Received: 7 July 2021 | Revised: 21 October 2021 | Accepted: 27 October 2021

DOI: 10.1111/faf.12630

FISH and FISHERIES WILEY

ORIGINAL ARTICLE

Attributes of climate resilience in fisheries: From theory to practice

Julia G. Mason[1,2] | Jacob G. Eurich[3,4] | Jacqueline D. Lau[5,6] | Willow Battista[1] | Christopher M. Free[4,7] | Katherine E. Mills[8] | Kanae Tokunaga[8] | Lily Z. Zhao[9] | Mark Dickey-Collas[10,11] | Mireia Valle[3,12] | Gretta T. Pecl[13,14] | Joshua E. Cinner[5] | Tim R. McClanahan[15] | Edward H. Allison[6] | Whitney R. Friedman[3,16] | Claudio Silva[17,18] | Eleuterio Yáñez[17] | María Á. Barbieri[17] | Kristin M. Kleisner[1]

[1]Environmental Defense Fund, Boston, Massachusetts, USA
[2]Cornell Atkinson Center for Sustainability, Ithaca, New York, USA
[3]National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, Santa Barbara, California, USA
[4]Marine Science Institute, University of California, Santa Barbara, Santa Barbara, California, USA
[5]ARC Centre of Excellence in Coral Reef Studies, James Cook University, Townsville, Queensland, Australia
[6]WorldFish, Penang, Malaysia
[7]Bren School of Environmental Science and Management, University of California, Santa Barbara, Santa Barbara, California, USA
[8]Gulf of Maine Research Institute, Portland, Maine, USA
[9]Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, Santa Barbara, California, USA
[10]International Council for the Exploration of the Sea (ICES), Copenhagen, Denmark
[11]National Institute for Aquatic Resources, Technical University of Denmark (DTU-Aqua), Lyngby, Denmark
[12]AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Sukarrieta, Spain
[13]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia
[14]Centre for Marine Socioecology, University of Tasmania, Hobart, Tasmania, Australia
[15]Wildlife Conservation Society, Global Marine Programs, Bronx, New York, USA
[16]The Nature Conservancy, Arlington, Virginia, USA
[17]Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile
[18]Centro de Investigación Océano Sustentable, Limache, Chile

Co-first authorship
Julia G. Mason, Jacob G. Eurich and Jacqueline D. Lau contributed equally

Correspondence
Jacob G. Eurich, National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, Santa Barbara, California, USA.
Email: jacobeurich@ucsb.edu

Abstract

In a changing climate, there is an imperative to build coupled social-ecological systems—including fisheries—that can withstand or adapt to climate stressors. Although resilience theory identifies system attributes that supposedly confer resilience, these attributes have rarely been clearly defined, mechanistically explained, nor tested and applied to inform fisheries governance. Here, we develop and apply a comprehensive resilience framework to examine fishery systems across (a) ecological, (b) socio-economic and (c) governance dimensions using five resilience domains: assets, flexibility, organization, learning and agency. We distil and define 38 attributes that confer climate resilience from a coupled literature- and expert-driven approach, describe how they apply to fisheries and provide illustrative examples of resilience attributes in action. Our synthesis highlights that the directionality and mechanism of these attributes depend on the specific context, capacities, and scale of the focal fishery system and associated stressors, and we find evidence of interdependencies among attributes. Overall, however, we find few studies that test resilience attributes in fisheries across all parts of the system, with most examples focussing on the ecological dimension. As such, meaningful quantification of the attributes' contributions to resilience remains a challenge. Our synthesis and holistic framework represent a starting point for critical application of resilience concepts to fisheries social-ecological systems.

KEYWORDS

adaptive capacity, coastal communities, fisheries management, global change, social-ecological systems, synthesis science

1 | INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has documented an "extraordinary array of observed changes" across ocean ecosystems and declared that it is "virtually certain" that the ocean will continue to respond to climate change with profound and pervasive changes on regional and global scales (Bindoff et al., 2019). There is high confidence that rising sea levels, acidification, loss of coastal habitats to inundation, and accelerating shifts in species distribution and productivity will significantly affect marine ecosystem services (Malhi et al., 2020; Mooney et al., 2009). This includes food provisioning (both from wild fisheries and aquaculture), oxygen provisioning, carbon mitigation, buffering against extreme weather events and the continued ability to deliver aesthetic, cultural and supporting services. Decreases in these and other ecosystem services will create social vulnerabilities in terms of lost livelihood and income opportunities (Badjeck et al., 2010; Stanford et al., 2017), conflicts over access to resources (Mendenhall et al., 2020) and decreased food and nutrition security (Golden, Koehn, et al., 2021). Climate change will also challenge both the governance and institutional frameworks used to manage fisheries (Barange et al., 2018; Ojea et al., 2017) and broader societal goals related to fisheries such as the United Nations Sustainable Development Goals of poverty reduction, food security and ocean health (Singh et al., 2019). Achieving these goals within the context of climate change will require building the capacity to prepare for, resist, cope with, recover from or adapt to a given stressor—that is, building *resilience*—to ensure the sustainability of marine ecosystems, fishery resources and human benefits.

However, the extent to which resilience can be operationalized in fisheries as complex coupled social-ecological systems remains a key question. Three key knowledge gaps hinder operationalizing resilience in fisheries. First, much of the existing research on bolstering resilience and adaptive capacity remains evaluative or theoretical. Numerous studies have hypothesized features or attributes of social-ecological systems that confer resilience (see Biggs et al., 2012). Several scholars have highlighted the need for further empirical exploration of linkages and feedbacks that determine when and how attributes act individually or create synergies and trade-offs in fisheries systems (Cinner et al., 2018; Ojea et al., 2017). Second, much of the available theoretical work (e.g. Barrett & Constas, 2014; Berkes et al., 2000; Biggs et al., 2012) is not specific to fisheries. Fisheries often have distinct property and access rights, political economies (Campling et al., 2012), legal regulatory systems (Ojea et al., 2017) and levels of exposure and sensitivity to different climate change impacts compared to other types of social-ecological systems, such as agriculture (IPCC, 2018). As such, many fisheries-specific aspects of social-ecological resilience have yet to be identified. Third, most existing studies of fisheries resilience have focussed on discrete parts of fisheries systems—such as particular species' ability to adapt or a coastal community's response to a particular stressor (e.g. Baudron et al., 2020; Dahlke et al., 2020)—rather than evaluating fisheries as integrated social-ecological systems. Lack of integrated assessments may hinder understanding of the feedbacks and linkages across the ecological, socio-economic and governance dimensions of fishery systems, which may in turn lead to ineffective interventions (Berkes et al., 2000; Levin et al., 2013).

To address these gaps, we synthesize attributes of climate resilient fisheries across (a) ecological, (b) socio-economic and (c) governance dimensions. We draw from literature and expert knowledge to distil and define both holistic resilience attributes and important cross-cutting contextual considerations that should be accounted for when trying to operationalize resilience. Within the three system dimensions, we further organize these attributes within five resilience domains, building on a conceptual model that comprehensively describes and links these domains (Cinner & Barnes, 2019; Cinner et al., 2018). To improve our understanding of how resilience is operationalized in fisheries, we form literature-based hypotheses of mechanisms, that is, how these attributes confer climate resilience in fisheries. Where possible, we illustrate these mechanisms with fisheries-relevant examples from the literature. Articulating these mechanisms allows us to explore linkages between attributes within and across the system dimensions that may be key for managing them in practice. We discuss several types of linkages and what they mean for climate resilience. Finally, we discuss opportunities for future empirical work to advance climate resilient fisheries from theory to practice.

2 | THEORETICAL AND CONCEPTUAL BACKGROUND

2.1 | Resilience and fisheries

Resilience theory has been incorporated in a broad range of contexts and academic disciplines, with an equally broad set of definitions and interpretations. In ecology, resilience is defined as the ability of an ecosystem or species to resist and recover from a disturbance (Holling, 1973). In social systems, the concept of resilience encompasses the ability of people, communities and institutions to cope with, reorganize and renew themselves in the face of change (Barrett & Constas, 2014; Gallopin, 2006; Grafton, 2010; Marshall & Marshall, 2007). The IPCC joins these concepts and defines resilience as a "system's capacity to anticipate and reduce, cope with, and respond to and recover from external disruptions," often employing a social-ecological systems framing (O'Brien et al., 2012, ch. 8). Thus, the resilience of social-ecological systems encompasses both the environment's ability to resist, recover and adapt to a disturbance as well as the ability of individuals and institutions to prepare for, cope with and adapt to such changes. Further, resilience theory emphasizes the bidirectional feedbacks between human and natural systems, which create trade-offs and synergies both among system components and across temporal and spatial scales (Walker & Salt, 2006). Thus, a resilience approach requires careful consideration of resilience of what, resilience to what, and resilience for whom (Carpenter et al., 2001).

In the face of mounting climate change impacts, institutions across sectors are increasingly seeking to "manage for resilience" (Camp et al., 2020). This provides a guiding principle for disaster risk reduction and climate adaptation planning in many sectors, such as city planning and agriculture. Recent work to conceptualize resilience for fisheries—for example resilience-based management of coral reefs (Mcleod et al., 2019), fisheries management regimes (Ojea et al., 2017) and more broadly for coastal communities associated with fisheries (Cinner et al., 2018; Whitney et al., 2017), is useful. However, broader conceptualization of resilience is still in the early stages.

Defining the bounds of the fishery social-ecological system is a key first step towards operationalizing resilience. These bounds could depend on the scale of the fisheries management system currently in place or the scale at which relevant attributes are distinct from other jurisdictions, communities or habitats (Anderson et al., 2015). The resilience attributes we describe can be applied across all contexts—including single- or multi-species fisheries—such that a practitioner may define their fishery system as the largest unit of fishery and fishery-associated social and ecological processes by which they consider resilience to be manageable.

2.2 | A heuristic for examining climate resilience attributes in fisheries

Within the ecological, socio-economic and governance dimensions of fisheries systems, we further categorize resilience attributes into five key domains of resilience: (a) assets, (b) flexibility, (c) organization, (d) learning and (e) agency (Cinner et al., 2018; Cinner & Barnes, 2019). We expand this domain framework, which was originally developed for social resilience, to serve as a general heuristic to organize key attributes of resilience in fishery systems.

Here, we provide a broad overview of each domain, building on the above framework. *Assets* are resources that can be drawn upon to buffer impacts or respond to change. Access to financial or technological resources are important social assets (Cinner & Barnes, 2019), while healthy fish stocks and diverse habitats represent important ecological assets. Resilience may be influenced by the amount, diversity and stability of assets across a given system. *Flexibility* is defined as the ability to switch strategies or make other adjustments in the face of change. Flexibility is enhanced by greater diversity of options, capacity and opportunities to use those options, and redundancy to compensate for declines or losses in each dimension of the system. *Organization* refers to the social and ecological relationships, networks and institutions that operate at different spatial and temporal scales to confer resilience. Thus, in addition to social capital (the connections among people and groups), organization encompasses connectivity of ecosystem components and functions, which supports mobility, dispersal and flow of fish populations. Both learning and agency concern only the socio-economic and governance dimensions of a fishery for the attributes we describe here. *Learning* is the process by which people and institutions recognize and identify factors contributing to change and analyse possible responses. Finally, *agency* is the capacity and freedom of people to make and act on choices and underpins people's ability to operationalize different aspects of resilience.

In keeping with Cinner et al. (2018), domains intersect and reinforce one another. For example, having more assets, agency or learning capacity can provide more flexibility to withstand or adapt to change. In addition, some attributes may contribute to multiple domains. The definitions within each domain are broad enough for individuals to tailor the use of this typology to the contexts of their particular fishery system, such that each application requires the consideration of the resilience of what, to what and for whom.

3 | METHODS

We used an iterative process of literature review and expert knowledge to generate, refine, define and exemplify attributes of resilience in fisheries systems. This work grew from a Science for Nature and People Partnership expert working group on Climate Resilient Fisheries, which convened 23 fisheries scientists and practitioners from seven countries with applied expertise in fisheries ecology, livelihoods, human geography and other disciplines for a five-day workshop in February 2020. Working group members engaged in an iterative discussion process to generate attributes of fisheries resilience across ecological, socio-economic and governance dimensions.

Following the workshop, we conducted a literature review of resilience attributes to refine and expand the expert-driven set of attributes. We considered recent (i.e. within the last decade) review papers that clearly articulated lists of system-level resilience attributes (e.g. in a table; attributes explicitly named rather than inferred). We identified six review papers that met these criteria and provided coverage across ecological, socio-economic and governance dimensions. The papers came from diverse disciplines including fisheries (Ojea et al., 2017), coastal social-ecological systems (Whitney et al., 2017), general social-ecological systems (González-Quintero & Avila-Foucat, 2019; Kerner & Thomas, 2014), development (Bahadur et al., 2013) and urban resilience (Tyler & Moench, 2012). We extracted and compiled the attributes of resilience identified in these papers.

We combined the expert- and literature-generated attributes and concepts, eliminated clear duplicates and removed attributes not relevant to fisheries. A small group (JL, KK, JM) thematically coded, grouped and renamed similar attributes, which were iteratively reviewed by additional authors (JE, CF, KM, KT, MV, LZ). Where governance attributes overlapped with the United Nations' (UN) eight principles of good governance (Sheng, 2009), we adopted the UN terminology for simplicity. Through this process, we generated a list of 38 attributes thought to confer resilience in fisheries systems (Figure 1; Tables 1–3). We framed these attributes in terms of resilience to climate change, but recognize that they could also be relevant to general or specific resilience to other stressors. We also determined that an additional six concepts identified through this process do not directly affect resilience but should be acknowledged and understood for developing management approaches. We termed these "contextual considerations" and discuss them separately (Figure 1).

For each attribute, we sought a clear definition, identified the mechanism for conferring resilience and provided evidence of its operation in a fisheries context (Tables 1–3). Except where noted otherwise, we selected examples that demonstrate enhanced resilience associated with the presence of an attribute, rather than loss of resilience due to the lack of an attribute. These definitions, mechanisms and examples were iteratively peer-reviewed by the author team, additional working group members, and external experts to ensure clarity, agreement and relevance to diverse fishery systems. Finally, attributes were organized based on the nested heuristics described above (Figure 1; Tables 1–3). See the Supplementary Information for a more detailed description of the resilience attribute workflow, comprehensive definitions, mechanisms, examples of resilience attributes and the list of participants.

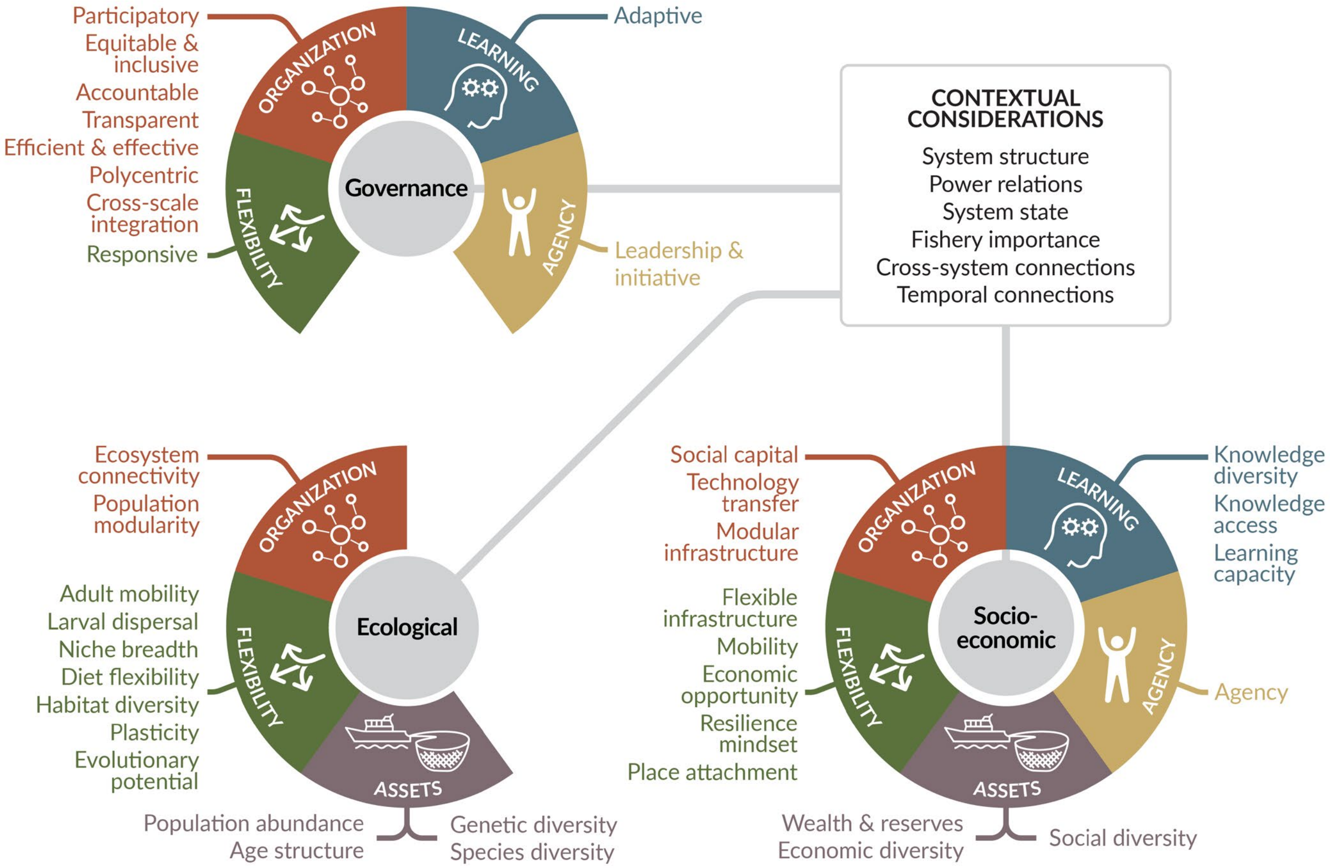

FIGURE 1 Thirty-eight literature- and expert-generated attributes of climate resilience across ecological, socio-economic and governance dimensions of fisheries, categorized across five resilience domains. Six additional contextual considerations do not directly affect resilience but should be acknowledged and understood for developing management approaches. Note that attributes may contribute to multiple domains, and domains may reinforce and intersect with one another. This figure is intended as an overarching heuristic to provide ease of comprehension. Attribute titles have been shortened for clarity

4 | RESULTS

4.1 | Overview

We identified 13 ecological, 15 socio-economic and 10 governance attributes thought to confer resilience in fisheries systems (Figure 1; Tables 1–3). Of these, only one social attribute (technology transfer) came directly from the working group discussion exercise; other expert-generated attributes were incorporated into broader attributes from the literature or characterized as contextual considerations. In the following sections, we provide an overview of how the attributes function and interact in each dimension to contribute to resilience. We group them within domains and highlight instructive fisheries examples, where applicable. We illustrate how these attributes collectively characterize resilience in two fisheries case studies in Box 1. In the final section, we discuss the contextual considerations.

4.2 | Ecological attributes

We framed the ecological attributes that influence resilience of natural populations and communities (i.e. non-human) within three domains: assets, flexibility and organization. Ecological assets operate at the population scale and encompass attributes relating to population abundance and structure. Ecological flexibility can operate at individual, population or community scales and includes attributes relating to capacity for spatial, behavioural and evolutionary adaptation. Ecological organization can operate at population or community scales and encompasses attributes relating to spatial structure and connectivity. For simplicity, we outlined most definitions and mechanisms at the population level and for a single-species fishery (but see species diversity). When applied to a multi-species fishery, the attributes confer resilience of a community of species rather than a single population.

TABLE 1 **Ecological attributes** that confer resilience to climate change in fisheries, including definition and proposed mechanisms. See the Supplementary Information for table references

Domain	Attribute	Definition	Mechanism
Assets	*Population abundance*	The abundance or biomass of a species present in a defined geographical range.	Large or stable population sizes confer resilience to climate change by avoiding Allee effects, buffering against variability, promoting genetic diversity and intact age structures, and increasing the chance of persistence during poor environmental regimes (Caughley, 1994; Hamilton, 1967).
	Age structure	The age distribution of individuals within a population.	An intact and well-distributed age structure (e.g. high numbers of large-bodied and fecund females) confers resilience to climate change by increasing the reproductive capacity of a population and its ability to recover from a disturbance event and/or environmental variability (Barneche et al., 2018; Hixon et al., 2014).
	Genetic diversity	The diversity or variability of genetic traits within a population.	Genetic diversity enhances the potential for adaptation and confers resilience to climate change by increasing the adaptive capacity of a species, thereby providing an expanded suite of functional responses that can offer mechanisms for plasticity or evolution (Jørgensen et al., 2007; Pinsky & Palumbi, 2014).
	Species diversity	The diversity of species within a community.	The targeted species in both single- and multi-species fisheries are members of a broader community of species. The diversity of species within this community confers resilience to climate change through portfolio effects that buffer both fisher livelihoods and ecosystem functioning against variability (Schindler et al., 2010; Sethi et al., 2014).
Flexibility			
Spatial flexibility	*Adult mobility*	The mobility of a population's mature adults.	Adult mobility (i.e. movement or migration capacity), described in terms of swimming ability, average swimming speed, and/or home range size, promotes range extensions and confers resilience to climate change by increasing the capacity for a species to relocate and track shifting environmental niches (Brooker et al., 2007).
	Larval dispersal	The degree to which eggs or larvae spread from a spawning site to a settlement location (benthic species) or until yolk sac re-adsorption (pelagic species).	Egg and larval dispersal, typically via passive transport as plankton carried by ocean currents (Pecl et al., 2014), influence the diversity of habitat conditions that an individual may encounter, thereby influencing survival probabilities. Wide dispersal is associated with a greater ability to colonize new habitats, thereby diversifying survival opportunities at the population level by increasing chances that individuals find suitable habitats (Hare et al., 2016).
	Environmental niche breadth	The degree and extent to which a species can tolerate or acclimate to changes in environmental conditions.	The existence, abundance and distribution of a species is largely determined by whether the levels of one or more abiotic or biotic factors fall within the range of tolerance for that species (MacNally, 1995). Tolerance of environmental stress, such as changes in sea surface temperature, confers resilience as a species cannot functionally survive outside of its optimal range without the capacity and/or time to acclimate or build a response.
Behavioural flexibility	*Dietary flexibility*	The range of prey items that a population can exploit or the diversity of feeding strategies available.	A species with high dietary flexibility is resilient because it can exploit a larger range of resources over time and can opportunistically adapt to fluctuating prey availability (MacNally, 1995). Conversely, specialized species with narrow dietary niches, despite typically displaying specialized prey-capture adaptations and effective competitive and/or feeding strategies, have low resilience if a change in prey abundance or competitive exclusion occurs.
	Habitat diversity	The range of suitable, adjacent and available habitats that a population can exploit.	A population that utilizes a range of diverse habitats, which includes variety, balance, and/or disparity among elements (i.e. a generalist species; MacNally, 1995), is more resilient to climate change by allowing the population to move or adapt if a habitat is altered or lost.

TABLE 1 (Continued)

Domain	Attribute	Definition	Mechanism
Evolutionary flexibility	*Plasticity*	The capacity for one genotype to yield more than one phenotype in response to environmental cues.	Phenotypic plasticity enables short-term biological responses that enable organisms to acclimate to new or changing environmental conditions through changes in their morphology, physiology, development or behaviour (Pigliucci et al., 2006). These responses can confer resilience to species within a certain range of tolerance, beyond which longer-term adaptive responses become necessary (Whitney et al., 2017).
	Evolutionary potential	The capacity of a population to evolve in response to environmental change.	Small populations often are subject to genetic drift and demographic stochasticity due to high levels of inbreeding and low levels of genetic variation (Willi et al., 2006). Preserving genetic variation by maintaining a large population size confers evolutionary resilience to climate change if environmental favourability approaches the extremes (Sgrò et al., 2011).
Organization	*Connectivity of ecosystem functions and components*	The degree to which an ecosystem facilitates the structural and physical connection among suitable, adjacent, and/or available ecosystem functions and components.	A functional network of connected and unfragmented ecosystem components, which provide greater opportunities for movement, migration and changes in distribution, are essential to the resilience of a population if the loss of an ecosystem component due to climate associated impacts or an ecosystem shock occurs. Strong connectivity supports ecosystem function and the movement or regeneration of nutrients, energy and organisms (Kinlan & Gaines, 2003).
	Modularity of populations	Modularity, the opposite of connectivity, refers to the compartmentalization of populations in space and time.	When populations are separated in space, disturbances to some will not impact all, and unaffected populations may provide important regional sources of larvae and other materials for recovery (Levin & Lubchenco, 2008). Networks in which the components differ and where incomplete connectivity causes modularity tend to have adaptive capacity in that they adjust gradually to change (Scheffer et al., 2012).

4.2.1 | Assets

A resilient system has multiple ways of meeting a given need through diverse natural *assets* so that not all components are affected by a given event at any one time (Tyler & Moench, 2012). Ecological assets that can act as a buffer or reserve against perturbations include (a) population abundance, (b) age structure, (c) genetic diversity of the exploited resource and (d) species diversity of the community or ecosystem. In a fisheries context, for example, "big old fat fecund female fish" disproportionately contribute to reproductive capacity in some populations. They spawn better-provisioned eggs earlier, more frequently, and in different locations than smaller females, which ensures reproductive success in variable environments or conditions (Barneche et al., 2018; Hixon et al., 2014). Thus, in fisheries that exploit these populations, management strategies that conserve age structure—whether by limiting exploitation rates (e.g. U.S. Mid-Atlantic striped bass *Morone saxatilis*, Moronidae; Secor, 2000) or implementing size limits (e.g. recreational northern pike *Esox lucius*, Esocidae fishery in Germany; Arlinghaus et al., 2010)—increase population abundance, genetic diversity and fishery resilience (Berkeley et al., 2004). However, even if population abundance, structure and diversity are reduced, species diversity in the adjacent ecosystem can buffer against variability through portfolio effects, where a decline in one species is balanced by the increase of another to help stabilize ecosystem functions and benefits (Schindler et al., 2010).

4.2.2 | Flexibility

Ecological *flexibility* is the ability of a population to enhance the probability of survival by shifting locations, adjusting behaviours or genetically adapting to changing environmental conditions (Isaac & Cowlishaw, 2004). We identified seven attributes that promote resilience to climate change through spatial, behavioural or evolutionary flexibility.

Spatial flexibility: In response to changing environmental conditions, a resilient species can either adapt in place, facilitated by a (a) broad environmental niche or track preferred conditions through (b) adult movement (e.g. climate-driven range expansion and spatial distribution shifts; Brooker et al., 2007; Sunday et al., 2015) and (c) larval dispersal when local conditions are unfavourable (Baetscher et al., 2019; Hare et al., 2016). For example, in a fisheries context, several of Indonesia's blue swimming crab (*Portunus pelagicus*, Portunidae) stock units have acclimated and populations remained in place and stable despite significant environmental change (Madduppa et al., 2021). Conversely, U.S. Mid-Atlantic black sea bass (*Centropristis striata*, Serranidae) have demonstrated ecological resilience to climate change by expanding their range in response to increasing niche availability, as opposed to spatially contracting or redistributing (Bell et al., 2015).

Behavioural flexibility: The resilience of a population to climate-driven shifts in habitat or prey availability is influenced by the population's ability to alter its behaviour in response to shifting resource availability. Thus, (d) habitat diversity and (e) dietary flexibility directly confer resilience. Generalist species that can exploit diverse prey items or habitats are more likely to be resilient to disturbance, which magnifies competitive interactions and resource partitioning, through behavioural flexibility (Eurich et al., 2018; MacNally, 1995). In response to coral bleaching, for example, fish characterized as resource generalists have been known to increase in abundance following a disturbance (Richardson et al., 2018).

Evolutionary flexibility: A species' ability to expand or shift physiological tolerance of environmental stress confers resilience to climate change through either (f) plasticity or its (g) evolutionary potential (i.e. threshold effect; Pörtner & Knust, 2007). Evolution operates at a generational timescale and thus implies adaptive capacity. While plasticity, through ecological effects, can facilitate evolutionary change when subject to selection pressure (Crozier & Hutchings, 2014), the evolutionary potential of a population is the capacity to evolve in response to change. By considering the evolutionary principles of a fishery (e.g. through fisheries genomics), management can integrate further aspects of resilience (Valenzuela-Quiñonez, 2016), as the restoration of genetic traits altered by fishing is slow and may even be impractical (Enberg et al., 2009).

4.2.3 | Organization

For a fishery, the *organization* of the ecosystem functions and components directly influences resilience (Paoli et al., 2017). We define ecosystem function as the interconnected ecological processes that provide direct or indirect ecosystem services. Thus, many attributes outlined above relate to, or even depend on, others within the organizational domain to confer resilience. The diversity of functions within an ecosystem directly influences (a) connectivity and (b) modularity—the two attributes of ecological organization. In Moreton Bay, Australia, connectivity between different habitat types greatly enhanced reserve performance, with higher harvestable fish biomass at locations where edge-to-edge isolation distance between habitats was low (Olds et al., 2012). Intact habitats confer resilience by allowing connected populations to recover from disturbance with assistance from linked populations, processes or food webs (e.g. Mumby & Alan, 2008). Second, the connectivity of habitats through larval dispersal can also foster resilience of distributed populations. Harrison et al. (2012) provided evidence that reserve networks significantly contribute to the replenishment of two commercially and recreationally targeted fish species through larval dispersal, on both reserve and fished reefs at a scale that benefited local stakeholders (Harrison et al., 2012). Furthermore, a network of MPAs can yield previously unrecognized stabilizing benefits that ensure a consistent replenishment of exploited fish stocks (Harrison et al., 2020).

4.3 | Socio-economic attributes

We framed the majority of the socio-economic attributes within the domains of assets and flexibility (Table 2), although many of the socio-economic attributes could be classified under multiple domains. The socio-economic attributes operate and confer resilience at a mixture of individual, household and community scales. Depending on the structure of the focal system, attributes may be relevant for resilience outcomes throughout the fishery's associated supply chain. Additionally, the socio-economic dimension has multiple attributes that address access. For these attributes, we defined access as the ability of individuals and communities to directly benefit from different types of socio-economic resources (sensu Ribot & Peluso, 2009).

4.3.1 | Assets

Socio-economic *assets*, specifically the (a) wealth and reserves, (b) economic diversity and (c) social diversity associated with a fishery system, represent resources or services that can be drawn on to confer resilience. Wealth and reserves at individual and community levels facilitate access to necessary resources or services that enhance resilience. For example, in Kenya, wealthier fishers were more likely to believe they could exit a severely declining fishery (Cinner et al., 2009). Economic diversity, which can also be considered at both individual and community levels, contributes to resilience by spreading risks across multiple sectors. For example, fishing communities in Cambodia diversified both within the fishing sector (e.g. different gears, fish processing) and among livelihoods (e.g. household businesses) to reduce risk and build wealth in response to market fluctuations, political instability, fish stock decline and forest fires (Marschke & Berkes, 2006). Social diversity has been theorized and modelled to confer resilience by providing, for example, more knowledge sources, capabilities and adaptive responses (Biggs et al., 2015; Folke et al., 2005). In other contexts, lower social and cultural diversity has been linked to reduced food production (Grêt-Regamey et al., 2019) and lower climate change policy commitments (Saavedra et al., 2012), both of which, in turn, reduce system resilience. However, Solomon et al. (2020) and Townshend et al. (2015) present social diversity as an impediment to trust and collective action in fishery systems, suggesting that social capital is an essential attribute to mobilize socio-economic assets (Saavedra et al., 2012), including the diversity of ideas, innovation and responses associated with social diversity. Rural-urban gradients may influence the distinction and consequences between community cohesion and the ability to agree on courses of action versus innovations that allow for alternative decisions and

TABLE 2 **Socio-economic attributes** that confer resilience to climate change in fisheries, including definition and proposed mechanisms. See the Supplementary Information for table references

Domain	Attribute	Definition	Mechanism
Assets	*Wealth and reserves*	The aggregate value of assets available to individuals, organizations and communities that contribute to human well-being.	The quantity and quality of wealth and reserves, including human, manufactured, natural and financial capital, that individuals and communities have access to determine their capabilities to adapt (Tyler & Moench, 2012).
	Economic diversity	The variety of income-earning activities that an individual, household or community can partake in.	Economic theory suggests that stability is achieved through diversity by spreading risk or opportunities over many activities. (Wegener & Deller, 1998). Economic diversity contributes to system resilience via a portfolio effect, in that different economic sectors or activities will respond to environmental and other socio-economic shocks differently (Chapin et al., 2006).
	Social diversity	The variety of social characteristics that shape the preferences, attitudes, values and norms in a particular population.	Social diversity, including racial, demographic and religious characteristics, contributes to resilience by increasing diversity of knowledge sources and skill sets.
Flexibility	*Flexible and agile infrastructure*	The ability of built structures and facilities to provide needed services under a wide range of conditions and to quickly respond to predictable and unpredictable changes.	Flexibility and agility are preconditions for adaptable infrastructure (Chester & Allenby, 2019). Flexible and agile infrastructure is able to withstand and respond to disruptions and meet changing demands (Chester & Allenby, 2019; Hudson et al., 2012).
	Mobility	An individual's and/or community's ability to move freely and easily, either temporarily or permanently.	Mobility increases flexibility across and within livelihoods, allowing fishers to respond to changes by changing fishing strategies, locations, and/or livelihoods. However, mobility requires certain enabling conditions, such as financial resources, technology and physical capacity (Young et al. 2019).
	Access to economic opportunity	Physical (e.g. transportation network) and non-physical (e.g. social relations) means and processes that enable individuals and communities to benefit from new or alternative income-earning or subsistence activities.	Access refers to the "ability to derive benefit from things" (Ribot & Peluso, 2009). Access to multiple and new opportunities allow individuals and communities to adjust to changing environments, which will contribute to resilience (Chapin et al., 2006).
	Resilience mindset	The degree to which individuals accept "resilience thinking" from a perspective that recognizes characteristics of complexity, uncertainty, non-linearity, thresholds, feedbacks, irreversibility, and multi-scale and multi-level interactions in a changing world.	Those with resilience mindsets, or thinking that considers the dynamics of complex social-ecological systems, accept the fact that things are going to change and account for this fact in planning, decision-making and management (Slootweg & Jones, 2011).
	Place attachment	The extent to which individuals and communities feel tied to the geographical location in which they live and operate, affecting their response to risk, including willingness to move homes, fishing grounds or processing location in the face of adverse conditions.	The relationship between place attachment and climate resilience is dependent upon the degree to which the system has been or is predicted to be disturbed. High place attachment can increase coping skills by promoting pro-environmental behaviour, but can lower climate resilience if system actors are unwilling to "transform," even after the system has reached a critical threshold.

TABLE 2 (Continued)

Domain	Attribute	Definition	Mechanism
Organization	*Social capital*	The strength of networks of relationships among people and organizations who live and work in a particular community.	Social capital, which includes bonding, bridging and linking social capital, forms the basis for collective action and enables society to function effectively. Strong social capital enables self-organization and can help to facilitate system reorganization (González-Quintero & Avila-Foucat, 2019), adopt recommendations and implement changes (Whitney et al., 2017).
	Technology advancement, adoption and transfer	The level and capacity of individuals and communities to develop and acquire new technologies and methods as well as the ease with which these technologies and methods are transferred between and among actors in the system.	Technology can help to buffer against environmental changes (Millennium Ecosystem Assessment, 2005) and improve the adaptive capacity of fisheries management, the economic outputs from the fishery and the well-being of stakeholders in the system. However, new technology could also alter flows and distributions of benefits and may lead to less equitable outcomes.
	Modular and open infrastructure	The degree of compartmentalization within and across built structures and facilities and the ease with which diffusion can proceed.	The modularity and openness of available infrastructure relates to the connectivity within the network. The networks' ability to confer resilience depends on whether the infrastructure network serves to facilitate flow of resources or human interactions. While modularity confers resilience if the infrastructure network serves to facilitate resource flow, openness confers resilience if the infrastructure network serves to facilitate human interactions (Yu et al., 2020).
Learning	*Diversity of knowledge sources*	The variety of types and origins of knowledge that are available to individuals and members of the community.	Different stakeholders have different levels and types of knowledge about the system, as well as different perspectives on risk and change (Tyler & Moench, 2012; Kerner & Thomas, 2014). Diverse knowledge sources enable individuals and communities to leverage the expertise of different knowledge systems and knowledge holders to create novel or hybrid understandings of the system.
	Access to knowledge	The ability of individuals and communities to obtain and derive benefit from existing knowledge about the system.	Equitable access to knowledge, including scientific, indigenous, cultural and community-held knowledge, contributes to the ability of individuals and communities to effectively participate in the resource management and governance process (Mbaru & Barnes, 2017). Uptake of both scientific and local indigenous knowledge and co-production of knowledge between both sources contribute to social-ecological system sustainability (Ishihara et al., 2021) and resilience (Berkes, 2007).
	Learning capacity	The degree to which individuals and communities are able to perceive risk, learn from experience, synthesize information and grow their own knowledge.	Individuals and communities with greater learning capacity are able to recognize change, attribute its causes, perceive risk and understand the relationship between climate change stressors and cumulative stressors and thus are able to better assess potential responses and adaptive actions (Berkes, 2007; Cinner et al., 2018).
Agency	*Agency*	The capacity of individuals and communities to negotiate, make decisions and act on their own free will.	Agency allows individuals and communities to transfer their existing capacities to build new capacities in multiple dimensions, including everyday, strategic, personal and political dimensions. Agency is fundamental for individuals and communities to develop and prosecute their visions to adapt to the changes (Cinner et al., 2018).

livelihoods (McClanahan et al., 2021). Thus, the social context may influence the degree to which cohesion versus innovation confer resilience of fisheries.

4.3.2 | Flexibility

Socio-economic *flexibility* enables individuals and communities to switch activities and strategies to accommodate changes. We identified four attributes that enhance socio-economic flexibility: (a) flexible and agile infrastructure, (b) mobility, (c) access to economic opportunity, and (d) resilience mindset, and one attribute that limits flexibility: (e) place attachment.

Enhanced flexibility: Built structures and facilities that can provide necessary services under multiple conditions enable communities to respond to shocks and adapt to changes to mitigate negative impacts. Because it is costly to build or re-design infrastructure, flexible and agile infrastructure can save community resources. Further, this conferred resilience can be increased if mobility is high. Mobility depends on preconditions such as availability of technologies (e.g. fishing vessels, navigation devices), infrastructure (e.g. highways, public transportation) or assets and resources. Mobility and flexible infrastructure both help to maintain and diversify access to economic opportunity, including alternative facilities or markets in the case of supply chain disruption (Plagányi et al., 2014). Economic diversity and access to economic opportunity, in conjunction with mobility, can enable fishers to employ tailored socio-economic resilience strategies for changing environmental conditions. For example, in small-scale fishing communities in Golfo de Ulloa in Baja California Sur, Mexico, species diversification contributed to risk mitigation and income stabilization despite inter-annual environmental change, while specialization during favourable conditions contributed to poverty reduction and wealth accumulation, enhancing adaptive capacity (Finkbeiner, 2015). However, flexibility alone may not be enough to confer resilience to disruptions further up the supply chain (Lim-Camacho et al., 2015), as seen when the COVID-19 pandemic disrupted global seafood supply chains, and many fisheries were unable to adapt to the consequent loss of tourism and global markets (Bassett et al., 2021). Lastly, a resilience mindset can synergistically activate or enhance mobility and thus support access to economic opportunity (Buheji, 2020).

Limited flexibility: Place attachment can help individuals and communities resist and recover from climate impacts; people attached to place are more likely to engage in stewardship of the area and may be more motivated to pursue collective action to withstand shocks (Amundsen, 2015). However, while it may foster resilience in the face of incremental change, strong place attachment can limit flexibility and thus hinder transformational change needed to deal with long term, chronic climate impacts (Marshall et al., 2012), such as sea level rise or the shift of a fish stock out of an area. In this case, place attachment may stop people from permanently relocating or spending more time away to pursue other fisheries or alternative livelihoods. For example, after coastal disasters, those with high place attachment are more likely to return to the disaster-stricken areas after the recovery, only to be stricken by a similar disaster in the near future (Ueda & Torigoe, 2012).

4.3.3 | Organization

Social *organization* enhances resilience by enabling members of a community to coordinate and cooperate to act collectively. We identified three social organization attributes: (a) social capital; (b) technology advancement, adoption and transfer; and (c) modular and open infrastructure. Social capital describes and characterizes different types of social relationships among individuals and how individuals are embedded in a certain social system or community (Cinner et al., 2018; Portes & Vickstrom, 2011). In addition to providing necessary social organization and cohesion to complement social diversity, social capital supports the three learning domain attributes by facilitating the flow of information and exchange of knowledge within and across communities. Learning in combination with social capital enables adoption and transfer of new technologies, which requires coordination across multiple individuals. For example, introducing satellite technology to help Chilean artisanal and industrial fishers efficiently target tuna (*Thunnus alalonga*, Scombridae) and swordfish (*Xiphias gladius*, Xiphiidae) along thermal fronts required a combination of formal courses and informal information sharing across professional networks tailored to the education levels, learning capacity and social capital of the specific user groups (Barbieri et al., 2002; Silva et al., 2015). The use of this satellite technology is now commonplace and is enhancing learning capacity by facilitating new research and climate change projections (Naranjo et al., 2021; Silva et al., 2015; Yáñez et al., 2018, 2020). Modularity and openness in infrastructure networks can confer or inhibit resilience depending on whether the infrastructure supports the flow of resources or human connections (Yu et al., 2020).

4.3.4 | Learning

Learning supports actors to recognize and assess risks and act on change in a system. All three attributes in this domain—(a) diverse knowledge sources, (b) access to knowledge and (c) learning capacity—occur at both the individual and community levels. Knowledge takes many forms and is derived from multiple ways of knowing, including scientific information and community, indigenous, cultural and cross-generational knowledge (Whitney et al., 2017). Individuals and organizations with greater learning capacity are better able to recognize changes, understand the source of the changes and assess risks and potential consequences of inaction to shape their adaptation strategies. In the Dolly Varden char (*Salvelinus malma malma*, Salmonidae) fishery in the Canadian Western Arctic, combining local

TABLE 3 **Governance attributes** that confer resilience to climate change in fisheries, including definition and proposed mechanisms. See the Supplementary Information for table references

Domain	Attribute	Definition	Mechanism
Flexibility	*Responsive*	The sensitivity, readiness, speed and accuracy with which a governance system handles, resolves and follows up on a management-relevant change to meet stakeholders' needs (Sheng, 2009).	Responsive governance follows from an informed governance structure that enables a social-ecological system to resist and recover from disturbances in a timely manner. Responsiveness is important for achieving strategic expectations of stakeholders and for facilitating short-term adjustments in the context of climate change (Holsman et al., 2019).
Organization	*Participatory*	The degree to which an institution empowers participants to influence and share control in processes of public decision-making, ranging from intermittent consultation opportunities to ongoing self-mobilization (Coghlan & Brydon-Miller, 2014; Leite & Pita, 2016).	Participatory governance confers resilience by including a diverse set of actors, supporting greater legitimacy and compliance, contributing to trust among stakeholders and providing greater transparency, inclusivity, accountability, communication and knowledge sharing (Citanovic et al., 2018; Fraser & Kirbyshire, 2017; Hall-Arber, 2005).
	Equitable and inclusive	The degree to which the governance system is fair in the distribution of benefits and burdens (risks), participatory in rule and decision-making for relevant actors, and engaged and inclusive of marginalized and disadvantaged groups (Bennett et al., 2020).	Equitable and inclusive governance decreases unrest and increases individual and community capacity to respond to change by increasing representation of rights, cultures, identities, values and visions of all actors. The mechanisms include increased buy-in and compliance with regulations, driven by positive perceptions of fairness and legitimacy, improved speed and efficacy of decision-making processes, and increased social cohesion, cooperation and adaptive capacity.
	Accountable	The degree to which decisions and decision makers can be held culpable to both the individuals and communities that they govern as well as to higher-level mandates, commitments, goals and objectives they serve (Battista et al., 2019; Lebel et al., 2006; Ostrom, 1990).	Accountability deters corruption or perverse actions that may undermine or diminish intended outcomes or other resilience attributes of a fishery through a system of checks and balances that holds the government culpable. Accountable governance increases system resilience by supporting other resilience attributes, including: efficacy of decisions, agency, equitability, inclusiveness and participatory governance.
	Transparent	The openness and accessibility of timely information, decision-making rules and procedures, and outcomes to members of the public or stakeholders affected by management actions (Clark et al., 2015; Davis & Hanich, 2020).	Transparency supports resilience by enabling the flow of information to support learning and decision-making, achieving greater equity in the sharing of benefits and costs of actions, and supporting the implementation and perceived legitimacy of actions (Davis & Hanich, 2020).
	Efficient and effective	The degree to which the governance system produces outcomes that achieve societal and/or fishery objectives while efficiently using available resources.	Effective governance is an enabling condition for a system to achieve social and ecological resilience attributes (Hilborn et al., 2020), and efficient use of resources would allow a system to achieve more of its goals with fewer trade-offs.
	Polycentric	The degree to which multiple bodies at different levels of the governance system overlap and interact to make and enforce rules within a specific policy arena or location (Folke et al., 2005; Ostrom, 2005).	Polycentricity allows authority to be transferred to different levels, which may enhance adaptive capacity by diversifying potential options for responding to uncertainty or change. Polycentricity can also improve efficacy and prevent corruption, while also supporting the agency of different actors and spreading legitimacy throughout the system.
	Integrated across scales and sectors	The degree to which actors and/or organizations acknowledge, work with, and attempt to understand the relevance and transition of scale and the interlinkages between various other organizations, institutions and management structures.	Fisheries are social-ecological systems with complex linkages that likely extend beyond the jurisdiction and/or capacity of fisheries governance and management structures. Thus, the inclusion and integration of relevant scales and diverse sectors can help to ensure that important trade-offs are acknowledged and that multiple streams of benefits are optimized when integrating climate planning and adaptation.

(Continues)

TABLE 3 (Continued)

Domain	Attribute	Definition	Mechanism
Learning	*Adaptive*	The capacity to implement a structured, iterative process of continual innovation, testing, learning and adjustment that facilitates robust, flexible decision-making and action in the face of uncertainty and complexity.	Adaptive decision-making processes confer resilience by reducing uncertainty, managing risk, and maintaining or even improving system functions and services under changing conditions. Anticipating and managing new risks and opportunities may also be necessary for adapting to novel conditions under climate change.
Agency	*Leadership and initiative*	A system that legitimizes and supports the development of leaders who are guided by collective interests, who mobilize and direct responses to disruptions (Kerner & Thomas, 2014, pp. 682) and who take responsibility and act when necessary (Bodin & Crona, 2009; Crona et al., 2017; Gutierrez et al., 2011).	Leadership is necessary to activate or position latent assets to produce a common good (e.g. social capital; Crona et al., 2017), support self-organization (Ostrom, 2009) and increase compliance and buy-in (Gutierrez et al., 2011). Leaders who take initiative are able to quickly and effectively catalyse action after a disruption and strategically plan for longer-term needs, thereby increasing system stability, responsiveness and adaptive capacity.

indigenous knowledge of the Gwich'in and the Inuvialuit with western scientific knowledge from Fisheries and Oceans Canada resulted in a more comprehensive understanding of the causes of char declines (Armitage et al., 2011). It also allowed place-based and locally acceptable management options to increase the resilience of this fishery.

4.3.5 | Agency

Individual and collective *agency* refers to the ability of people to freely make choices and act on adaptive strategies. In the context of climate change adaptation, individuals and groups with high agency are better able to decide and mobilize available resources to adapt to changes. For example, in the Maine lobster (*Homarus americanus*, Nephropidae) fishery, fishers who believed that they were able to influence management decisions and recognized their role in shaping the fishery were more likely to have plans to adapt to changing conditions (McClenachan et al., 2020).

4.4 | Governance attributes

We framed the majority of governance attributes under the domain of organization, with one attribute categorized within each of the flexibility, agency and learning domains (Table 3). In distilling and defining governance attributes, we understood fisheries governance to mean the sum of legal, social, economic and political arrangements in place, both formal and informal (McClanahan & Abunge, 2019), to coordinate and manage fisheries. We use the term "governance" throughout for brevity, recognizing that some mechanisms and examples are more relevant to fisheries management as nested within the broader systems of fisheries governance. For instance, adaptive management requires flexibility at multiple scales provided through adaptive governance (Ogier et al., 2016), which in turn requires the "monitoring and feedback loops created through adaptive management" (Brunner et al., 2005; Chaffin et al., 2016). The governance attributes operate at the community and social-ecological system scales and may link between and beyond them, depending on the particular governance arrangements of the focal system. Governance capacity appears critical to the willingness to accept restrictions that lead to more productive and resilient fisheries (McClanahan & Abunge, 2020).

4.4.1 | Flexibility

Responsive governance confers flexibility in fisheries by acting on and adjusting to social-ecological systems change (Sheng, 2009). These actions enable the system to resist and recover from short-term stressors and system variability. For example, in a modelling study of northeast U.S. stocks, Kritzer et al. (2019) compared a fixed harvest control rule (that did not change) with a responsive harvest control rule that changed annually based on stock biomass. They found that the responsive rule better mitigated biomass losses for climate-vulnerable species and that the effect was even greater with scientific uncertainty included in the model. Similarly, adjusting harvest control rules based on survey indices enables responsive management of European stocks with varying data availability (ICES, 2021). Responsiveness confers greater resilience when paired with other attributes; alone it risks both an inordinate focus on short-term "putting out fires" rather than transformational change and failure to clarify trade-offs and prioritize objectives when addressing disparate needs. For example, responsive governing becomes adaptive when paired with learning (see below) and can more effectively and equitably address social needs when participation is increased.

4.4.2 | Organization

We identified seven governance attributes that shape a fishery system's *organization* and confer resilience by enabling, for instance, cooperation, knowledge sharing and, timely, forward-looking action (Table 3). Many of these attributes—(a) participation, (b) equity and inclusion, (c) accountability and (d) transparency—enhance legitimacy, which in turn increases (e) governance effectiveness and efficiency (Bennett et al., 2019; Hall-Arber, 2005). Thus, these attributes contribute to achieving and maintaining desired ecological and social outcomes through enhanced social cohesion, buy-in and compliance with management (Battista, Kelly, et al., 2018; Battista, Romero-Canyas, et al., 2018). For example, in the Sumilon and Apo Islands in the Philippines, a shift from centralized, exploitation-oriented governance to a participatory arrangement empowered local stakeholders and ultimately assisted in recovering local fish stocks and fisheries (Alcala & Russ, 2006; Cvitanovic et al., 2018).

Two additional organizational attributes—(f) polycentricity and (g) integration of governance across sectors and scales—confer resilience by providing redundancy and connectivity. For example, polycentricity in the U.S. fisheries governance system, where responsibilities overlap across local, state and national levels, has provided checks and reinforcements to promote sustainable fishing despite failures in leadership at various levels (Battista, Kelly, et al., 2018; Battista, Romero-Canyas, et al., 2018; Ostrom, 1990). These attributes also create linked and overlapping structures that provide opportunities for experimentation and learning and can address stressors acting on different scales and dimensions of complex fisheries social-ecological systems (Biggs et al., 2012; Folke et al., 2005). In Vietnam, policies that integrated climate adaptation, poverty reduction and disaster recovery goals at multiple governance levels were a key step towards addressing the complexity of climate stressors in social-ecological systems and preventing resilience interventions from inadvertently increasing other vulnerabilities (Charles et al., 2019).

4.4.3 | Learning

Adaptive governance is a systematic process of *learning* and experimentation (Armitage & Plummer, 2010). It confers resilience by applying past knowledge to prepare for the future, thereby enabling robust and flexible decision-making in the face of uncertainty and complexity. Adaptive governance is facilitated by polycentricity and participatory co-management arrangements (Ogier et al., 2016), which provide structure for knowledge exchange and experimentation (Folke et al., 2005). For example, the Great Barrier Reef Marine Park Authority actively connected stakeholder groups (e.g. fishers, tourist operators, scientists) to mobilize diverse ecological knowledge in response to severe and interconnected threats to the reef. Fostering knowledge sharing enabled collaborative measures to build ecological resilience, as well as subsequent multisectoral and adaptive arrangements to address land-based stressors (Schultz et al., 2015). The shift to adaptive governance can be a messy process; it often emerges in response to crisis (Schultz et al., 2015), or through the will of the people to manage a system holistically (Chaffin et al., 2016). Additionally, adaptive governance requires sustained political support and fiscal underpinning of capacity building (Kalikoski & Allison, 2010). As climate change redistributes stocks across international boundaries (Scheffers & Pecl, 2019), integrating adaptive approaches across multiple governance scales will be highly complex, yet critical for addressing emerging challenges, such as reconciling disparate goals, capacities, management approaches and perceptions of equity (Østhagen et al., 2020; Pinsky et al., 2018).

4.4.4 | Agency

Agency is realized at the governance level when individual leadership and initiative is legitimized and oriented towards collective interests. Leadership has been identified as a key predictor for effective co-management in fisheries through increased legitimacy and buy-in (Gutiérrez et al., 2011). Effective leaders can facilitate quicker responses to and recovery from shocks (Kerner & Thomas, 2014), and set the vision, develop knowledge networks and build support for longer-term adaptation and transformation (Folke et al., 2005; Schultz et al., 2015). For example, community leaders in Gazi, Kenya, created incentive schemes (e.g. food and lodgings) for migrant fishers and encouraged collective action in the management of the fishery, thus increasing investments in the landing site (Bodin & Crona, 2009; Murunga et al., 2021). Agency alone, however, will not prevent overexploitation, often because there is a weak feedback between local control and the state of resources in many fisheries (McClanahan et al., 2021).

4.5 | Contextual considerations

In addition to the resilience attributes, we identified six properties of social-ecological system state, structure and interconnections that do not directly affect resilience, but rather mediate how resilience interventions function and flow within and across dimensions. We discuss these *contextual considerations* separately because acknowledging and understanding these aspects of context—termed "complex adaptive systems thinking" as part of "resilience thinking"—is critical for developing effective and appropriate management approaches (Biggs et al., 2012; Levin et al., 2013; Walker & Salt, 2006). The (a) underlying complex system structure of the fishery, including non-linearities and feedbacks, can influence dramatic or hard-to reverse system dynamics in response to disturbance, such as shifts to alternate ecological stable states, paradigm shifts or poverty traps (Cinner et al., 2012; Levin et al., 2013). Considering these underlying structures can thus inform managers' decisions about when and how to intervene while avoiding unintended consequences. Critical to understanding socio-economic and governance dynamics are the (b) power relations that shape how the benefits and costs of stressors and interventions are distributed, how trade-offs are approached, and who defines a "desirable" state or even the need for intervention or adaptation. Scholars increasingly point to these power relations as a critical gap in the resilience literature (Brown, 2014; Cinner & Barnes, 2019; Fabinyi et al., 2014; Matin et al., 2018).

In addition, the (c) current state of the system in terms of fishery resource status and human well-being and the (d) importance of the fishery to the community for economic, cultural, nutritional and other key value systems will shape how resilience attributes can be operationalized. Even if many resilience attributes are present, an "undesirable" system state may limit adaptive options. For example, severely depleted stocks may limit diversification capacity or, conversely, if political unrest arises, fisheries management may be deprioritized. Similarly, the importance of the fishery to the community relative to other livelihood activities may influence whether adaptive, transformative or coping responses are desirable and additionally, even possible. Further, the fishery's dependence on and degree of (e) connections to other systems, shape adaptive pathways and can create unintended consequences. In the highly globalized and interconnected seafood trade system, fishery resilience outcomes could be contingent on the demands of distant markets, policy changes or disruptions in adjacent industries such as transportation or manufacturing (Gephart et al., 2017). In addition to feedbacks across spatial and sectoral scales, managers must consider (f) temporal connections. Recognizing the historical context may affect choices for future management. For example, a stock with a long history of overfishing may require specific management approaches; institutions and infrastructure can create path dependency and inertia that shape adaptive pathways; and past experience with shocks or stressors may be a key factor in determining agents' response to change (Levin et al., 2013; Matin et al., 2018; Penas, 2007). Building resilience attributes—such as learning capacity, diverse knowledge sources, participation and integration of governance across scales and sectors—may bolster managers' ability to recognize and work with these contextual considerations (Biggs et al., 2012).

5 | DISCUSSION

5.1 | Summary

This holistic typology of attributes represents a starting point to comprehensively consider and build in the principles of climate resilience for various scales across fishery social-ecological systems. By articulating the above attributes and mechanisms, we reveal complex linkages where these attributes may contribute to the various dimensions influencing resilience. In the subsequent sections, we outline different ways in which attributes are connected, discuss caveats and suggest future research directions to understand and thereby enable climate resilient fisheries.

5.2 | Dependencies among resilience attributes

Many attributes do not function independently but emerge from, or are influenced by, other attributes. Some attributes—especially those in the organizational domain—may require others to be activated or may erode resilience without the presence of others. For instance, in the social dimension, social diversity without social capital and cohesion may inhibit collective action; and in the governance dimension, transparency and participation without accountability could erode effectiveness (Schneider, 1999; Tanner, 2009). Governance effectiveness in turn may not in itself confer resilience. Rather it is a necessary precondition for achieving resilience through other ecological and social attributes, such as the implementation of protections to sustain stocks, diversity and connectivity; or investments in infrastructure and education (McClanahan & Abunge, 2020). Similarly, social capital and polycentricity provide the necessary structures for knowledge transfer to link awareness about the social-ecological system and its stressors to adaptive actions; in systems with high learning capacity and wealth and reserves, these structures also enable technology transfer. Lastly, agency emerged as a key activating attribute that can leverage assets and organizational structures to break through maladaptive system inertia and catalyse desired social and ecological outcomes (Crona, 2017; Folke et al., 2005).

5.3 | Weakest link hypothesis

Individual attributes appear to have the greatest effect when they limit the cumulative effects of multiple attributes. This conjecture is related to the weakest link hypothesis, which states that adaptive capacity is limited by the weakest of its underlying components (Yohe & Tol, 2002). For example, climate-related loss of productivity and diversity of fisheries species in tropical nations may limit access to new economic opportunities, economic diversity and other adaptive capacities (Cheung et al., 2013). In the social dimension, poverty traps (i.e. lack of wealth and reserves; Cinner et al., 2012) or interventions that reduce access to fish (i.e. lack of access to economic opportunity) may prevent flexibility by hindering mobility and economic diversity, thus eroding social-ecological system resilience (Golden, Gephart, et al., 2021). For instance, in Mexico, fishing cooperatives' ability to access ecological resources and pursue diversified livelihoods depended, in part, on having a greater suite of rights conferred through fishing permits (Finkbeiner, 2015). The North Atlantic mackerel example (Box 1) demonstrates how the lack of adaptive mechanisms in the governance dimension led to the breakdown of international cooperation despite a system with otherwise strong attributes across dimensions—indeed, one of the most established, well-resourced, science-based management systems in the world (Østhagen et al., 2020; Spijkers & Boonstra, 2017).

BOX 1 Resilience attributes applied to two fishery case studies

Box 1: Resilience attributes applied to two fishery case studies

Tasmanian Rock Lobster

The commercial southern rock lobster (*Jasus edwardsii*, Palinuridae) fishery is the second largest wild catch fishery in Tasmania, Australia, primarily exported to high-value Asian markets. The fishery occurs within one the fastest warming regions in the southern hemisphere. The climate-driven intrusion of the long-spined sea urchin (*Centrostephanus rodgersii*, Diadematidae) has decimated key kelp forest lobster habitat as urchins overgraze the forests leaving 'urchin barrens.' However, royalties from an abalone (*Haliotis* spp., Haliotidae) fishery in the same kelp habitat subsidize dedicated commercial fishing of *C. rodgersii*, which has helped control the urchin population. Community support and alternative markets also helped the lobster fishery respond to supply chain and trade policy disruptions associated with the COVID-19 pandemic, but cumulative ecological impacts of climate change, overfishing, and a lack of climate leadership continue to threaten resilience.

Sources: Pecl et al., 2009; Nursey-Bray et al., 2012

Northeast Atlantic Mackerel

The mid-2000s "Mackerel Wars" demonstrate resilience challenges and trade-offs in a transboundary fishery. Multilateral, science-based management of the highly-lucrative industrial Atlantic mackerel (*Scomber scombrus*, Scombridae) fishery among the EU, Norway, and Faroe Islands failed when mackerel shifted northward with warming waters, establishing spawning grounds in Iceland. Iceland demonstrated national-level resilience by rapidly capitalizing on the new economic opportunity, but at the international level, the governance process was slow to include Iceland and it remains unable to resolve disputes over equitable quota allocation. Cooperative management devolved into unilateral quotas that sparked trade sanctions and broader political conflict. Persistent fishing above scientific advice, the 2019 suspension of Marine Stewardship Council certification, and the entry of a new negotiating party post-Brexit may further limit this fishery's resilience to climate-driven changes.

Sources: Spijkers & Boonstra, 2017; Østhagen et al., 2020

While kelp forest loss due to urchin barrens and warming paired with historical overfishing has lowered lobster **population abundance,** the stock status is considered sustainable due to an intact **age structure**. Although the high-value fishery provides **wealth and reserves** contributing to well-being, there is limited management capacity to address issues beyond day-to-day fishing responsibilities.

Abundant populations and diverse **age structure** enable mackerel to withstand changes in temperature and fishing pressure. Ample **wealth and reserves** support fisher flexibility and agency (i.e. political influence), learning via scientific capacity, and multilevel governance organization. However, differing levels of **economic diversity** and fishery dependence among nations contribute to conflicting views on equitable quota allocation.

Lobster **adult mobility** is low and although **larval dispersal** is high, there is no poleward habitat past Tasmania. **Access to economic opportunity** via domestic markets facilitated adaptation to pandemic disruption. However, for climate stressors, high **place attachment**, low occupational **mobility** in the widely older workforce and the lack of **resilience mindsets** largely prevent adaptation. Many management restrictions limit fishery flexibility.

Adult mobility and **dietary flexibility** allow mackerel to exploit new environments in response to temperature change. Fishers throughout the region have high **mobility** to follow mackerel stocks, **agile supply chain infrastructure** to market them, and innovative **resilience mindsets** to embrace new species. However, the rigid governance system precludes **responsiveness** to environmental and political change.

Limited **connectivity**, since Tasmania is the last habitat before Antarctica, prevents lobster redistribution. Strong **social capital** supported fishers' transition to alternative markets. **Participatory** and **transparent** management arrangements could facilitate climate responses, if resources were made available. Moderate **integration across scales and sectors** facilitates collaboration and engagement between managers, industry, and researchers.

Connectivity facilitates mackerel's northward expansion. Strong **social capital** helps fishers advocate for their goals, but entrenches national interests. Well-developed **participatory** and **polycentric** governance structures were highly **effective** for already-established parties but not **inclusive** to new entrants. Similarly, inadequate **integration across scales and sectors** hinders inclusion of other stakeholders such as mackerel retailers.

A robust scientific system provides high **access to knowledge** and moderate **learning capacity**, which are key for evidence-based co-management. However, some denial of climate change within the industry and limited **adaptive governance mechanisms** may erode resilience.

A robust scientific system provides high **access to knowledge** and **learning capacity**, which are key for evidence-based management and mackerel fishery development. However, lack of **adaptive governance mechanisms** for incorporating new actors and resolving disputes continues to erode resilience.

In the co-management structure, fishers have strong **agency** and **leadership** but there is also a disconnect between quota owners and fishery operators in terms of industry goals and agency. The fishery is in need of a **leadership** champion to push forward climate adaptation.

Fishers have strong **agency** and **leadership** to advocate for their interests at the subnational and national levels, but the rigid consensus-based structure at the international level stifles **leadership and initiative**.

5.4 | Bi-directional feedbacks

While the absence of an attribute can clearly erode resilience, attributes in excess can have the same effect. Many attributes may have a mixed or bi-directional relationship to resilience, such that there is an optimum level beyond which the attribute directly erodes resilience or conflicts with other attributes (see Relationship and Mechanism entries in the Supplementary Information). These bi-directional feedbacks are evident in the organizational attributes of the governance dimension: Increasingly layered and complex governance systems can drain assets through escalating costs and obstruct flexibility, learning and agency through bureaucratic stagnation (Biggs et al., 2012; Folke et al., 2005; Hilborn, 2007). For instance, under the U.S. fisheries management system, conflict between agencies and slow-moving procedures prevented responsiveness to environmental change for salmon in Washington (Ostrom, 2009). These bi-directional feedbacks operate across dimensions as well. There may be trade-offs between building ecological versus social resilience, for example, if increased mobility leads fishers to deplete fishing grounds and move on (e.g. Adger, 2000; Ojea et al., 2017).

We further posit that strong resilience attributes can inhibit the development of others. In systems with high ecological resilience due to a stable population size, healthy age structure or large environmental niche breadth, there may be decreased emphasis on building resilient social and governance structures because community members are accustomed to the system absorbing any pressure and shocks that have occurred. In the commercial California Dungeness crab (*Metacarcinus magister*, Cancridae) fishery, for example, high productivity and population size historically conferred ecological resilience to environmental variability with minimal management oversight (Richerson et al., 2020). As such, risk perception in the fishery was low and building responsive and adaptive governance structures was deprioritized, leaving the fishery unprepared for, and slow to respond to, unprecedented harmful algal blooms related to a climate-driven marine heatwave, which caused significant economic losses (Santora et al., 2020).

5.5 | Context and scale

Additionally, the directionality and mechanism of these attributes will depend on the specific context, capacities and scale of the focal system and associated stressors—that is, resilience of what, to what and for whom; the bounds of the system; and the time scale of responses. In an effort to be relevant to fisheries across the gamut of large-scale and industrial to small-scale and artisanal, we included a wide range of attributes, broadly defined, recognizing that not all will be needed or beneficial to a particular social-ecological system, nor will they necessarily function as in the examples we present here. Further, we discuss these attributes in the context of climate resilience, but since we drew them from a variety of disciplines, we believe they would be applicable in fostering resilience to other stressors. While we did not look for examples specific to shocks beyond climate change, the Tasmanian rock lobster example (Box 1) demonstrates how these attributes were also relevant to social and economic disruptions related to the COVID-19 pandemic. Further, emerging work has shown that regional seafood systems that were more resilient in the face of the COVID-19 pandemic exhibited similar attributes to what we describe here. In the United States and Canada, factors including financial capital (wealth and reserves), alternate online or local markets (access to economic opportunity) and strong relationships (social capital) collectively allowed small-scale seafood suppliers to thrive despite pandemic-related upheaval in seafood demand (Stoll et al., 2021). In Pacific Island Countries and Territories, flexible and agile infrastructure bolstered the production, processing and storage of seafood from regional fisheries when international trade ceased (Farrell et al., 2020). Lastly, we focussed on fisheries here, but recognize that they represent just one aspect of coupled food systems that support broader social-ecological well-being. While these fisheries-specific attributes could be informative in a food systems context, it would be useful to expand or integrate them with existing frameworks and processes for diagnosing resilience in agricultural systems (e.g. Meuwissen et al., 2019) in an effort towards more comprehensive approaches of building resilient food systems.

5.6 | Caveats and limitations

The attributes described here are intended to provide a holistic starting point to assess and operationalize resilience in fisheries, rather than a systematic and exhaustive list of all potential attributes of resilience in fishery systems. In particular, a lack of concrete examples using standardized language to characterize resilience precluded an in-depth, literature-supported examination of each attribute, and meaningful quantification of the attributes' contributions to resilience. Organizing these attributes across dimensions and domains revealed potential gaps. For instance, governance assets and capacity—that is, funding for personnel and operations—has been identified as one of the most important factors in management success in other systems (e.g. Gill et al., 2017; Leach & Pelkey, 2001). We initially considered funding for fisheries management as an attribute generated in expert elicitation, but determined that funding was wholly nested under the effectiveness and efficiency of governance; securely funded but ineffective governance would be maladaptive. Additionally, ecological memory, which facilitates recovery following a disturbance at the species- or habitat-level, builds resilience by persisting or being incorporated into the ecosystem as it recovers, thereby increasing the functional diversity of species and habitat heterogeneity (Nyström & Folke, 2001). However, while a potentially important mechanism of resilience, no concrete examples of ecological memory independently conferring resilience in a fishery context were found.

Overall, we found few clear examples that directly link attributes to resilience outcomes, likely because of complex linkages and siloed literature. For instance, most explicit examples, particularly examples that quantified attributes, were in the ecological dimension. The social and governance attributes that build or protect ecological attributes and mobilize the knowledge and agency to access them were likely not prioritized for analysis. The clearest social and governance examples discussed how attributes contributed to meeting ecological goals with social licence, but these were not explicitly framed in terms of resilience. We also found that, across all dimensions, "negative" examples of a lack of an attribute eroding resilience were more common than evidence of the attribute conferring resilience. We hypothesize that success stories may be understudied and that the importance of attributes is more difficult to identify when a system is stable.

5.7 | Future research

Our synthesis highlights four important directions for future research. First, empirical studies of how attributes operate in different types of fisheries (e.g. gleaning fisheries, inland fisheries and different development contexts) are necessary to better inform place-based attempts to operationalize resilience. Second, a broader suite of comparative case studies exploring which attributes and combinations thereof result in resilient and adaptive responses—both generally, and to climate change specifically—is essential for ground truthing and refining the framework we provide here. Such empirically grounded (rather than theoretical) studies could elucidate the relative importance and applicability of these attributes and reveal additional attributes and relationships among them. Third, studies that examine whether and how attributes can be meaningfully measured or managed, which can be managed by traditional fisheries management entities or jurisdictions, and which require integrated approaches will be invaluable for operationalizing resilience. Nascent comparative studies (e.g. Green et al., 2021) would be strengthened by a wider spread of more granular cases. Finally, further research on risk perceptions and willingness to change in fisheries is warranted. This research could draw on work on risk perceptions and resilience more broadly (e.g. Jacobi et al., 2019), work on climate change risk perceptions in fisheries that have yet to be connected to building resilience (e.g. Nursey-Bray et al., 2012) and institutional and other barriers to change in fisheries management systems (Fulton, 2021).

6 | CONCLUSION

Fisheries researchers and practitioners face a daunting task: protect the myriad cultural, ecological, human health and well-being, economic and other services that fisheries provide in the face of complex climate impacts. By synthesizing, defining and presenting mechanistic evidence for a holistic set of fishery-relevant resilience attributes, we took a step towards simplifying this task. Specifically, we identified 38 attributes across ecological, socio-economic and governance dimensions. Our synthesis highlighted that the directionality and mechanism of these attributes depends on the specific context, capacities and scale of the focal fishery system and associated stressors. We also found evidence of dependencies among individual resilience attributes; some attributes may require others to be activated or may erode resilience without the presence of others. Overall, we found few concrete examples measuring resilience attributes in fisheries across all parts of the system (but see Kleisner et al., 2021); most explicit examples, and particularly those that quantified attributes, were in the ecological dimension. As such, meaningful quantification of the attributes' contributions to resilience remains a challenge. Our synthesis thus highlights the need for further holistic empirical studies—including comparative cases—of how attributes confer resilience in different fisheries. Studies that indicate clear success stories with standardized language; specify resilience of what, to what and for whom; articulate clearly defined resilience attributes; and examine linkages between attributes and resilience will substantially contribute to enabling practitioners and communities to identify fruitful pathways towards building climate resilience in their fisheries systems.

ACKNOWLEDGEMENTS

This paper resulted from the Science for Nature and People Partnership (SNAPP) Climate Resilient Fisheries Working Group. SNAPP is a partnership of The Nature Conservancy and Wildlife Conservation Society. This SNAPP working group is part of a cohort of research funded by the generosity of the David and Lucile Packard Foundation Grant #2018-68222 to address the theme of Oceans, Climate, and Equity. The manuscript greatly benefited from all working group leaders, members and advisors and from additional external experts (see Supplementary Information for full list) who assisted in the development, conceptualization and peer review of the resilience attributes. George Freduah was a core part of the literature review and thematic coding. We are particularly grateful to Pat Sullivan for thoughtful comments that improved the manuscript and Hannah Epstein and Hugo Harrison for their thoughtful discussions and inputs to the resilience attributes. We thank Derek Armitage, Lyall Bellquist, Merrick Burden, Beth Fulton, Rod Fujita, Steve Gaines, Christopher Golden, Anne Hollowed, Sangeeta Mangubhai, Essam Mohammed, Myron Peck, Andy Pershing, Jöern Schmidt and Lynne Shannon for their peer review of the resilience attributes and Petri Tuohimaa for his graphic design work. We are also grateful for the financial support of the David R. and Patricia D. Atkinson Foundation (to JGM), the National Science Foundation (CNH 1826668 to JGE), the ARC Centre of Excellence in Coral Reef Studies, James Cook University, the CGIAR Research Program on Fish Agri-Food Systems (FISH) led by WorldFish, and the CGIAR Trust Fund (to JDL) and the Australian Research Council (CE140100020, FT160100047 to JEC). The manuscript greatly benefited from the input of two anonymous reviewers.

CONFLICT OF INTEREST

The authors have no conflict of interest to report.

DATA AVAILABILITY STATEMENT

This manuscript does not contain data. However, Supplementary Information is available for this paper and includes a more detailed description of the resilience attribute workflow, comprehensive definitions, mechanisms, examples of resilience attributes and the list of participants.

ORCID

Julia G. Mason https://orcid.org/0000-0002-8828-353X
Jacob G. Eurich https://orcid.org/0000-0003-1764-7524
Jacqueline D. Lau https://orcid.org/0000-0002-0403-8423
Willow Battista https://orcid.org/0000-0002-2616-2740
Christopher M. Free https://orcid.org/0000-0002-2557-8920
Katherine E. Mills https://orcid.org/0000-0001-6078-7747
Kanae Tokunaga https://orcid.org/0000-0002-6171-5187
Lily Z. Zhao https://orcid.org/0000-0001-6001-295X
Mark Dickey-Collas https://orcid.org/0000-0003-3154-8039
Mireia Valle https://orcid.org/0000-0001-8517-8518
Gretta T. Pecl https://orcid.org/0000-0003-0192-4339
Joshua E. Cinner https://orcid.org/0000-0003-2675-9317
Tim R. McClanahan https://orcid.org/0000-0001-5821-3584
Edward H. Allison https://orcid.org/0000-0003-4663-1396
Whitney R. Friedman https://orcid.org/0000-0001-9176-8397
Claudio Silva https://orcid.org/0000-0002-5831-2993
Kristin M. Kleisner https://orcid.org/0000-0002-6918-1546

REFERENCES

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, *24*(3), 347–364. https://doi.org/10.1191/030913200701540465

Alcala, A. C., & Russ, G. R. (2006). No-take marine reserves and reef fisheries management in the Philippines: A new people power revolution. *AMBIO: A Journal of the Human Environment*, *35*(5), 245–254.

Anderson, J. L., Anderson, C. M., Chu, J., Meredith, J., Asche, F., Sylvia, G., Smith, M. D., Anggraeni, D., Arthur, R., Guttormsen, A., McCluney, J. K., Ward, T., Akpalu, W., Eggert, H., Flores, J., Freeman, M. A., Holland, D. S., Knapp, G., Kobayashi, M., … Valderrama, D. (2015). The fishery performance indicators: A management tool for triple bottom line outcomes. *PLoS One*, *10*(5), e0122809. https://doi.org/10.1371/journal.pone.0122809

Amundsen, H. (2015). Place attachment as a driver of adaptation in coastal communities in Northern Norway. *Local Environment*, *20*(3), 257–276. https://doi.org/10.1080/13549839.2013.838751

Arlinghaus, R., Matsumura, S., & Dieckmann, U. (2010). The conservation and fishery benefits of protecting large pike (*Esox lucius* L.) by harvest regulations in recreational fishing. *Biological Conservation*, *143*(6), 1444–1459. https://doi.org/10.1016/j.biocon.2010.03.020

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, *21*(3), 995–1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Armitage, D., & Plummer, R. (2010). Adapting and transforming: Governance for navigating change. In D. Armitage, & R. Plummer (Eds.), *Adaptive capacity and environmental governance* (pp. 287–302). Springer. https://doi.org/10.1007/978-3-642-12194-4_14

Badjeck, M.-C., Allison, E. H., Halls, A. S., & Dulvy, N. K. (2010). Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy*, *34*, 375–383.

Baetscher, D. S., Anderson, E. C., Gilbert-Horvath, E. A., Malone, D. P., Saarman, E. T., Carr, M. H., & Garza, J. C. (2019). Dispersal of a near-shore marine fish connects marine reserves and adjacent fished areas along an open coast. *Molecular Ecology*, *28*(7), 1611–1623. https://doi.org/10.1111/mec.15044

Bahadur, A. V., Ibrahim, M., & Tanner, T. (2013). Characterising resilience: Unpacking the concept for tackling climate change and development. *Climate and Development*, *5*(1), 55–65. https://doi.org/10.1080/17565529.2012.762334

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, K. L., Funge-Smith, S., & Poulain, F. (2018). *Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge*. Adaptation and Mitigation Options.

Barbieri, M. A., Nieto, K., Silva, C., Yáñez, E., & Morales, J. (2002). Evaluation of potential swordfish (*Xiphias gladius*) fishing grounds along central Chile, by the use of remote sensed sea surface temperature satellite data. In J. Morales (Ed.), *Remote sensing applications for fisheries sciences, from science to operation: Eight computer-based learning module (Bilko for Windows)*. ITC ; Unesco, Paris VI, 246 pp. ITC Publication N° 83, ISBN 90616420949, 49-62.

Barneche, D. R., Robertson, D. R., White, C. R., & Marshall, D. J. (2018). Fish reproductive-energy output increases disproportionately with body size. *Science*, *360*(6389), 642–645. https://doi.org/10.1126/science.aao6868

Barrett, C. B., & Constas, M. A. (2014). Toward a theory of resilience for international development applications. *Proceedings of the National Academy of Sciences*, *111*(40), 14625–14630. https://doi.org/10.1073/pnas.1320880111

Bassett, H. R., Lau, J., Giordano, C., Suri, S. K., Advani, S., & Sharan, S. (2021). Preliminary lessons from COVID-19 disruptions of small-scale fishery supply chains. *World Development*, *143*, 105473. https://doi.org/10.1016/j.worlddev.2021.105473

Battista, W., Kelly, R. P., Erickson, A., & Fujita, R. (2018). Fisheries governance affecting conservation outcomes in the United States and European Union. *Coastal Management*, *46*(5), 388–452.

Battista, W., Romero-Canyas, R., Smith, S. L., Fraire, J., Effron, M., Larson-Konar, D., & Fujita, R. (2018). Behavior change interventions to reduce illegal fishing. *Frontiers in Marine Science*, *5*(403), 1–15. https://doi.org/10.3389/fmars.2018.00403

Baudron, A. R., Brunel, T., Blanchet, M.-A., Hidalgo, M., Chust, G., Brown, E. J., & Kleisner, K. M. (2020). Changing fish distributions challenge the effective management of European fisheries. *Ecography*, *43*, 494–505. https://doi.org/10.1111/ecog.04864

Bell, R. J., Richardson, D. E., Hare, J. A., Lynch, P. D., & Fratantoni, P. S. (2015). Disentangling the effects of climate, abundance, and size on the distribution of marine fish: an example based on four stocks from the northeast US shelf(*ICES Journal of Marine Science*, *72*, (5), 1311. –1322. https://doi.org/10.1093/icesjms/fsu217

Bennett, N. J., Di Franco, A., Calò, A., Nethery, E., Niccolini, F., Milazzo, M., & Guidetti, P. (2019). Local support for conservation is associated with perceptions of good governance, social impacts, and ecological effectiveness. *Conservation Letters*, *12*(4), e12640.

Berkeley, S. A., Hixon, M. A., Larson, R. J., & Love, M. S. (2004). Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries*, *29*(8), 23–32.

Berkes, F., Folke, C., & Colding, J. (2000). *Linking social and ecological systems: Management practices and social mechanisms for building resilience*. Cambridge University Press.

Biggs, R., Schluter, M., Biggs, D., Bohensky, E. L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L., & West, P. C. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annual Review of Environment and Resources*, *37*(1), 421–448. https://doi.org/10.1146/annurev-environ-051211-123836

Biggs, R., Schlüter, M. & Schoon, M. L. (2015). *Principles for building resilience: Sustaining ecosystem services in social-ecological systems*.

Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781316014240
Bindoff, N. L., Cheung, W. W. L., Kairo, J. G., Arístegui, J., Guinder, V. A., Hallberg, R., Hilmi, N. J. M., Jiao, N., Karim, M. S., Levin, L., O'Donoghue, S., Cuicapusa, S. R. P., Rinkevich, B., Suga, T., Tagliabue, A., & Williamson, P. (2019). Changing ocean, marine ecosystems, and dependent communities. In H.-O. Portner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegria, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate* (pp. 477–587). Intergovernmental Panel on Climate Change. https://eprints.qut.edu.au/206805/
Bodin, Ö., & Crona, B. I. (2009). The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change*, *19*(3), 366–374.
Brooker, R. W., Travis, J. M. J., Clark, E. J., & Dytham, C. (2007). Modelling species' range shifts in a changing climate: The impacts of biotic interactions, dispersal distance and the rate of climate change. *Journal of Theoretical Biology*, *245*(1), 59–65. https://doi.org/10.1016/j.jtbi.2006.09.033
Brown, K. (2014). Global environmental change I: A social turn for resilience? *Progress in Human Geography*, *38*(1), 107–117. https://doi.org/10.1177/0309132513498837
Brunner, R. D., Steelman, T. A., Coe-Juell, L., Cromley, C. M., Tucker, D. W., & Edwards, C. M. (2005). *Adaptive governance: Integrating science, policy, and decision making*. Columbia University Press.
Buheji, M. (2020). *Visualising Resilient Communities*. AuthorHouse.
Camp, E. V., Kaemingk, M. A., Ahrens, R. N. M., Potts, W. M., Pine, W. E. I., Weyl, O. L. F., & Pope, K. L. (2020). Resilience management for conservation of inland recreational fisheries. *Frontiers in Ecology and Evolution*, *7*(498), 1–17. https://doi.org/10.3389/fevo.2019.00498
Campling, L., Havice, E., & Howard, P. M. (2012). The political economy and ecology of capture fisheries: market dynamics, resource access and relations of exploitation and resistance. *Journal of Agrarian Change*, *12*(2-3), 177–203. https://doi.org/10.1111/J.1471-0366.2011.00356.X
Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems*, *4*(8), 765–781. https://doi.org/10.1007/s10021-001-0045-9
Chaffin, B. C., Garmestani, A. S., Gunderson, L. H., Benson, M. H., Angeler, D. G., Arnold, C. A., Cosens, B., Craig, R. K., Ruhl, J., & Allen, C. R. (2016). Transformative environmental governance. *Annual Review of Environment and Resources*, *41*, 399–423.
Charles, A., Kalikoski, D. C., & Macnaughton, A. (2019). *Addressing the climate change and poverty nexus* (p. 104). Rome, Italy: Food and Agriculture Organization of the United Nations.
Cheung, W. W. L., Watson, R., & Pauly, D. (2013). Signature of ocean warming in global fisheries catch. *Nature*, *497*(7449), 365–368. https://doi.org/10.1038/nature12156
Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. J., Gelcich, S., Hicks, C. C., Hughes, T. P., Lau, J., Marshall, N. A., & Morrison, T. H. (2018). Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change*, *8*(2), 117–123. https://doi.org/10.1038/s41558-017-0065-x
Cinner, J. E., & Barnes, M. L. (2019). Social dimensions of resilience in social-ecological systems. *One Earth*, *1*(1), 51–56. https://doi.org/10.1016/j.oneear.2019.08.003
Cinner, J. E., Daw, T. M., & McClanahan, T. R. (2009). Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. *Conservation Biology*, *23*(1), 124–130. https://doi.org/10.1111/j.1523-1739.2008.01041.x
Cinner, J. E., McClanahan, T. R., Graham, N. A., Daw, T. M., Maina, J., Stead, S. M., Wamukota, A., Brown, K., & Bodin, Ö. (2012). Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, *22*(1), 12–20. https://doi.org/10.1016/j.gloenvcha.2011.09.018
Crona, B., Gelcich, S., & Bodin, O. (2017). The importance of interplay between leadership and social capital in shaping outcomes of rights-based fisheries governance. *World Development*, *91*, 70. –83. https://linkinghub.elsevier.com/retrieve/pii/S0305750X16301176
Crozier, L. G., & Hutchings, J. A. (2014). Plastic and evolutionary responses to climate change in fish. *Evolutionary Applications*, *7*, 68–87. https://doi.org/10.1111/eva.12135
Cvitanovic, C., Hobday, A., McDonald, J., Van Putten, E., & Nash, K. (2018). Governing fisheries through the critical decade: The role and utility of polycentric systems. *Reviews in Fish Biology and Fisheries*, *28*(1), 1–18.
Dahlke, F. T., Wohlrab, S., Butzin, M., & Pörtner, H.-O. (2020). Thermal bottlenecks in the life cycle define climate vulnerability of fish. *Science*, *369*, 65–70.
Enberg, K., Jørgensen, C., Dunlop, E. S., Heino, M., & Dieckmann, U. (2009). Implications of fisheries-induced evolution for stock rebuilding and recovery. *Evolutionary Applications*, *2*(3), 394–414. https://doi.org/10.1111/j.1752-4571.2009.00077.x
Eurich, J. G., McCormick, M. I., & Jones, G. P. (2018). Direct and indirect effects of interspecific competition in a highly partitioned guild of reef fishes. *Ecosphere*, *9*(8), e02389. https://doi.org/10.1002/ecs2.2389
Fabinyi, M., Evans, L., & Foale, S. J. (2014). Social-ecological systems, social diversity, and power: Insights from anthropology and political ecology. *Ecology and Society*, *19*(4), art28. https://doi.org/10.5751/ES-07029-190428
Farrell, P., Thow, A. M., Wate, J. T., Nonga, N., Vatucawaqa, P., Brewer, T., Sharp, M. K., Farmery, A., Trevena, H., Reeve, E., Eriksson, H., Gonzalez, I., Mulcahy, G., Eurich, J. G., & Andrew, N. L. (2020). COVID-19 and Pacific food system resilience: Opportunities to build a robust response. *Food Security*, *12*(4), 783–791. https://doi.org/10.1007/s12571-020-01087-y
Finkbeiner, E. M. (2015). The role of diversification in dynamic small-scale fisheries: Lessons from Baja California Sur, Mexico. *Global Environmental Change*, *32*, 139–152. https://doi.org/10.1016/j.gloenvcha.2015.03.009
Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, *30*(1), 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511
Fulton, E. A. (2021). Opportunities to improve ecosystem-based fisheries management by recognizing and overcoming path dependency and cognitive bias. *Fish and Fisheries*, *22*(2), 428–448. https://doi.org/10.1111/faf.12537
Gallopin, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change-Human and Policy Dimensions*, *16*(3), 293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004
Gephart, J. A., Deutsch, L., Pace, M. L., Troell, M., & Seekell, D. A. (2017). Shocks to fish production: Identification, trends, and consequences. *Global Environmental Change*, *42*, 24–32. https://doi.org/10.1016/j.gloenvcha.2016.11.003
Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., Craigie, I., Darling, E. S., Free, C. M., Geldmann, J., Holst, S., Jensen, O. P., White, A. T., Basurto, X., Coad, L., Gates, R. D., Guannel, G., Mumby, P. J., Thomas, H., … Fox, H. E. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*, *543*(7647), 665–669. https://doi.org/10.1038/nature21708
Golden, C. D., Koehn, J. Z., Shepon, A., Passarelli, S., Free, C., Viana, D., Matthey, H., Eurich, J. G., Gephart, J. A., Fluet-Chouinnard, E., Nyboer, E., Lynch, A., Kjellevold, M., Bromage, S., Charlebois, P., Barange, M., Vannuccini, S., Cao, L., Kleisner, K. M., … Thilsted, S. H.

(2021). Aquatic foods for nourishing nations. *Nature*, *598*, 315–320. https://doi.org/10.1038/s41586-021-03917-1

Golden, C. D., Gephart, J. A., Eurich, J. G., McCauley, D. J., Sharp, M. K., Andrew, N. L., & Seto, K. L. (2021). Social-ecological traps link food systems to nutritional outcomes. *Global Food Security*, *30*, 100561. https://doi.org/10.1016/j.gfs.2021.100561

González-Quintero, C., & Avila-Foucat, V. S. (2019). Operationalization and measurement of social-ecological resilience: A systematic review. *Sustainability*, *11*(21), 6073. https://doi.org/10.3390/su11216073

Grafton, R. Q. (2010). Adaptation to climate change in marine capture fisheries. *Marine Policy*, *34*(3), 606–615. https://doi.org/10.1016/j.marpol.2009.11.011

Green, K. M., Selgrath, J. C., Frawley, T. H., Oestreich, W. K., Mansfield, E. J., Urteaga, J., Swanson, S. S., Santana, F. N., Green, S. J., Naggea, J., & Crowder, L. B. (2021). How adaptive capacity shapes the Adapt, React, Cope response to climate impacts: Insights from small-scale fisheries. *Climatic Change*, *164*(1), 15. https://doi.org/10.1007/s10584-021-02965-w

Grêt-Regamey, A., Huber, S. H., & Huber, R. (2019). Actors' diversity and the resilience of social-ecological systems to global change. *Nature Sustainability*, *2*(4), 290–297. https://doi.org/10.1038/s41893-019-0236-z

Gutiérrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, *470*(7334), 386–389. https://doi.org/10.1038/nature09689

Hall-Arber, M. (2005). Co-management at the eleventh hour? Participation in the governance of the New England groundfish fishery. In Tim S Gray (Ed.), *Participation in fisheries governance* (pp. 141–162). Springer.

Hare, J., Morrison, W., Nelson, M., Stachura, M., & Teeters, E. (2016). A vulnerability assessment of fish and invertebrates to climate change on the northeast U.S. Continental Shelf. *PLoS One*, *11*, 146756.

Harrison, H. B., Bode, M., Williamson, D. H., Berumen, M. L., & Jones, G. P. (2020). A connectivity portfolio effect stabilizes marine reserve performance. *Proceedings of the National Academy of Sciences of the USA*, *117*, 595-600.

Harrison, H. B., Williamson, D. H., Evans, R. D., Almany, G. R., Thorrold, S. R., Russ, G. R., Feldheim, K. A., Herwerden, L., Planes, S., Srinivasan, M., Berumen, M. L., & Jones, G. P. (2012). Larval export from marine reserves and the recruitment benefit for fish and fisheries. *Current Biology*, *22*(11), 1023–1028. https://doi.org/10.1016/j.cub.2012.04.008

Hilborn, R. (2007). Defining success in fisheries and conflicts in objectives. *Marine Policy*, *31*(2), 153–158. https://doi.org/10.1016/j.marpol.2006.05.014

Hixon, M. A., Johnson, D. W., & Sogard, S. M. (2014). BOFFFFs: On the importance of conserving old-growth age structure in fishery populations. *ICES Journal of Marine Science: Journal Du Conseil*, *71*(8), 2171–2185. https://doi.org/10.1093/icesjms/fst200

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

ICES (2021). *Advice on fishing opportunities. In Report of the ICES Advisory Committee, 2021. ICES Advice 2021, section 1.1.1.*. ICES. https://www.ices.dk/sites/pub/PublicationReports/Forms/DispForm.aspx?ID=37345

IPCC (2018). Summary for Policymakers. V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor & T. Waterfield, *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. (32). Geneva, Switzerland: World Meteorological Organization.

Isaac, N. J., & Cowlishaw, G. (2004). How species respond to multiple extinction threats. *Proceedings of the Royal Society of London B*, *271*, 1135–1141.

Jacobi, J., Mukhovi, S., Llanque, A., Toledo, D., Speranza, C. I., Käser, F., Augstburger, H., Delgado, J. M. F., Kiteme, B. P., & Rist, S. (2019). Actor-specific risk perceptions and strategies for resilience building in different food systems in Kenya and Bolivia. *Regional Environmental Change*, *19*(3), 879–892. https://doi.org/10.1007/s10113-018-1448-x

Kalikoski, D. C., & Allison, E. H. (2010). Learning and adaptation: The role of fisheries comanagement in building resilient social-ecological systems. In D. Armitage, & R. Plummer (Eds.), *Adaptive capacity and environmental governance* (pp. 69–88). Springer. https://doi.org/10.1007/978-3-642-12194-4_4

Kerner, D., & Thomas, J. (2014). Resilience attributes of social-ecological systems: Framing metrics for management. *Resources*, *3*(4), 672–702. https://doi.org/10.3390/resources3040672

Kleisner, K. M., Ojea, E., Amoros, S., Battista, W., Burden, M., Cunningham, E., Fujita, R., Karr, K., Mason, J., Rader, D., Rovegno, N., & Thomas-Smyth, A. (2021). Identifying policy approaches to build social-ecological resilience in marine fisheries with differing capacities and contexts. *ICES Journal of Marine Science*, fsab080. https://doi.org/10.1093/icesjms/fsab080

Kritzer, J. P., Costello, C., Mangin, T., & Smith, S. L. (2019). Responsive harvest control rules provide inherent resilience to adverse effects of climate change and scientific uncertainty. *ICES Journal of Marine Science*, *76*(6), 1424–1435. https://doi.org/10.1093/icesjms/fsz038

Leach, W. D., & Pelkey, N. W. (2001). Making watershed partnerships work: A review of the empirical literature. *Journal of Water Resources Planning and Management*, *127*(6), 378–385.

Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J. R., & Walker, B. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132. https://doi.org/10.1017/S1355770X12000460

Lim-Camacho, L., Hobday, A. J., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B., Norman-Lopez, A., Pecl, G. T., Plaganyi, E. E., Schrobback, P., Thebaud, O., Thomas, L., & van Putten, I. (2015). Facing the wave of change: Stakeholder perspectives on climate adaptation for Australian seafood supply chains. *Regional Environmental Change*, *15*(4), 595–606. https://doi.org/10.1007/s10113-014-0670-4

MacNally, R. C. (1995). *Ecological versatility and community ecology*. Cambridge University Press.

Madduppa, H., Martaulina, R., Zairion, Z., Renjani, R. M., Kawaroe, M., Anggraini, N. P., Subhan, B., Verawati, I., & Sani, L. M. I. (2021). Genetic population subdivision of the blue swimming crab (*Portunus pelagicus*) across Indonesia inferred from mitochondrial DNA: Implication to sustainable fishery. *PLoS One*, *16*(2), 1–14. https://doi.org/10.1371/journal.pone.0240951

Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton, N. (2020). Climate change and ecosystems: Threats, opportunities and solutions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*, 20190104.

Marschke, M. J., & Berkes, F. (2006). Exploring Strategies that Build Livelihood Resilience: A Case from Cambodia. *Ecology and Society*, *11*(1), JSTOR. https://www.jstor.org/stable/26267795

Marshall, N. A., & Marshall, P. A. (2007). Conceptualizing and operationalizing social resilience within commercial fisheries in Northern

Australia. *Ecology and Society*, *12*(1), http://www.jstor.org/stable/26267830
Marshall, N. A., Park, S. E., Adger, W. N., Brown, K., & Howden, S. M. (2012). Transformational capacity and the influence of place and identity. *Environmental Research Letters*, *7*(3), 34022. https://doi.org/10.1088/1748-9326/7/3/034022
Matin, N., Forrester, J., & Ensor, J. (2018). What is equitable resilience? *World Development*, *109*, 197–205. https://doi.org/10.1016/j.worlddev.2018.04.020
McClanahan, T. R., & Abunge, C. A. (2019). Conservation needs exposed by variability in common-pool governance principles. *Conservation Biology*, *33*(4), 917–929. https://doi.org/10.1111/cobi.13258
McClanahan, T. R., & Abunge, C. (2020). Perceptions of governance effectiveness and fisheries restriction options in a climate refugia. *Biological Conservation*, *246*, 108585. https://doi.org/10.1016/j.biocon.2020.108585
McClanahan, T. R., Darling, E. S., Mangubhai, S., Gurney, G. G., Lestari, W. P., Fox, M., & D'agata, S. (2021). Views of management effectiveness in tropical reef fisheries. *Fish and Fisheries*, *22*(5), 1085–1104. https://doi.org/10.1111/faf.12570
McClenachan, L., Scyphers, S., & Grabowski, J. H. (2020). Views from the dock: Warming waters, adaptation, and the future of Maine's lobster fishery. *Ambio*, *49*, 144–155. https://doi.org/10.1007/s13280-019-01156-3
Mcleod, E., Anthony, K. R. N., Mumby, P. J., Maynard, J., Beeden, R., Graham, N. A. J., Heron, S. F., Hoegh-Guldberg, O., Jupiter, S., MacGowan, P., Mangubhai, S., Marshall, N., Marshall, P. A., McClanahan, T. R., Mcleod, K., Nyström, M., Obura, D., Parker, B., Possingham, H. P., … Tamelander, J. (2019). The future of resilience-based management in coral reef ecosystems. *Journal of Environmental Management*, *233*, 291–301. https://doi.org/10.1016/j.jenvman.2018.11.034
Mendenhall, E., Hendrix, C., Nyman, E., Roberts, P. M., Hoopes, J. R., Watson, J. R., & Lam, V. W. Y. (2020). Climate change increases the risk of fisheries conflict. *Marine Policy*, *117*, 103954. https://doi.org/10.1016/j.marpol.2020.103954
Meuwissen, M. P. M., Feindt, P. H., Spiegel, A., Termeer, C. J. A. M., Mathijs, E., de Mey, Y., Finger, R., Balmann, A., Wauters, E., Urquhart, J., Vigani, M., Zawalińska, K., Herrera, H., Nicholas-Davies, P., Hansson, H., Paas, W., Slijper, T., Coopmans, I., Vroege, W., … Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656. https://doi.org/10.1016/j.agsy.2019.102656
Mooney, H., Larigauderie, A., Cesario, M., Elmquist, T., Hoegh-Guldberg, O., Lavorel, S., & Mace, G. M. (2009). Biodiversity, climate change, and ecosystem services. *Current Opinion in Environmental Sustainability*, *1*, 46–54. https://doi.org/10.1016/j.cosust.2009.07.006
Mumby, P. J., & Alan, H. (2008). The impact of ecosystem connectivity on coral reef resilience. *Journal of Applied Ecology*, *45*, 854–862. https://doi.org/10.1111/j.1365-2664.2008.01459.x
Murunga, M., Partelow, S., & Breckwoldt, A. (2021). Drivers of collective action and role of conflict in Kenyan fisheries co-management. *World Development*, *141*, 105413.
Naranjo, L., Castillo, J., & Yáñez, E. (2021). Carbon footprint of the hake fishery (*Merluccius gayi* gayi) in "Caleta Portales" of Valparaíso, Chile. *Latin American Journal of Aquatic Research*, *49*(4), 538–550. http://doi.org/10.3856/vol49-issue4-fulltext-2662
Nursey-Bray, M., Pecl, G. T., Frusher, S., Gardner, C., Haward, M., Hobday, A. J., Jennings, S., Punt, A. E., Revill, H., & van Putten, I. (2012). Communicating climate change: Climate change risk perceptions and rock lobster fishers. *Tasmania. Marine Policy*, *36*(3), 753–759. https://doi.org/10.1016/j.marpol.2011.10.015
Nyström, M., & Folke, C. (2001). Spatial resilience of coral reefs. *Ecosystems*, *4*(5), 406–417. https://doi.org/10.1007/s10021-001-0019-y
Østhagen, A., Spijkers, J., & Totland, O. A. (2020). Collapse of cooperation? The North-Atlantic mackerel dispute and lessons for international cooperation on transboundary fish stocks(*Maritime Studies*, *19*, (2), 155. –165. https://doi.org/10.1007/s40152-020-00172-4
O'Brien, K., Pelling, M., Patwardhan, A., Hallegatte, S., Maskrey, A., Oki, T., Oswald-Spring, Ú., Wilbanks, T., Yanda, P. Z., Giupponi, C., Mimura, N., Berkhout, F., Biggs, R., Brauch, H. G., Brown, K., Folke, C., Harrington, L., Kunreuther, H., Lacambra, C., … Viguié, V. (2012). Toward a sustainable and resilient future. In C. B. Field, V. Barros, T. F. Stocker, & Q. Dahe (Eds.), *Managing the risks of extreme events and disasters to advance climate change adaptation* (pp. 437–486). Cambridge University Press. https://doi.org/10.1017/CBO9781139177245.011
Ogier, E. M., Davidson, J., Fidelman, P., Haward, M., Hobday, A. J., Holbrook, N. J., & Pecl, G. T. (2016). Fisheries management approaches as platforms for climate change adaptation: Comparing theory and practice in Australian fisheries. *Marine Policy*, *71*, 82–93. https://doi.org/10.1016/j.marpol.2016.05.014
Ojea, E., Pearlman, I., Gaines, S. D., & Lester, S. E. (2017). Fisheries regulatory regimes and resilience to climate change. *Ambio*, *46*, 399–412.
Olds, A. D., Connolly, R. M., Pitt, K. A., & Maxwell, P. S. (2012). Habitat connectivity improves reserve performance. *Conservation Letters*, *5*, 56–63.
Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.
Ostrom, E.(2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422. https://www.sciencemag.org/lookup/doi/10.1126/science.1172133
Paoli, H., Heide, T., Berg, A., Silliman, B. R., Herman, P. M. J., & Koppel, J. (2017). Behavioral self-organization underlies the resilience of a coastal ecosystem. *Proceedings of the National Academy of Sciences of the United States of America*, *114*, 8035–8040.
Plagányi, É. E., Van Putten, I., Thébaud, O., Hobday, A. J., Innes, J., Lim-Camacho, L., Norman-López, A., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B., Hoshino, E., Jennings, S., Pecl, G., Pascoe, S., Schrobback, P., & Thomas, L. (2014). A quantitative metric to identify critical elements within seafood supply networks. *PLoS One*, *9*(3), e91833. https://doi.org/10.1371/journal.pone.0091833
Penas, E. (2007). The fishery conservation policy of the European Union after 2002: Towards long-term sustainability. *ICES Journal of Marine Science*, *64*(4), 588–595. https://doi.org/10.1093/icesjms/fsm053
Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., & Cheung, W. W. (2018). Preparing ocean governance for species on the move. *Science*, *360*(6394), 1189–1191. https://doi.org/10.1126/science.aat2360
Portes, A., & Vickstrom, E. (2011). Diversity, social capital, and cohesion. *Annual Review of Sociology*, *37*(1), 461–479. https://doi.org/10.1146/annurev-soc-081309-150022
Pörtner, H. O., & Knust, R. (2007). Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science*, *315*, 95–97. https://doi.org/10.1126/science.1135471
Ribot, J. C., & Peluso, N. L. (2009). A Theory of Access. *Rural Sociology*, *68*(2), 153–181. https://doi.org/10.1111/j.1549-0831.2003.tb00133.x
Richardson, L. E., Graham, N. A. J., Pratchett, M. S., Eurich, J. G., & Hoey, A. S. (2018). Mass coral bleaching causes biotic homogenization of reef fish assemblages. *Global Change Biology*, *24*(7), 3117–3129. https://doi.org/10.1111/gcb.14119
Richerson, K., Punt, A. E., & Holland, D. S. (2020). Nearly a half century of high but sustainable exploitation in the Dungeness crab (Cancer magister) fishery. *Fisheries Research*, *226*, 105528. https://doi.org/10.1016/j.fishres.2020.105528

Saavedra, C., Budd, W. W., & Lovrich, N. P. (2012). Assessing resilience to climate change in US cities. *Urban Studies Research*, *2012*, 1–10. https://doi.org/10.1155/2012/458172

Santora, J. A., Mantua, N. J., Schroeder, I. D., Field, J. C., Hazen, E. L., Bograd, S. J., Sydeman, W. J., Wells, B. K., Calambokidis, J., Saez, L., Lawson, D., & Forney, K. A. (2020). Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. *Nature Communications*, *11*(1), 536. https://doi.org/10.1038/s41467-019-14215-w

Scheffers, B. R., & Pecl, G. (2019). Persecuting, protecting or ignoring biodiversity under climate change. *Nature Climate Change*, *9*(8), 581–586. https://doi.org/10.1038/s41558-019-0526-5

Schindler, D. E., Hilborn, R., Chasco, B., Boatright, C. P., Quinn, T. P., Rogers, L. A., & Webster, M. S. (2010). Population diversity and the portfolio effect in an exploited species. *Nature*, *465*(7298), 609–612. https://doi.org/10.1038/nature09060

Schneider, H.(1999). Participatory governance for poverty reduction. *Journal of International Development: The Journal of the Development Studies Association*, *11*(4), 521–534.

Schultz, L., Folke, C., Österblom, H., & Olsson, P. (2015). Adaptive governance, ecosystem management, and natural capital. *Proceedings of the National Academy of Sciences*, *112*(24), 7369–7374. https://doi.org/10.1073/pnas.1406493112

Secor, D. H. (2000). Longevity and resilience of Chesapeake Bay striped bass. *ICES Journal of Marine Science*, *57*(4), 808–815. https://doi.org/10.1006/jmsc.2000.0560

Sheng, Y. K. (2009). *What is Good Governance?* (p. 3). United Nations Economic and Social Commission for Asia and the Pacific. https://www.unescap.org/resources/what-good-governance

Silva, C., Yáñez, E., Barbieri, M. A., Bernal, C., & Aranis, A. (2015). Forecasts of swordfish (*Xiphias gladius*) and common sardine (*Strangomera bentincki*) off Chile under the A2 IPCC climate change scenario. *Progress in Oceanography*, *134*, 343–355.

Singh, G. G., Hilmi, N., Bernhardt, J. R., Montemayor, A. M. C., Cashion, M., Ota, Y., Acar, S., Brown, J. M., Cottrell, R., Djoundourian, S., González-Espinosa, P. C., Lam, V., Marshall, N., Neumann, B., Pascal, N., Reygondeau, G., Rocklöv, J., Safa, A., Virto, L. R., & Cheung, W. (2019). Climate impacts on the ocean are making the Sustainable Development Goals a moving target travelling away from us. *People and Nature*, *1*(3), 317–330. https://doi.org/10.1002/pan3.26

Solomon, C. T., Dassow, C. J., Iwicki, C. M., Jensen, O. P., Jones, S. E., Sass, G. G., Trudeau, A., van Poorten, B. T., & Whittaker, D. (2020). Frontiers in modelling social–ecological dynamics of recreational fisheries: A review and synthesis. *Fish and Fisheries*, *21*(5), 973–991. https://doi.org/10.1111/faf.12482

Spijkers, J., & Boonstra, W. J. (2017). Environmental change and social conflict: The northeast Atlantic mackerel dispute. *Regional Environmental Change*, *17*(6), 1835–1851. https://doi.org/10.1007/s10113-017-1150-4

Stanford, R. J., Wiryawan, B., Bengen, D. G., Febriamansyah, R., & Haluan, J. (2017). The fisheries livelihoods resilience check (FLIRES check): A tool for evaluating resilience in fisher communities. *Fish and Fisheries*, *18*, 1011–1025.

Stoll, J. S., Harrison, H. L., De Sousa, E., Callaway, D., Collier, M., Harrell, K., Jones, B., Kastlunger, J., Kramer, E., Kurian, S., Lovewell, M. A., Strobel, S., Sylvester, T., Tolley, B., Tomlinson, A., White, E. R., Young, T., & Loring, P. A. (2021). Alternative seafood networks during COVID-19: Implications for resilience and sustainability. *Frontiers in Sustainable Food Systems*, *5*(614368). https://doi.org/10.3389/fsufs.2021.614368

Sunday, J. M., Pecl, G. T., Frusher, S., Hobday, A. J., Hill, N., Holbrook, N. J., Edgar, G. J., Stuart-Smith, R., Barrett, N., Wernberg, T., Watson, R. A., Smale, D. A., Fulton, E. A., Slawinski, D., Feng, M., Radford, B. T., Thompson, P. A., & Bates, A. E. (2015). Species traits and climate velocity explain geographic range shifts in an ocean-warming hotspot. *Ecology Letters*, *18*(9), 944–953. https://doi.org/10.1111/ele.12474

Tanner, T., Mitchell, T., Polack, E., & Guenther, B.(2009). Urban governance for adaptation: assessing climate change resilience in ten Asian cities. *IDS Working Papers*, *315*, 1–47. https://doi.org/10.1111/j.2040-0209.2009.00315_2.x

Townshend, I., Awosoga, O., Kulig, J., & Fan, H. (2015). Social cohesion and resilience across communities that have experienced a disaster. *Natural Hazards*, *76*(2), 913–938. https://doi.org/10.1007/s11069-014-1526-4

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. *Climate and Development*, *4*(4), 311–326. https://doi.org/10.1080/17565529.2012.745389

Ueda, K., & Torigoe, H. (2012). Why do victims of the tsunami return to the coast? *International Journal of Japanese Sociology*, *21*(1), 21–29. https://doi.org/10.1111/j.1475-6781.2012.01159.x

Valenzuela-Quiñonez, F. (2016). How fisheries management can benefit from genomics? *Briefings in Functional Genomics*, *15*(5):352–357.

Walker, B. H., & Salt, D. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Island Press.

Whitney, C. K., Bennett, N. J., Ban, N. C., Allison, E. H., Armitage, D., Blythe, J. L., Burt, J. M., Cheung, W., Finkbeiner, E. M., Kaplan-Hallam, M., Perry, I., Turner, N. J., & Yumagulova, L. (2017). Adaptive capacity: From assessment to action in coastal social-ecological systems. *Ecology and Society*, *22*(2), art22. https://doi.org/10.5751/ES-09325-220222

Yáñez, E., Lagos, N., Norambuena, R., Silva, C., Letelier, J., Muck, K., San Martin, G., Benítez, S., Broitman, S., Contreras, H., Duarte, C., Gelcich, S., Labra, F., Lardies, M., Manríquez, P., Quijón, P., Ramajo, L., González, E., Molina, R., … Böhm, G. (2018). Impacts of climate change on marine fisheries and aquaculture in Chile. In: P. Bruce, & M. Pérez (Eds.) *The impacts of climate change on fisheries and aquaculture* (Volume 1, Chapter 10, pp. 239–332). Editorial Wiley.

Yáñez, E., Sánchez, F., Barbieri, M. Á., Silva, C., & Soto, L. (2020). *Cambio climático y proyecciones de capturas chilenas de pez espada: Una primera aproximación* (Revista Versión Diferente, Año 17, N°32, pp. 70–71).

Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity—Moving toward a working definition of adaptive capacity. *Global Environmental Change*, *12*(1), 25–40. https://doi.org/10.1016/S0959-3780(01)00026-7

Yu, D. J., Schoon, M. L., Hawes, J. K., Lee, S., Park, J., Rao, P. S. C., Siebeneck, L. K., & Ukkusuri, S. V. (2020). Toward General principles for resilience engineering. *Risk Analysis*, *40*(8), 1509–1537. https://doi.org/10.1111/risa.13494

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Mason, J. G., Eurich, J. G., Lau, J. D., Battista, W., Free, C. M., Mills, K. E., Tokunaga, K., Zhao, L. Z., Dickey-Collas, M., Valle, M., Pecl, G. T., Cinner, J. E., McClanahan, T. R., Allison, E. H., Friedman, W. R., Silva, C., Yáñez, E., Barbieri, M. Á., & Kleisner, K. M. (2021). Attributes of climate resilience in fisheries: From theory to practice. *Fish and Fisheries*, 00, 1–23. https://doi.org/10.1111/faf.12630