptation and support desirable outcomes; (3) the identification of specific conditions under which mariculture, aquaculture, spatial relocation of resources, no-take zones, and increased inclusion and representation are implemented; and (4) the role of local belief and mental models, agency, and external support in the transferability and adoption of adaptive responses. Future research should focus on understanding these and related questions regarding the drivers and outcomes of adaptive responses. Gaining this understanding would have substantial implications for effectively translating adaptive responses across different systems and scales.

Our findings provide strong evidence for the generalizability of adaptive responses in SSFs. A key implication is that adaptive responses may be transferable across systems and domains, or at the very least, can be supported exogenously by policy and management. Generalizability is likely a necessary condition for the active transfer of adaptive responses from one system to another. Future research should investigate how pathways of transferability may emerge within and between SSFs , how both generalizability and transferability can be leveraged by marine governance practitioners and resource users to enhance resilience in SSFs, and how possible unintended negative outcomes of transferring policies and other actions across SES may be avoided or minimized. This research provides a novel framework and empirical foundation for understanding the generalizability of adaptive responses, contributing to the pursuit of more sustainable and resilient SSFs management in Latin America and across the world.

6. Declarations

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Artificial Intelligence Generated Content

ChaptGPT-4o was used to generate the icons depicting the 10 adaptive responses and four domains. The agent was prompted with the metanarratives and asked to generate 10 individual icons. It was then asked to generate four additional icons using the contents of Box 1.

Data availability statement

All data and code are available on GitHub at https://github.com/jcvdav/generalizable_adaptation, and mirrored in a stable DOI in zenodo (Villaseñor-Derbez, 2025).

Conflict of interest statement

The authors declare they do not have any conflict of interests.

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