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How adaptive capacity shapes the Adapt, React, Cope response to climate impacts: insights from small-scale fisheries

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Abstract
As the impacts of climate change on human society accelerate, coastal communities are vulnerable to changing environmental conditions. The capacity of communities and households to respond to these changes (i.e., their adaptive capacity) will determine the impacts of climate and co-occurring stressors. To date, empirical evidence linking theoretical measures of adaptive capacity to community and household responses remains limited. Here, we conduct a global meta-analysis examining how metrics of adaptive capacity translate to human responses to change (Adapt, React, Cope response) in 22 small-scale fishing case studies from 20 countries ($n = 191$ responses). Using both thematic and qualitative comparative analysis, we evaluate how responses to climate, environmental, and social change were influenced by domains of adaptive capacity. Our findings show that adaptive responses at the community level only occurred in situations where the community had Access to Assets, in combination with other domains including Diversity and Flexibility, Learning and Knowledge, and Natural Capital. In contrast, Access to Assets was nonessential for adaptive responses at the household level. Adaptive households demonstrated Diversity and Flexibility when supported by strong Governance or Institutions and were often able to substitute Learning and Knowledge and Natural

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Capital with one another. Standardized metrics of adaptive capacity are essential to designing effective policies promoting resilience in natural resource-dependent communities and understanding how social and ecological aspects of communities interact to influence responses. Our framework describes how small-scale fishing communities and households respond to environmental changes and can inform policies that support vulnerable populations.

Keywords Small-scale fisheries · Adaptive capacity · Social-ecological systems · Environmental change · Quantitative meta-analysis · Qualitative comparative analysis

1 Introduction

Climate change is affecting communities around the world. Impacts that communities experience from climate perturbations are frequently intertwined with nonclimatic stressors (e.g., pollution, overfishing). These co-occurring stressors may exacerbate impacts to individuals, households, communities, and nations. Affected populations must respond to these stressors, therefore understanding how and why they respond, and their ability and willingness to adapt to these changes, is critical for climate adaptation planning. Coastal communities and, in particular, small-scale fishing communities, are at the forefront of climate change (Cheung et al. 2009; Badjeck et al. 2010; Barange et al. 2014). Studying trajectories of change within and across these sentinel communities provides an informative lens through which to study the process of climate adaptation. These findings could help other communities dependent on natural resources for their livelihoods to respond to climate change.

Small-scale fisheries (SSF) provide occupations for 90% of the world's capture fishers, supply food and livelihoods for many millions of individuals around the globe (Seggel and De Young 2016) and produce around half of the global catch directly consumed by humans (Pauly and Zeller 2016). SSF communities are particularly sensitive to global environmental change due to their high dependence on natural resources, direct environmental exposure, and limited capacity for geographic redistribution (Allison et al. 2009; Cheung et al. 2009; Miller et al. 2018). The ability of these communities to navigate variable social and ecological conditions is a defining characteristic that has enabled their long-term persistence (Adger 2016; Ford et al. 2011; Oestreich et al. 2019). Yet, progressive environmental trends like ocean acidification, changes in precipitation, increased sea surface temperature, and more frequent extreme events (e.g., marine heat waves, cyclones, and floods) have begun to exert unprecedented pressures on these systems (Perry 2005; Pörtner et al. 2014; Stott et al. 2016). Increasingly co-occurring with political and socioeconomic change or instability, such processes are acting in tandem to undermine the persistence and viability of many SSF systems worldwide (Barange et al. 2014; Selgrath et al. 2018; Frawley et al. 2019a).

Many social and ecological impacts resulting from climate change on SSF are already apparent. Coral reef fisheries are highly susceptible to ocean warming that causes coral bleaching (Cinner et al. 2015) while fish populations are migrating poleward, potentially displacing fishermen (Morley et al. 2018). As a result of these changes, scholars, resource-managers, and policy-makers are increasingly looking to coastal communities to understand the lived experience of adaptation. In particular, the notion of adaptive capacity, or "the ability of systems, institutions, humans, and other organisms to adjust to

potential damage, take advantage of opportunities, or to respond to the consequences" (IPCC 2014) has been the focus of much recent study (Cinner et al. 2018).

Assessments of adaptive capacity are typically grounded in social-ecological systems thinking and the theory of resilience or the capacity of human-natural systems to persist, adapt, or transform in response to change (Berkes and Folke 1998; Folke 2006; Gallopín 2006). Evaluating adaptive capacity relies upon measurements of diverse characteristics and conditions (i.e., the "domains" of adaptive capacity) to predict future responses (Brooks et al. 2005; Gupta et al. 2010; Whitney et al. 2017; Cinner et al. 2018). Given that such literature largely concerns itself with hypothetical processes and potentials and rarely includes post hoc evaluation of community change (Whitney et al. 2017), its utility to decision-makers trying to promote adaptation and manage impacts in complex SES may be limited (Côté et al. 2016). Scholars and policy makers are developing practical climate adaptation and mitigation strategies for industrial fisheries (Miller et al. 2018), but SSF have received considerably less attention (Blasiak et al. 2017). Consensus exists that assessments of observed adaptive response in SSF could help illuminate critical patterns, processes, and feedbacks and facilitate the design and implement adaptive strategies tailored to specific geographies (Cinner et al. 2015; Whitney et al. 2017; Guillotreau et al. 2017; Chuenpagdee and Jentoft 2018). But assessments and meta-analyses of adaptation within and across such natural resource systems remain scarce (Galappaththi et al. 2019; Oestreich et al. 2019; Siders 2019).

To address this gap, we ask three questions: (1) What type of stressors are impacting SSF around the globe? (2) What is the Adapt, React, Cope response (ARC response) of communities to these stressors? and (3) In what ways, if at all, do adaptive capacity domains influence (amplify or dampen) observed responses? We first develop a novel framework conceptualizing the broad-scale domains that group established determinants of adaptive capacity with on-the-ground responses to change. Using this framework, we then analyze whether responses to external stressors—categorized as adapting, reacting, or coping behavior as defined by Bennett et al. (2014)—are amplified or dampened by different domains of adaptive capacity within 22 case studies from 20 countries from a global literature review. We evaluate how different combinations of adaptive capacity domains are related to adaptive responses at the community and household levels in SES. Finally, we highlight the need for increased standardization in adaptive capacity literature to facilitate synthesis and understanding of adaptive responses. Below, we outline the analytical framework we use in our meta-analysis (Oestreich et al. 2019; Fig. 1; Table 1) and present our results organized according to the three research questions.

2 Adapt, React, Cope framework overview

Our approach consisted of three steps: (1) identification of relevant case studies in the existing literature; (2) systematic coding of case study attributes (Wilson 2009); and (3) analysis of codified data using thematic analysis and qualitative comparative analysis (QCA) to identify how individual or relational domains of adaptive capacity influence the relationship between stressors and responses.

2.1 Case study selection

To identify SSF case studies, we conducted a tiered, systematic review of the literature (Berrang-Ford et al. 2015). First, we conducted a Google Scholar search using the following

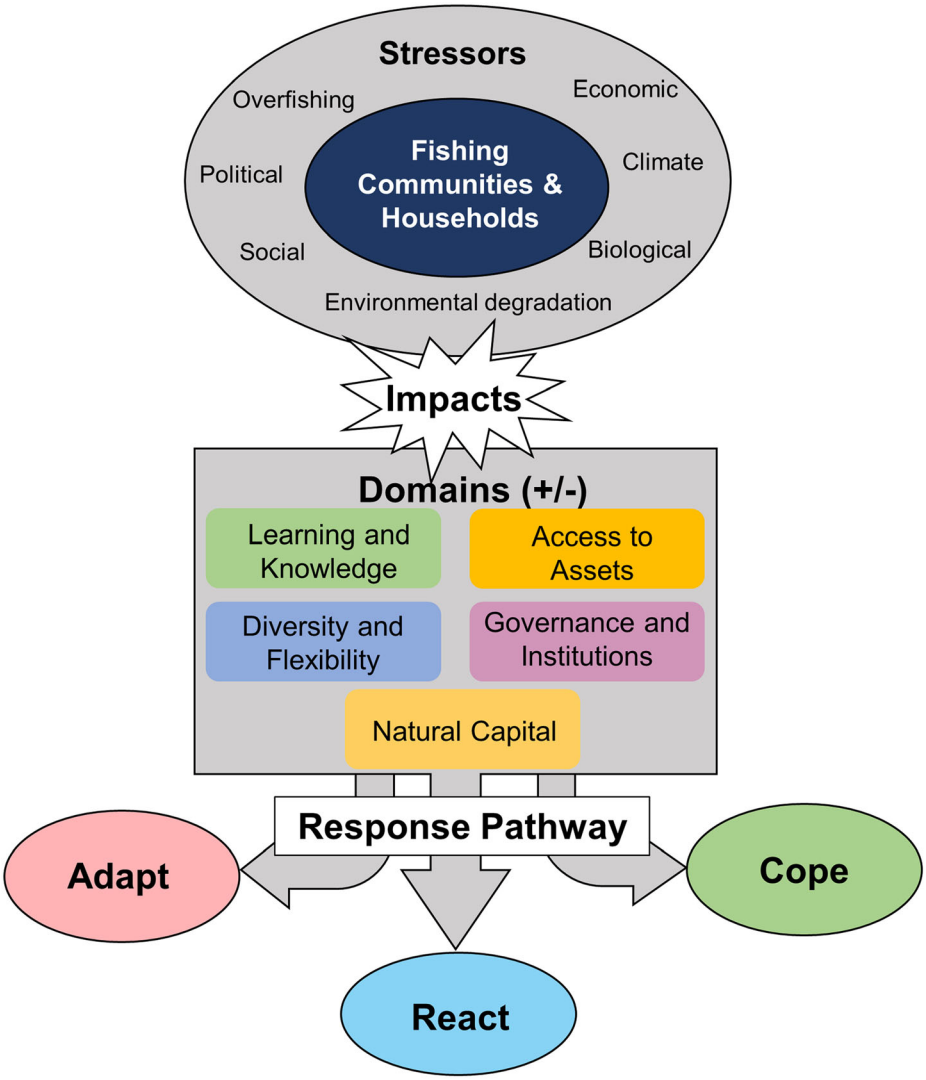

Fig. 1 Conceptual response: Adapt, React, Cope (ARC) response framework for analysis of response to stressors (climate, biological, economic, environmental degradation, overfishing, political, and social) that impact small-scale fishing communities. Presence (+) or absence (−) of adaptive capacity domains (Learning and Knowledge, Access to Assets, Diversity and Flexibility, Governance and Institutions, and Natural Capital) will influence (amplify or dampen) response to stressors

strings ("small-scale fisheries" OR "artisanal fisheries" OR "subsistence fisheries") and ("social ecological systems" "community resilience environmental change response" OR "adapt") to identify instances of SSF responses to biological or physical stressors. The first set of terms allowed us to focus on the responses to stressors of SSF, defined by Teh and Sumaila (2013) as follows: (1) targeting species for household consumption or local markets; (2) occurring at a relatively low level of economic activity; (3) minimally mechanized; (4) operated nearshore; (5) performed by the fisher/fisher's family; (6) minimally managed; and/or (7) undertaken for cultural or ceremonial purposes. The second set was used to find studies

Table 1 Definitions and examples of Adapt, React, Cope (ARC) responses; a description of the determinants within the five broad domains of adaptive capacity and references; and the effect of domains on a response

ARC responses	Definition
Adapt	Proactive planning of individual or collective actions based on knowledge of past or anticipated future environmental change (Bennett et al. 2014)
Example	Overfishing caused a decline in fish stocks; fishers adapted by developing harvesting techniques for other species.
React	An unplanned response to a stressor or change (Bennett et al. 2014)
Example	Overfishing caused a decline in fish stocks; the government reacted by restricting fishing.
Cope	Passively accepting consequences of an environmental stressor (Bennett et al. 2014)
Example	Overfishing caused a decline in fish stocks; fishers coped by waiting for a fishery recovery rather than adjusting their livelihoods.
Domains	Determinants
Diversity and Flexibility	Livelihood diversity (Adger et al. 2005; Whitney et al. 2017), occupational mobility (Whitney et al. 2017), geographic flexibility (Whitney et al. 2017), room for autonomous change (Gupta et al. 2010)
Access to Assets	Community infrastructure (Brooks et al. 2005), household material assets (Whitney et al. 2017), decision-making/ regulatory authority (Biermann 2007; Gupta et al. 2010), human resources (Biermann 2007, Gupta et al. 2010), financial resources (Smit and Pilifosova 2003; Gupta et al. 2010; Nelson et al. 2010), access to credit (Brooks et al. 2005; Cinner et al. 2015; Whitney et al. 2017), access to aid (Brooks et al. 2005), access to markets (Poulain et al. 2018), access to information (Gupta et al. 2010), fishing gear (Coulthard 2008), technology use (Smit and Pilifosova 2003)
Learning and Knowledge	Local ecological knowledge (LEK) (Gerhardinger et al. 2009), learning capacity (Gupta et al. 2010), diversity of knowledge (Whitney et al. 2017), risk perception (Whitney et al. 2017)
Governance and Institutions	Trust (Gupta et al. 2010; Whitney et al. 2017), leadership (Gupta et al. 2010; Whitney et al. 2017), gender (Whitney et al. 2017), social capital (Adger 2010; Whitney et al. 2017), regulations (Whitney et al. 2017), stakeholder engagement (Bouamrane et al. 2016; Whitney et al. 2017)
Natural Capital	Access to natural resources generating ecosystem goods and services (Costanza et al. 1997; Allison and Ellis 2001)
Effect of domain on response	Definition
Amplify	Enhancing the intensity of a response
Dampen	Weakening the intensity of a response

where empirical responses to stressors (verified through the case study methods) were documented for social ecological systems, as we were interested specifically in the adaptive capacity of intertwined human-natural systems. Second, we reviewed abstracts for the initial

1650 search results. We excluded nonpeer-reviewed primary research articles (i.e., government reports, unpublished theses, book chapters, and synthesis papers) that were unrelated to SSF or that focused on hypothetical adaptive capacity rather than empirical assessments of responses. This yielded 85 potential case studies for further evaluation. Third, we limited our final analysis to case studies that met two criteria: (1) explicitly examined empirical adaptive response of SSF communities or households to a specific stressor (or set of stressors) and (2) considered situations where at least one primary stressor was biological or physical. The inclusion of biological or physical stressors ensured that our work was relevant to climatic adaptation. Responses were scaled by community and household to determine if domains influenced adaptive capacity response differently at these two levels. This selection process yielded examples of responses from 22 case studies (Fig. 2); case study summaries can be found in the Electronic supplementary material 1 (ESM 1).

2.2 Characterizing stressors

We characterized three aspects of the stressors facing communities and households: type, timescale, and impact. Overall, we categorized stressors into seven types, as follows: climate (which encompassed physical stressors), biological, economic, environmental degradation, overfishing, political, and social. Importantly, co-occurring stressors can interact in complex ways in SSF and influence the impacts of climate change on communities and households and their response (Freduah et al. 2019). We categorized nonclimatic stressors as economic (e.g., market fluctuation), environmental degradation (e.g., pollution or deforestation), overfishing, political (e.g., civil war) and social (e.g., poor health of fishers) (Fig. 1). In some case studies with co-occurring stressors, a distinct response to individual stressors was recorded. In cases where multiple stressors were described together (e.g., climate and overfishing) and could not be disaggregated to distinct responses, we listed these stressors as "multiple," and noted the individual component stressors (see ESM 2). We classified timescale of stressors as acute, chronic, or mixed. We defined acute stressors as time-limited disturbances (e.g., flood) and defined chronic stressors as ongoing threatening conditions lacking a specific date or range of dates (e.g., weakening monsoon seasons)

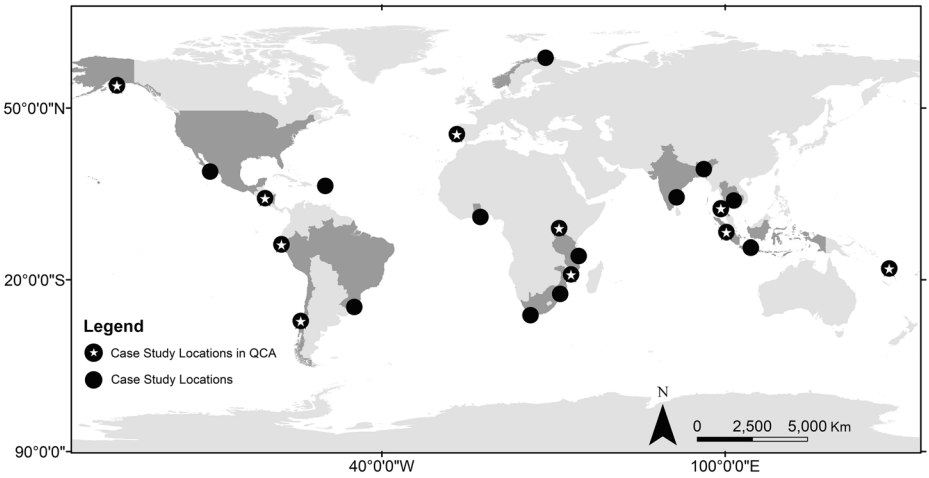

Fig. 2 Twenty-two case study locations (black circle) in meta-analysis from 20 countries (dark gray). Fourteen case studies were included in the qualitative comparative analysis (QCA) (black circle with white star)

(Lazarus 2006). "Mixed" stressors contained a combination of acute and chronic timescales. We recorded the impact(s) that each stressor had on communities and households (e.g., overfishing caused declining catch rates in a cod fishery).

2.3 How do communities and households respond?

We coded responses to single stressors (or multiple stressors) into three response categories coined the ARC response: Adapt (proactive planning and/or collective action), React (unplanned response, but some action was taken), and Cope (no action, a passive acceptance) (Table 1; Bennett et al. 2014; Oestreich et al. 2019). We considered the ARC response at two levels: community and household/individual (hereafter "household"). We assigned these levels according to the case study authors' description. Responses at the level of an individual or household were assigned to the household level (e.g., individual or household choice to buy a new type of fishing gear). Responses at levels of organization broader than a household were assigned to community (e.g., fishing associations that pursued aquaculture farming). We grouped one response from a private company as part of community responses and co-listed responses at both community and household levels if they were dually categorized in the case study. Four responses were co-listed at the community and national level; we excluded responses at the national level due to small sample size.

2.4 What adaptive capacity domains affect responses?

Building on the existing adaptive capacity literature, we coded for presence or absence of four broad categories of domains anticipated to influence adaptive capacity: Diversity and Flexibility, Access to Assets, Learning and Knowledge, and Governance and Institutions (Adger et al. 2003; Brooks et al. 2005; Allison et al. 2009; Bennett et al. 2014; Whitney et al. 2017; Table 1). Additionally, we added a fifth category—Natural Capital—stock(s) of natural resources generating ecosystem goods and services (Costanza et al. 1997). Access to Natural Capital has previously been considered a determinant of assets (Whitney et al. 2017). We considered it separately because many case studies identified Natural Capital as a unique domain, and it appeared to play an important role in responses. Each of the five domains was composed of specific determinants (Table 1). If any determinants were reported to be present, the parent domain was considered present. If none of the determinants were reported, we considered the parent domain absent. We recorded "not available" (N/A) for determinants/domains that were not described by the original authors to assure the coders did not infer associations that were not directly reported. Initially, we planned to code responses at the determinant level, but few case studies recorded determinant detail across all domains. Thus, we analyzed responses at an aggregated level. We also recorded whether the adaptive capacity domain amplified or dampened the response (Table 1). Specifically, if the presence or absence of a domain was described as enhancing the intensity of a response, (+1) was assigned to indicate an amplifying effect. If the presence or absence weakened the intensity of a response, (−1) was assigned to indicate dampening. For example, the absence of Learning and Knowledge dampened an Adapt response characterized by fishermen diversifying their fishery portfolio since lack of fishery-specific knowledge was a potential barrier to efficiency in new fisheries (Cline et al. 2017). In Badjeck et al. (2010), favorable government regulations (Governance and Institutions) amplified an Adapt response to obtain permission to establish sea scallop farms. No effect or N/A was recorded if the effect on response could not be determined from the case study review. In Fig. 3, we show a hypothetical example of a stressor, impact, and how adaptive capacity domains might influence an Adapt response for a community.

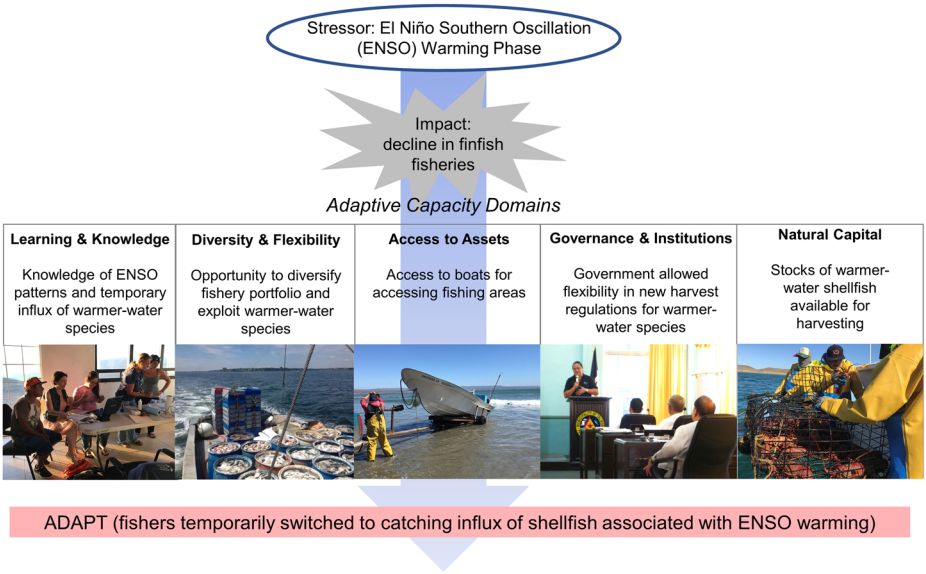

Fig. 3 Hypothetical stressor (El Niño Southern Oscillation warming), impact (decline in finfish fisheries), and influence adaptive capacity domains on an Adapt response

3 Analytical methods

To ensure consistency, coding for qualitative and quantitative analyses was performed by a subset of three co-authors (JU, SS, JN), hereafter referred to as the "coding team." The coding team coded case studies in two stages. First, two of the three coders independently reviewed and coded stressors, responses, and domains as described above using the standardized set of definitions from the recent literature (Table 1) in their coding efforts. Second, multiple coders reviewed each case study, allowing for a consensus interpretation to establish intercoder reliability (Campbell et al. 2013). After the initial round of coding, the pair of coders returned to their assigned studies and repeated this two-step process to code the domains and their effect on the response.

3.1 Qualitative thematic analysis

In addition to following the coding protocol outlined above, the coding team conducted thematic analysis, identifying, analyzing, and documenting reoccurring themes in the data (Braun and Clarke 2006) to describe case study data. They analyzed patterns in key takeaways of each study, quality and type of stressors, and the observed responses to stressors. These summaries were reviewed by the noncoding authors with original studies to cross-check the coding team's summaries for accuracy and agreement (ESM 1). These initial qualitative themes served to validate subsequent quantitative results and interpret the amplification and dampening effect of domains on responses.

3.2 Understanding combinations of domains with QCA

To identify combinations of domains that are associated with ARC response outcomes (Adapt, React, or Cope), we conducted a meta-analysis using QCA (Ragin and Rihoux 2009).

Combinations of conditions (in this study, domains) identified with QCA highlight relationships and can suggest possible levers for moving communities and households towards adaptive responses to future stressors. Using Boolean minimization algorithms, QCA undertakes a systematic matching and contrasting of cases to establish common causal relationships by eliminating all other possibilities (Ragin and Rihoux 2009). QCA systematically identifies combinations of contextual factors, termed "causal pathways," leading to a specific outcome. The QCA method assumes that (1) multiple pathways can lead to the same outcome (equifinality) and (2) some domains may have no effect on the outcome alone but may lead to an outcome in combination with other domains (conjectural causation).

Crisp-set QCA (csQCA), used here, assigns a binary membership to domains. We assigned the domains a binary value to indicate if it was present [1] or absent [0] or not described [N/A]. We conducted separate QCA for the different ARC response outcomes at the community and household levels. Since QCA requires complete cases, we restricted analyses to responses containing presence or absence information for all five domains. To ensure that we had a diversity of domains represented in each analysis, we did additional research on a limited number of case studies that were missing information on some domains. We contacted the original authors of the study and/or looked at other studies in the same region to complete missing domains. This increased our sample from 41 to 64% of the total case studies and from 6 to 12% of the total number of responses documented in our review (community-level $n = 13$ responses; household-level $n = 17$ responses). Cope responses were excluded from the QCA due to small sample size. Effect on response was interpreted as a subsequent step as we felt a qualitative interpretation would be more appropriate to our data. Furthermore, since QCA requires "complete cases," this would have limited our sample size unnecessarily.

QCA can be minimized in a variety of ways, and we used two criteria: complex (i.e., most conservative) and intermediate (i.e., less conservative). For the complex solution, only combinations of domains that have been observed are used in the minimization procedure. For the intermediate solution, logically possible combinations of domains are considered, including those that have not been observed (logical remainders). Causal combinations of domains (solutions) are expressed using Boolean notation, whereby upper-case letters represent presence (GOVERNANCE), lower-case letters represent absence (assets), (+) indicates a logical OR, and (*) indicates a logical AND. The QCA procedure reports measurements of the empirical importance of solutions, including raw coverage (proportion of cases with an outcome that fit that causal pathway; range: 0–1) and on unique coverage (proportion of cases only explained by that causal pathway; range: 0–1). We set the inclusion cutoff at 0.75 and graphed inclusion scores to confirm this was a logical break (Ragin and Rihoux 2009). QCA runs were conducted in the cs/QCA software 3.1 (Ragin and Davey 2014), and inclusion scores were graphed in R (R Core Team, 2019).

4 Results

From the 22 case studies, we documented 191 responses (Adapt, React, or Cope) to impacts from stressors. Of these, we obtained information on all domains from 13 case studies allowing us to document complete information for 30 responses. We present our results in two sections. Section 4.1 incorporates descriptive statistics and a qualitative theme analysis of all 191 responses. Section 4.2, describes the QCA results, focusing on the responses with complete information about domains.

4.1 Overview of case studies

Despite the complexity of impacts from climate and other stressors, we found recurring patterns among diverse communities and households in SSF. As expected, given our search terms, climate stressors and overexploitation due to fishing were common stressors for SSF, but we found the timescale (acute or chronic) for all stressors was similar. The most frequently reported impact was declines in fisheries catch, followed by impacts to farming and food production. Other impacts included loss of infrastructure, damage to fishing or farming equipment, reduction in fish markets, and storm impacts on tourism (ESM 2). Households adapted and reacted to stressors at similar rates (rarely coping), while communities were more likely to Adapt than React or Cope.

4.1.1 Characterizing stressors

The case studies documented a total of 55 stressors or combinations of stressors. We recorded thirteen instances where more than one stressor was implicated in the same responses (i.e., "multiple stressors"). Of the 55 stressors, 44% were acute, 40% were chronic, and 16% were a mixed acute and chronic.

Climate stressors dominated both acute (42%) and chronic (32%) stressors (see ESM 3). Overfishing was the second most common chronic stressor (27%), while biological (e.g., red tide) was the second most common acute stressor (25%; ESM 3). All biological stressors were classified as acute, and all social stressors were chronic, likely because biological stressors tended to be short term (e.g., red tide event) while social stressors were long term (e.g., chronic health issues). Economic and political categories of stressors were found in both chronic and acute timescales, but the environmental degradation category was only recorded as a "multiple" stressor (ESM 3).

4.1.2 How do communities and households respond?

The majority of the case studies provided examples of the ARC response focused on responses at the household level ($n = 130$; 68%), with fewer cases at the community level ($n = 61$; 32%). Six responses (3%) were co-listed as household and community. We found that responses at the household level were similar in their tendency to Adapt (44%) and React (48%); Cope responses (7%) were uncommon (see ESM 4). Case studies at the community level documented a higher percentage of Adapt responses (59%) compared to React (39%) and Cope (2%) responses (ESM 4). Since few case studies documented Cope responses (Table 2), we focus analyses and discussion on Adapt and React responses.

Acute stressors caused rapid impacts, quickly changing the nature of the fishing ecosystem (for example, repeated tsunami waves damaging fishery and port infrastructure; ESM 2). These types of stressors were more likely to result in an unplanned reactive response for households, but communities were able to Adapt more than React to both acute and chronic stressors (ESM 4). The majority of chronic stressors led to an Adapt response for communities but not for households (ESM 4). Both acute and chronic stressors were rarely associated with a Cope response. Because timescale was important to the nature of the response, mixed timescale stressors are not shown by response type.

4.1.3 Which adaptive capacity domains affect responses?

When considering if the influence (presence or absence) of a domain was amplifying or dampening, we hypothesized that the domains would have both types of effect on the

Table 2 Percentage of present or absent adaptive capacity domains and sample size (*n*) coded from the 22 case studies for the Adapt, React, Cope (ARC) responses for communities and households

Response	Domain	Diversity and Flexibility	Access to Assets	Learning and Knowledge	Governance and Institutions	Natural Capital
Community level						
Adapt % (*n*)	Present	95 (19)	94 (17)	90 (19)	88 (28)	80 (12)
	Absent	5 (1)	6 (1)	10 (2)	12 (4)	20 (3)
React % (*n*)	Present	79 (11)	88 (15)	67 (4)	89 (16)	83 (5)
	Absent	21 (3)	12 (2)	33 (2)	11 (2)	17 (1)
Cope % (*n*)	Present	100 (1)	100 (1)	100 (1)	100 (1)	0 (0)
	Absent	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Household level						
Adapt % (*n*)	Present	100 (50)	79 (27)	90 (28)	82 (19)	72 (23)
	Absent	0 (0)	21 (7)	10 (3)	18 (4)	28 (9)
React % (*n*)	Present	73 (38)	51 (20)	71 (10)	16 (4)	47 (17)
	Absent	27 (14)	49 (19)	29 (4)	84 (21)	53 (19)
Cope % (*n*)	Present	40 (4)	50 (4)	100 (3)	100 (5)	40 (2)
	Absent	60 (6)	50 (4)	0 (0)	0 (0)	60 (3)

Adaptive capacity domains that were not described in a case study (N/A) are not shown in the community level

responses. However, we found that domains nearly always amplified the responses (95% of all responses), and thus we do not report amplifying or dampening influence by domain due to small sample sizes for dampening effects.

Overall, the presence of individual domains was high when communities and households responded to change by adapting (community 80–95%; household 72–100% of responses; Table 2). Diversity and Flexibility was the most frequently reported individual domain. Access to Assets was notably important in Adapt responses at the community level, while comparatively less prevalent at the household level. React responses were characterized by the relative absence of domains, particularly at the household level. In examples where communities responded to change by reacting, the majority of domains were present (67–89%; Table 2). In contrast, households that responded to change by reacting had substantial variability in the combination of domains present, from Governance and Institutions (16%) to Diversity and Flexibility (73%; Table 2).

4.2 Understanding combinations of domains with QCA

Using QCA, we found domains could be combined in various ways to generate responses. We conceptualized these causal pathways for Adapt and React responses at the community and household levels (Fig. 4a, b). Below, we explain in detail each response pathway. Full QCA results can be found online (ESM 5). For all QCA runs, the complex and intermediate results were identical so only the complex results are presented below.

4.2.1 Pathways to adapting

From the subset of case study responses used in the QCA, 54% of communities and 35% of households had the capacity to respond to stressors with the agility and foresight that characterizes adaptive responses. In impacted communities that adapted to change, Access to Assets was a necessary domain, appearing in all three causal pathways (Fig. 4a). Access to Assets included material or financial assets but could also include access to decision-making

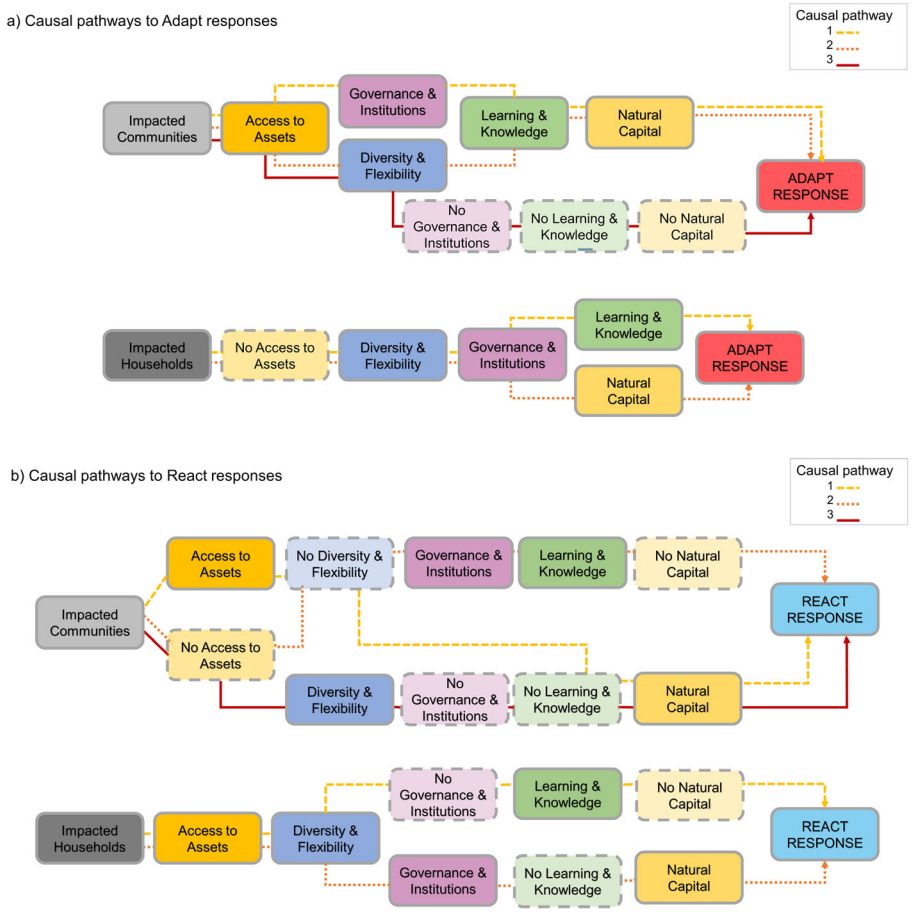

Fig. 4 Causal pathways to **a** Adapt and **b** React responses for communities and households impacted by stressors resulting from qualitative comparative analyses (QCA). Causal pathways depicted by yellow dashed line (1), red dotted line (2), and solid red line (3) include combinations of domains (Access to Assets, Diversity and Flexibility, Governance and Institutions, Learning and Knowledge, and Natural Capital). Domains are present (solid color/outline) or absent (transparent color/dashed outline)

authority, education, or technology (Table 1). Access to Assets independent of other domains, however, was insufficient for adaptation. In addition to Access to Assets, we observed that in adaptive communities, Governance and Institutions and Diversity and Flexibility could be substituted for one another as a necessary condition. The presence of one of these two domains led to adaptation when combined with the presence of both Learning and Knowledge and Natural Capital (Fig. 4a). To illustrate a set of causal pathways in which Diversity and Flexibility was substituted for Governance and Institutions, we look to Willroth et al. (2012) where a community in Thailand was affected by a tsunami that destroyed infrastructure. The community exhibited Diversity and Flexibility through realizing the opportunity for mitigation in replanting mangroves in conjunction with community holidays after the tsunami. This action was based on Learning and Knowledge from previous tsunamis and Natural Capital in the form of availability of mangroves and land to replant. Finally, they required Access to Assets through financial aid to implement the restoration.

Alternatively, adaptive communities that possessed both Access to Assets and Diversity and Flexibility were able to Adapt in situations where Governance and Institutions, Learning and Knowledge, and Natural Capital were all absent (Fig. 4a). This pathway was seen in a community in Nicaragua, where Diversity and Flexibility and Access to Assets (aid from the United Nations Environmental Program) were combined to enhance aquaculture in a lagoon (Benessaiah and Sengupta 2014). This was accomplished by using ecosystem-based management after multiple environmental and overfishing stressors caused a decrease in fisheries productivity. At the community level, 88% of adaptive responses were explained by these three causal pathways and there was high consistency (1.0) (ESM 5: Community complete solution), indicating that the causal pathway is almost always sufficient for the specific outcome (Ragin 2009).

Impacted households that adapted to change were notably different from communities. Households often lacked Access to Assets and benefited from the presence of both Diversity and Flexibility and Governance and Institutions (Fig. 4a). In the household causal pathways, Learning and Knowledge and Natural Capital could be substituted for one another, creating two equally sufficient pathways to adaptation. In Indonesia, fisher households facing income loss and declining fisheries in response to multiple environmental and fishing stressors adapted using causal pathways that included Learning and Knowledge (Perret and Yuerlita 2014). These households learned new skills, representing Learning and Knowledge, to diversify their income to include tourism and transport (Diversity and Flexibility). Their motivation to pursue nonfarming and fishing activities was in part due to the presence of Governance and Institutions. Governance and Institutions took the form of local clan land property laws that limited land ownership to wealthier, larger families. At the household level, 50% of adaptive responses were explained by these two causal pathways and high consistency (1.0) (ESM 5: Household complete solution). Notably, situations where adaptive households possessed Access to Assets existed but were not explained by the model.

4.2.2 Pathways to reacting

From the subset of cases studies used in the QCA, 38% of communities and 35% of households reacted to stressors in the absence of domains. In impacted communities that reacted to change, the three causal pathways were diverse and few domains were present in all pathways. The most common pathway for communities that Reacted to change included Access to Assets and Natural Capital but lacked both Diversity and Flexibility and Learning and Knowledge (Fig. 4b). This pathway occurred in a variety of countries and contexts, with most examples coming from communities that were impacted by climate or overfishing. For example, in Karadzic et al. (2014), Portuguese Fish Producer Organization leaders responded to environmental change and market fluctuations in fish price by enforcing daily landing limits, representing Access to Assets via their regulatory authority of fish (presence of Natural Capital). The other two causal pathways for communities under study that reacted to stressors both lacked Access to Assets but did not share any other patterns in the presence or absence of domains. Overall, at the community level, 80% of Reactive responses were explained by these three causal pathways (ESM 5: Community Complete Solution).

Impacted households that reacted to change had clear differences from those that adapted. In both causal pathways where households reacted, they possessed Access to Assets and Diversity and Flexibility but lacked other domains (Fig. 4b; ESM 5). In the causal pathways where households reacted, Learning and Knowledge, Natural Capital, and Governance and

Institutions were often substituted for each other. This pattern is illustrated in Badjeck et al. (2010) in the case of migratory Peruvian fishers exhibiting Diversity and Flexibility to fish a boom of high-value sea scallops caused by warming sea temperatures from El Niño Southern Oscillation. They were further enabled to migrate through Access to Assets (boats, fishing gear) and via information exchange about scallop fishing opportunities through social networks (Learning and Knowledge). At the household level, 80% of reactive responses were explained by these two causal pathways (Fig. 4b; ESM 5: Household complete solution).

5 Discussion

5.1 Overview

We present a novel meta-analysis to link observed responses to climate change, environmental change, and socio-political stressors within SSF communities and households. We found climate-related stressors in our review were the most frequent stressor to SSF. We also found that households adapted to chronic stressors more often than acute stressors. Adaptation was most commonly facilitated by Diversity and Flexibility at both the community and household levels, but based on the QCA results, Access to Assets was necessary for adaptation only at the community level. Compared to adaptive responses, fewer domains characterized the reactive responses in the descriptive analyses. QCA causal pathways to reactive responses were also typified by the absence of domains. This was especially true at the household level where the absence of Governance and Institutions and Natural Capital characterized over half of responses in the descriptive analyses. Below we summarize these themes, discuss them in the context of the case studies and the adaptive capacity literature, and highlight future directions for research and policy.

5.2 Adaptive capacity in SSF

Adaptation is generally seen as the preferred response to disasters and other perturbations, while reacting or coping are considered less desirable (Coulthard 2009; Bennett et al. 2014). In the ARC response review of case studies, we found an almost equal number of adapting and reacting responses, yet far fewer coping responses. Coping is considered to be a widespread response to climate change (Pahl-Wostl 2009; Bennett et al. 2014), indicating a potential disconnect between empirical data and the theoretical literature. The broader literature does not consistently distinguish or define coping from other responses within adaptive capacity (Wamsler and Brink 2014), which we also found in our case studies. In the natural disaster literature, coping is sometimes defined as the immediate reaction to the stressor or hazard while adaptation strategies can follow coping and lead to transformative change (Birkmann 2011). The definition we applied to our case studies (Bennett et al. 2014) was specific to SES and required an Adapt or React response to have a response *action* by a community or household, while Cope examples were based on *inaction* or the passive acceptance of the consequences of stressor. The low number of case studies where we documented coping according to our definition may emerge from a bias in the types of communities that are studied, imprecise or absent definitions for coping, or in the research methodology—identifying the absence of action may be less apparent or require longer observation periods in a community.

If adapting is indeed the desired strategy by SSF globally, community and household leaders as well as policy-makers need to understand how to move towards adaptive strategies. In our study, we found adaptation was more common in response to chronic stressors versus acute stressors. As stressors that were once acute and infrequent are now increasingly becoming chronic (e.g., marine heat waves), communities and households can mobilize resources in various combinations to increase their adaptive capacity.

5.3 Diversity and Flexibility enable adaptation

Successful adaptation can share similar underlying patterns despite profound differences in the environmental and social contexts where they occur (Nelson et al. 2016). At both the community and household levels, Diversity and Flexibility was an important component of Adapt responses regardless of geography or country development status. We documented many examples of chronic climate stressors in developing nations, whose resource-dependent fishers are considered among the most vulnerable and exposed to resource scarcity and environmental change (Adger et al. 2003). Yet, these fishers have successfully negotiated threats linked to climate variability in the past (Agrawal and Perrin 2001). Communities and households that have agency to pursue multiple pathways of adaptation (whether through informal or formal governance structures) are best poised to adapt to stressors. For example, the Diversity and Flexibility determinant of autonomous change allowed communities in Vanuatu to respond to a tropical cyclone that destroyed crops (Eriksson et al. 2017). The cyclone caused fishers to lose an important income and food supplement to their fishing. The community decided to temporarily open areas that community leaders had previously closed to fishing, allowing them to maintain food supplies while rebuilding their agricultural production. Fisheries portfolio diversification and occupational multiplicity have long been considered important livelihood strategies for resource-dependent coastal communities (Allison and Ellis 2001; Anderson et al. 2017) and these were prevalent in our meta-analyses, especially in the presence of Natural Capital (Coulthard 2008; Selgrath et al. 2018).

5.4 Assets critical for communities but not mandatory for households

Access to Assets is described in the theoretical literature as important for adaptive capacity (Whitney et al. 2017), but our findings demonstrate that this benefit is scale dependent. Access to Assets at the community level was a necessary domain for adaptive strategies, likely due to the size and quality of community responses. For example, determinants of Access to Assets like financial capital enabled communities of fishers to replace lost or damaged equipment following extreme weather events (Willroth et al. 2012; Forster et al. 2014). In other cases, financial capital enabled fishing communities to invest in the materials and infrastructure required to negotiate climatic and other interacting stressors (Joseph et al. 2013; Benessaiah and Sengupta 2014). These results mirror the broader literature, where small-scale fishers have been shown to take advantage of determinants of Access to Assets including technologies like global positioning systems, which are used to fish more accurately (Frawley et al. 2019b). However, care must be taken with the use of technology, which has the potential to work as a double-edged sword, driving inequality among fishermen with privileged access to these fisheries aids and potentially increasing overexploitation (Finkbeiner et al. 2017). Motorized boats are also an important asset used to travel to more lucrative fishing grounds in inclement weather (Thoya and Daw 2019).

When the scale of response is narrowed to the household level, the importance of Access to Assets in causal pathways diminishes, likely due to the differences in stressors affecting communities versus households. While crises that cause large-scale impacts immediately draw attention and national or international financial support, many chronic stressors impact households at a smaller scale that may pass unnoticed and therefore reduce availability of assets. Small-scale fishers are often considered among the most asset-poor and marginalized populations (Béné et al. 2010). Even when programs are designed to offer financial support to SSF, often the benefits are accrued by local elites and/or administrative agencies before they can be accessed by harvesters (Choudhury et al. 2018). The impoverished state of SSF is especially true in the predominately developing nations in our case studies. We hypothesize that to adapt to these long-term stressors, households rely on nonasset domains already embedded into social structures, i.e., Diversity and Flexibility and/or Governance and Institutions, combined with either Natural Capital or Learning and Knowledge. In our analyses, we documented adaptive examples where household members relied on learning new skills to start small businesses that were not highly asset dependent (Blythe et al. 2014; Perret and Yuerlita 2014). Household fishers in Alaska adapted to an oceanographic regime shift that caused market and fishery instability by diversifying their fishery portfolio through the help of permit pooling or permit lease programs (Cline et al. 2017). Instead of relying on assets, they used the regulatory determinant of Governance and Institutions.

In our household Adapt analysis, the absence of Access to Assets was necessary yet Access to Assets was present in all causal pathways for reactive households. Relatively asset-rich households may have more opportunities for short-term reactive choices (selling or trading excess livestock for money or fishing gear) or having fishing boats large enough to quickly transition between a nearshore and offshore fishery. By using available assets to maintain their livelihoods and/or associated socioeconomic status, Access to Assets in wealthier households could delay adaptive responses. For example, Thailand business owners heavily invested in the tourism industry reacted to tsunami damage by continuing to invest in the same mass-tourism business strategy rather than alternative options that might attenuate future risk (Willroth et al. 2012). Households could be more likely to react in the presence of Access to Assets than communities where social norms in consensus-based decision making and organizational time needed to distribute assets by Governance and Institution efforts facilitate adaptive response (Cinner et al. 2018). Furthermore, households with increased Access to Assets may have less flexibility for changing livelihoods, as in the examples of asset-rich fishers who reacted to declining fish stocks by increasing fishing effort (Blythe et al. 2014).

5.5 Investing in social capital and local knowledge for adaptive capacity

Social capital (a determinant of Governance and Institutions) and local knowledge (a determinant of Learning and Knowledge) were often combined in Adapt responses at both community and household levels. The shared experience of hardship and resource scarcity from stressors promote social capital, or "trust, reciprocity, and exchange; the evolution of common rules; and the role of networks" (Adger 2010). In turn, this facilitates the transfer of local knowledge, the acquisition of new skills, and the development of alternative livelihoods (Willroth et al. 2012; Joseph et al. 2013). These were important domains for both communities and households to collaborate in developing adaptive solutions. For example, Ugandan villagers organized to establish a co-fisheries management committee after a drought that impacted lake fisheries (Goulden et al. 2013). These collaborative and adaptive management

solutions may be amplified by investing in Learning and Knowledge, specifically local, diverse, ecological knowledge that can be used to evaluate risk from past experiences. Fazey et al. (2007) describe several types of knowledge necessary for adaptive capacity, including knowledge about current problems and the direction of change needed to address the problem, combined with proactive behavior. Eriksson et al. (2017) describe examples of proactive behavior and intentional change in Vanuatu, where a tropical cyclone damaged crops and caused an increased reliance on marine resources for food. The community organized to develop a fishery for scad (*Carangidae*), including learning new techniques to catch this previously unexploited species.

5.6 Critiques, caveats, and challenges

Meta-analysis is a means of synthesizing knowledge in a research field; however, caution must be taken in generalizing details and simplifying interactions between variables. Fitting the data to our structured and linear framework required simplification. Furthermore, our results may have biases from data that authors did not report in the study, and our relatively small sample size (22 studies) may amplify some biases. Future clarification of terminology and definitions will allow for further synthesis of future case studies (Gallopín 2006; Siders 2019).

Comparative work requires specificity in terminology to accurately measure outcomes or concepts. Siders (2019), in a review of the adaptive capacity field, has noted that a major goal should be to "develop standard indicators or a comparison of different indicators to enable cross-study comparisons of future works." In line with her conclusion, we found inconsistency of frameworks, terminology, and definitions across case studies. Not all papers used the Adapt, React, Cope terminology and many papers did not address the full suite of domains. These nuances required careful review, and our classification of case studies was limited by our ability to connect published descriptions to the framework we engaged.

Further studies on adaptive capacity would benefit from recording multiple types of climatic and nonclimatic stressors (Freduah et al. 2019). We purposefully documented the presence of multiple stressors, but found these had complicated community and household responses that were difficult to disentangle through coding. However, these combined stressors can create larger impacts and may become more common as climate change accelerates. Understanding the multi-dimensional impacts of overlapping stressors is important for developing multi-faceted solutions. Furthermore, although quantifying biological and physical stressors that are specifically related to anthropogenic climate warming versus stressors that are within the natural variability of a system was outside the scope of our case study review, we believe that this is an important area that could be used to identify adaptive capacity determinants specific to climate change. Finally, we found the literature tended to report negative examples of stressors and impacts, which is a potential bias we could not control for.

5.7 Future research

We also highlight areas for future research in adaptive capacity domains and determinants. Of the broad adaptive capacity categories, we coded for, Natural Capital and Learning and Knowledge were not given due consideration in the literature we surveyed despite their importance for adaptive capacity in cases where they were described and should be considered in future studies documenting adaptive capacity domains and determinants. Our meta-analysis also showed that equitable adaptation with respect to gender, a determinant of Governance and

Institutions was not widely documented despite women fishers' significant global contribution to fisheries (Harper et al. 2020). Environmental and/or climate stressors—as experienced by SSF in this study—have been shown to be a key depressor of women's agency (Rao et al. 2019). Thus, fostering equitable adaptation with respect to all participating fishers is a concern for programs aiming to support communities experiencing climate impacts. Women are often excluded from research on fishing communities yet critical to food security (Kleiber et al. 2015). Over half of our case studies mentioned gender, yet less than a quarter of case studies explicitly included gender as a dimension of response to stress. Given that women represent key linkages between fisheries and food security, it will be important to explicitly consider how women are influenced by—and respond to—climate change and other stressors.

Finally, all of the domains that we documented consisted of detailed determinants based on the literature. We only coded for the broader categories of domains given our meta-analysis structure; however, additional research/standardization of these determinants would allow for more detailed cross-study comparisons in the future. Siders (2019) review of determinants, definitions, and example indicators derived from the adaptive capacity literature can be used to aid standardization in adaptive capacity research, although authors will have to select specific determinants and indicators that are relevant within their geographic and cultural contexts.

5.8 Considerations for policy-makers, community, and household leaders

The generality of our framework allows broad application to global SSF and other natural resource-based fields, however, we recognize that the practical application of the ARC response at local and regional scales also requires specificity. To aid decision-makers in moving towards adaptation, we reflect on specific determinants that may be influential at the community and household level.

At the community level, investing in access to infrastructure and access to credit/aid were reoccurring determinants that helped communities Adapt, particularly to acute perturbations. However, prior experience is often needed to procure these assets proactively. We believe that combining the risk perception and learning capacity determinants of Learning and Knowledge in combination with these assets is critical. Specifically, the sharing of adaptive behaviors from other SSF that have experienced similar stressors will facilitate the transfer of knowledge about what, when, and how to invest in proactive infrastructure or funding sources. This information could be shared though scenario-planning workshops facilitated by NGOs and local government to set the stage for adaptation planning, which is also a component of the "room for autonomous change," determinant of Diversity and Flexibility.

At the household level, focusing on strengthening collaborations between and among households and individuals through social capital, a determinant of Governance and Institution may strengthen adaptation to stressors. Strong social networks can be supported in a variety of ways, for example, membership in fisher's groups can provide services including advocacy for fisher's rights and access to information. These fisher's groups can also be used to empower women fishers (determinant of Governance and Institutions) through required quotas in membership and leadership that reflect the SSF regional participation of women fishers and facilitate their involvement in strategic decisions in response to stressors. Focusing on these specific determinants can also bring the variety of experiences and perspectives needed to foster Diversity and Flexibility determinants that is increasing capacity of individuals to self-organize, innovate, and diversify livelihoods.

6 Conclusion

Ongoing empirical evaluations of adaptive capacity are important to understand how theoretical measures of adaptive capacity translate into the actual responses of households and communities (Whitney et al. 2017). While biophysical scientists have made significant progress in forecasting the future impacts of climate change using models, projections, and other top-down approaches, there is a need for bottom-up approaches focused on how individuals, households, and communities are responding to recent climate events and conditions (Conway et al. 2019; Frawley et al. 2019b). Furthermore, we urge authors to consider standardized metrics of adaptive capacity in future research efforts so communities worldwide can add to their understanding of domains and determinants that influence adaptive capacity. Although our case studies focus on SSF, we believe this approach could be applicable in other settings where natural resource use, e.g., forestry and agrarian-based communities where fostering adaptive capacity may limit negative impacts from climate and nonclimatic stressors on livelihoods.

The results of our meta-analysis deviate from previous research to analyze empirical data relating to adaptive capacity. Although we found strengthening Diversity and Flexibility at both the community and household level and Access to Assets at the community level can most help translate adaptive capacity to adaptive responses, the importance of linkages between adaptive capacity domains is also critical. When communities and households can combine domains to best fit the stressor, impact, and local culture, this can facilitate adapting and prevent reacting or coping. If adaptive capacity is generated through a combination of resource availability and willingness to translate resources into adaptive actions then successful examples from adaptive responses in communities and households that have already faced stressors can provide guidance and vision for paths forward.

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