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Identifying policy approaches to build social–ecological resilience in marine fisheries with differing capacities and contexts

Kristin M. Kleisner [1]*, Elena Ojea [2], Willow Battista[1], Merrick Burden[1], Erica Cunningham[1], Rod Fujita[1], Kendra Karr [1], Samuel Amorós[1], Julia Mason [1], Doug Rader[1], Nicolas Rovegno[3], and Alice Thomas-Smyth[1]

[1]*Oceans Program, Environmental Defense Fund, 257 Park Ave S, New York, NY 10010, USA*
[2]*CIM-Universidade de Vigo, Future Oceans Lab, Campus Lagoas Marcosende, Vigo 36310, Spain*
[3]*World Wildlife Fund Peru, Trinidad Morán 853, Lince, Lima-14, Peru*

**Corresponding author: tel: 1-617-406-1833; e-mail: kristin.kleisner@gmail.com.*

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Fisheries are critically important for nutrition, food security, livelihoods, and culture of hundreds of millions of people globally. As climate impacts on ocean ecosystems increase, policy-makers are asking critical questions about how to implement reforms at local and national levels to reach goals around improving performance of management systems, sustainability, equity, and resilience to climate change. These goals can be achieved by enhancing the structure, function, and biodiversity of marine ecosystems as climate change proceeds, together with adaptive, sustainable management. However, resource, technical, and governance capacities vary widely across management systems. These capacities will determine, in part, the best policy approaches to build resilience and overcome systemic challenges to equity and sustainability to stressors such as climate change. To illuminate how fisheries resilience can be improved within the constraints imposed by these capacity limits, we present case studies from Myanmar, Belize, Peru, and Iceland, which offer a spectrum of capacity conditions to explore social–ecological resilience challenges and solutions. Using a set of nine social–ecological resilience criteria, we examine each system's attributes that may confer or undermine resilience and explore interactions between them. We use this assessment to identify policy approaches that can help build resilience in each particular context.

Keywords: climate resilient fisheries, social–ecological systems, fisheries sustainability

Introduction

Climate change is affecting the distribution, abundance and productivity of marine biota from primary producers to top predators, creating challenges for fishers and fishery managers that require new solutions and ways of thinking (e.g. Poloczanska *et al.*, 2013; Free *et al.*, 2019; García Molinos, 2020). Free *et al.* (2020) found that despite the forecasted declines in productivity of global marine fisheries, implementing climate-adaptive fisheries management reforms could help protect yields and profits, and ameliorate many of the negative outcomes for livelihoods and food provisioning from climate change. Researchers have noted that there will be differences in the scale, scope, and severity of climate effects resulting in disproportionate impacts on different regions and groups of people (Cheung *et al.*, 2010; Lotze *et al.*, 2019; Österblom *et al.*, 2020), and that the inherent capacity of different ecological and socio-economic components of each system will affect the ability to deal with particular changes. These differences mean that there will likely not be one silver bullet solution (Ojea *et al.*, 2020), and how a particular fishery system can implement reforms will be highly nuanced and context dependent.

Against this backdrop, it is important to bring principles of fairness and equity forward to guide policies that promote sustainability and resilience in fisheries (Österblom *et al.*, 2020). Here, we are referring to sustainability as the ability to maintain ecosystem benefits (Zanotti *et al.*, 2020). Resilience is the ability of a social–ecological system to continue to deliver ecosystem benefits across a range of perturbations. Resilient systems do this in three main ways: (i) by resisting the perturbation and retaining their structure and function; (ii) by recovering their basic structure and function after a perturbation changes them; or (iii) by transforming into another system state or type of system such that ecosystem benefits continue to be delivered but by a fundamentally altered system (Ojea *et al.*, 2017; Zanotti *et al.*, 2020). Fairness and equity considerations are fundamental for stakeholder buy-in and cooperation among groups, and thus critical to attaining desired outcomes from management design and decision-making processes (Campbell and Hanich, 2015; Klinsky *et al.*, 2017; Cisneros-Montemayor *et al.*, 2019; Österblom *et al.*, 2020). Lack of fairness and equity with regard to procedural justice and/or outcomes may also create conflict, lack of compliance, and low social capital, thereby reducing the capacity of the system to deliver benefits across a range of perturbations (i.e., reducing its sustainability and resilience). Desired outcomes may include more common, resource-based values such as yields, profits, livelihoods, and food security. However, they also extend to a range of socio-cultural domains including the realization of values beyond yield and profits (Thornton and Kitka, 2015), varying from recreational pursuits to the consideration of local knowledge, to spiritual and cultural well-being (Donkersloot *et al.*, 2020). The need to prioritize equity and fairness in fisheries management is brought into even sharper relief as climate change affects access to marine resources and ecosystem services unevenly. This results in adverse effects to the environment, livelihoods and financial opportunities, food security and nutritional outcomes, and human health, producing greater impacts to vulnerable populations (e.g. Golden *et al.*, 2016; Thiault *et al.*, 2019). Equity principles must therefore help guide policy approaches for responding to climate change in fisheries.

Fisheries are complex social–ecological systems (SES) that have some common features, but are comprised of many different actors and processes that vary dramatically among them (Ostrom, 2009). Hence, fishery SES are appropriate foci for evaluating resilience to climate change (e.g. Ojea *et al.*, 2017; Free *et al.*, 2020) across a range of social and ecological contexts. Dealing with various challenges, including climate change, will depend largely on the system's ability to adapt and respond—that is, whether species, habitats, ecological processes, and human interactions with ecosystems can adjust in a timely manner such that desired outcomes are maintained. In practical terms, the system's inherent management and governance capacities, and the willingness of stakeholders to alter practices and embrace adaptations, will determine the ability to adapt. These capacities include the ability to assess how the system is responding to stressors and evaluate necessary strategies; financial resources and personnel to effectively execute a positive adaptive response; the ability of the governance system to adequately mobilize, coordinate, and manage the response needed; and the ability to engage in cooperation and foster buy-in of new policies (Bennett *et al.*, 2014; Pinsky and Mantua, 2014; Ojea *et al.*, 2020). A system with few economic resources and limited governance, scientific, technical and/or social capacity should have a more limited range of responses available relative to a system with more of these capacities. Furthermore, even in systems with relatively high capacities, responses may be limited by the need to allocate resources to other priorities, and be constrained by investment in a sophisticated (but perhaps less adaptive) infrastructure and management system, as well as by the need to ensure fairness and equity in the allocation of, and access to, resources (Österblom *et al.*, 2020). Understanding these limitations, and also where the most impactful leverage and intervention points are in a given system, will be critical for identifying the changes needed and the optimal approaches for achieving them.

Developing a framework for adaptive policy approaches

Researchers and practitioners have identified some basic elements of fisheries management that can help to make fisheries systems more sustainable and resilient that may be broadly applicable, but that need to be tailored to specific contexts in practice. For example, there are nine working principles for fisheries management presented in the Food and Agriculture Organization's Fishery Managers' Guidebook (Cochrane and Garcia, 2009). We can broadly summarize these principles into three main approaches:

A. **Develop inclusive, participatory management systems** in which power is shared and responsibilities are devolved appropriately. This can take the form of co-management at the local, regional, or national scales (Gutierrez *et al.*, 2011; Wilson *et al.*, 2018) and includes procedurally just decision-making processes at larger scales (e.g., for highly migratory species; Pentz *et al.*, 2018),
B. **Employ effective data collection and monitoring systems** (Barange *et al.*, 2018; Bradley *et al.*, 2019), which become increasingly important as climate change affects the distribution and productivity of stocks, and
C. **Adopt adaptive, science-based management approaches** designed to deliver benefits sustainably by managing human impacts based on objective observations of stock and fishery status. These approaches become even more critical in the face of climate change as conditions are altered (Pinsky and Mantua, 2014).

More recently, studies of climate change impacts and adaptation (e.g. Pinsky *et al.*, 2018; Holsman *et al.*, 2019; Free *et al.*, 2020; Holsman *et al.*, 2020) have noted several related approaches for achieving climate-resilient fisheries, including:

D. **Use forward-looking science to inform management**, which is focused on managing towards future conditions (e.g. climate adaptive approaches) rather than for past conditions that will not exist in a climate-altered future,
E. **Improve cooperation and coordination** through the effective use of subnational and international transboundary agreements and collaborations across borders as stock distributions and productivities change, and
F. **Consider the interplay of wider socio-economic and ecosystem components** to help to build whole-system resilience. This should include attempts to mitigate the effects of

systemic inequities that can be exacerbated by climate change, make societies inherently vulnerable to such change, and limit the benefits and resilience of a system overall.

Together, these six approaches for achieving equitable, sustainable, resilient fisheries can be considered as examples of adaptation policy approaches. These approaches are not independent, or mutually exclusive, in that they do not represent six distinct or unique routes for a fishery. Instead, depending on the situation in a given fishery system, combinations of the six approaches may be needed. Furthermore, as these approaches have been identified through an examination of the literature, they necessarily represent only those interventions which have been previously tried or suggested. As fisheries work to build socio-ecological system resilience in their own contexts, and to adapt to the specific impacts that manifest in their systems, it is possible that novel and innovative policy approaches may be identified in the field, which are not yet represented here.

In general terms, fisheries managers might begin by focusing on approaches A–C that help bolster sustainable fisheries management, which may then lay a foundation for engaging in approaches D–F that help build social-ecological resilience to a range of ecosystem impacts, including climate change (Cochrane *et al.*, 2011; Gaines *et al.*, 2018). For example, an adaptive management system (C) may first be needed to initiate approach D to effectively adjust planning that incorporates new scientific forecasts (Free *et al.*, 2020). However, these approaches do not need to be pursued in a strict stepwise manner. In particular, building awareness around the inequitable impacts that climate change will have on fisheries and vulnerable societies (F), both due to the disparate impacts of climate change and the magnification of existing inequalities, is something that would be worthwhile to engage on as early as possible. Building societal equity can be helpful in improving the economic growth and potential of developing countries and can help to build system resilience (Hewawasam and Matsui, 2020; Klassen and Murphy, 2020). Successfully implementing any of the approaches could serve as an entry point depending on the particular resource, technical, and governance capacity limitations in a system, and cumulatively, their implementation can enhance overall system sustainability, equity and resilience. As more of the approaches are implemented successfully, the system's ability to adapt should improve, potentially allowing for the continued production of desirable levels of ecosystem services, and for more equitable distributions of risks and benefits, even as climate change and other stressors interact unpredictably over time.

In order to respond to climate change and other stressors effectively at the local and regional scales, managers could focus on the specific policy approaches that are most needed in their context, and that are most feasible given their current levels of capacity. Using this framework as a guide, we explore whether managers could focus capacity-building efforts on enabling pursuit of the remaining approaches, as appropriate and necessary. Given that fisheries are SES (e.g. Ostrom, 2009; Basurto *et al.*, 2013; Palomo and Hernández-Flores, 2019), assessments of resilience to stressors should be integrated across ecological and social domains and scales. Not addressing resilience in such a multifaceted manner precludes an understanding of the tradeoffs and synergies between these dimensions, compromising the identification of the appropriate policy approaches.

In this article, we describe a way to diagnose the status of social-ecological resilience criteria in specific case studies of fisheries in Myanmar, Belize, Peru, and Iceland that vary in their inherent resource, technical and governance capacities. We use these diagnoses to recommend context-specific policy approaches for building sustainable, equitable, resilient systems. The case studies examined here exemplify highly disparate fishery systems in terms of system properties and characteristics (e.g. capacities, management goals, ecosystem properties like biodiversity and foodweb intricacy, climate impacts etc.), whose resilience can be qualitatively evaluated with nine social-ecological criteria defined by Ojea *et al.* (2017) for fisheries (definitions provided in Table S1). In addition to different levels of capacity in each of these systems, we consider, to the extent possible, the conditions promoting or hindering equity and fairness (e.g. whether or not these considerations are incorporated into management goals), as well as anticipated climate related impacts. We also examine how particular social–ecological resilience criteria may exhibit tradeoffs or enhance other criteria, which we view as a necessary step in evaluating which of the policy approaches might minimize these tradeoffs, and be a logical entry point to improving the sustainability, equity, and resilience of each system.

Methods

Our framework for analysis (Figure 1) is designed to help close the gap between general recommendations about the required responses to climate change in fisheries and the specific policy approaches that can be implemented at the local and national levels. We combined information on capacity shortfalls and socio-ecological resilience in several case studies, and we used resilience criteria from Ojea *et al.* (2017) to characterize the fisheries systems in Belize, Iceland, Myanmar, and Peru. We then used these characterizations to identify gaps in capacity and resilience components that allow us to discuss the best resilience policy approaches to better address the challenges of future climate change. To the extent possible, we considered the expected future conditions in the system under climate change or other stressors, and the extent to which fairness and equity are considered in management goals and may affect system resilience. Understanding the system context is key to determining what policy approaches are most needed and most feasible.

Fisheries social-ecological resilience

Ojea *et al.* (2017) defined three ecological resilience criteria and six social resilience criteria for assessing fisheries resilience. Supplementary Table S1 provides definitions and information on each criterion's ability to promote resilience, sustainability, and equity. We present these nine SES resilience criteria with an explanation of which climate adaptation policy approaches (A–F) they most closely link to in order to help us identify potential strategies to address specific resilience gaps (Table 1). For example, when a fishery system has a low qualitative score in one of the resilience criteria, this table helps us identify which policy approaches may result in increased resilience. This allows us to operationalize the resilience criteria and use them as a diagnostic instrument for the case studies.

Ojea *et al.* (2017) acknowledged that these ecological or social resilience criteria can interact. These interactions create a complicated set of tradeoffs between criteria that necessitate a clear

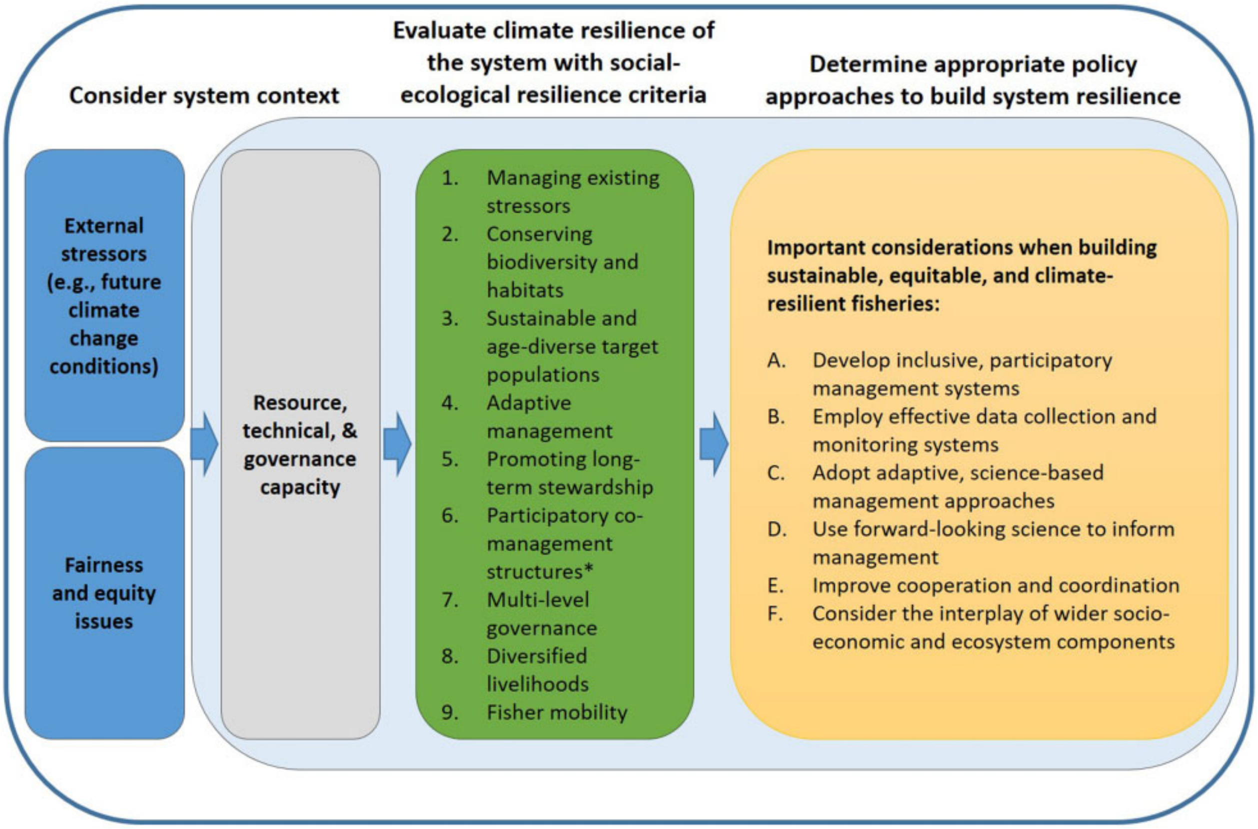

Figure 1. Framework for identifying potential global social-ecological resilience policy approaches (a–f). First build an understanding of the system context by considering the expected climate impacts and any inherent equity issues (dark blue boxes). In this study, we focus on the elements in the light blue box: assessing the existing resilience to climate change across systems with different resource, technical, and governance capacities (grey box) using social-ecological resilience criteria (green box), and using this information to determine appropriate policy approaches to build equitable, sustainable system resilience (yellow box). *Note that we have broadened one of the original Ojea *et al.* (2017) resilience criteria, "Community-based management" to "Participatory co-management structures" to be more inclusive of a wider array of inclusive management systems.

understanding of goals and objectives, and the likelihood for optimizing across goals in multiple dimensions (social, economic, and ecological). In particular, Ojea *et al.* (2017) noted tradeoffs occur when implementing management interventions to achieve ecological criteria, impacting social resilience. Those authors suggest that ecological criteria like 'Supporting sustainable and age-diverse populations' and 'Conserving biodiversity' can have both ecological and social benefits (e.g. increased income from sustainably managed stocks), but there may be less optimal societal outcomes as well (e.g. small vessel fishers with limited mobility and high fishery dependence may be disproportionately impacted by spatial restrictions and fishing mortality controls aimed at achieving these goals). We looked for evidence of tradeoffs and synergies in the case studies, and also hypothesized how particular criteria may interact in different ways.

Four case study systems

Using these nine social–ecological resilience criteria identified in Ojea *et al.* (2017), we evaluated the resilience of fishery systems in four countries that were selected because they represent a spectrum of governance and capacity settings (Figure 2). We explored the resilience of each fishery system across the nine criteria using a set of 21 open-ended questions (see Supplementary Materials) that we used to solicit answers posed to eight external experts familiar with each system (Supplementary Table S2). The questions were designed to capture information that could be used to assess each of the resilience criteria. Questionnaires were administered by telephone, video call, or email correspondence by the case study leads (i.e. designated case study co-authors, see Supplementary Table S2), who all have experience working in each of the case study regions. They were undertaken voluntarily by the external experts in English for Myanmar, Iceland, and Belize, and in Spanish for Peru. The case study leads synthesized answers from the participating external experts to obtain a nuanced picture of resilience along each of the criteria and produced a case study narrative for each country. The level of detail provided by the external experts varied with their areas of expertise. The case study leads used information obtained with the questionnaire to assess, to the degree possible, how resilience along one criterion might support or detract from resilience along another criterion, summarized in Table 2. These assessments were reviewed by the rest of the co-authors and were also provided to the external experts for their review and validation. In the case of Myanmar, we were only able to obtain cross-validation reviews from one of three external reviewers due to extenuating

Table 1. Mapping the social–ecological system (SES) resilience criteria onto the general fisheries policy approaches (A–F).

	Policy approaches required						
SES resilience criteria	**A**	**B**	**C**	**D**	**E**	**F**	**Approaches for building system resilience**
Managing existing stressors	x	x	x		x	x	Will require management approaches that bring together diverse stakeholders from multiple sectors into a participatory process (A), build on robust data and monitoring (B), and that are adaptive to multiple stressors beyond just fishing mortality (C). If stressors are managed by various entities with differing jurisdictions, inter-jurisdictional and/or international cooperation (E) will also be necessary. Managing existing stressors requires a comprehensive understanding of the system to build socio-economic and ecosystem resilience (F).
Conserving biodiversity and habitats	x	x	x		x	x	A participatory approach (A) will be key to ensure the equitable distribution of the costs and benefits associated with conserving biodiversity and habitats. Good data collection and monitoring (B) will also be required, as will the use of these data to inform adaptive management interventions (C). In some cases (e.g. when ranges and habitats, and threats to them, span jurisdictions), cooperation across jurisdictions (E) will be necessary. A comprehensive understanding of the system (F) will also be needed.
Sustainable, age-diverse populations		x	x	x			Will necessitate collecting robust data over time (B), using these data in adaptive, science-based management approaches (C), and anticipating future conditions so that management interventions can be altered if needed (D).
Adaptive management	x	x	x	x	x	x	Participatory approaches (A) foster equitable outcomes of adaptive management as well as increase buy-in necessary for good compliance. Collecting robust data over time (B) will allow managers to be responsive and nimble to the effects of climatic and environmental variability by driving science-based adaptive measures (C). Forward-looking science (D) will be necessary for planning adaptive responses. Because some stocks are likely to shift across jurisdictions, inter-jurisdictional coordination (E) and consideration of the wider socioeconomic context of the fishery (F) will be necessary to ensure that management is adaptive.
Promoting long-term stewardship	x	x	x	x	x	x	The responsible use of natural resources, balancing the interests of society, future generations, and other species, as well as of private needs will be aided by establishing inclusive, participatory co-management systems that confer rights to fishers, incentivizing protection of resources (A). Ensuring the long-term effects of good stewardship will require the collection of data and ecological knowledge (B) that can help monitor variability in the system and allow for management to make changes as needed to protect resources (C). Will be aided by an understanding of future changes to drive planning processes (D) and by cooperation across jurisdictions to reduce overfishing (E). Considering the wider socioeconomic context of a fishery (F) may reveal other opportunities to promote long-term stewardship (e.g. activities that add value to the catch or generate additional income streams to increase planning horizons, which is associated with long term stewardship).
Participatory co-management structures	x		x		x		Inclusive and participatory processes (A) are essential for co-management (i.e. community-based management as well as effective management at higher national and international scales). The incorporation of local knowledge into adaptive management interventions and regulations (C) can increase social capacity and buy-in to management measures. Establishing clear roles, rights, and responsibilities of management entities and other governance institutions (E)—including power-sharing arrangements—is also necessary.
Multi-level governance	x			x	x	x	Will necessitate inclusive, participatory management that operates across multiple scales (A), which has been shown to increase socio-ecological resilience through improved capacity to deal with climate impacts and balance ecosystem dynamics (F). Will be aided by an understanding of future changes to drive planning (D). Establishing clear roles, rights, and responsibilities of all entities engaged in fisheries governance across governance levels and jurisdictions (E)—including power-sharing arrangements—is also necessary.
Diversified livelihoods		x		x		x	Will necessitate collecting robust data over time (B) that will allow managers to be responsive. Adaptive, forward-looking approaches will aid in planning efforts (D). Considering the wider socio-economic context of fisheries (e.g., demand for certain products or services, access to capital, infrastructure, labor markets, etc.) is necessary for successfully diversifying livelihoods (F).
Fisher mobility	x		x	x	x		Inclusive and participatory processes (A) are necessary to foster mobility without compromising stewardship incentives or encouraging encroachment upon established fishing territories. Management responses may have to become even more adaptive (C) as fisher mobility increases. Forward-looking science (e.g. projections of stock shifts; D) will be necessary for planning and for weighing the costs associated with chasing fish (e.g. fuel, ice, labour) relative to benefits. International or inter-jurisdictional cooperation (E) may be necessary to facilitate fisher mobility for fisheries with long-range vessels experiencing rapid stock shifts cross borders.

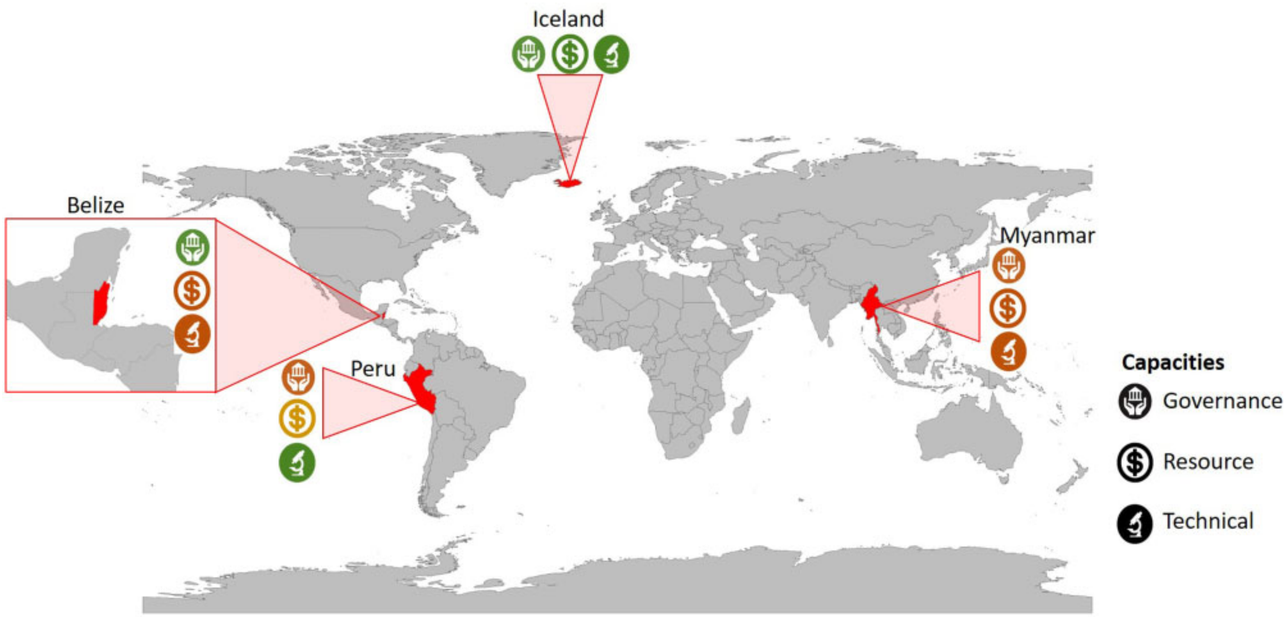

Figure 2. Map of the case study systems with a qualitative (high = green, medium = yellow, and low = red) assessment of each countries' governance, resource, and technical capacities.

circumstances (COVID-19 pandemic and *coup d'etat* in January 2021). We then determined, based on consideration of approaches for building sustainable and resilient fisheries (Figure 1), particular policy approaches that might be most critical for each fishery system to focus on to build stronger and more climate resilient fisheries management. Finally, we used the qualitative responses from each case study questionnaire to synthesize examples of synergies and tradeoffs among the resilience criteria and present this information in a synthesis table (Table 3), identifying examples we noted in the case studies along with some additional theoretical examples.

Results

Myanmar's nearshore small-scale fisheries

Historical records from the late 1880s suggest that Myanmar's coastal waters once contained a great diversity of fish species across large coral reef, estuarine, and mangrove habitats (Day, 1889). Until the 1960s, Myanmar's marine fisheries were considered to be lightly exploited owing largely to a preference for freshwater fish among the domestic population and a lack of major investments in seagoing vessels, ports, and other infrastructure (Tezzo *et al.*, 2018). However, over the past six decades, a variety of factors have coalesced to increase pressure on the country's marine resources both for domestic consumption and export, and they are now generally considered to be severely overexploited. The rise in fishing pressure in Myanmar traces back to 1962 when the People's Pearl and Fisheries Board was established, and domestic marine fishing activity using motorized vessels developed (Tezzo *et al.*, 2018). Over-use and poor management of agricultural resources drove many former farmers into the fishing industry. Then, in the 1970s, international agencies contributed to fishing capacity enhancements by providing funds for fisheries development. Beginning in 1989, foreign countries began to lease fishing rights from the Myanmar government to fish in offshore waters (Tezzo *et al.*, 2018). This rapid influx of foreign vessels increased fishing mortality and stock depletion substantially during the 1990s.

Currently, the government divides management of marine fisheries between inshore and offshore sectors, with inshore fisheries taking place within 10 nautical miles of shore and consisting of relatively small vessels (9 m in length, engines limited to 25 horsepower). Offshore fisheries occur outside 10 nautical miles and consist of larger vessels using more intensive gear types, as well as foreign vessels that have leased fishing rights from the government (Pe, 2004). Today, inshore marine fisheries in Myanmar are generally small-scale in terms of numbers of fishers employed and domestic importance, and predominantly employ gillnet, driftnet, and long line gears (Tezzo *et al.*, 2018). Offshore fishers predominately using trawls and, increasingly, light-boat purse seines generate most of the fish that are exported by Myanmar.

Myanmar has seen considerable economic growth in recent years, reporting an annual GDP growth rate of 6.4% compared to an average for ASEAN countries of 5% (The World Bank, 2017a). This has stemmed in part from fisheries, which are the second most important sector in the country, following agriculture, for its economic value and nutritional contribution. However, Myanmar also has the highest share of its population living below the poverty line of all ASEAN countries (Asian Development Bank, 2019), and rural areas in Myanmar, which include most coastal small-scale fishing communities, tend to be the most impoverished in the country (The World Bank, 2017b). Fisheries are a key source of nutrition and income for many coastal communities in Myanmar (Tezzo *et al.*, 2018). Predicted climate-driven stock shifts are therefore likely to increase levels of poverty as well as the risk of malnutrition for these already vulnerable communities (Golden *et al.*, 2016). Thus, improving the sustainability of fisheries and the health and resilience of the ecosystems

Table 2. Comparative evaluation of Myanmar's nearshore small-scale fisheries, Belize's reef-based finfish fisheries, Peru's giant squid fishery, and Iceland's demersal fisheries across the nine social–ecological resilience criteria.

Social-ecological resilience criteria	Qualitative assessment				Comparative assessment
	Myanmar	Belize	Peru	Iceland	
Managing existing stressors	Low	Medium–High	Low	Medium–High	Myanmar: Low capacity for resource management. Belize: Extensive MPA network, MAAs, funded initiatives to reduce stressors, and adaptive management of high value stocks have reduced existing stressors. Peru: Lack of monitoring of ecosystem conditions precludes assessment of marine resource impacts. Iceland: Ranks high in environmental quality evaluations but not a fisheries policy priority.
Conserving biodiversity and habitats	Low	Medium–High	Medium–Low	Medium–High	Myanmar: Widespread biodiversity and habitat loss—low capacity for assessment/management. Belize: Improved conservation has increased the scope for good fishery outcomes. Peru: Lack of specific regulations in place to prevent habitat or biodiversity loss. Iceland: Relatively extensive networks of protected areas and closures focused on commercial stocks
Sustainable and age-diverse target populations	Low	Medium–Low	Medium–Low	High	Myanmar: Age structure of many stocks is truncated—low capacity for assessment/management. Belize: Size and fishing mortality limits should help restore age diverse conch/lobster populations. Peru: Lack of robust management of most stocks, but may have capacity to improve. Iceland: Fisheries are generally sustainable, age-diverse, and considered healthy.
Adaptive management	Low	Medium–Low	Medium–Low	High	Myanmar: Adaptive management capacity is low; may increase with successful co-management. Belize: Adaptive management for conch, but adaptive management of other stocks has been limited. Peru: Low adaptive capacity of management for most species due to limited monitoring and assessment and resource capacity. Iceland: Highly adaptive management process and fishers can choose and specialize among stocks.
Promoting long-term stewardship	Low	High	Medium–Low	Medium–High	Myanmar: Lack of secure fishing rights for the nearshore fishery is limiting stewardship. Belize: Extensive MPA network and MAAs (with secure access rights) supported by community. Peru: Fishery regulations for giant squid are lacking for the artisanal fleet. Iceland: ITQs generated stewardship incentives within an economic framework
Participatory management structures	Medium–Low	High	Low	Low	Myanmar: Community-based co-management is in the early stages of development. Belize: MAAs are facilitating the development of adaptive community-based management systems. Peru: Participation remains low for artisanal fleet; community-based management not recognized. Iceland: Few opportunities for fishers to participate in decision-making.
Multi-level governance	Low	Medium–High	Low	Medium–Low	Myanmar: Highly centralized governance precludes effective co-management. Belize: Fisheries Law and coordination between MAA and central government has been effective. Peru: Highly centralized governance is inadequate for the highly migratory giant squid fishery. Iceland: Highly centralized governance limits participatory management structures at local levels.
Diversified livelihoods	Low	Medium–Low	Medium	Medium	Myanmar: Lack of infrastructure to access diverse markets, absence of skilled workforce, and limited capital are contributing to a heavy reliance on fisheries for livelihoods and food security. Belize: Relatively high dependence on fishing in coastal communities, few efforts to diversify. Peru: Giant squid fishers target other species. However, few livelihood options outside of fishing. Iceland: High quota prices have tied some fishers to industry, and made it difficult for newcomers.
Fisher mobility	Low	Medium	Medium–High	High	Myanmar: Fisher mobility is highly constrained due to size of vessels and fuel constraints. Belize: Fisher mobility is somewhat limited due to size of vessels and may be constrained by MAA. Peru: High mobility helps to limit concentration of impacts, but may result in conflicts between fishers. Iceland: Fishers are highly mobile with technology allowing distant-water fishing and longer trips.

Table 3. Synergies and tradeoffs between the SES resilience criteria.

Resilience criteria	Managing existing stressors	Conserving biodiversity and habitats	Sustainable and age-diverse target populations	Adaptive management	Promoting long-term stewardship	Participatory co-management structures	Multi-level governance	Diversified livelihoods	Fisher mobility
Managing existing stressors		B: (+) Buffers against external stressors	B, I: (+) Buffers against external stressors	B: (+) Strengthens system resilience and increases the scope for adaptive management (−) Diverts funding from fisheries	B: (+) Fosters pride via better whole system condition and increases ecosystem capacity to generate goods and services	(+) Brings together diverse stakeholders to address existing stressors	(+) Strengthens linkages between scales and institutions and facilitates managing existing stressors across governmental siloes	B: (+) Could increase scope for alternative livelihoods by increasing ecosystem goods and services I: (−) Limits via regulations in other sectors	(−) Could reduce access to the resource via regulations in other sectors
Conserving biodiversity and habitats	B: (+) Improves ecosystem buffers		B, I: (+) Improves ecosystem buffer	B: (+) Strengthens system resilience	B: (+) Fosters pride via better whole system condition	(+) Fosters pride via better whole system condition	(+) Improves conservation at scale	B: (+) Improves options for other resource-based livelihoods	I: (-) Reduces access to the resource
Sustainable and age-diverse target populations	(+) Improves population buffer	(+) Improves population buffer and ecosystem function		I: (+) Strengthens system resilience by producing multiple cohorts	(+) Fosters pride via better whole system condition, and produces multiple cohorts that can maintain yield over time	(+) Fosters pride via better whole system condition	(+) Improves restoration of age structure at scale	(+) Can increase diversity of market channels	(−) Reduces access to the resource
Adaptive management	(+) Improves flexibility in response	(+) Improves flow of science to management	I: (+) Improves flow of science to management		(+) Helps keep options open for long-term flow of benefits	(+) Improves prospects for collective action that facilitates adaptive management I: (−) If participation and inclusion are not prioritized	(+) Could improve flexibility to respond rapidly to change I: (−) Adaptive management may still operate within a highly centralized system limiting options for collaborative decision-making	(+) Improves capacity for dealing with social-ecological impacts I: (−) If economic incentives are prioritized above social equity (e.g., consolidation)	I: (+) Promotes flexibility in response
Promoting long-term stewardship	B: (+) Buffers against stressors	B: (+) Motivates use of better management	B, I: (+) Motivates use of better management, produces more cohorts	B: (+) Motivates use of better management		B: (+) Improves prospects for collective action aligned with long term stewardship	I: (+) Motivates use of better management	(−) May increase fishery dependence thereby reducing incentives to pursue other livelihoods options	(+) Motivates stewardship behavior when fishing in new areas M: (−) Secure tenure rights may promote long-term stewardship at the expense of fisher mobility

Continued

Table 3. continued

Resilience criteria	Managing existing stressors	Conserving biodiversity and habitats	Sustainable and age-diverse target populations	Adaptive management	Promoting long-term stewardship	Participatory co-management structures	Multi-level governance	Diversified livelihoods	Fisher mobility
Participatory co-management structures	(+) Fosters better management at multiple levels	(+) Fosters conservation via vested interest	(+) Fosters conservation via vested interest	B: (+) Fosters assimilation of local data and collective action to implement adaptive management	(+) Generates incentives for stewardship		(+) Good management at community levels could promote better governance if tied into higher levels	(+) Identifies opportunities for alternative livelihoods based on community need and collective action to create them	(+) If management entities allow access to portfolios of species as mixes are changing may increase fisher mobility (−) If assignment of rights is to exclusive areas, may impede fisher mobility
Multi-level governance	(+) Strengthens linkages between scales and institutions	B: (+) Strengthens linkages between scales and institutions	B: (+) Strengthens linkages between scales and institutions	B: (+) Improves capacity for adaptive management at multiple scales (−) May reduce flexibility for rapid response	(+) Builds trust/ longevity via networked governance structure (−) Depending on structure, could reduce incentives for long-term stewardship	B: (+) Strengthens linkages between community and other scales of management		(+) Could mobilize more resources for development of alternative livelihoods (−) Limits via regulations at other levels	(+) May allow for local fishers to access migratory species that are managed at higher levels (−) May limit flexibility via regulations at other levels

The entries in the table are the effect of a high level of the criteria in the first column on the criteria in the subsequent columns. A '+' signifies a positive (synergistic) effect, a '−' signifies a negative (tradeoff) effect. Cells in white note where a particular linkage was observed in one of the case studies (M: Myanmar, B: Belize, P: Peru, I: Iceland). Cells in grey indicate a hypothesized linkage. Note that most tradeoffs were identified in resilience criteria that scored Medium-High or High.

they depend on will be critical to addressing existing and future inequities in this country.

While recent efforts have been made to characterize small-scale fishing communities in discrete locations in Myanmar (e.g. MacKeracher *et al.*, 2021; Mizrahi *et al.*, 2020; Exeter *et al.*, 2021), the condition of marine resources in Myanmar remain poorly understood, and there is little peer-reviewed documentation of catch or other data that can help assess the status and health of fisheries in this region (Tezzo *et al.*, 2018). Evidence from fishery-independent research cruises, anecdotal records, historical natural history observations, and local sources suggests that years of inadequate management and heavy exploitation has led to the near-collapse of many marine fish stocks, including the depletion of many predatory species (e.g. Day, 1889; Strømme, 1981; Krakstad *et al.*, 2014; Akester, 2019). Indeed, survey data from a Norwegian/FAO research vessel, the "Dr. Fridtjof Nansen," suggest that a significant prey release has occurred as a result of relatively unmanaged fishing activity and the subsequent reduction of upper trophic level predators (Krakstad *et al.*, 2014). The relative lack of data collection and capacity to assess the diversity of multi-species stocks in this region has contributed to a significant decline in the fisheries in this country, and the ability to maintain *sustainable and age-diverse populations* (one of the nine social-ecological resilience criteria assessed; Table 2) has suffered. Recently, the Department of Fisheries (DoF) outlined a vision and set of objectives for managing fisheries to rebuild resources and improve the lives of people dependent on them (although it is not known whether these objectives will be prioritized by the government going forward in light of the recent *coup d'état* in January 2021 (The results presented in the Myanmar case study pertain to the pre-*coup d'état* period. We note this as a caveat as there may be effects on fisheries management and social well-being that may affect the interpretations made here.)). In addition to these spatial divisions, Myanmar's fishing regulations include licensing, seasonal closures, species-specific protected areas, co-management areas, gear limitations, and bans on blast fishing. Additionally, closed areas have been established to protect juveniles and other wildlife. However, Myanmar suffers from a lack of resources to adequately monitor and enforce regulations, so illegal fishing and violations are common (Tezzo *et al.*, 2018; MacKeracher *et al.*, 2019; Mizrahi *et al.*, 2019).

In addition, the ability to *conserve biodiversity and habitats* and to *manage external stressors* has been hampered by weak management and low governance capacity and a lack of monitoring and enforcement in Myanmar (Table 2). The country's marine ecosystems have suffered damage due to direct impacts stemming from coastal development, effects of population growth and increasing demand for fish, and the impacts of climate change, including increasing seawater temperatures and acidity, sea level rise, and increased frequency and intensity of storms and coral bleaching events (Vivekanandan *et al.*, 2016). Climate-driven losses in fishery productivity threaten to increase rates of malnutrition for the most vulnerable and fisheries-dependent communities throughout the equatorial tropics, and the coastal communities of Myanmar are no exception (Golden *et al.*, 2016). Furthermore, the impacts of overfishing have been exacerbated in Myanmar by upstream impacts, including increased runoff due to extensive deforestation, altered water flow patterns due to damming and irrigation, and pollution resulting from poor waste management, infrastructure, and agriculture (Rao *et al.*, 2013). The result of these compounding stressors is that Myanmar's marine ecosystems are far less complex, diverse, and abundant now compared to several decades ago, and are dominated by species at relatively low trophic levels. Together, these changes have led to drastically altered habitat structures and ecosystem mosaics throughout the country's coastal waters, which reduce system resilience, fishery productivity, and the ability for vulnerable coastal communities to support themselves now and into the future.

The low level of governance capacity in Myanmar (especially in light of the recent *coup d'état*) underscores the need for *multi-level governance* (Table 2) as a means to fishery reforms in this country. Polycentric or *multi-level governance* systems can partially safeguard management decisions through periods of national-level governance transition and turmoil. Furthermore, Myanmar's highly centralized governance structure tends to result in management that does not fully account for the local context, and therefore decisions are taken that do not have support from all stakeholders (Tezzo *et al.*, 2018). Most management regulations are created at the national level with minimal regional variation, and are generally applicable to both offshore industrial and nearshore small-scale fisheries. Furthermore, the very limited financial resources and personnel capabilities of the central governing agency further limit the efficacy of fishery regulations (Table 2). A multi-level governance structure would promote collaboration, connectivity, and learning across institutions and scales, enabling faster responses to change and disturbance.

In addition to decentralization, Myanmar's fisheries would benefit greatly from the development of a *participatory co-management structure* to facilitate community-based management (Table 2). Such a system could greatly increase the equitability of the management process by ensuring all impacted stakeholders, and especially groups who have historically been marginalized in this sector and country, such as women, ethnic and religious minorities, are represented in management decision-making. However, the cultural complexity that exists in many coastal societies within Myanmar appears to be a limiting factor for the progress rate of community-based management, meaning that in some places effective decentralization of fisheries management may face stiff challenges (Crawford *et al.*, 2006). Myanmar has recently begun implementing secure fishing rights as part of the implementation of locally managed marine areas (LMMAs), with similar efforts taking place in the fishery co-management system for the nearshore, small-scale fisheries. This can help to ensure the benefit flows from fishery reforms are distributed equitably (as the rights-holders will be the ones who gain from increased productivity as overfishing is reduced and stocks recover). Co-management systems have been implemented in some small-scale fisheries along the coast of Myanmar, such as one for crab conservation in 2017, a co-management area applied to multi-species management in 2018, and the establishment of several LMMAs that secure exclusive fishing rights for island communities in the Myeik Archipelago. Additionally, the crab conservation area is expanding to safeguard multiple species via more protections for mangrove nursery areas and important fishing grounds for several historic fishing communities in the area. Currently, the government of Myanmar is developing a set of Co-Management Guidelines under the Department of Fisheries, and is in the process of establishing a Marine Protected Area Policy, under which the co-management areas would also fall. Recently, the government was approving co-management plans that do not conflict with national level regulations and that demonstrate sufficient capacity to manage a fishery. However, given that the Department of Fisheries will continue to be the party responsible for enforcement actions and approval of co-management plans, it is unclear how these roles and processes will continue moving forward. The capacity for local community associations to develop management plans and petition for a co-management area are limited; however, several communities have expressed the goal of better stewardship, and are working with NGOs for technical guidance. Success of these co-management systems may provide incentives for *promoting long-term stewardship*, which are currently lacking, and allow for an increase in *adaptive management* if managers are more directly involved with their fisheries and have the ability to tailor regulations to the system. However, time will be needed to assess these types of outcomes (Table 2).

Alternative income sources are scarce for Myanmar's nearshore, small-scale fishing communities (Mizrahi *et al.*, 2020), which makes these communities especially vulnerable to any shocks to this industry. Often the only alternatives to fishing in these areas, which are typically remote with variable accessibility depending on the season, are seasonal agriculture or animal husbandry. The women in these communities are active participants in post-harvest activities and have even fewer income opportunities available to them. Women are thus one of the most vulnerable groups within a vulnerable sector (small-scale fisheries), in a highly vulnerable country (Weeratunge *et al.*, 2010; Harper *et al.*, 2013). Other vulnerable groups include marginalized ethnic communities, such as the Moken (https://www.frontiermyanmar.net/en/moken-fear-a-sea-grab-in-the-myeik-archipelago/), whose well-being is particularly vulnerable due to their cultural ties to fishing and their history as an ocean-based nomadic society, and Rohinga Muslims (Human Rights Watch, 2020). Myanmar's nearshore fishing communities would clearly benefit from *diversified livelihoods* (Table 2) to help increase socio-ecological system resilience, particularly as members of some of these communities report that illegal fishing during closed seasons is especially high due to the lack of other sources of income (K. MacKay, pers. comm.). Fisheries in Myanmar are highly multi-species, and while nearshore fishers may seek to target certain high value species on their trips, they catch and sell a wide variety of species (Mizrahi *et al.*, 2020; Exeter *et al.*, 2021). This characteristic may in fact confer some resilience, as fishers and buyers may be more able to adapt to changing mixes of species that occur as suitable oceanographic and habitat conditions for species are altered by climate change. In this sense, there is a limited amount of *fisher mobility* to allow catch of a variety of stocks, which may create enabling conditions for a*daptive management* (Table 2). However, this mobility is limited by the high costs of switching gears, meaning most fishers specialize on different functional groups of fish (i.e. pelagic or demersal). In many areas, small-scale fishers are also able to travel to a wide range of nearshore fishing grounds. However, with the establishment of co-management areas, this movement is likely to be limited, demonstrating a tradeoff between two of the socio-ecological resilience criteria.

In Myanmar, low resource, governance, and technical capacity has severely limited the ability to institute effective and robust fisheries management, which has reduced socio-ecological resilience and reinforced systemic inequities, with disproportionate poverty and vulnerability impacting rural small-scale fishing communities, and especially women and other marginalized groups. The barriers to effective management, and the ongoing degradation of stocks has also curtailed a sense of long-term stewardship, which has compounding effects for the ecological resilience criteria. Community-based co-management is in the early stages of development in Myanmar, and has the potential to promote long-term stewardship, appropriate levels of decentralization of governance, and the use of adaptive management. Future and ongoing co-management endeavours can help address inequities by including marginalized ethnic groups and women in the co-management development process. However, this transition is in jeopardy as the democratically elected government has recently been overthrown in a coup. The lack of livelihood diversification and low fisher mobility both act to concentrate ties to the resource, which may place greater strain on the resource in a given area, and it is important to note that assignment of rights in particular areas may further impede fisher mobility. However, with the right incentives in place, low levels of diversification outside of the fishery, and low mobility within the fishery, could actually work to improve stewardship and possibly community-based management via the strengthening of ties to the resource and community, and potentially reduce engagements in other activities that are damaging to the ecosystem.

Belize's reef-based fisheries

The waters of Belize contain a large section of the Western hemisphere's largest coral reef ecosystem, the Mesoamerican Reef (MAR), which sustains high-revenue fisheries for spiny lobster (*Panulirus argus*) and queen conch (*Lobatus gigas*), as well as finfish resources that are critical for local sustenance, reef health, and tourism, the nation's greatest economic driver. The MAR ecosystem is species-rich, with more than 500 species of finfish and large numbers of invertebrate species. Nearly 3000 Belizeans are engaged in fishing; most of them are small-scale operators, and most work within a cooperative structure for marketing purposes (Mayhew and Basurto, 2016; Fujita *et al.*, 2019). Key revenue fisheries have experienced significant increases in exploitation through the 1990s, with a fairly stable, though fluctuating, production level since about 2004 (Fujita *et al.*, 2019). Heavy exploitation has resulted in conch being depleted throughout its range, and highly desirable species like Nassau grouper (*Epinephelus striatus*) and goliath grouper (*Epinephelus itajarra*), which aggregate to spawn, are regionally depleted and listed as critically endangered on the IUCN Red List. As in Myanmar and other places throughout the coral world, multi-species finfish fisheries with high diversity and low levels of production for each individual species make traditional species-by-species management difficult, especially given the limited resources available for management in the developing tropics. Maintaining *sustainable and age-diverse target populations* is therefore challenging in this context (Table 2). However, as discussed above, multi-species fisheries may prove to be an enabling condition for *adaptive management* in some cases (Table 2). Belize has seen some success on both fronts due to recent conservation and management strategies.

Belize has been a leader in traditional marine conservation for many years. The national government, private philanthropies, non-governmental organizations, and others have made major investments to establish a network of Marine Protected Areas (MPAs) beginning in the late 1980s. General fisheries management proceeded under an old law adopted in 1948, expanded in 1980, and revised in 2000 that focused on the basics of marine fisheries management (licensing, compliance and enforcement, etc.). However, significant conservation outcomes were achieved in 2009, when the take of algal grazers (e.g. parrotfishes) was prohibited, and catch of depleted Nassau groupers was more strictly managed through a combination of size limits and closures of spawning sites (Usher, 2018). In 2020, the government unanimously passed a new Fishery Law, providing a legal framework to increase national efforts on the sustainable use and management of all fisheries resources. The new Fishery Law formalizes the adoption of ecosystem-based management for the country of Belize and institutes the development of a fisheries advisory council to allow fishing communities to more actively participate in decision-making. Thus, the law creates enabling conditions for both *conservation of biodiversity and habitats* and for *multi-level governance* (Table 2).

While Belize had done relatively well in terms of implementing national efforts to conserve biodiversity and habitats up through the mid-2000s, even large MPA systems by themselves are known to be inadequate to achieve conservation of coral ecosystems at scale (Cox *et al.*, 2017). In general, with coral, mangrove, and seagrass habitats, there are many additional threats including coastal development and pollution, which are exacerbated by climate change, and cascading effects such as acidification, rapid sea level rise, and storm intensification. At present, the health of the MAR ecosystem remains in doubt, although the most recent MAR "Report Card" noted an improvement from overall poor condition to fair (McField *et al.*, 2020) indicating that there has been some improvement in *managing existing stressors* (Table 2).

In 2008, local fishers began to work with local and international non-governmental organizations (NGOs) to establish two area-based management pilot sites in 2011, at Glover's Reef and Port Honduras Marine Reserve. The goal of these pilots was to test the effectiveness of providing secure fishing rights within designated areas to eligible fishers who were already fishing in those areas, with the aim of enhancing resource stewardship by reducing illegal fishing, improving catch reporting, and incentivizing higher compliance with conservation regulations. These pilots were seen by experts as highly successful (Fujita *et al.*, 2019). Fishers who historically depended on these areas for their livelihoods were granted secure and exclusive rights to fish there, and were expected to become actively engaged in management design and integrated into co-management committees for each site. In essence, these pilots *promoted good long-term stewardship* of these areas because participants were able to reap the potential benefits associated with adherence to regulations, including higher sustainable catch rates (Table 2). Fishing permits were no longer issued to ineligible out-of-area fishers, which reduced the total number of fishers using these areas. Illegal fishing violations reportedly dropped by more than 60% in the pilot sites. Catch rates appear to be increasing in Glovers Reef Managed Access Area (MAA), and seagrass, mangrove, and coral cover appear to have stabilized in both Managed Access pilot sites (Fujita *et al.*, 2019), countering the regional trend of decreasing coral cover (McField *et al.*, 2020). Importantly, fisher support is broad and deep; in 2015, the Belizean government implemented a strong *participatory community-based co-management* program across the country (Table 2). A participatory process engaged about 2000 of Belize's 2700 fishers in the design of the national Managed Access system, led by a team that included fishers, government officials, and NGOs. Elected Managed Access committees for each of Belize's eight MAAs determine who is eligible for Managed Access. Based on the success of the pilots and the participatory process, this expanded the MAA program to all of the territorial waters of Belize in 2016 (Fujita *et al.*, 2017; Fujita *et al.*, 2019; Government of Belize, 2019; Wade *et al.*, 2019), a highly inclusive and participatory process that involved the majority of the country's fishers (Fujita *et al.*, 2019).

Management of lobster and conch is proceeding under newly developed adaptive management plans, both developed through the Adaptive Management Framework of McDonald *et al.* (2017), and NGOs are working with the fishery cooperatives on their implementation. Conch had a hard quota for the first time in 2017–2018, and the season closed when the quota filled. These examples of effective *adaptive management* relied on data-limited stock assessment and management protocols, which are far simpler to apply and require less data, time, and money than conventional methods (Table 2). Available performance information suggests that such tools, properly applied, can effectively prevent overfishing and generate desirable levels of sustainable yield, when key assumptions are met (Babcock and MacCall, 2011; Carruthers *et al.*, 2014; Fulton *et al.*, 2016). A critical remaining step for sustainable fisheries management in Belize will be to add effective finfish management and standardized data collection to the MAA program, enabling the implementation of the Adaptive Management Framework, based on best-available data-limited approaches. Belize's existing co-management entities are adding capacity to the government's efforts to establish adaptive management plans for finfish.

Additionally, the success of the MAA program helped stimulate a resurgence of interest in expanding the no-take components of Belize's MPA network. The government proceeded to work with all stakeholders, including quasi-government and non-governmental organizations and actors, through formal consultation, which represented a relatively effective *multi-level governance* process (Table 2). The result was the expansion, in 2019, of the no-take components from 4% to 12% including key areas on Belize's border with Honduras and Guatemala that may help with controlling *existing stressors* (Table 2), such as illegal fishing and national security (Government of Belize, 2019). This expansion would not have been possible without the success of the MAA program.

The MAA program was designed to empower traditional fishers by ensuring greater participation in the decision-making process. However, some components of the program have been viewed neutrally or negatively by many fishers. This reaction may stem in part from fishers feeling more locked into fishing by their investments into the program, thereby diminishing their ability to *diversify livelihoods* (Table 2). Restrictions that limit fishing to particular areas, while beneficial for monitoring and enforcement and reducing pressure on the resource, may also reduce *fisher mobility* (Table 2). Additionally, the participatory and multi-stakeholder driven process, while allowing for greater inclusion, has raised questions about the feasibility and potential success of the program without more funding and resources dedicated to facilitating collaboration. An important consideration in Belize is the fact that the new and comprehensive laws just adopted have not yet had time to be translated into detailed implementation programs, which is limited by resource scarcity. Global stressors like the COVID-19 pandemic have exacerbated these effects with huge reductions in incomes from tourism. These management changes in Belize represent a great step forward but will require time and resources to succeed in the future.

There are several resilience criteria in Belize that may be exhibiting tradeoffs with other criteria. In particular, the extensive

MPA network, funded initiatives to reduce stressors, adaptive management of high value stocks, and the community-based co-management structure of the MAAs have reduced existing stressors, improved conservation of marine biodiversity and habitats, increased the scope for adaptive management, and generated incentives for long-term stewardship. Equity in terms of secured access to marine resources among individual fishers has long been a contentious issue. The MAA program represents an important step forward in promoting equity and participation among individuals. However, MAA conservation efforts may reduce fisher livelihood and increase dependence on fishing. Since most fishing is by small vessels, fisher mobility is limited and could be constrained by the MAA system, which, without robust management, could place additional stress on resources in a particular area.

Peru's artisanal giant squid fishery

The Humboldt Current region (Chile, Peru, and southern Ecuador) produces more fish per unit area than anywhere else in the world, more than 20% of global landings in some years (Chavez *et al.*, 2008; FAO, 2020). It is home to the biggest single-species fishery in the world by volume, Peruvian anchoveta (*Engraulis ringens*), which is caught mainly by industrial vessels and used mostly for fishmeal and fish oil production (FAO, 2020). Peru's fisheries are nourished in large part by the Humboldt Current, which drives intense upwelling, supporting high levels of primary productivity—the base of a rich food web (see Gutiérrez *et al.*, 2017 and references therein). Interannual variability in basin-scale processes such as El Nino Southern Oscillation modulates upwelling intensity in the region, causing fluctuations in biomass and species composition. This variability, compounded by climate change, has created challenges for Peru's fisheries managers that have pushed them to find adaptive, forward-looking, science-based approaches to ensure sustainability in the anchoveta fishery. However, these advances have not yet translated to the management of other fisheries.

Peru defines several fisheries sectors: (i) the industrial sector operates vessels over 32.6 m^2 hold capacity, (ii) the artisanal sector operates vessels up to 32.6 m^2 hold capacity and up to 15 m in length, generally with manual fishing gear, and (iii) the small-scale sector with vessels of up to 32.6 m^2 of hold capacity that use modern equipment and fishing systems. For most industrial fisheries, the Instituto del Mar de Peru (IMARPE) estimates biomass, calculates total allowable catches (TACs), and makes technical recommendations to the Ministry of Production (PRODUCE). Two industrial fisheries are managed by individual fishing quotas: Peruvian anchoveta and Peruvian hake (*Merluccius gayi peruanus*), and there are about a dozen other major fisheries, including giant squid (*Dosidiscus gigas)* (which we focus on here) that are managed with a fishery-wide TAC. Most minor commercial fisheries, especially the artisanal sector, do not yet have TACs. In terms of climate-adaptive management, Peru's industrial anchoveta fishery has long been hailed as exemplary in terms of capacity to frequently monitor current and near-term future physical and biological conditions on the water and quickly make necessary changes (Gutiérrez *et al.*, 2017). The robust science-to-management process for this fishery has helped to ensure adherence to quotas by the industry and allowed the government to streamline the flow of revenue from licensing fees and other payments to fund a portion of fisheries science and monitoring. Such efficiency is necessary, but lacking, in most other fisheries in Peru.

The second most important species fished in Peru is giant squid, which, as of 2011, is caught only by Peru's artisanal fishing fleet operating at least 4000 vessels, with annual landings of around 500,000 tonnes (FAO, 2020). Since the early 2000s, the artisanal fleet has developed a large dependence on giant squid as oceanographic regime shifts and overfishing reduced abundance of other fisheries. Equity in terms of access to particular fisheries in Peru between the industrial fleet and the artisanal fleet has long been a contentious issue. In 2008, legislation was passed in Peru that granted exclusive individual catch quotas per vessel to the industrial vessel owners in the anchovy fishery. This decree prompted the artisanal fleet, particularly in northern Peru, to push for exclusive access to the giant squid fishery, which was achieved in 2011 (Paredes and De la Puente, 2014). It is important to note that there is no legal impediment to the development of a Peruvian industrial squid fishery beyond 200 nautical miles.

Recently, giant squid has become an even more important fishery due to increasing demand from Asian and European markets, representing more than 845 million US$FOB in exports during 2019 according to PRODUCE. Because giant squid is caught solely by Peru's artisanal fleet, which remains largely unmanaged and without secure fishing rights, this fishery is essentially open access. While squid vessels are small ($<$15 m in length) with limited storage capacity and manual fishing gears, they are capable of fishing far offshore and spending up to two weeks at sea when giant squid shifts offshore (Csirke *et al.*, 2018). Most squid landings are exported, but a smaller, still significant, proportion is sold for direct human consumption in Peru, highlighting the importance of this species for local livelihoods and food provisioning. However, the importance of this species has not yet resulted in robust assessment and management although a portion of the fleet does use acoustic technology to estimate biomass. Direct monitoring by observers is believed to be the better approach to determine whether *sustainable and age-diverse populations* of giant squid are being maintained (Table 2). Prior to 2011, when the industrial fleet (mainly comprised of distant water vessels from Asia) was allowed to fish for squid, observers were onboard each vessel. However, this measure has not been adopted for the artisanal sector, which currently has very limited observer coverage (Yamashiro *et al.*, 2018).

Giant squid are a highly mobile, widespread stock, found in pelagic and coastal waters of neighboring countries, and in the High Seas. Fished with highly selective gear, impacts on oceanic habitats are likely minimal. However, it is common practice to gut giant squid at sea, generating large amounts of organic waste that are thrown overboard as bait to attract more squid, but which may exacerbate anoxic conditions in shallow areas with high concentrations of fishing vessels (Rovegno, 2017). This species has proved to be resilient to a changing climate as they are voracious, omnivorous predators, and are habitat generalists, tolerating relatively low oxygen conditions (Trueblood and Seibel, 2013).

These characteristics have caused management challenges for Peru and other nations that fish this species in terms of *adaptive management* of this stock (Table 2). This is mainly due to difficulties in measuring and monitoring changes in distribution and productivity, and understanding effects of predation on other species (Ibáñez, 2013). In particular, current quotas for giant squid are based on simple surplus production models, which account for environmental variability in a limited manner, but only assess *post-facto* stock declines, thereby limiting nimble, and forward-looking management responses. Additionally, monitoring is a challenge because, although Peru's research surveys collect a variety of important physical oceanographic data critical for understanding changes in squid habitat, the surveys were originally designed to assess pelagic finfish biomass and are not equipped to capture the full picture of squid biomass and distribution. However, since 2015, specific research surveys for giant squid have begun (Csirke *et al.*, 2018), which may help improve the capacity for adaptive management. In general, an expansion of Peru's research cruises to allow for more comprehensive multi-species, ecosystem-based assessments would also help the country realize goals for improving *conservation of biodiversity and habitats* and *managing existing stressors* (Table 2). In 2017, in an attempt to improve the management of giant squid and to better account for wider ecosystem considerations and stressors, the South Pacific Regional Fisheries Management Organization (SPRFMO) took over the assessment and monitoring of giant squid. Their goal is to achieve a more integrated stock assessment by 2022 across multiple countries and determine appropriate management measures by 2023.

A critical goal for the management system is to increase social capital and organization of the fishery through formalization of the artisanal sector in Peru. Secure fishing rights would help incentivize *long-term stewardship*, which is currently lacking (Table 2). In addition, the artisanal fishers that fish giant squid have very little ability to influence management through *participatory co-management* structures due to the low levels of social capital and high fragmentation within the different fishing organizations. *Multi-level governance* is lacking in Peru and management decrees are issued through a top-down process, with only a small window for public commentary on regulations before publication (Table 2). There is very little coordination between national and local levels of government in Peru, despite coordination at the international level with the SPRFMO. This centralization makes it challenging for the government to perceive needs at local scales, resulting in informal and disorderly growth of the fleet (Rovegno, 2017).

Poor supply chain dynamics within the artisanal sector have resulted in low ex-vessel prices and fisher dependency on intermediaries for financing fishing activities. Fortunately, many of the artisanal fishers are diversified within the fishing sector, allowing them flexibility to fish other species to supplement their income or in response to changes in squid abundance. Likewise, a growing number of artisanal fishers are increasing participation in other sectors of the value chain, illustrating an ability to *diversify livelihoods*, which gives them additional income and helps to diversify risk (Table 2). However, the relatively low level of economic development in Peru may preclude some fishers from leaving the fishing sector. This is especially worrisome, as it has been estimated that giant squid fishers' income has been oscillating both above and below the minimum wage over the past few years (De la Puente *et al.*, 2020). The ability to target other species does confer relatively high levels of *fisher mobility*; fishers move both along Peru's coast to fish, and also, to some extent, far offshore, providing them ample opportunity to increase their catch, but often at the expense of their own safety (Table 2).

Overall, the key challenges for building resilience in Peru's giant squid fishery are the highly centralized governance structure, the exclusion of the artisanal fleet from this governance, and the lack of recognition of community-based management by the central government, factors which limit equity and participation, and which are also likely negatively affecting ecological criteria. Some potentially positive signs are the relatively recent management of giant squid by the SPRFMO, which should help improve the science and management for this stock resulting in positive effects on the ecological resilience criteria. However, adaptive capacity in the giant squid fishery is relatively low due to limited monitoring and assessment capacity, which complicates the implementation of timely management measures, and may negatively affect other ecological resilience criteria, and long-term stewardship. Although giant squid fishers are highly mobile, target other pelagic species, and a growing number are expanding their participation in the value chain, there are very few other livelihoods options outside of the fishing sector. Additionally, a considerable number of giant squid fishers have very little influence and negotiating power when selling their catch, as they work with intermediaries that finance their fishing trips and set prices to their convenience. This can encourage an increase in catches that may lower prices, influencing stock abundance. Likewise, lack of formal regulation over artisanal fisheries in Peru could negatively affect the ecological resilience criteria if the engagement in other livelihoods has negative impacts on the ecosystem or if there are adverse effects on the resource over larger areas. Finally, conflicts can arise when a community landing area becomes oversaturated with landings from other communities, an issue that is likely to be exacerbated by lack of community-based and adaptive management.

Iceland's demersal fisheries

Iceland is a global fishing powerhouse, ranking among the world's 20 top producers in marine fisheries (FAO, 2020). Converging warm Atlantic and cold Arctic currents interacting with submarine ridges create highly productive waters around Iceland (Astthorsson *et al.*, 2007). These waters support abundant populations of demersal species such cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), fished with bottom trawls, and pelagic species such as capelin (*Mallotus villosus*) and Atlantic mackerel (*Scomber scombrus*), fished with pelagic trawls and purse seines (Knutsson *et al.*, 2011). From 2010 to 2019, Iceland's fisheries landed around 1.2 million tonnes annually, with fisheries and fish processing directly contributing on average 7.8% of GDP according to Statistics Iceland (https://www.statice.is/statistics/economy/national-accounts/production-approach/, last accessed 17 September 2020).

Given the economic importance of fisheries and Iceland's high governance and technical capacity, fishery management is comprehensive, tightly monitored, and highly technical. As of 1990, Iceland manages nearly all fishing activity (~98% of catch) through a nation-wide multi-species individual transferable quota (ITQ) system, which we focus on here. Key features of the ITQ system include annual scientific surveys and stock assessments to advise the TAC set each year, a ban on discards, real-time catch data sharing, and the ability to convert quota among species to account for fluctuations in catch (Knutsson *et al.*, 2011; Knútsson *et al.*, 2016; Chambers and Carothers, 2017). Additionally, permanent and temporary spatial closures protect spawning areas and nursery grounds for particular species, and gear restrictions prevent bycatch of small individuals (Knutsson *et al.*, 2011).

The ITQ system was developed out of concern over collapsing stocks and has been credited with promoting *sustainable and age-diverse target populations* (Table 2) and bringing overfishing under control (Arnason, 2005; Kokorsch *et al.*, 2015). Fisheries management explicitly focuses on commercially exploitable stocks rather than broader efforts toward *conserving biodiversity and habitats* (Table 2), but Iceland is party to international biodiversity conventions and its 2000 Nature Conservation Act includes provisions for protecting "sites of natural interest at sea." Iceland performs highly in environmental quality evaluations (such as the Organization for Economic Cooperation and Development's Environmental Performance Review), but *managing existing stressors* in Iceland's marine environment has not historically been a policy focus (OECD, 2014). The impacts of coastal development, expanding tourism, and heavy industry may represent emerging concerns for Iceland's marine ecosystems (OECD, 2014).

Individual quota systems are thought to *promote long-term stewardship* (Table 2) by eliminating the "race to fish" and fostering self-interest in preserving stocks (Costello *et al.*, 2008). While Iceland's ITQ system does appear to have prevented stock collapse, it was primarily economic forces (consolidation and vertical integration) that drove reductions in fishing effort and fleet overcapacity (Arnason, 2005; Knutsson *et al.*, 2011). Surveys of fishers have revealed perceptions that the economic goals of the ITQ system have overshadowed environmental goals, incentivizing environmentally damaging behavior if it maximizes value within catch limits (Arnason, 2005; Chambers and Carothers, 2017). For example, fishers report continued "high-grading," or illegally dumping lower-value fish to maximize profits, enabled by limited observation and enforcement mechanisms (Chambers and Carothers, 2017; Gisladottir *et al.*, 2020). A common critique of the ITQ system is that there are no formalized *participatory management structures* (Table 2) and social equity has been deprioritized in relation to economic goals (Benediktsson and Karlsdóttir, 2011; Kokorsch *et al.*, 2015; Chambers and Carothers, 2017). Small-scale fishers, particularly those in rural communities and/or who do not possess quota, have felt especially disenfranchised in part due to a lack of community-based management (Chambers and Carothers, 2017).

Iceland developed its ITQ system through an *adaptive management* process (Table 2), experimenting with various quota and effort restriction arrangements before expanding the ITQ (Kokorsch *et al.*, 2015). The resulting management system includes sophisticated mechanisms for continued adaptive response to change, including through the annual TAC and quota-setting process and provisions for incorporating new species into the quota system. Additionally, the flexible quota transfer system and data accessibility allows fishers to make finely honed decisions about what and when to fish, for example, maximizing their catch value by metering their quota for holiday demand, or avoiding competition by specializing in underutilized species (Knútsson *et al.*, 2016).

As a highly centralized system, Iceland's fisheries management does not exhibit *multi-level governance* at the sub-national level (Table 2). Apart from fishing organizations' efforts to lobby the Fisheries Minister, who ultimately sets TAC levels, there is little opportunity for fishers to participate in decision-making (Kokorsch *et al.*, 2015; Chambers and Carothers, 2017). A community quota system implemented in 2003 provides municipalities some flexibility in allocation, but stakeholders report that the amount (~5% of TAC) is insufficient to empower communities or reverse inequalities (Chambers and Carothers, 2017; Kokorsch, 2018; Kokorsch and Benediktsson, 2018). At the international level, Iceland engages in bilateral agreements with neighboring fishing countries over trans-boundary stocks (Knutsson *et al.*, 2011). However, the 2007 "mackerel war," in which the movement of Atlantic mackerel into Iceland's waters led to a breakdown of negotiations with the EU and overexploitation of the stock, points to a need for more effective international governance for climate-driven species shifts (Pinsky *et al.*, 2018).

The ITQ system does not limit spatial effort, so *fisher mobility* is quite high (Table 2); indeed, larger trawlers with at-sea freezing capacity can operate in deep and distant waters (Knutsson *et al.*, 2011). However, consolidation of processing facilities around Reykjavik and other regional hubs following the implementation of the ITQ system may limit options for landing sites (Kokorsch and Benediktsson, 2018). In terms of ability to switch to other fisheries such as non-ITQ options, individuals who possess quota tend to be the most flexible, whereas the cost of quota can be prohibitive for non-ITQ fishers or newcomers (Chambers and Carothers, 2017), another indication of inequities in this system.

Many rural coastal communities in Iceland were built around fishing and/or a single processing facility, and the high value of quota following ITQ implementation created a form of gilded trap (Steneck *et al.*, 2011), where towns committed to retaining quota became deeply indebted and unable to invest in new industries (Kokorsch and Benediktsson, 2018). Thus, options for *livelihood diversity* have become concentrated along with processing facilities (Table 2), while more remote towns have experienced unemployment and depopulation due to fishery consolidation (Kokorsch and Benediktsson, 2018). Those towns that relinquished quota and diversified into tourism, marine research, and development, the arts, and aluminium smelting have maintained more stable populations (Kokorsch, 2018).

In summary, Iceland's highly centralized and adaptive governance system has created positive synergies with ecological criteria and fisher mobility, but incurred trade-offs with those social resilience criteria that promote equity and participation. Rich natural resources and effective governance have allowed managers to focus on efficiently maintaining sustainable stocks without needing to divert resources toward conserving biodiversity or addressing other stressors, but this focus limits integration with other sectors and other governance levels. Efforts to address social equity and international cooperation may reduce this adaptiveness and efficiency if groups have different or competing objectives and timelines. Finally, future trade-offs and/or negative synergies between ecological and social criteria could arise depending on how communities develop and diversify livelihoods, and whether lack of community ownership and participation erodes long-term stewardship.

Synergies and tradeoffs between resilience criteria

As noted in each of the case studies, it was possible to observe some indications of synergies and tradeoffs between individual social-ecological resilience criteria. This was particularly the case when a fishery scored medium-high or high on a particular resilience criterion (Table 2) as was observed in the case studies for Belize, Peru, and Iceland. These interactions are noted for the particular case study where they were observed (Table 3). In Myanmar, the low or medium-low assessments of each of the resilience criteria resulted in compounding negative feedbacks. For example, low levels of community-based management is likely curtailing long-term stewardship, which in turn may negatively affect the ecological resilience criteria. Similarly, in Myanmar there is a tradeoff between the need for secure tenure and increased flexibility for fishers. In addition, we hypothesize general ways in which a particular resilience criterion may serve to promote another criterion in both negative and positive ways. Some of these theoretical interactions are presented in Table 3 to encourage critical thinking about system changes as a fishery works to improve particular aspects of resilience. It is important to note, however, that these social–ecological criteria could interact in many nuanced ways and that there may also be a temporal component to interactions that should be considered. One example is that conserving biodiversity may reduce access to a particular resource in the near-term but may provide more harvesting opportunities in the longer-term that allow for greater mobility and livelihoods options.

Identification of adaptive policy approaches

Each of the case study systems examined represents different capacities and contexts that must be accounted for when determining best approaches for improving the sustainability and resilience of the fishery system. There may be multiple approaches that should be taken, and some approaches may be able to be implemented sooner than others depending upon particular capacities and contexts (Table 4). We present the rationale for prioritizing particular approaches for implementation in the near- and longer-terms in each case study system below.

Myanmar is a tropical, multi-species fishery that is expected to experience disproportionate negative effects (relative to countries in higher latitudes) from climate change due to impacts such as species distribution and productivity shifts away from warming waters, loss of biodiversity, sea level rise, and ocean acidification. Small-scale fishing communities, and particularly the women and other marginalized groups in these communities, face significant risks of loss of livelihoods and increased malnutrition due to these impacts (Harper *et al.*, 2013; Lau *et al.*, 2021). Low levels of the resilience criteria across the board are accentuating the challenges for building social–ecological resilience in Myanmar's nearshore, small-scale fisheries. Highly centralized governance with few financial and personnel resources is a key issue. Given the success of early co-management projects and low scientific capacity, approaches A and B could be logical entry points to improving overall fisheries management and general resilience in this fishery system. In particular, approach A, developing inclusive, participatory co-management systems, would help to engender a sense of ownership, stewardship, attention to issues of fairness and equity, and trust in local stakeholders, who are more in tune with local needs and goals (e.g. food provisioning, access to resources, livelihoods needs). Additionally, approach B, building a better system to monitor, assess, and manage these fisheries, will be critical to help improve overall outcomes for the nearshore fisheries in Myanmar, helping to provide the information needed to assess changes in resource levels and health. If these monitoring systems were built to inform local managers (following implementation of approach A), then this could help to build a sense of long-term stewardship. The other approaches (C–F) would be unlikely to realize successful implementation in the current context, given the low levels of capacity and resilience, but might eventually be achieved if approaches A and B are successful. Approaches that are currently being implemented versus those that could reflect nearer-term and longer term options, as well as approaches that would require additional building for robust engagement for each case study system are identified in Table 4. Of course, the success of these recommended approaches are uncertain now with the current government upheaval.

In Belize, higher governance capacity has led to recent improvements in conservation and management strategies. In particular, more inclusive and participatory co-management structures (approach A) and more effective adaptive management strategies (approach C) that rely on data-limited stock assessment and management protocols have helped to reduce the propensity for overfishing on key resources like lobster and conch. Going forward, the goal is to expand the Managed Access Area (MAA) program to all finfish, based on best-available data-limited approaches. Doing so will necessitate engaging approach B, employing effective data collection and monitoring systems, so that data are available for assessment. The recent adoption of ecosystem-based management in Belize should help to lay the foundation for approach F, consideration of the wider socio-economic and ecosystem context. The capacity for co-management and multi-level governance should help foster the need for and use of this type of information in goal setting and planning

Table 4. Summary of recommendations for prioritization of adaptive policy approaches based on context and capacity in the four case studies.

Adaptive Policy Approach:	A: Develop inclusive, participatory management systems	B: Employ effective data collection and monitoring systems	C: Adopt adaptive, science-based management approaches	D: Use forward-looking science to inform management	E: Improve collaboration and cooperation	F: Consider the interplay of wider socio-economic and ecosystem components
Myanmar	Near-term priority approach	Near-term priority approach	Requires increased capacity	Requires increased capacity	Requires increased capacity	Requires increased capacity
Belize	Progress underway or goal attained	Near-term priority approach	Progress underway or goal attained	Requires increased capacity	Requires increased capacity	Longer-term priority approach
Peru	Near-term priority approach	Near-term priority approach	Longer-term priority approach	Requires increased capacity	Progress underway or goal attained	Requires increased capacity
Iceland	Longer-term priority approach	Progress underway or goal attained	Progress underway or goal attained	Near-term priority approach	Longer-term priority approach	Longer-term priority approach

processes. Continuing to build adaptive management capacity in Belize (approach C), may also pave the way toward more forward-looking science (approach D) so that the effects of climate change can be built into planning efforts. Although Belize is still relying on data-limited approaches within its adaptive management strategies, there are examples of how to account for climate impacts in fisheries policy decisions in other data limited contexts (e.g. Cisneros-Mata *et al.*, 2019).

Peru's management of giant squid could be improved through approach A, the development of inclusive, participatory co-management systems, specifically through efforts to ensure inclusion of the artisanal sector into management at local, national, and international levels. Successful implementation of approach A via the establishment of secure fishing rights would help to ensure that managers consider issues of fairness and equity, especially with respect to markets and supply chain dynamics, to find means for addressing inequities, which help to ensure long-term stewardship. Both the inclusion of the stock into the SPRFMO and collaborative fisheries approaches, which engage fishers and researchers, may improve outcomes for monitoring and data collection (approach B) and adaptive management (approach C), both of which should continue to be priorities for improving management of this important resource. Additionally, given the widespread distribution of giant squid and its propensity for expansion with changing climatic conditions, the engagement with the SPRFMO is a positive sign of fostering international cooperation (approach E), but more must be done to ensure that interests of the artisanal sector are represented within this international management forum. Peru's government science agency, IMARPE, has high technical capacity as witnessed by the exemplary adaptive management in place for Peruvian anchoveta. Currently, given the commercial importance of anchoveta to the country, the bulk of financial and human resources are devoted to improving the management of this species. Allocation of more funds, including from the establishment of fishing rights in the giant squid fishery, to allow for a holistic multi-species, ecosystem-based fisheries science approach would help to promote forward-looking science for other resources (approach D) and would allow for better understanding of the wider socio-economic and ecosystem conditions (approach F). This could help with ensuring equitable outcomes for fishers as climate change impacts stock distribution and abundance.

With the highest levels of capacity of the four systems, Iceland is well situated to incorporate forward-looking science (approach D) into management to help understand and plan for changes, which may include climate "benefits" as many species continue to shift poleward with warming waters. Incorporating scientific forecasts could enable Iceland to capitalize sustainably on these new fishery opportunities by proactively adapting managing and monitoring frameworks, and improving fisher portfolio and supply chain flexibility. As stocks shift into and out of national waters, Iceland could also work towards better international cooperation (approach E) to ensure stocks are not overfished. Iceland might also improve opportunities for participation and inclusion in fisheries by looking for opportunities to ensure marginalized sectors (e.g. small-scale operators) and communities can meaningfully participate in the management system (approach A) by considering the wider socio-economic outcomes (approach F) of the quota management system, especially under climate change. Such considerations, carried out through an inclusive process, will help in goal-setting and evaluating tradeoffs between participation/equity/multi-level governance and adaptive management/sustainable stocks/profitability. Pursuing approach F will also help in planning efforts to navigate tradeoffs between new or alternate livelihoods like heavy industry and conservation of coastal habitats, biodiversity, and sustainable stocks.

Discussion

Fisheries have always had to cope with fluctuations in stock abundance and distribution. However, climate change is accelerating the magnitude and frequency of these types of fluctuations, and is also introducing new challenges. Active measures to increase the resilience of fisheries to climate change will be necessary in order to maintain the yields and profits necessary to support food security and the tens of millions of jobs that depend on fishing. Because fisheries vary dramatically in many ways, they will require different kinds of interventions to increase resilience to climate change.

In general, higher resource, technical, and governance capacities allow more options for building social-ecological resilience among the case study systems presented here, as exemplified by the contrast between the systems in Iceland and Myanmar (see Table 4). Additionally, some resilience criteria, such as the management of existing stressors, conservation of biodiversity and habitats, the ability to maintain sustainable and age-diverse populations, and adaptive management are explicitly linked to the capacities of a system. For example, conducting robust stock assessments in a species-rich system, or developing an ecosystem-based fisheries model, requires sound and plentiful data, and technical scientific capacity to build these models and interpret results (e.g. Townsend *et al.*, 2019). Implementing data collection systems and developing scientific and technical capacity require financial resources. Similarly, effective spatial conservation measures, like MPAs, require enforcement and compliance capabilities, which can be expensive depending on the location and expanse protected (Gill *et al.*, 2017). Critically, in high capacity systems with relatively robust management reforms in place, not accounting for wider social implications of goals and policies can disadvantage particular groups of people, eroding the equity and social resilience of the system and potentially resulting in declining support for particular policies (Benediktsson and Karlsdóttir, 2011; Chambers and Carothers, 2017; Human Rights Watch, 2020).

However, even in low capacity settings, certain policy approaches can lay the foundation for building a more sustainable, equitable, and resilient fisheries system, improving long-term stewardship and investment, and paving the way for more robust monitoring, assessment, and management (Cochrane *et al.*, 2011). Indeed, not having an entrenched or highly developed fisheries management system may actually allow for greater adaptive capacity and scope for realizing system changes that benefit both the ecosystem and humans, if the governance system is equipped to allow for inclusive, participatory co-management approaches (Cinner *et al.*, 2018). For example, low capacity fisheries often lack long time-series of historical data, thus requiring analytical methods that use other types of more readily available and shorter time-series data such as data on length frequencies in the recent catch. Just a few years of length-frequency data can be used to implement methods such as length-based spawning potential ratios (LBSPR) or length-based integrated mixed effects model (LIME; Rudd and Thorson, 2018). In the case of LIME, the minimum requirement is a single year of length data and basic biological information that could be obtained from FishBase (www.fishbase.org) but can utilize multiple years of length data, catch, and an abundance index if available. These methods have been shown to perform as well as other catch-based methods in many scenarios (Pons *et al.*, 2020), and may be conducive to adaptive management as they can be performed frequently with relatively low investments of time, money, and expertise. This is certainly the case in Myanmar where the fisheries governance system is functioning at very low levels or is, in some aspects, non-existent, requiring basic steps be taken to improve marine resource health and the ability to derive livelihoods from them. Taking these steps will help the fishery system improve now, and will also contribute to building system resilience for the future.

In this article, we focus on capacity constraints, and tradeoffs and synergies between resilience criteria across four systems, as understanding these dimensions can help point to the best policy approaches for building the sustainability, equity, and resilience of a fisheries system. To bound our study, we focused on highly disparate cases, but this approach would be straightforward to replicate across additional systems with similar and different features. Additionally, more detailed analysis of anticipated climate impacts on a given system, via climate modeling of habitat alteration and spatial changes in species distributions, phenology of life history events, and direct impacts on fishery outcomes (i.e. yield, profits, quota allocations, etc.) would help tailor specific climate resilience responses from particular policy approaches. Further research on how system capacities impact the synergies and tradeoffs between resilience criteria would also allow for a more nuanced look at whether a particular system might be better served by coping, adapting, or transforming in response to a stressor (Supplementary Figure S1). Such an analysis will require a deep understanding of the intensity of and the transactional costs associated with the stressor. We view such an analysis as a logical next step to the current analysis.

The framework presented here illustrates ways in which any fishery can work to build resilience, regardless of capacity. It also explores trade-offs among resilience criteria that can occur even in high capacity settings, underscoring the importance of clear management goals that encompass sustainability and equity (e.g. Iceland's well-documented prioritization of economic efficiency and ecological sustainability, which has reduced social equity and inclusion). A more inclusive, participatory multi-layer governance may be one way to ensure all impacted parties are included in the decision-making, to help avoid such conflicts. A robust assessment of system resilience should therefore consider the likely magnitude and type of climate change impacts, the capacity of the system to allow for adaptation, whether goals of management consider and address issues of fairness and equity, and the inherent resilience characteristics of the system. Understanding these dimensions can help point to the best policy approaches for building the sustainability, equity, and resilience of the fisheries system. Such assessments will become ever more necessary as climate impacts increase in the future.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Data availability

No new data were generated or analysed in support of this research.

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References

Akester, M. J. 2019. Productivity and coastal fisheries biomass yields of the northeast coastal waters of the Bay of Bengal Large Marine Ecosystem. Deep Sea Research Part II: Topical Studies in Oceanography, 163: 46–56.

Arnason, R. 2005. Property rights in fisheries: Iceland's experience with ITQs. Reviews in Fish Biology and Fisheries, 15: 243–264.

Asian Development Bank. 2019. Basic Statistics 2019. https://www.adb.org/publications/basic-statistics-2019. Last Accessed 15 April 2021.

Astthorsson, O. S., Gislason, A., and Jonsson, S. 2007. Climate variability and the icelandic marine ecosystem. Deep Sea Research Part II: Topical Studies in Oceanography, 54: 2456–2477.

Babcock, E. A., and MacCall, A. D. 2011. How useful is the ratio of fish density outside versus inside no-take marine reserves as a metric for fishery management control rules? Canadian Journal of Fisheries and Aquatic Sciences, 68: 343–359.

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, K. L., Funge-Smith, S., and Poulain, F., eds. 2018. Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. 628 pp.

Basurto, X., Gelcich, S., and Ostrom, E. 2013. The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. Global Environmental Change, 23: 1366–1380.

Benediktsson, K., and Karlsdóttir, A. 2011. Iceland: crisis and regional development – thanks for all the fish? European Urban and Regional Studies, 18: 228–235.

Bennett, N. J., Dearden, P., Murray, G., and Kadfak, A. 2014. The capacity to adapt? Communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. Ecology and Society, 19.

Bradley, D., Merrifield, M., Miller, K. M., Lomonico, S., Wilson, J. R., and Gleason, M. G. 2019. Opportunities to improve fisheries management through innovative technology and advanced data systems. Fish and Fisheries, 20: 564–583.

Campbell, B., and Hanich, Q. 2015. Principles and practice for the equitable governance of transboundary natural resources: cross-cutting lessons for marine fisheries management. Maritime Studies, 14: 8.

Carruthers, T. R., Punt, A. E., Walters, C. J., MacCall, A., McAllister, M. K., Dick, E. J., and Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research, 153: 48–68.

Chambers, C., and Carothers, C. 2017. Thirty years after privatization: a survey of Icelandic small-boat fishermen. Marine Policy, 80: 69–80.

Chavez, F. P., Bertrand, A., Guevara-Carrasco, R., Soler, P., and Csirke, J. 2008. The northern Humboldt Current System: brief history, present status and a view towards the future. Progress in Oceanography, 79: 95–105.

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R. E. G., Zeller, D. I. R. K., and Pauly, D. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology, 16: 24–35.

Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. J., Gelcich, S., *et al.* 2018. Building adaptive capacity to climate change in tropical coastal communities. Nature Climate Change, 8: 117–123.

Cisneros-Mata, M. A., Mangin, T., Bone, J., Rodriguez, L., Smith, S. L., and Gaines, S. D. 2019. Fisheries governance in the face of climate change: assessment of policy reform implications for Mexican fisheries. PLoS One, 14: e0222317.

Cisneros-Montemayor, A. M., Moreno-Báez, M., Voyer, M., Allison, E. H., Cheung, W. W. L., Hessing-Lewis, M., Oyinlola, M. A., *et al.* 2019. Social equity and benefits as the nexus of a transformative Blue Economy: a sectoral review of implications. Marine Policy, 109: 103702.

Cochrane, K. L., Andrew, N. L., and Parma, A. M. 2011. Primary fisheries management: a minimum requirement for provision of sustainable human benefits in small-scale fisheries. Fish and Fisheries, 12: 275–288.

Cochrane, K. L., and Garcia, S. M. 2009. Fishery managers' guidebook. 2nd ed. Rome, FAO; and Oxford, UK, Blackwell Publishing.

Costello, C., Gaines, S. D., and Lynham, J. 2008. Can catch shares prevent fisheries collapse? Science, 321: 1678–1681.

Cox, C., Valdivia, A., McField, M., Castillo, K., and Bruno, J. F. 2017. Establishment of marine protected areas alone does not restore coral reef communities in Belize. Marine Ecology Progress Series, 563: 65–79.

Crawford, B., Kasmidi, M., Korompis, F., and Pollnac, R. B. 2006. Factors influencing progress in establishing community-based marine protected areas in Indonesia. Coastal Management, 34: 39–64.

Csirke, J., Argüelles, J., Alegre, A., Ayón, P., Bouchon, M., Castillo, G., Castillo, R., *et al.* 2018. Biología, estructura poblacional y pesquería de pota o calamar gigante (Dosidicus gigas) en el Perú. Bol Inst Mar Perú, 33: 302–364.

Day, F. 1889. The Fauna of British India, Including Ceylon and Burma. Taylor and Francis, London.

De la Puente, S., López de la Lama, R., Benavente, S., Sueiro, J. C., and P., D. and 2020, 1950. Growing into poverty: reconstructing Peruvian small-scale fishing effort between. Frontiers in Marine Science, 7: 2018.

Donkersloot, R., Black, J. C., Carothers, C., Ringer, D., Justin, W., Clay, P. M., Poe, M. R., *et al.* 2020. Assessing the sustainability and equity of Alaska salmon fisheries through a well-being framework. Ecology and Society, 25(2): 18.

Exeter, O. M., Htut, T., Kerry, C. R., Kyi, M. M., Mizrahi, M. i., Turner, R. A., Witt, M. J., *et al.* 2021. Shining light on data-poor coastal fisheries. Frontiers in Marine Science, 7: 1234.

FAO. 2020. The state of world fisheries and aquaculture 2020. Sustainability in Action.

Free, C. M., Mangin, T., Molinos, J. G., Ojea, E., Burden, M., Costello, C., and Gaines, S. D. 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PLoS One, 15: e0224347.

Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., and Jensen, O. P. 2019. Impacts of historical warming on marine fisheries production. Science, 363: 979–983.

Fujita, R., Epstein, L., Battista, W., Karr, K. A., Higgins, P. L., Landman, J., and Carcamo, R. 2017. Scaling territorial use rights in fisheries (TURFs) in Belize. Bulletin of Marine Science, 93: 137–153.

Fujita, R., Tourgee, A., Carcamo, R., Epstein, L., Gedamke, T., McDonald, G., and Wilson, J. R. 2019. Assessing and managing small-scale fisheries in Belize. *In* Viability and Sustainability of Small-Scale Fisheries in Latin America and the Caribbean, pp. 177–195. Ed. by S. Salas, M. J. Barragán-Paladines, and R. Chuenpagdee. Springer International Publishing, Cham.

Fulton, E. A., Punt, A. E., Dichmont, C. M., Gorton, R., Sporcic, M., Dowling, N., Little, L. R., *et al.* 2016. Developing risk equivalent data-rich and data-limited harvest strategies. Fisheries Research, 183: 574–587.

Gaines, S. D., Costello, C., Owashi, B., Mangin, T., Bone, J., García Molinos, J., Burden, M., *et al.* 2018. Fixing fisheries management could offset many negative effects of climate change. Science Advances, 4: eaao1378.

García Molinos, J. 2020. Global marine warming in a new dimension. Nature Ecology & Evolution, 4: 16–17.

Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., Craigie, I., *et al.* 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature, 543: 665–669.

Gisladottir, J., Sigurgeirsdottir, S., Stjernquist, I., and Ragnarsdottir, K. V; Fighting Corruption in the Developed World: Dimensions, Patterns, Remedies. 2020. Corruption risks in renewable resource governance: case studies in Iceland and Romania. Politics and Governance, 8: 167–179.

Golden, C. D., Allison, E. H., Cheung, W. W., Dey, M. M., Halpern, B. S., McCauley, D. J., Smith, M., *et al.* 2016. Nutrition: fall in fish catch threatens human health. Nature, 534: 317–320.

Government of Belize. 2019. Cabinet Paper for Expansion of Fisheries Replenishment (No-Take) Zones. https://www.pressoffice.gov.bz/expansion-of-fisheries-replenishment-no-take-zones/. Last Accessed 15 April 2021.

Gutiérrez, M. T., Castillo, J. P., Naranjo, L. B., and., and Akester, M. J. 2017. Current state of goods, services and governance of the Humboldt Current Large Marine Ecosystem in the context of climate change. Environmental Development, 22: 175–190.

Gutierrez, N. L., Hilborn, R., and Defeo, O. 2011. Leadership, social capital and incentives promote successful fisheries. Nature, 470: 386–389.

Harper, S., Zeller, D., Hauzer, M., Pauly, D., and Sumaila, U. R. 2013. Women and fisheries: contribution to food security and local economies. Marine Policy, 39: 56–63.

Hewawasam, V., and Matsui, K. 2020. Equitable resilience in flood prone urban areas in Sri Lanka: a case study in Colombo Divisional Secretariat Division. Global Environmental Change, 62: 102091.

Holsman, K. K., Haynie, A. C., Hollowed, A. B., Reum, J. C. P., Aydin, K., Hermann, A. J., Cheng, W., *et al.* 2020. Ecosystem-based fisheries management forestalls climate-driven collapse. Nature Communications, 11: 4579.

Holsman, K. K., Hazen, E. L., Haynie, A., Gourguet, S., Hollowed, A., Bograd, S. J., Samhouri, J. F., *et al.* 2019. Towards climate resiliency in fisheries management. ICES Journal of Marine Science, 76: 1368–1378.

Human Rights Watch. 2020. An Open Prison without End: Myanmar's Mass Detention of Rohignya in Rakhine State. 183 pp. https://www.hrw.org/report/2020/10/08/open-prison-without-end/myanmars-mass-detention-rohingya-rakhine-state#1354. Last Accessed 15 April 2021.

Ibáñez, C. M. 2013. Ecological impact of *Dosidicus gigas* over hake populations in the eastern Pacific Ocean. Amici Molluscarum, 21: 7–16.

Klassen, S., and Murphy, S. 2020. Equity as both a means and an end: lessons for resilient food systems from COVID-19. World Development, 136: 105104–105104.

Klinsky, S., Roberts, T., Huq, S., Okereke, C., Newell, P., Dauvergne, P., O'Brien, K., *et al.* 2017. Why equity is fundamental in climate change policy research. Global Environmental Change, 44: 170–173.

Knútsson, Ö., Kristófersson, D. M., and Gestsson, H. 2016. The effects of fisheries management on the Icelandic Demersal fish value chain. Marine Policy, 63: 172–179.

Knutsson, O., Valtýsson, H., Saevaldsson, H., Helgi Gestsson, H., and Eiriksson, B. 2011. A comprehensive overview of the Icelandic fish industry.

Kokorsch, M. 2018. The tides they are a changin': resources, regulation, and resilience in an Icelandic coastal community. Journal of Rural and Community Development, 12(2/3): 59–73.

Kokorsch, M., and Benediktsson, K. 2018. Prosper or perish? The development of Icelandic fishing villages after the privatisation of fishing rights. Maritime Studies, 17: 69–83.

Kokorsch, M., Karlsdóttir, A., and Benediktsson, K. 2015. Improving or overturning the ITQ system? Views of stakeholders in Icelandic fisheries. Maritime Studies, 14: 15.

Krakstad, J.-O., Michalsen, K., Krafft, B., Bagøien, E., Alvheim, O., Strømme, T., Than Tun, M., *et al.* 2014. Cruise Report "Dr. Fridtjof Nansen". Myanmar Ecosystem Survey, 13 November – 17 December 2013. 100 pp.

Lau, J. D., Kleiber, D., Lawless, S., and Cohen, P. J. 2021. Gender equality in climate policy and practice hindered by assumptions. Nature Climate Change, 11: 186–192.

Lotze, H. K., Tittensor, D. P., Bryndum-Buchholz, A., Eddy, T. D., Cheung, W. W. L., Galbraith, E. D., and Barange, M. 2019. Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. Proceedings of the National Academy of Sciences, 116: 12907–12912.

MacKeracher, T., Diedrich, A., and Simpfendorfer, C. A. 2019. Sharks, rays and marine protected areas: a critical evaluation of current perspectives. Fish and Fisheries, 20: 255–267.

MacKeracher, T., Mizrahi, M. i., Bergseth, B., Maung, K. M. C., Khine, Z. L., Phyu, E. T., Simpfendorfer, C. A., *et al.* 2021. Understanding non-compliance in small-scale fisheries: shark fishing in Myanmar's Myeik Archipelago. Ambio, 50: 572–585.

Mayhew, J., and Basurto, X. 2016. Perceptions of Fisheries Management, Gill Net Use and Income Diversification among Small-Scale Fishers in Belize, p. 49. Duke University.

McDonald, G., Harford, B., Arrivillaga, A., Babcock, E. A., Carcamo, R., Foley, J., Fujita, R., *et al.* 2017. An indicator-based adaptive management framework and its development for data-limited fisheries in Belize. Marine Policy, 76: 28–37.

McField, M., Kramer, P., Petersen, A. G., Soto, M., Drysdale, I., Craig, N., and Flores, M. R. 2020. 2020 Mesoamerican Reef Report Card.

Mizrahi, M. i., Duce, S., Khine, Z. L., MacKeracher, T., Maung, K. M. C., Phyu, E. T., Pressey, R. L., *et al.* 2020. Mitigating negative livelihood impacts of no-take MPAs on small-scale fishers. Biological Conservation, 245: 108554.

Mizrahi, M. i., Duce, S., Pressey, R. L., Simpfendorfer, C. A., Weeks, R., and Diedrich, A. 2019. Global opportunities and challenges for Shark Large Marine Protected Areas. Biological Conservation, 234: 107–115.

OECD. 2014. Environmental Performance Reviews: Iceland. OECD Environmental Performance Reviews, OECD Publishing, Paris, https://doi.org/10.1787/9789264214200-en.. Last Accessed 15 April 2021.

Ojea, E., Lester, S. E., and Salgueiro-Otero, D. 2020. Adaptation of fishing communities to climate-driven shifts in target species. One Earth, 2: 544–556.

Ojea, E., Pearlman, I., Gaines, S. D., and Lester, S. E. 2017. Fisheries regulatory regimes and resilience to climate change. Ambio, 46: 399–412.

Österblom, H., Wabnitz, C. C. C., Tladi, D., Allison, E. H., Arnaud-Haond, S., Bebbington, J., Bennett, N. J., *et al.* 2020. Towards ocean equity. Washington, DC: World Resources Institute. Available online at www.oceanpanel.org/how-distribute-benefits-ocean-equitably.

Ostrom, E. 2009. A general framework for analyzing sustainability of social-ecological systems. Science, 325: 419–422.

Palomo, L. E., and Hernández-Flores, A. 2019. Application of the Ostrom framework in the analysis of a social-ecological system with multiple resources in a marine protected area. PeerJ, 7: e7374-e7374.

Paredes, C. E., and De la Puente, S. 2014. Situación actual de la pesquería de la pota (*Dosidicus gigas*) en el Perú y recomendaciones para du mejora. Informe Final, 112 pp. Available online at http://www2.congreso.gob.pe/sicr/cendocbib/con4_uibd.nsf/AF579F67269CB59505257D8E004DCB6F/$FILE/1._doc._final_cies.pdf

Pe, M. 2004. National Report of Myanmar On the Sustainable Management of The Bay of Bengal Large Marine Ecosystem (BOBLME). GCP/RAS/179/WBG, 61 pp.

Pentz, B., Klenk, N., Ogle, S., and Fisher, J. A. D. 2018. Can regional fisheries management organizations (RFMOs) manage resources effectively during climate change? Marine Policy, 92: 13–20.

Pinsky, M. L., and Mantua, N. J. 2014. Emerging adaptation approaches for climate-ready fisheries management. Oceanography, 27: 146–159.

Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., and Cheung, W. W. L. 2018. Preparing ocean governance for species on the move. Science, 360: 1189–1191.

Poloczanska, E. S., Brown, C. J., Sydeman, W. J., Kiessling, W., Schoeman, D. S., Moore, P. J., Brander, K., *et al.* 2013. Global imprint of climate change on marine life. Nature Climate Change, 3: 919–925.

Pons, M., Cope, J. M., and Kell, L. T. 2020. Comparing performance of catch-based and length-based stock assessment methods in data-limited fisheries. Canadian Journal of Fisheries and Aquatic Sciences, 77: 1026–1037.

Rao, M., Saw, H., Platt, S. G., Tizard, R., Poole, C., Than, M., and Watson, J. E. M. 2013. Biodiversity conservation in a changing climate: a review of threats and implications for conservation planning in Myanmar. Ambio, 42: 789–804.

Rovegno, N. 2017. Diagnóstico Del Estado Poblacional y de la Pesquería de Calamar Gigante (Dosidicus Gigas) en Términos de su Impacto en el Ecosistema Oceánico Peruano. Universidad Nacional Federico Villareal, Lima, Peru.

Rudd, M. B., and Thorson, J. T. 2018. Accounting for variable recruitment and fishing mortality in length-based stock assessments for data-limited fisheries. Canadian Journal of Fisheries and Aquatic Sciences, 75: 1019–1035.

Steneck, R. S., Hughes, T. P., Cinner, J. E., Adger, W. N., Arnold, S. N., Berkes, F., Boudreau, S. A., *et al.* 2011. Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conservation Biology, 25: 904–912.

Strømme, T., O. Nakken,. Aung, S., Saetersdal. G. 1981. Surveys on the marine fish resources of Burma (Sep.-Nov. 1979 and Mar.-Apr. 1980). Reports on surveys of the R/V Dr Fridtjof Nansen. Institute of Marine Research, Bergen. 89 pp.

Tezzo, X., Belton, B., Johnstone, G., and Callow, M. 2018. Myanmar's fisheries in transition: current status and opportunities for policy reform. Marine Policy, 97: 91–100.

The World Bank. 2017a. GDP growth: world bank national accounts data, and OECD national accounts data files. https://data.worldbank.org/. Last Accessed 04/15/21.

The World Bank; Myanmar Ministry of Planning and Finance. 2017b. An Analysis of Poverty in Myanmar, Part 1: Trends between 2004/05 and 2015. World Bank, Yangon. © World Bank. https://openknowledge.worldbank.org/handle/10986/28220 License: CC BY 3.0 IGO. Last Accessed 15 April 2021.

Thiault, L., Mora, C., Cinner, J. E., Cheung, W. W. L., Graham, N. A. J., Januchowski-Hartley, F. A., Mouillot, D., *et al.* 2019. Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries. Science Advances, 5: eaaw9976.

Thornton, T. F., and Kitka, H. 2015. An indigenous model of a contested Pacific herring fishery in Sitka, Alaska. International Journal of Applied Geospatial Research (IJAGR), 6: 94–117.

Townsend, H., Harvey, C. J., deReynier, Y., Davis, D., Zador, S. G., Gaichas, S., Weijerman, M., *et al.* 2019. Progress on implementing ecosystem-based fisheries management in the united states through the use of ecosystem models and analysis. Frontiers in Marine Science, 6: 641.

Trueblood, L. A., and Seibel, B. A. 2013. The jumbo squid, *Dosidicus gigas* (Ommastrephidae), living in oxygen minimum zones I: oxygen consumption rates and critical oxygen partial pressures. Deep Sea Research Part II, 95: 218–224.

Usher, M. A. 2018. The United Nations Convention on the Law of the Sea and Belize's legal and institutional framework for ocean affairs, including legal and institutional requirements for sustainable marine fisheries, sustainable marine aquaculture, seafood processing and marine and coastal tourism. 36 pp. Available online at https://unctad.org/system/files/official-document/ditctedinf2019d11_en.pdf. Last Accessed 15 April 2021.

Vivekanandan, E., Hermes, R., and O'Brien, C. 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environmental Development, 17: 46–56.

Wade, E., Spalding, A. K., and Biedenweg, K. 2019. Integrating property rights into fisheries management: the case of Belize's journey to managed access. Marine Policy, 108: 103631.

Weeratunge, N., Snyder, K. A., and Sze, C. P. 2010. Gleaner, fisher, trader, processor: understanding gendered employment in fisheries and aquaculture. Fish and Fisheries, 11: 405–420.

Wilson, J. R., Lomonico, S., Bradley, D., Sievanen, L., Dempsey, T., Bell, M., McAfee, S., *et al.* 2018. Adaptive comanagement to achieve climate-ready fisheries. Conservation Letters, 11: e12452.

Yamashiro, C., Mariátegui, L., Tafur, R., Castillo, G., Argüelles, J., Goicochea, C., Alegre, A., *et al.* 2018. Sistema de monitoreo de la pesquería del calamar gigante Dosidicus gigas en el Perú. Bol Inst Mar Perú, 33: 222–252.

Zanotti, L., Zhao, M., Johnson, J. L., Johnson, D. R., Yu, D. J., Burnham, M., and., and Carothers, C. 2020. Sustainability, resilience, adaptation, and transformation: tensions and plural approaches. Ecology & Society, 25: 1–11.

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