Building Climate-Resilient Fisheries

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Prepared by:

EcoAdvisors
Consulting services for a better world

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IN THIS REPORT

This report includes specific assessments, resilience diagnoses and resilience-based-management (RbM) recommendations to inform WFF strategies and potential investments and actions to build climate-resilient fisheries.

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Background on climate change and fisheries management

General trends, outlook, approaches

Marine fisheries provide critical services to people around the world, particularly in the forms of food and livelihoods (Millenium Ecosystem Assessment 2005; FAO 2014), and substantial efforts to increase long-term fisheries sustainability have been invested by stakeholders from public, private, and non-profit sectors, as well as fishing industries and communities.

Attention to potential effects of climate change on marine fisheries and on the humans that depend on them has increased significantly in recent years (e.g., Allison et al. 2009; Cheung et al. 2010; Barange et al. 2014; 2018). Climate change is disrupting physical, chemical, and biological aspects of marine ecosystems in several ways that negatively affect fisheries, manifesting in changes in distributions and abundance of target stocks (Allison et al. 2009; Cheung et al. 2010; Barange et al. 2014; 2018; Gaines et al. 2018; Ojea et al. 2020). These changes, in turn, have significant implications for human communities from local to global scales, though effects of climate-induced changes in marine fisheries will likely exacerbate existing inequalities among communities and nations depending on their relative capacity to adapt to climate change (Grafton 2010; Barange et al. 2014; 2018; Gaines et al. 2018; Burden and Battista 2019; Cohen et al. 2019; Ojea et al. 2020).

Many studies focus on potential changes on overall food production among countries (e.g., Cheung et al. 2010; Barange et al. 2014), while less attention has been paid to how humans might respond to adapt fisheries to these changes (Gaines et al. 2018; EDF 2019). Fisheries management efforts have generally focused on attaining sustainability--i.e., fisheries production levels that maximize yield and/or profit while maintaining target stocks above established biological reference points--which largely relies on understanding past conditions to manage present activities (Burden and Fujita 2019). Climate change threatens to undermine the progress made toward sustainability in many fisheries in many parts of the world. However, few governance systems or

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MANY STUDIES FOCUS ON:

- Potential changes on overall food production
- Attaining sustainability through fishery production levels that maximize yield and/or profit while maintaining target stocks above established biological reference points

Few governance systems or management regimes explicitly account for climate change effects on fisheries in their decision-making and policy implementation.

management regimes explicitly account for climate change effects on fisheries in their decision-making and policy implementation (Burden and Fujita 2019; Ojea et al. 2020; Oremus et al. 2020). Therefore, although solidifying core principles of fisheries sustainability is critical for ensuring sustainable fisheries in the future, managing for sustainability alone is insufficient. Fisheries systems need to build forward-looking, resilience-based approaches on the foundation of sustainability principles to ensure that fisheries can thrive in the face of climate change (Burden and Battista 2019; Burden and Fujita 2019; EDF 2019).

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Purpose and structure of this report

The Walton Family Foundation (WFF) Oceans Team and Evaluation and Learning Team commissioned this project to identify opportunities for building climate-resilience into fisheries management and inform WFF strategies and potential investments to strengthen the climate resilience of priority fisheries. This report provides an analysis that evaluates the current state of, and concerns related to the resilience of six selected fisheries to climate change, and it prepares program officers with current science and relevant tools to advance fisheries management and strengthen fisheries resilience in the context of climate change.

For context, we first provide a brief summary of climate resilience theory and its application to fisheries. We then describe our approach to evaluating resilience needs and opportunities in the selected fisheries and present our summary findings, key observations, and potential resilience interventions for each fishery. Finally, we present recommendations for resilience interventions applicable to specific fisheries as well as fisheries in general.

1. Brief summary of climate resilience theory and its application to fisheries.
2. Approach to evaluating resilience needs and opportunities and summary of findings.
3. Recommendations for resilience interventions applicable to specific fisheries as well as fisheries in general.

1

Resilience theory and its application to fisheries

Resilience refers to the ability of a system, by its configuration and management, to maintain its function and expected services under stresses and shocks and to transform to a new, stable function when prior conditions cannot be maintained (Holling 1996; Walker et al. 2004; Folke et al. 2010; Boltz et al. 2019).

When looking at marine fisheries, these human-managed ecological systems are managed for their production of fish and fish products for human consumption and use. Fisheries, as a whole, are social-ecological-technological systems (SETs) that are complex, integrated systems in which humans are part of nature and in which social norms, networks, institutions, and technologies have particular influence and agency (Berkes and Folke 1998; Markolf et al. 2018). Fisheries exist in a dynamic equilibrium comprising social, ecological, and technological aspects that define how the system functions what it produces and determine its vulnerabilities as well as its resilience. While not exhaustive, SET attributes that influence fisheries resilience are described in Table 1 below.

Several factors within Social, Ecological, and Technological (SET) domains influence fisheries resilience (Table 1).

Social (S)	Ecological (E)	Technological (T)
• governance systems	• species physiology	• monitoring
• institutional integrity	• species life history	• data
• norms	• stock characteristics	• knowledge systems
• inclusion & equity	• nutrient availability	• management practices
• trust	• prey characteristics	• fishing capacity
• agency & leadership	• biodiversity	• harvest technology
• networks	• habitat status	• physical infrastructure
• access to capital	• refugia	• cyber infrastructure
• economic incentives	• connectivity	
• livelihood diversity	• environmental conditions	
• social safety nets		

Building fisheries resilience requires not only ecological interventions aimed to preserve extant stocks, but also social and technological interventions aiming to manage human reliance on fisheries and to adapt management practices and productive use of harvested products. Resilient fisheries, by their SET configuration and by their management, are able to maintain their function and productivity under disturbance, adapt to protracted and permanent change in their environment and to other stressors (e.g., changes in temperature, pH, oxygen, habitat and species composition), and to transform to a new production system when conditions require. Transformation is an imperative when harvested species decline in abundance and productivity or when they migrate to novel habitats, such as the poleward migration observed currently in many species.

General and specific resilience

General Resilience refers to the capacity of a system to adapt or transform in response to any disturbance, particularly to unexpected and extreme shocks (Carpenter et al. 2012), such as natural disasters, pandemics, and wars. Attributes necessary for the general resilience of fisheries are common and many are well-established principles of responsible management. They include social aspects of good governance, economic incentives and access to capital, ecological factors such as sustainable stocks and habitat integrity and technological attributes including sustainable practices, data and monitoring systems (EDF 2019).

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>
> *Carpenter et al. 2012*

Moreover, while climate change will affect the distribution and productivity of fish, there are established ways to manage these dynamics, as fish distribution and productivity have always been variable (Burden and Fujita 2019). Established principles and practices for responsible and sustainable fisheries management are generally beneficial to fisheries resilience to climate change (Burden and Battista 2019) and to other stressors (Table 2).

Several common interventions within social, ecological, and technological domains are beneficial to the general resilience of fisheries (Table 2).

Social (S)	Ecological (E)	Technological (T)
• improve governance	• maintain sustainable stocks	• enhance monitoring
• provide economic incentives	• conserve key habitats	• manage and share knowledge
• enhance access to capital	• mitigate stressors	• inform management standards & harvest controls

These broadly applicable General Resilience practices are necessary, but not sufficient to ensure resilience to climate change in specific fisheries. Specific Resilience refers to the resilience of a system, or a component of a system, to a particular kind of stress or disturbance (Walker and Salt 2012). Fisheries differ in their specific resilience requirements, for instance sessile species facing productivity declines due to ocean warming differ dramatically from pelagic species that migrate to higher latitudes in response to this same stressor.

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> *Walker and Salt 2012*

Understanding the fishery as **a dynamic, human-managed natural system driven by particular social, ecological and technical factors** provides a means of assessing system-specific vulnerabilities, strengths and needs for their resilience, and thereby determining specific RbM options. While improving governance is always a good thing, developing cross-jurisdictional agreements and catch and price sharing arrangements will be particularly warranted for migrating stocks. Similarly, conserving habitat is generally recommended; however, enhanced connectivity and climate refugia are of specific benefit to shelf-dwelling species. In the following section, we consider the specific resilience of target fisheries and suggest what interventions may be particularly warranted given their specific vulnerabilities and strengths.

What is the difference between "sustainable" and "resilient" fisheries management?

As described above, managing fisheries for sustainability is essential to fisheries resilience to climate change and to other stressors, but it is not sufficient to ensure that climate-resilient fisheries management is successfully realized. Core sustainability principles must be intentionally tailored and enhanced to bolster climate resilience in fisheries (Fig. 1). Shifting to resilience-based management requires that we understand and manage a changing system, for which the magnitude and pace of change are riddled by uncertainty. This implies a dynamic approach to management, informed by historic data but also by current, real-time inputs and forecast trends. Resilience-based management also relies upon adaptive social, governance and management systems, structured to incorporate and adjust to changes both incremental and rapid.

First, sustainability, then resilience: How core sustainability principles can be enhanced to bolster climate resilience in fisheries (Figure 1).

	1. Sustainability	2. Resilience
Ecological	• Critical habitats, species and ecosystem traits are conserved *in situ* • Stock management practices are informed by historic data and trends	• Habitat and species conservation efforts incorporate climate-induced changes such as species shifts, habitat change, altered environmental conditions • Stock management practices are informed by historic as well as forecasted data and trends • Management of specific stocks contextualized in ecosystem perspective, favoring diversity, functional species, adaptive species and overall ecosystem health
Social	• Inclusive, participatory, polycentric governance and co-management involving multiple stakeholders • Information and management shared across jurisdictions relevant to stock distribution • Incentives available to promote sustainability in fishery • Diverse fishing livelihoods available, sustainable reliance on specific stocks	• Adaptive governance practices, incorporating response to stock and ocean ecosystem changes, extreme events, and related socio-economic impacts • Cross-jurisdictional governance agreements, addressing species migration and regional ocean system changes • Market incentives address uncertainty and risk, encouraging shift to resilience-based management • Enhanced ability to shift to alternative stocks, strengthened local markets, increased supply chain species diversification
Technological	• Fishery performance and productivity data sufficient for stock assessments • Robust stock assessments inform quantitative management targets • Catch limits (TAC, quotas) based on sustainability goals established and monitored • Adaptive management based on recommendations derived from stock assessments	• Ocean system data capturing stock, ecosystem and key environmental conditions inform stock assessments and management guidance • Stock assessments incorporate effects of variation in environmental conditions on key productivity parameters (e.g., growth, reproduction) • Catch limits (TAC, quotas) established and monitored to account for variation in environmental conditions in near-real-time, based on climate vulnerability assessments • Adaptive management draws upon near 'real-time' ocean observation and warning system data

2

Approach to evaluating resilience needs and opportunities in six selected fisheries

The six fisheries were selected in consultation with WFF Oceans Team staff with two objectives in mind: 1) to include fisheries in which WFF has already invested significantly, and 2) to represent a diverse set of 'fishery archetypes' (i.e., fisheries systems with specific characteristics or dynamics that are representative of other fisheries) in order to ensure both fishery-specific as well as generalizable findings and recommendations about climate resilient fishery management.

The **six fishery systems** that we evaluated were:

- Global octopus source and consumer markets
- Jumbo flying squid
- Coldwater crabs, Chile
- Indonesia blue swimming crab
- Mexico finfish complex (mainly targeting snapper and grouper; Pacific and Caribbean)
- Alaska cod and pollock.

Photo Source (clockwise): octopus by Serena Repice-Lentini, Unsplash; Humboldt-squid © Carrie Vonderhaar, Ocean Futures Society; cod by Ricardo Resende, Unsplash; grouper by John Bergman, Unsplash; Chile stone crabs © Rodrigo Fernández; blue crab by Girish Dalvi, Unsplash.

This suite of individual fishery systems represented several fisheries archetypes that reflect **different themes in climate-resilient fisheries management**, and in which:

- Stocks move across jurisdictions; new or changing species interactions
- Stock abundance declines due to environmental stressors
- Supply chains are complex, opaque and based on vulnerable sources
- Effective management is being undermined by climate change effects.

Our approach to evaluating climate resilience needs and opportunities in the selected fisheries involved a **Discovery phase** followed by a **Synthesis and Evaluation phase**, which are described in the following sections.

Discovery Phase

During the Discovery phase, we first compiled and reviewed research publications and reports on climate change effects on fisheries and climate resilience of marine ecosystems and species generally. We also compiled and reviewed similar types of information about the fisheries, including background about governance, management, performance, and any observed or suspected climate change effects. We then augmented this background research with interviews with 18 individuals with specific knowledge about one or more of the selected fisheries, or with expertise in climate-resilient fisheries management. The interviews were based on a standardized set of questions that were tailored for each interviewee's expertise. The question set and list of interviewees are included in Appendix A.

Synthesis and Evaluation phase

In order to systematically assess resilience needs and relevant interventions, we developed a resilience diagnostic framework for fisheries, articulating social, ecological, and technological (SET) domains and factors relevant to fishery resilience in order to assess the climate resilience of specific fisheries (Figure 2). SET domains and factors are consistent with contemporary literature on evaluation of climate vulnerability or resilience of fisheries (Appendix B provides detailed SET domains, factors, subfactors, and supporting literature). We then synthesized the information reviewed during the Discovery Phase to evaluate each fishery's relative climate vulnerability or resilience to climate change within each SET domain, using the defined factors and subfactors. This standardized approach ensured that our evaluation of resilience was performed consistently across fisheries, and allowed us to identify potential resilience interventions in relation to specific evaluation factors.

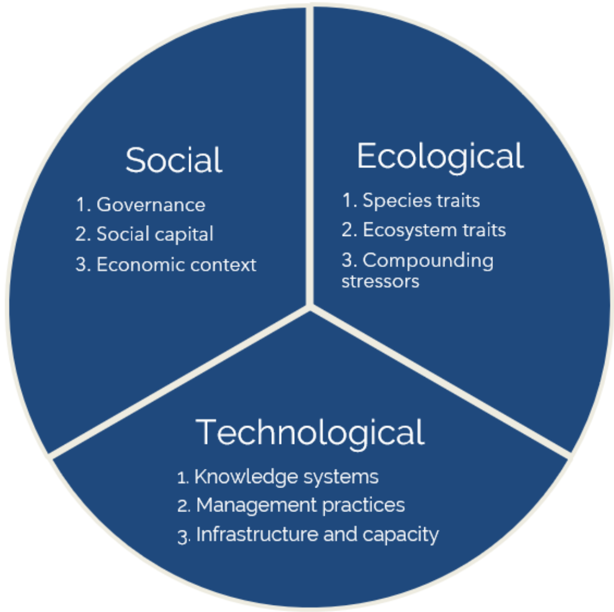


Figure 2. Resilience Diagnostic Framework for Fisheries

We created a standard template to characterize fisheries resilience considerations (Table 3). As part of our resilience evaluation, we assessed the extent to which core sustainability principles (i.e., scientifically determined catch limits; secure tenure rights; inclusive, participatory, adaptive decision-making processes; polycentric governance[1] structures to ensure compliance [*sensu* Ostrom 1990; Burden and Battista 2019; Burden and Fujita 2019]) are already in place in each fishery, recognizing that RbM approaches should build upon a foundation of sustainable fishery management practices.

We used a standard template to evaluate climate resilience of each fishery that consisted of background information, social/ecological/technological factors, and existing and potential resilience interventions (Table 3).

Element	Definition
Geography	Where in the world the fishery occurs
Current status	Stock status relative to established standards, or stock-specific biological reference points
Stressor(s)	Climate or other stressors; e.g., increased temperatures, acidification, IUU fishing
Vulnerability(ies)	Observed or expected adverse effects of climate change and compounding stressors on the fishery
Social factors	Governance Systems, Social Capital, Economic Context

[1] A form of governance with multiple centers of decision making, each of which operates with some degree of autonomy, nested at multiple scales of jurisdiction and across stakeholder groups (Ostrom 1990).

Element	Definition
Ecological factors	Species Traits, Ecosystem/Habitat Traits, Compounding Stressors
Technological factors	Knowledge Systems, Management Practices, Infrastructure and Capacity
Relevant existing interventions	Relevant projects and actions underway, e.g. FIPs cooperative governance agreements, certification, environmental monitoring
Potential resilience interventions	Specific measures recommended per our assessment

In addition to the text evaluations for each template element, we also adapted the conceptual framework in Figure 3 to provide clear, standardized visual summaries of our SET evaluations for each fishery. These SET 'radar' diagrams were designed to illustrate qualitatively the relative extent of resilience in each SET domain for each fishery, and to facilitate comparisons across fisheries.

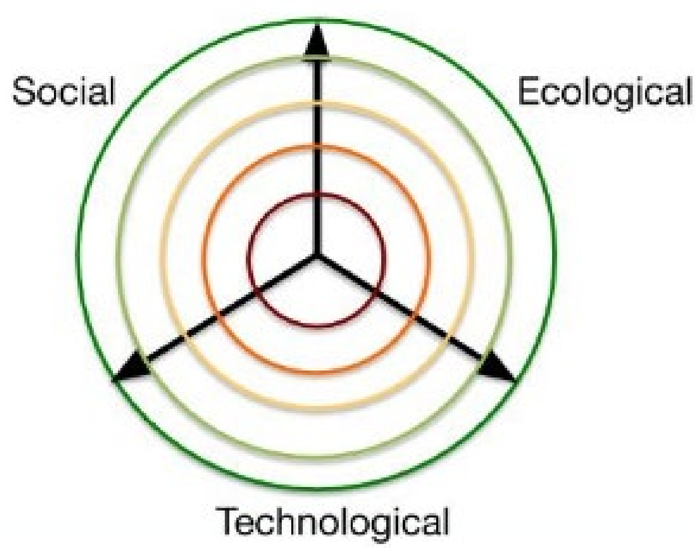


Figure 3. Illustrative figure to summarize evaluation of SET domains for each fishery. Resilience increases from center to perimeter of the circle for each domain. See Fishery-specific analyses section

Caveats to the present analysis

Our approach was robust, well-resourced with literature and expert interviews, and grounded in established concepts and analyses in fisheries management (see Appendix B). However, our analysis was necessarily limited due to project scope and logistical constraints. Accordingly, we feel it imperative to raise key cautions to ensure that our findings and recommendations are interpreted appropriately.

First, our assessments were based solely on desktop research of largely publicly available information, as well as interviews with individuals via videoconference. We were unable to perform site visits, consult directly with multiple stakeholders in each fishery, or engage extensively with experts.

Secondly, identifying climate change "signals" for species and ecosystems was limited by sparse available data and high uncertainty about climate change effects. This uncertainty was often confounded by concomitant lack of sufficient fishery-specific data to discern whether possible changes in stock abundance or distribution may be attributed to climate or fishing practices.

Additionally, our findings are summarized at the level of SET domains; factors and sub-factors were not evaluated in great detail and would benefit from greater investigation and expert input. Accordingly, our findings and recommendations concerning resilience interventions should be viewed as indicative and non-exhaustive. While we are confident in the findings, further work is warranted to verify them and to derive suitably tailored recommendations for resilience actions. A more extensive diagnosis and planning for climate resilience in selected fisheries could be readily performed following the structure and methodology described here. Such an in-depth analysis would provide greater detail and insight about fishery vulnerabilities and strengths related to climate resilience, and would enable a more tailored, expert-validated and stakeholder-driven articulation of resilience aspirations and actions.

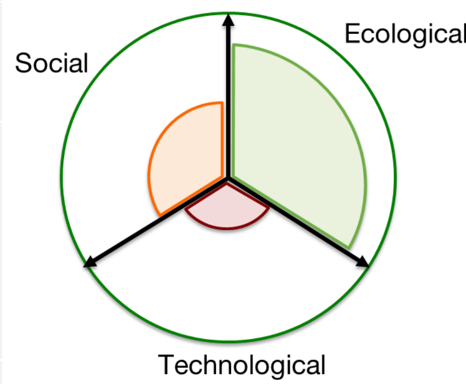
Synthesis Findings

Our resilience diagnostic framework revealed key vulnerabilities and strengths in the specific fisheries as well as general resilience needs across the portfolio. Collective findings allowed us to identify climate vulnerabilities, SET domain vulnerabilities, and potentially relevant intervention types that are generalizable to the fisheries archetypes represented in the suite of WFF's priority fisheries (Appendix C). These generalized findings highlight broad patterns that are not unique to specific fisheries. The identification of fishery-specific vulnerabilities and interventions derived from fishery-specific resilience evaluations presented in the next section.

We present our synthesis findings in the standard format for each fishery below. Findings and recommendations across fisheries, and resources that supported our evaluations are included in Appendix D.

Octopus (*Octopus vulgaris*, *O. cyanea*, *O. sinensis*; others)

Geography	Global
Current Status	Stocks likely fully exploited in Morocco, West Africa, Mexico (Yucatán)
Stressors	Warming, habitat degradation; IUU fishing pressure
Vulnerabilities	Possible changes in stock distribution and abundance
Ecological factors	Species traits highly adaptive, resilient (temp, hypoxia); rubble-reef habitat fairly resilient, tropical reef habitats vulnerable; IUU pressures significant
Social factors	Core sustainability principles somewhat in place at local scales, but not collectively at global or individual market scales; fragmented governance, poor regulation; highly fluid supply (multiple species from many locations to major markets) diminishes potential sustainability incentives; women comprise workforce in some locales
Technological factors	Core sustainability principles not in place; uncertainty about stock status because data & monitoring inadequate; management practices not uniform or sustainable (few exceptions)**;** Gear in many cases highly selective
Existing interventions	FIPs in progress (Indonesia, Madagascar, Pacific Mexico, Mauritania), including strengthening local governance, input controls, closures

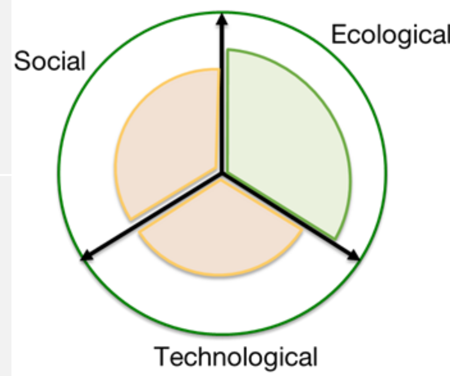


Resilience interventions:

- Improved local monitoring capacity to support adaptive, species-specific harvest control rules and identification and adaptation of closures/refugia
- Facilitate polycentric governance, especially local to regional
- Support nascent efforts to coordinate sustainability efforts among importers to major markets
- Consumer markets could drive movement toward sustainable and resilient management practices

Jumbo flying squid (*Dosidicus gigas*)

Geography	Eastern Pacific Ocean, i.e. Gulf of California and Humboldt Current
Current Status	Within biological reference points, excepting Mexico; Effects of Chinese distant water harvest in Humboldt Ecosystem poorly understood
Stressors	Warming, indirect effects on prey and habitat; IUU fishing pressure
Vulnerabilities	Possible changes in stock distribution and abundance
Ecological factors	Species highly mobile, adaptive, resilient to env. change (temp, hypoxia); uncertainty about size-productivity relationships and climate effects; env. conditions highly variable in pelagic upwelling systems; IUU fishing pressures significant
Social factors	Core sustainability principles somewhat in place; Fisheries systems well-established within countries; International coordination lacking, but efforts exist to improve coordination and information sharing; Robust global markets, access to capital, developed supply chain; Diverse fishing-based livelihoods; Productivity volatile, so local infrastructure development economically difficult
Technological factors	Core sustainability principles somewhat in place; Quotas established and monitored, but much catch unreported; Basic monitoring is occurring but not harmonized regionally; Systems being developed to improve coordinated collection and analysis of catch and env. data to adaptively manage in Humboldt ecosystem; Gear highly selective
Existing interventions	New Humboldt Ecosystem monitoring system in development to support adaptive management; increasing effort to manage regionally including ABNJ through SPRFMO; FIPs in progress (MX, PE)

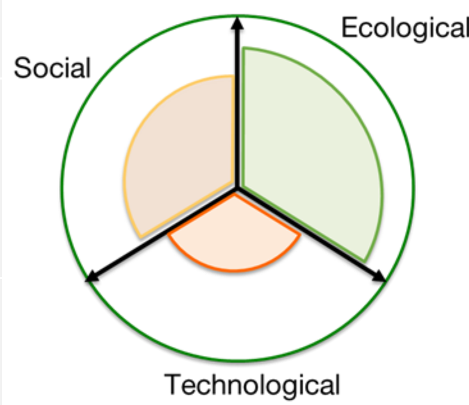


Resilience interventions:

- Improved, coordinated environmental and catch monitoring (SAPO, Humboldt Current)
- Regionally coordinated, multi-jurisdictional governance, development of adaptive harvest control rules
- Catch/profit sharing between Peru and Chile in response to fluctuating productivity

Chile stone crabs (*Metacarcinus edwardsi*), king crabs (*Lithodes antarctica* L. santolla)

Geography	southern Chile
Current Status	Apparently at full exploitation, but uncertain
Stressors	warming, hypoxia, acidification; IUU fishing pressure
Vulnerabilities	possible changes in stock abundance (reproduction effects) and distribution (increased depth and distance from shore)
Ecological factors	Species highly resilient to env. change (temp, hypoxia, salinity); Climate change effects expected to be modest in southern Chile; significant IUU fishing pressure
Social factors	Core sustainability principles somewhat in place; Governance structure and social capital very strong; Polycentric governance, robust consultation among stakeholders; Management plans not developed; USA market could incentivize sustainability
Technological factors	Core sustainability principles somewhat in place; Uncertainty about stock status because data and monitoring inadequate; Large % of fishery unregulated, effort mostly unmonitored; Output controls in place, but not well-monitored; Moving toward input controls; Adaptive management lacking
Existing interventions	Working on FIP for stone crab, improved monitoring efforts

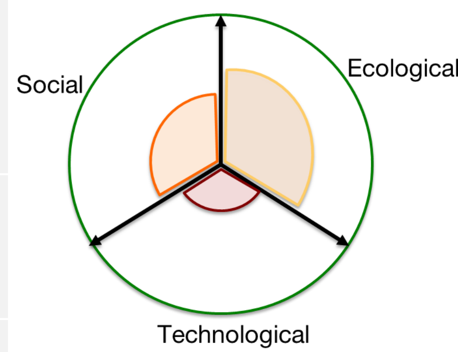


Resilience interventions:

- Improved, coordinated environmental and catch monitoring and established harvest control rules
- Identify and adapt marine protected areas and refugia
- Enhanced monitoring of fishing effort and enforcement of input controls
- Consumer markets could drive movement toward sustainable and resilient management practices (especially USA)

Indonesia blue swimming crabs (*Portunus pelagicus*)

Geography	Java Sea, Indonesia
Current Status	Apparently at full exploitation, but uncertain
Stressors	warming, acidification, decreased water quality from agricultural runoff; IUU fishing pressure
Vulnerabilities	possible changes in species abundance (effects on reproduction) and distribution (increased depth, ↑ distance from shore)
Ecological factors	Species fairly resilient, some sensitivity to warming (changes in reproduction); Coastal, benthic habitats vary in sensitivity to warming (coral reefs to mudflats); possible indirect effects of HABs; Significant IUU fishing pressure
Social factors	Core sustainability principles not in place; Governance weak and poorly coordinated; Low access to capital; Women comprise processing workforce
Technological factors	Core sustainability principles not in place; Uncertainty about stock status because data and monitoring inadequate; Large % of fishery unregulated; Management plans not developed, no harvest strategies in place; Some output controls established but not enforced; Fishing gear not selective
Existing interventions	Several efforts underway to improve governance, coordination, e.g., FIP development, industry group assuming monitoring responsibilities, official BSC harvest strategy

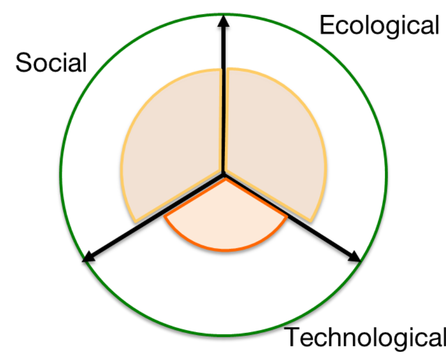


Resilience interventions:

- Improved catch monitoring, stock assessments incorporating potential environmental effects, adaptive harvest control rules
- Vulnerability assessment of BSC and key habitats
- In fishing communities, diversification and value-add of other catch and capture of more supply chain
- Consumer markets could drive movement toward sustainable and resilient management practices

Mexico finfish complex (Pacific and Caribbean) targeting snapper/grouper (e.g., red snapper: *Lutjanus peru*, yellowtail snapper: *Ocyurus chrysurus*; red grouper: *Epinephelus morio*)

Geography	Yucatan (Y), and Gulf of California (G), Mexico
Current Status	Y: overfished; G: at or below MSY
Stressors	warming, acidification, hypoxia, habitat degradation, indirect prey effects, IUU fishing pressure
Vulnerabilities	possible changes in species abundance (effects on reproduction) and distribution (↑ depth, ↑ distance from shore)
Ecological factors	Species highly mobile, high adaptive capacity but vulnerable life history traits; species-specific responses to increased temperatures (direct and indirect effects); warming effects on prey distribution and abundance
Social factors	Governance system established; Stakeholder consultation lacking (Y); G model: Strengthening polycentric governance and shared information collection for decision-making; Fishers have diverse portfolio, shift to higher value catch; Low incentives for sustainability
Technological factors	Y: Core sustainability principles not met; Stock status uncertain because monitoring inadequate; Input and output control regulations unenforced; G: Core sustainability principles somewhat in place; Monitoring underway; Implementing MPAs
Relevant existing interventions	G: Developing network of fishing communities, shared management, sensors analyzed with catch information; FIPs underway for red grouper (Y), finfish (G)

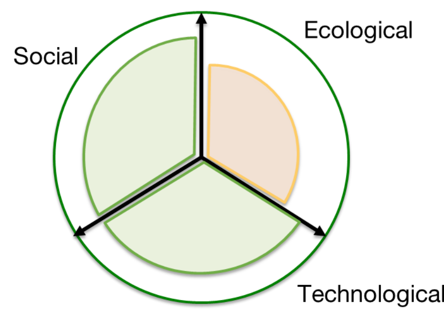


Resilience interventions:

- Improved catch monitoring, stock assessments incorporating potential environmental effects, and established harvest control rules, especially Yucatán
- Bolster regional environmental monitoring, management efforts
- Vulnerability assessment of finfish species and key habitats
- Identify and adapt marine protected areas and refugia
- Increase value in local markets for sustainably caught fish

Alaska cod (*Gadus macrocephalus*) and pollock (*Gadus chalcogrammus*)

Geography	Gulf of Alaska (GoA), East Bering Sea (EBS)
Current Status	GoA cod significantly declined, MSC certification suspended; major implications for the fisheries and for MSC; GoA pollock declining, recent declines in EBS cod, EBS pollock stable, still sustainable *MSC Certified
Stressors	warming, indirect prey effects
Vulnerabilities	range shifts and expansion; reduced recruitment, abundance
Ecological factors	Species generally resilient to temperature fluctuations, but recent declines tied to poor juvenile recruitment due to lack/mismatch of prey; Potential shifts poleward
Social factors	Core sustainability principles firmly in place; Effective governance & sustainable management systems with high capacity and coordination from fishers to managers to processors all under management council; Fishers have agency in the system; Well-developed supply chains locally and globally; Remote communities potentially vulnerable; Poleward range shifts could create multi-jurisdictional issues; Sustainability certification not responsive to climate change effects
Technological factors	Core sustainability principles firmly in place; Robust monitoring, assessments, and harvest control rules; need to better account for climate effects in establishing TAC, especially as species shift poleward
Existing interventions	Adaptively managing TAC as stocks decline, accounting for env. conditions; ongoing discussions about accounting for climate change effects in MSC certification; existing coordination among USA, Canada, and Russia to build on



Resilience interventions:

- Support efforts to improve sustainability standards by including climate change effects and recognizing resilience interventions
- Multi-national cooperative agreement(s) to share catch, profits
- In remote fishing communities, diversification and value-add of other catch and capture of more supply chain

General Findings for Resilience-based Management (RbM) in six selected fisheries and fisheries archetypes

Looking across the fishery systems, some overarching observations were apparent and worth highlighting (summarized in Table 4), including unexpected insights about how the COVID-19 pandemic has provided a 'stress test' for resilience of priority fisheries (Box 1).

First, target species in **the selected fisheries appear to be fairly (to very) ecologically resilient to climate change effects**. Among target stocks, species traits (e.g., short lifespans, high fecundity, high physiological tolerances, high mobility) are generally resilient to climate stressors at present. It is unknown to what extent or for how long this ecological resilience can persist under continued and intensified climate effects. However, **while ecological resilience appears high among target stocks we evaluated, we also identified examples of apparent stock migrations and changes in abundance** (e.g., GoA cod, Mexico fisheries finfish), including across jurisdictions (e.g., jumbo flying squid, AK cod/pollock). Further, significant IUU fishing pressure was identified for nearly all six fisheries, which undermines resilience in other ecological traits and in social and technological domains (Table 4).

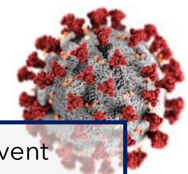
In contrast to the finding of general ecological resilience, **we identified several vulnerabilities in social and technological domains across fisheries** (Table 4). In particular, vulnerabilities in fisheries governance and management reveal the need to shift to RbM.

To enhance resilience, core sustainability principles first need to be implemented in several fisheries (e.g., octopus, Indonesia blue swimming crab, and Chile cold-water crabs). Further, there is a need in all fisheries to incorporate potential climate effects in assessments and management, even in those that are otherwise well-managed (e.g., Alaska cod and pollock). There is also a critical need to integrate resilience principles into existing incentive measures such as (but not limited to) certification systems, community-based conservation programs, and subsidies for improved gear adoption.

Finally, for small-scale fishing-dependent communities--which employ more people than all other marine economic sectors combined--**sustainability and resilience interventions must also encompass social goals relating to equity and participation to ensure intended livelihood and food security gains** (Cohen et al. 2019). To build adaptive capacity in small-scale fishing communities, resilience interventions should contribute to participatory, inclusive governance systems that facilitate co-management and joint information collection and sharing; diversification and value-add enhancement in multi-species fisheries; strengthened participation in supply chains by improving connections between food production and consumer markets; and equitable distribution of food security and livelihood benefits (Cohen et al. 2019). In addition to being important objectives in and of themselves, equity and participation are vital to adaptive capacity because without them, growing tension and conflict are likely to undermine any efforts to improve governance for resilience.

Taken together, our analysis of specific fisheries systems and the archetypes that they represent highlighted fundamental principles for general resilience of fishery systems (see Table 4 and Appendix C for more details):

- Development of RbM approaches, building on and adapting core sustainability principles, including adequate data collection, monitoring, and 'real-time' adaptation of management policies that incorporate environmental drivers of target stock productivity;
- Bolstering ecological resilience through mitigation of compounding stressors and protection/restoration of key habitats and refugia to maintain connectivity and diversity;
- Strong, inclusive, participatory, polycentric governance and co-management to support effective management practices and promote equity goals.



Box 1. COVID-19 as a 'stress test' of fisheries resilience

Although the global COVID-19 pandemic is different from climate change because it is a crisis event with unforeseen effects on fisheries, it has provided important insights about fisheries resilience. Following contraction in both volume and value in 2019, largely due to geopolitical conflict between China and the US, global seafood production in 2020 has been severely impacted by COVID-19 (FAO 2020). Public health measures aimed at containing virus transmission had unavoidable negative effects on economic activity across sectors around the world, including demand for internationally traded seafood products. These measures have caused a near elimination of food service demand (e.g., Italy and Spain demand for octopus) and market volatility characterized by periods of panic buying followed by long periods of inactivity. However, increased household demand for non-perishable food products has increased both online distribution and demand for canned and frozen products. As market demand has declined overall, supply has also suffered, with labor shortages related to idle fishing fleets and processors. Climate change effects on fisheries could create similar conditions under which productivity is reduced or becomes less predictable, thereby negatively affecting fishing-related livelihoods and creating market uncertainty.

The global dynamics caused by COVID-19 have also played out in the fisheries we evaluated. A collective message we heard from several interviewees was that COVID-19 was less like an 'act of God' type of crisis, and more of a 'rehearsal' or 'stress test' for climate resilience in different fisheries systems, particularly with respect to disruption in supply chains. Interviewees highlighted several lessons learned for different fisheries operating at different scales, foremost that single-species fisheries systems are inherently vulnerable to unstable conditions, whether in the environment, markets, or both. Communities, governments, and supply chains recognize the need for more robust, resilient plans that could include the ability to diversify catch for different markets. This could include opportunities to obtain value not just for high-priced export species, but also for other species (including bycatch) taken in the same fisheries or fishing areas. Fishing communities could also invest in processing capacity to capture more market share (e.g., Indonesia blue swimming crab, Mexico finfish, globally traded resources like octopus). Local markets and consumption could provide 'safe harbor' for products that might typically be exported, and could enhance sustainability and food security (e.g., Indonesia blue swimming crabs, Chile crabs, Mexico finfish, octopus). These recognized needs align with several of our recommended 'no regrets' interventions for specific fisheries (Table 4) and fisheries generally (next section).

Although specific effects of climate change on fisheries will be different from those of COVID-19 pandemic, the latter is providing fisheries systems with an impetus for developing measures that will enhance resilience to the former. The remainder of the report focuses on our recommended interventions that stem from aforementioned fundamental resilience principles, underscored by existing resilience challenges that our evaluation revealed.

EcoAdvisor's climate resilience analysis of six fisheries highlighted key social, ecological, and technological vulnerabilities and identified specific interventions that would enhance resilience in each fishery (Table 4).

Note, recommendations described in this document do not reflect the Foundation's funding priorities going forward—they are EcoAdvisor's recommendations only.

Fishery system	Key social vulnerabilities	Key ecological vulnerabilities	Key technological vulnerability(ies)	Specific Resilience Interventions
Octopus	• Weak, uncoordinated governance systems, locally to globally	• Unsustainable fishing pressure, including IUU	• Inadequate data collection and monitoring; lack of catch limits, input/output controls	• Bolster, expand efforts to strengthen governance • Adaptive management, incorporating monitoring & data sharing • Identify and implement fishing refugia/closures
Jumbo flying squid	• Bi-national, international governance lacking	• Highly responsive to env conditions; • Unsustainable fishing pressure, including IUU	• Fishery performance and environmental data not harmonized at scale of the stock's distribution	• Accelerate improved, coordinated monitoring and early warning system (SAPO, Humboldt Current) • Strengthen multi-jurisdictional governance and management, including development of adaptive harvest control rules, possible catch/profit sharing between Peru and Chile in response to fluctuating productivity
Chile crabs	• Governance process has not produced guidance on performance goals and management practices	• Unclear climate effects; • Unsustainable fishing pressure, including IUU	• Inadequate data collection and monitoring; lack of enforcement of catch limits, input/output controls	• Accelerate work of management committees • Conduct climate vulnerability assessment of crab species and habitats • Identify potential climate refugia for crabs as candidate no fishing zones • Increase value in local markets for sustainably caught crabs

Fishery system	Key social vulnerabilities	Key ecological vulnerabilities	Key technological vulnerability(ies)	Specific Resilience Interventions
Indonesia blue swimming crabs (BSC)	• Weak, uncoordinated governance and stakeholder coordination	• Unclear climate effects; Unsustainable fishing pressure, including IUU	• Inadequate data collection and monitoring; lack of enforcement of catch limits, input/output controls	• Conduct climate vulnerability assessment of BSC stocks and habitats • Identify potential climate refugia for crabs as candidate no fishing zones • Locally, promote diversification and value-add of other catch and capture more of supply chain
Mexico snapper/ grouper complex	• Stakeholder coordination and consultation insufficient (esp Yucatán) • Low incentives for sustainability	• Species-specific responses to warming, hypoxia; • Unsustainable fishing pressure, including IUU	• Yucatán: Inadequate data collection and monitoring; lack of catch limits, input/output controls • Gulf of California: Need to adaptively manage multi-species catch accounting for climate effects	• Bolster, expand efforts to strengthen governance • Adaptive management, incorporating monitoring & data sharing • Conduct climate vulnerability assessment of finfish spp and key habitats • Identify and adapt marine protected areas and refugia • Locally, promote diversification and value-add of other catch and capture more of supply chain
Alaska cod, pollock	• Remote communities potentially vulnerable; • Poleward range shifts could create multi-jurisdictional issues; • Sustainability certification not responsive to climate change effects	• Warming reduces juvenile survival • Warming drives northward distribution shift	• Need to adaptively manage TAC accounting for climate effects, especially as species shift poleward	• Support efforts to improve sustainability standards by including climate change effects and recognizing resilience interventions • Locally, promote diversification and value-add of other catch and capture more of supply chain

3

Recommended Resilience Interventions

Our evaluation highlighted several fishery-specific as well as general climate vulnerabilities and potential resilience interventions, based on the current resilience state of fisheries archetypes (Appendix C) and the six selected fisheries (previous section). In addition, there are numerous emerging innovations in the marine resource management sector and other sectors that are worth highlighting in a resilience context. Therefore, in this section, we describe several potential resilience interventions to provide WFF with detailed insights that could inform ongoing strategic planning about resilience opportunities in fisheries.

These recommendations are characterized based on whether they:

- address essential and emergent resilience needs, particularly for in social and technological domains;
- could allow for enhancing resilience once the fundamental interventions are in place; and
- are more aspirational interventions that require additional thought, experimentation, and adaptation to evaluate feasibility in particular fisheries.

INTERVENTION TYPES:

(1) Essential
Actions, tools, or approaches that are essential or emergent to buttress existing investments and enhance resilience in fisheries.

(2) Portfolio-wide
Resilience actions and innovations that would be strategic across the WFF portfolio to leverage investment and capture economies of scale

Essential resilience interventions

This category of interventions refers to actions, tools, or approaches that are essential or emergent to buttress existing investments and enhance resilience in specific fisheries. These 'no regrets' interventions may form the foundation of a resilience-based funding strategy, as these actions will build upon existing efforts, orienting them towards a resilience-approach, while addressing key vulnerabilities in the six fisheries (Table 5). Essential resilience interventions should be addressed first to solidify sustainability progress to date, pivot toward building resilience, and increase cohesion among fishery system components.

Portfolio-wide innovations

Fishery-specific tailoring is necessary for the majority of resilience building actions we have identified. However, given the particular social-ecological-technological factors at work, there are several broadly applicable interventions that are relevant across the six fisheries (and beyond). Their broad relevance, consistency in design requirements, leveraging of existing efforts and 'infrastructure', and scale of execution indicate that portfolio-wide strategy is warranted, as WFF may gain particular efficiencies and economies of scale. In particular, our recommended portfolio-wide investments in innovations and economies of scale are intended to address the significant vulnerabilities in social and technological domains within and among fisheries highlighted in our evaluation (Table 6).

Essential resilience interventions

Essential resilience interventions are 'no regrets' actions that will bolster existing interventions and enhance resilience by addressing specific social, ecological, or technological vulnerabilities in fisheries systems (Table 5).

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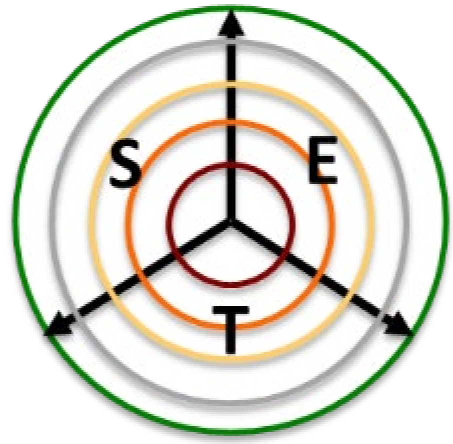
Key Vulnerabilities	**Intervention**	How resilience would be enhanced	WFF fisheries that would benefit immediately from investment
• Ecological climate vulnerabilities not well-understood or addressed in management • No adaptive management based on environmental conditions	**Resilience- based Management**	• Key climate vulnerabilities of stocks and habitats characterized, specific interventions identified • Improved stock assessments that incorporate environmental considerations • Early warning systems using environmental data to inform management decisions	• octopus • Indonesia blue swimming crab • Chile coldwater crabs
• Fishery system does not include spatial management of habitat or harvest to ensure sustainable productivity	**Ecological interventions**	• Climate refugia and/or fishing refugia identified and managed to bolster target stock resilience	• octopus • jumbo flying squid • Indonesia blue swimming crab • Chile coldwater crabs • Mexico finfish complexes
• Stakeholders poorly coordinated, unclear decision-making processes • Multi-jurisdictional governance lacking for trans-boundary stocks	**Strengthening governance**	• Established and strengthened cooperatives and fisherfolk associations • Strengthened regional fisheries management associations that clarify overlapping mandates; • Established representative multi-jurisdictional and multi-level coordination mechanisms	• jumbo flying squid • Mexico finfish complexes • Indonesia blue swimming crab • Chile coldwater crabs
• Fishing communities depend heavily on a single stock or archetype, increasing their vulnerability to volatility in productivity and markets	**Livelihood diversification and value capture**	• Fishing communities are able to access and serve multiple markets for their catch, can diversity target species in response to fluctuations in availability and market signals	• Mexico finfish complexes • Indonesia blue swimming crab • Alaska cod and pollock

Resilience-based Management (RbM) planning and adaptive management

Each fishery system we evaluated would benefit from a strategic RbM planning initiative. RbM planning would rely on participatory, multi-stakeholder involvement to undertake climate vulnerability assessments of the fishery systems, focusing on key factors within SET domains, in an ecosystem context. This exercise would identify specific vulnerabilities in the fishery system as targets for interventions to enhance resilience. For example, stakeholders in each fishery could assess climate vulnerability of target stocks and habitats, which would identify key interventions to enhance ecological resilience, such as protection or restoration of key habitats as potential climate refugia or critical areas to maintain connectivity or diversity. In particular, an ecologically focused climate vulnerability assessment would be particularly relevant in the Indonesia blue swimming crab fishery, where a lack of basic information about species and habitat traits, as well as climate stressors and vulnerabilities, hinders development of resilience-based management approaches.



The RbM planning effort would also identify critical gaps in information about fishery performance and key environmental drivers to support monitoring and adaptive management. Stock assessments and derived fishery performance targets such as total allowable catch and quotas should explicitly incorporate environmental drivers of stock productivity and address uncertainties driven by climate and environmental change. Catch restrictions should account for relationships between environmental conditions and species biology and life history that influence population dynamics and thus productivity, such as larval survival and recruitment, size at maturity, fecundity, and geographic distributions (Holsman et al. 2019). This resilience-based suite of monitoring approaches would underpin adaptive management of fishing activities to adapt and achieve sustainability goals in the face of climate change.

Ecological interventions

Although current data and trends suggest that six examined fisheries are generally ecologically resilient, interventions to bolster the ecological resilience of these fisheries are critically important (Tables 4 and 5). Climate vulnerability assessments of target stocks, their habitats and relevant other species (predators, prey, functional) are recommended to guide RbM interventions in each fishery and should be conducted periodically to improve knowledge of impacts and trends. Understanding of climate change influences on these fisheries is at best emergent and, in many instances, absent. Building data, analysis, and expert input on climate-relevant impacts and trends is paramount to overcoming knowledge gaps precluding effective RbM efforts.

Among core ecological interventions, fishing refugia can be highly effective to build the resilience of target stocks to consistent fishing pressure and fluctuating environmental conditions (Micheli et al. 2012), including for several of the selected fisheries (Tables 4 and 5). Micro-climates that harbor more favorable environmental conditions for target stocks (e.g., temperature, oxygen concentrations, pH) in the midst of broader-scale climate change effects can serve as targets for protection and reduced or eliminated fishing activity (Woodson et al. 2018). Fishing refugia can be used as a management tool to promote recovery of stock abundance by protecting reproduction areas or by allowing juvenile fish and other target stock species to grow safely to minimum allowable body sizes (Micheli et al. 2012). Such fishing refugia are used by many community-based fishing operations, particularly in places where fishing areas are adjacent to the communities themselves, allowing for locally-based monitoring and enforcement, such as in Baja California Sur, Mexico, Indonesia, and Madagascar (e.g., Oliver et al. 2015).

Preserving species and habitat diversity is key to strengthening natural processes of adaptation to changing environmental conditions. Diversity provides redundancy and thus ecological alternatives among prey species and functional species, as well as alternative harvest options among species groups (e.g. finfish), enhancing economic options and resilience. Spatial heterogeneity among habitats, as well as enhanced protection and connectivity bolsters ecological resilience throughout the life cycle.

Photo Source: © Vlad1949, Dreamstime.com

Mitigating compounding stressors on fisheries is essential for their ecological resilience to climate change (Ojea et al. 2020). In nearly all of the six fisheries, unregulated fishing pressures were identified as significant challenges to achieving and sustaining effective governance and management (Table 4). Thus, reducing unregulated fishing pressure on target stocks though improved licensing practices, monitoring of fishing effort on-the-water (e.g., electronic catch monitoring and VMS to record fishing effort) and at port (e.g., increasing traceability in supply chains), coupled with enhanced catch monitoring should be considered ‘no regrets’ interventions to bolster ecological resilience in fisheries.

Strengthening governance

Governance plays a critical role in enabling both sustainable and resilient fisheries management. Indeed, many of the most critical threats to fisheries, from overcapacity to IUU, relate to poor governance practices from local to global scales. Governance structures and practices that ensure co-management, sharing and incorporation of knowledge and experience, stakeholder consultation and coordination, and achievement of equity goals under uncertain climate change scenarios are a common and fundamental fisheries resilience need. Effective institutions, regulatory regimes and enforcement are essential to any prospect of sustainable and resilient management of common fisheries, particularly as they are now changing in abundance, location and behavior with the changing climate.

Efforts to advance polycentric governance are particularly warranted in instances of multi-jurisdictional management and of in-migration from farms to fisheries in developing countries. Polycentric governance connects local to regional, national, and international centers of decision-making, with well-understood rules and mechanisms for how these different decision-making centers relate to one another, including effective conflict resolution processes (Ostrom 1992; Carlisle and Gruby 2019). The concept is considered of particular relevance to resilience as it connotes:

- Broad-based participation
- Collective action across and within governance hierarchies
- Rapid, tailored response to localized change
- Targeted learning and experimentation
- Open multi-directional flows of information and lessons learned
- Risk mitigation through overlapping redundancies in governance authority and capacity
- Incorporation of traditional and local knowledge as well as science-based approaches

Our analysis highlighted the importance of these features for resilience-oriented governance of fisheries (e.g., Alaska cod and pollock; abalone, lobster, and finfish in Baja California Sur, Mexico; Chile's *comites de manejo*). Notably, the absence of such governance features in several cases results in poor information flows and murky decision-making arrangements, and ultimately in management vacuums (e.g., global octopus, Indonesia blue swimming crab).

Resilience planning and strategy will be for naught without investment in institutional development that clarifies and rationalizes roles and responsibilities of relevant governance structures, and establishes clear mechanisms for their constructive interaction (Table 5). Our analysis revealed that official government can play essential roles, particularly those that backstop local governance structures and management practices, such as through enhanced enforcement capacity. However, particularly for locally managed fisheries, one interviewee stated that a goal of fisheries resilience interventions in this domain should be "to strengthen governance so that government becomes less necessary." Interventions to this end include support for establishing and strengthening cooperatives and fisherfolk associations, particularly efforts to collectively protect and manage fishery resources (for example, see Box 2. Climate Resilient TURFs); strengthening regional fisheries management associations while clarifying overlapping mandates;

establishing representative multi-jurisdictional and multi-level coordination mechanisms; and cross-cutting institutional arrangements to mainstream resilience thinking throughout polycentric governance components.

Box 2: Climate-resilient TURFs?

Territorial Use Rights for Fisheries (TURFs) is a property rights-based fishery management approach intended to align incentives with sustainability. To address the perverse incentive dynamics seen in open access contexts, TURFs give fishers ownership of marine resources in a specified area, positing that owners of exclusive harvest rights have an incentive to adhere to sustainable management. These rights can take various forms, such as full ownership of a geographically defined area, or the exclusive right to fish in a publicly owned area. Afflerbach et al. (2014) note that customary marine tenure systems in some small-scale fishing communities amount to a form of TURFs, as in traditional Pacific Island fishing communities. Villaseñor-Derbez et al. (2019) describe community-based TURF reserves off Mexico's Baja California and Yucatan Peninsulas. When TURFs are well-designed and enforced, they eliminate the race to fish and encourage resource conservation and habitat protection by owners. The enhanced sustainability that may be achieved by TURFs thus also contributes to resilience.

However, shifts in species ranges caused by climate change threaten to undermine TURF systems, as they are based on fixed geographic delimitations of use or ownership rights. From the perspective of fishers, there may be little difference between declining resource abundance due to species decline or range shifts; either way, a dwindling resource within a TURF area can serve as a signal to intensify fishing effort before the resource disappears. Even without this perverse incentive, the resource may be moving from a managed area to an open access area and therefore become vulnerable to overfishing. Consequently, while a fish population may be adapting to climate change impacts by migrating, intensified extraction may negate this adaptive process. In the meantime, the basis for socioeconomic wellbeing is eroded.

Thus, TURFs are an example of a fisheries management tool that has shown success in various settings, but can become ineffective or even work adversely as a result of climate change impacts. For climate resilience, policy makers and stakeholders need to explore how TURFs may be adjusted or combined with other management tools in response to shifting ranges. For example, interviews with experts involved in particular fishery systems described existing efforts to expand TURF boundaries to accommodate resource movements and to ensure that the area covered by the TURF includes enough stock to sustain fishing activity. A more complex avenue for exploration could be TURF design incorporating tenets of dynamic ocean management (Maxwell et al. 2015), such as flexible or mobile boundaries, anchored by climate refugia. Similar scrutiny is required of other marine resource management interventions designed assuming stable habitat conditions; adapting known fisheries tools for resilience-based management offers wide scope for innovation.

Livelihood diversification and value capture

Fisher livelihoods and, indeed, fishing economies are defined by resource availability and market demand, which together drive most fisheries to rely on a single species or archetype (e.g., cod/pollock, cold water crabs). This path dependency is a significant vulnerability for fisheries facing prospects of declining availability of historically harvested stocks. Path dependency constraints a system's ability to change – to adapt and transform – given prohibitive costs, risks, and resource limits (e.g., Arthur 1989; Markolf et al. 2018). Interventions enabling diversification both within fisheries and beyond fishing to alternative livelihoods would greatly facilitate transitions beyond path dependency on changing stocks and strengthen fisheries ability to respond to uncertainty and unexpected, transient events such as productivity changes during protracted periods of ocean warming.

Within fisheries, diversification may be stimulated by market changes that favor greater harvest diversification, such as expanding the species suited for whitefish products. Diversification within fisheries may also be stimulated by improving knowledge and harvest capacity, facilitating transitions to other stocks. Beyond fisheries, diversification may be facilitated through access to capital, training, and enterprise development efforts. Economic stimulus for major economic and livelihood shifts may likely depend on government action, but cooperative efforts in public, private and philanthropic partnership are also suited to address such challenges in blended financing efforts optimizing the use of these distinct sources of financing.

Photo Source: Arek Socha, Pixabay

Significant economic value is left in the boat and in processing units of the fishery production and supply chain. Capturing the full value of harvested products is not only a wise economic and conservation intervention, but also an important contributor to resilience as greater income yields greater ability to weather the volatility of changing stocks, build social and financial safety nets, and mitigate fisheries vulnerability to extreme events. Interventions to enhance harvest efficiency, prevent quality deterioration, and add value to fish products may significantly increase value capture and reduce losses. For example, cold storage systems are well-established in developed country fisheries, but often limited in small-scale fisheries of the developing world, resulting in significant loss and waste. Enhancing market access for premium, certified, and value-added products may also improve value capture and build the resilience of fishers and fisheries alike.

Portfolio-wide innovations and economies of scale

Portfolio-wide innovations and economies of scale can build resilience by addressing specific social, ecological, or technological vulnerabilities in fisheries systems (Table 6).

Note, recommendations described in this document do not reflect the Foundation's funding priorities going forward—they are EcoAdvisor's recommendations only.

Key Vulnerabilities	Intervention	How resilience would be enhanced
• Data on stock, ecosystem and environmental conditions limited in extent, quality, access, undermining informed, adaptive management	**Ocean observation and monitoring**	• Access to improved, expanded, real-time data, analytics and forecasts enables adaptive management and responsiveness to ocean system change
• Fishers unable to respond efficiently to changing stock availability or productivity, limited position in supply chains. • Fishers face limited livelihood, value capture and adaptation options, exacerbating path dependency and poverty traps	**Mobile money**	• Access to capital to allow fishers to efficiently adjust operations, capture and add value in response to changing stock availability, productivity • Strengthens livelihood diversification, adaptation and security • Potential channel for incentive-based interventions
• Fishers disconnected from key actors in the supply chain are unable to access information, capital, and capacity to adapt fishery management; • Supply chain fragmentation leads to inefficient, ineffective response to stressors impacting fishery production, yielding consequences across the chain	**Supply chain ICT connectivity**	• Enhanced access to supply chain enables information sharing, access to markets, capital, networks, diversifying fishery assets and options • Supply chain connectivity strengthens overall efficiency, effectiveness and responsiveness to change, builds collective adaptive capacity
• Sustainability certifications do not account for efforts to enhance resilience, nor climate change effects on fishery performance • Certification systems themselves risk losing credibility and effectiveness as a market signal if climate change undermines sustainability	**Updating certification systems**	• Certifications incentivize resilience interventions, incorporation of climate change in management targets and decisions • Certification systems themselves retain relevance in the face of climate change
• Subsidies promote over-capacity and excess harvest, which undermines coordinated management, and • Affects the sustainability and resilience of stocks	**Addressing perverse subsidies (esp. those that support distant-water fleets)**	• Reduce pressure on stocks • Encourage diversification • Greater scope for sustainable management enhances resilience to climate change

Key Vulnerabilities	**Intervention**	How resilience would be enhanced
• Inefficient fishery system supply chains leave them more susceptible to volatility in production, market forces, environmental drivers • Mismatch in cashflows for investor needs • Investments in fisheries constrained by perceived downside risk, lack of previous performance history, concerns about governance	**Financial Innovations that:** • **Create the investment case and build efficiencies** • **Align transactional arrangements with cash flows** • **Manage downside risk** • **Incorporate uncertainty**	• Increased, sustained, and appropriately structured investments allow fishers to implement RbM approaches and strengthen their economic position to respond to changing stock availability, productivity • Insurance products, floor-price guarantees, other schemes help absorb negative shocks on ecological stocks and assets • Technology solutions to streamline information transfer within supply chain are identified, incubated, and commercialized to enhance efficiency and preserve profit margins

Ocean observation and monitoring

Monitoring, data sharing, and analytics on key attributes of ocean ecosystem health, species behavior and trends, environmental conditions, and climate-driven disruptive events are essential to guide fisheries management for resilience. Absent data and monitoring capabilities, fisheries management decisions would rely upon historical data that is largely obsolete, best guesses related to ocean system trends, and an extraordinary, rapid adaptive capacity to respond to extreme events and other surprises. Once costly, technically complex and limited to simple metrics, technological advances in ocean observation systems, monitoring and data sharing are enabling unprecedented access to and action upon key ocean system information. Prior cost and logistical impediments are being overcome by advances in robotics and connectivity across Internet of Things networks. Autonomous sensors and robotic floats can be deployed to monitor ocean health at a global scale, at all times of the year, in all kinds of conditions, and at a fraction of the cost of conventional data gathering expeditions. A range of technological advances has emerged rapidly over the past decade, from simple simple transponders to ecogenomic sensors, from moored logging buoys to automated boats and underwater drones. Ocean observation capabilities are a rapidly evolving field, exhibiting exponential advances in technological capabilities at rapidly declining costs and with considerable economies of scale.

Enhanced monitoring and data sharing can provide real-time guidance to fishers and fisheries relative to stock status and important environmental signals, such as temperature, salinity, pH, oxygen and nutrients, essential components of 'dynamic ocean management' (Maxwell et al. 2015). Data systems may also inform Early Warning Systems to alert fisheries of extreme events, including ocean storms but also environmental disruptions, such as warming, bleaching, hypoxia, and nutrient changes. In such efforts, *in situ* measurements of key environmental variables should guide decision-making before, during, and after fishing seasons. Measurements should be continuous, using *in situ* sensor arrays, and data should be accessed and analyzed at least annually to discern relationships between these key environmental variables and fishery performance metrics (Micheli et al. 2012; Niparajá 2019).

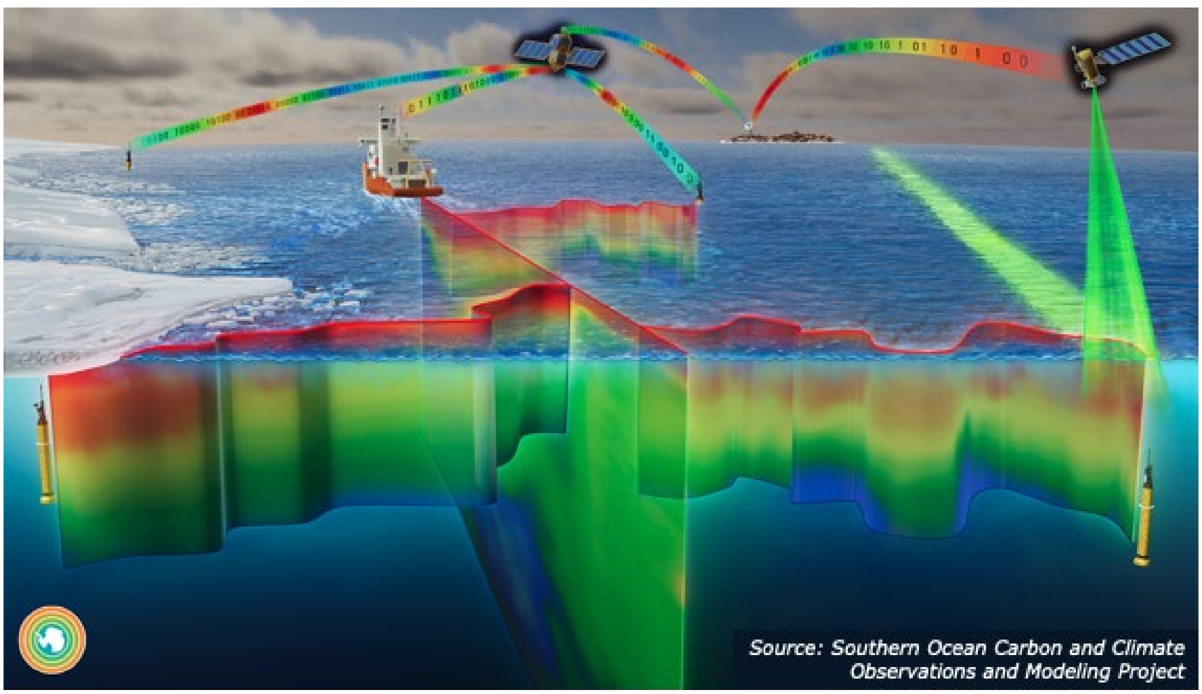
Ecuador, Peru and Chile have launched an ocean observation system for the Humboldt Current ecosystem to guide the management of anchoveta and other commercially valuable species. The Humboldt "Sistema de Alerta, Predicción, y Observación—SAPO" supports adaptive, multi-jurisdictional management of resources shared across the 3 countries' fishing sectors (EDF 2020). SAPO provides current information and alerts enabling fisheries managers to respond to data on the status of anchoveta stocks and on prevailing environmental conditions and trends (Burden and Battista 2019).

Ambitious global efforts are underway to establish a comprehensive ocean observation system deploying state of the art sensors and drones to continuously log and transmit data, freely available to the public (see Box 3). These systems offer an unprecedented opportunity to understand, measure and track the state of the ocean and of key fisheries. Such data is fundamental to managing for resilience.

Efforts to enhance ocean observation and monitoring could focus on one or more of the following opportunities:

- equipping specific fisheries with data capture and transmission technology - from simple transponders to more advanced sensors and drones
- connecting specific fisheries to observation systems, enabling data provision from observation networks to fisheries and fishers (and vice-versa)
- extending observation systems - leveraging compatible public investments in building and utilizing ocean observation arrays (eg Box 3) to incorporate key regions and data relevant to specific fisheries
- enhancing data access and interpretation, such as through open source data and analytics, e.g. NOAA's OceanReports web tool
- enhancing observation systems - increasing sensor coverage, deploying more sophisticated instruments to capture fisheries specific interests (eg ecogenomic sensors), and supporting targeted data collection efforts (e.g., underwater autonomous vehicle "swarms" to investigate ocean events.

Box 3. Comprehensive ocean monitoring system under development



On October 29, 2020, the National Science Foundation awarded a \$53 million, five-year grant[2] to build and deploy 500 robotic ocean-monitoring floats around the globe. This Global Ocean Biogeochemistry Array, will collect and transmit data on ocean chemistry and biology from the surface to a depth of 2 kilometers, augmenting the existing Argo Array that monitors ocean temperature and salinity. Data from both arrays will be freely available to the public.

[2] Investigators include Monterey Bay Aquarium Research Institute the University of Washington; Scripps Institution of Oceanography; the Woods Hole Oceanographic Institution; and Princeton University

Mobile money

Mobile money can enhance resilience in fishery systems by allowing fishing communities to respond more efficiently to shifts in stock productivity or distribution, or in markets, or both. Financial services transacted via mobile phones, including payments, savings, credit, and micro-insurance products, or mobile money, have been particularly transformative for those in the informal economy, such as smallholder farmers and fishers. In addition to facilitating access to formal financial services, mobile money can enable markets to connect with rural economies and last-mile communities before transformation and value addition processes take place (Tricarico 2018). In 2018, mobile money users included more than 866 million registered accounts in 90 countries and $1.3 billion transacted every day (Pasti 2019). As an indication of potential in the fisheries sector, the disconnected and often financially excluded 259 million inhabitants of the 17,508 islands of Indonesia in 2017 included 326 million mobile phone accounts and over 500,000 mobile money subscribers. Among persons above the age of 15, 83% reported sending or receiving a remittance or payment transaction in the previous month.

As a development intervention, mobile money has been most actively deployed in smallholder agriculture. Digitizing agricultural payments has been shown to enhance financial inclusion for smallholder farmers, reduce transaction costs and make agricultural value chains more efficient, safe and transparent (Raithatha 2020). Farmers with greater access to formal financial services are able to build savings, a financial footprint and establish credit.

Applications to the fishery sector are more limited, but opportune given the similarities with this proven agriculture sector model, particularly for smallholders. Important gains in resilience may be driven through efforts to connect informal fishers and fishery economies to financial services by enhancing access to capital, credit and insurance products and establishing access and transparency for investment in value addition and livelihood diversification. Given the global scale of connectivity and growth of this sector, economies of scale may be readily achieved in fishery applications.

2018

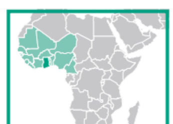
MOBILE MONEY BY THE NUMBERS

866 million registered accounts
90 countries
$1.3B transactions/day

INDONESIA'S FISHERY SECTOR POTENTIAL

of the 259 million inhabitants often financially excluded, there are…

326 million mobile phone accounts
500+ mobile money subscribers



West Africa
Ghana

MAJOR VALUE CHAINS

OIL CROPS | COCOA | TROPICAL FRUITS

In 2018, MTN Ghana launched mAgric, a mobile app that enables an agribusiness to record crop procurement from farmers digitally and pay farmers for their produce instantly via mobile money.

The solution has been piloted in the cocoa value chain, together with Royal Commodities, a licensed buying company for cocoa. MTN Ghana is expanding the use of the tool to other value chains with a pilot launched in 2019 to trial mAgric in the poultry value chain.

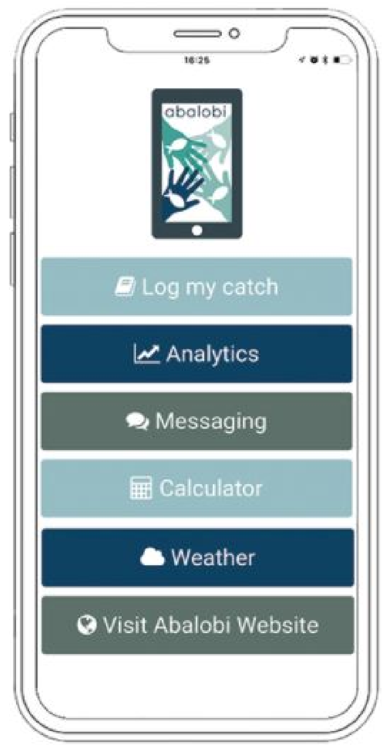
Source: GSMA (2019). Digitizing the last agricultural mile in Ghana: MTN Mobile Money's mAgric

Supply chain ICT connectivity

Increasingly, development projects are successfully deploying information and communication technology (ICT), particularly smartphone apps, to connect formerly isolated and marginalized farmers, fishers, and other communities to formal markets, information services and governance structures. As discussed above, mobile money is enabling informal producers to connect to formal financial services. ICT is also increasingly deployed in marketing, monitoring, tracing, training, disaster risk reduction, and adaptive management efforts. The increasing availability and affordability of mobile devices, open source software, connectivity to the internet, and ease of use of applications, provide an exciting opportunity to resolve key marginalization challenges facing fisheries and fishers.

Building connectivity across fishery supply chains could greatly enhance resilience, particularly of otherwise isolated fisheries, by strengthening access to capital and markets, building knowledge and capacity, and providing early warning related to extreme events, and enhancing transparency and traceability "from hook to cook". A leading example of ICT deployment in the fisheries sector is ABALOBI, an South African-based, fisher-driven social enterprise aiming to empower small-scale fishers through the co-development and use of ICT (See http://abalobi.info/). ABALOBI has developed and deployed a mobile app suite for small-scale fisheries, which includes the following capabilities:

- verifying fishers' rights and legitimacy in relation to regulatory requirements
- formalizing co-operatives and strengthening polycentric governance
- enhancing inclusion and equity, particularly for women in the fishery sector
- sustainable sourcing and supply chain accountability
- seafood traceability and origin verification
- monitoring, data collection, and knowledge generation
- training and learnership programs



Source: ABALOBI, abalobi.info

Efforts to further develop and expand the availability of and inclusion of fishers in ICT applications across the supply chain could address social, ecological and technological vulnerabilities – from governance and access to capital challenges, to real-time information on stock status, protected ecosystems and harvest quotas to monitoring and adaptive management practices. Given the rapid growth of ICT applications to supply chains, financial services, data exchange and reporting, a funder could leverage considerable investment, infrastructure, and gain important economies of scale by promoting the broader adoption of proven applications, supporting their tailoring to specific fisheries and contexts, and enhancing participation and use across fishery supply chains. While we have not rigorously vetted Abalobi, it should serve at least as an informative model with potential for such replication.

Updating certification systems

Pursuit of certification in those fisheries that have not yet done so remains a potential contribution to sustainability. However, as noted in earlier sections, sustainability does not necessarily mean resilience. This is evident particularly in fisheries where sustainability requirements for certification are met, but trends indicate room for improvement with respect to resilience, such as Gulf of Alaska cod.

The Gulf of Alaska example raises two questions:

1) how well do current certification frameworks capture sustainability to begin with, and
2) how can these frameworks be elaborated to encompass requirements for resilience?

Improving certification systems would generate potential portfolio-wide benefits. This would involve innovation in definition of indicators and metrics, with potential synergies linked to development and deployment of innovative monitoring technology. A particular emphasis of evolution in certification systems should be to consider standards related to outcomes and responsiveness to changes in stock and habitat conditions, rather than the prevailing focus on management policies and practices believed to contribute to positive sustainability outcomes. Updating certification systems to account for climate resilience would also ensure that they retain their credibility and utility in the face of climate change.

Addressing perverse subsidies

Among the single-most pervasive obstacles to sustainability and, equivalently, a threat to resilience is the use of subsidies to support the industrial fishing sector. Subsidies account for one-fifth or more of the total value of global fish and seafood trade.[3] By inflating the economic returns to fishing, these subsidies promote persistent overcapacity and create a perverse incentive to overharvest. In addition, as long as these subsidies are in place, they inflate the cost of many interventions intended to enhance resilience.

Subsidies account for **1/5 or more** of the total value of global fish and seafood trade.

The UN's Sustainable Development Goal Target 14.6 set a deadline of 2020 for ending perverse fisheries subsidies. Target 14.6 states that: "By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation." The agenda of the World Trade Organization has included fisheries subsidies since the beginning of this century--including recent negotiations [4]--but little has changed over the past two decades.

[3] https://unctad.org/project/regulating-fisheries-subsidies
[4] WTO Members Advance Text Negotiations on Fisheries Subsidies (link)

Investment in efforts to advance progress on eliminating perverse subsidies would benefit all fisheries, by reducing direct pressure on individual stocks, with attendant benefits linked to by-catch reduction, and also reducing pressure on habitat. Possible measures include:

- support for policy- and action-oriented research in this arena;
- support for organizations that provide technical assistance to country delegations involved in global negotiations; and
- support for targeted public awareness campaigns to expand the constituency for subsidy reform in key countries.

Financial Innovations

Creating the Investment Case and Building Efficiencies

There remains an open-ended question around the economic viability of sustainable and/or resilience-based fisheries management systems. The primary challenge is to ensure that the cost of implementing required activities is covered, with appropriate margins, relative to the price consumers pay for the end product. There is also the notion of transition or opportunity costs, especially for small scale producers, that must be accounted for. Successful financial innovations must be designed to account for relevant costing, real and perceived costs and cash flow dynamics in order to meet these benchmarks.

This equation changes depending on the stock, fishing method, supply chain, commodity value, subsidies, among other factors. What is consistent across many fisheries are inefficiencies which lead to lower marginal value across the supply chain. Investments in technology, consolidation of entities, vertical integration within fisheries, and encouraging strategic partnerships can all lead to efficiencies that result in higher marginal profits. However, fisheries present a fairly unique challenge from societal, governance, and equity perspectives, especially considering the bifurcated nature of the sector (i.e., industrial and small-scale). In any scenario where value and investment grade opportunities are created, it is imperative human-rights, governance, and equity are given due consideration. While not necessarily specific to resilience-based management, appropriate financing is critical to ensuring that resilience-based interventions are possible. Specific interventions under this theme could include:

- research, cost-modeling, cash flow and financial projections;
- identification, incubation, and commercialization of technology solutions, and;
- education and partnership creation.

Aligning Transactional Arrangements with Cash Flows and Smoothing Volatility

Once opportunities for RbM are prioritized and capital is identified, there remains the critical function of structuring appropriate transactional arrangements. Resilience-based approaches often require upfront costs and incorporation of uncertainty, but should produce increased value and therefore revenue over time. There is a surprising paucity of creativity when it comes to financial deal structuring, and we sometimes see failure not because the underlying investment was not sound, but because the structure was inappropriate (e.g., debt used when taking equity-type risk; coupon or dividend guarantees for long-term recovery and extended cash flows).

There is significant opportunity to address the upfront resourcing requirements for structuring the connection between capital and resilience-based solutions – considering the type of capital (e.g., return-seeking, concessionary, extinguishable), the nature of the interventions and how they produce cash flows, incorporating uncertainty into financial flows, and the appropriate transactional arrangements. Measures include investing in the time, capacity and contextual aspects of structuring appropriate, flexible, and enduring arrangements. Examples of relevant structures include:

- deferred coupon bonds, coupon performance guarantees, or delayed project financing arrangements; and
- parametric insurance products to manage sharply negative volatility on ecological stocks and ecological assets.

Managing downside risk

An identified barrier for conventional finance to enter the sustainable / RbM fisheries space is downside risk protection (cross reference ocean finance work conducted in collaboration with PfC Social Impact). This is due to the relative novelty of the asset class, lack of identifiable track record, ownership and governance concerns, and volatility in the asset base. While mainstream investors often want demonstration of results[5], there is a growing pool of private and institutional investors who would engage in emergent opportunities with some downside protection. Measures that can be supported include floor price/off-take guarantees for RbM and junior finance/first loss positions to crowd-in conventional finance. Insurance products, both parametric and non-parametric, are conventional risk management tools that can be adapted for the RbM fisheries space. Once demonstrated, these approaches can enter mainstream onboarding, diligence, and transaction processes among conventional investors.

Initial insights on prioritization of investments

Although prioritization of resilience investments and identification of particular capabilities and resources for their deployment is beyond the scope of this effort, we offer some initial insights about such prioritization. Fundamental criteria might include the probability of success and significance of impact, and factors underpinning these criteria might include the following:

- **Probability of success**
  - Political appetite for sharing of management responsibilities and authority
  - Relative strength of existing management institutions, and the nature of the relationships between them
  - Baseline capacity and political will to enforce relevant laws and regulations
  - Adequacy of existing legal and regulatory provisions vs. need to have new legislation or regulations enacted
- **Significance of impact**
  - Scale (number of stakeholders, size of industry)
  - Trends in/degree of threat to the resource base

[5] In an interview for our fisheries finance project with WFF, one commercial bank remarked that they won't even consider an offering unless two successes in the same space have already demonstrated risk adjusted returns.

- Value as demonstration/learning case (archetypal vs. idiosyncratic context)
- Prospects for replication

Conclusions

Core principles of sustainable fisheries management provide a solid foundation on which to build climate resilience in fisheries. However, **these principles must be adapted and expanded to incorporate climate change effects on fisheries to successfully build resilience.** EA's evaluation of climate resilience in six selected fisheries identified relatively high ecological resilience in target stocks and their habitats, but several important vulnerabilities in social and technological domains. Further, our analysis surfaced several potential interventions that would address key ecological, social, and technological vulnerabilities and thus bolster resilience in specific fisheries as well as across the WFF portfolio.

First, we recommend a suite of essential resilience interventions that would solidify existing investments and immediately bolster resilience in specific fisheries. Examples of such 'no regrets' interventions include resilience-based management planning, adapting climate and fishing refugia zones, strengthening polycentric, multi-jurisdictional governance, and enhancing livelihood diversification and value capture. These essential interventions merit prioritization in WFF's forthcoming investment strategy as they address urgent resilience needs in specific fisheries, and, in many cases, they leverage ongoing sustainability and resilience-building efforts.

To enhance resilience beyond the essential, fishery-specific interventions, we also highlight a suite of portfolio-wide interventions that pursue innovation and economies of scale. These portfolio-wide interventions are relevant to multiple fisheries, and represent potentially impactful innovations from fisheries and other natural resource sectors to gain efficiencies and economies of scale across and beyond the WFF portfolio of fisheries. WFF's investments in these interventions could attract collaborative investments from other entities that invest in fisheries sustainability and resilience, thereby catalyzing significant advances in climate-resilient fisheries management at broad scales. Examples of such 'portfolio-wide' innovations include mobile money, enhanced monitoring technologies, supply chain digital connectivity, updating certification systems, and financial tools.

Our recommended interventions lay the collective groundwork for a more extensive diagnosis and planning for climate resilience in selected fisheries, using the resilience evaluation framework we developed, as well as more detailed inputs about individual fisheries, stakeholder perspectives, and expert assessments. Such an effort would be a novel investment in resilience-based management approaches because it would generate robust, expert-validated, and stakeholder-driven guidance for prioritizing climate resilience interventions in fisheries within and beyond WFF's portfolio.

Note, recommendations described in this document do not reflect the Foundation's funding priorities going forward—they are EcoAdvisor's recommendations

Acknowledgements

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Appendix A. Interviews during Discovery Phase

Interview questions

The goal of the list below was to cover all relevant topics among the pool of interviewees. Not all questions were relevant for all interviewees. For example, we were likely to talk about management topics more than market-based incentives or vice versa depending on the individual whom we're interviewing. Thus, we subsampled the below list for each interview, and kept these conversations to less than 90 minutes.

1. Quick refresh on what the study is, purpose of the interview; invite any questions before getting started.
2. Is any specific information available about climate impacts on X fishery (fisheries)? What about for comparable fisheries elsewhere?
3. What biological aspects (e.g., life history traits, specific life stage, key habitat) of target species of X fishery might be particularly vulnerable to climate change? What research and reports have been produced on this matter?
4. What current fisheries management practices strengthen or weaken the health of the fishery and its ecological sustainability (as it's defined for fishery X)? Example features:
    a. How does the fishery operate? E.g., spatio-temporal changes in fishing effort, gear modifications, no fishing zones to protect habitat for a critical life stage
    b. How is the fishery monitored? E.g., harvest control limits, catch shares, quotas, observers, environmental variables?
    c. Policy considerations?
    d. Jurisdictional considerations? (especially for shared stocks): which entity is in charge? If multiple, how is their interaction governed? How is the resource jointly managed?
5. What information/data, technologies, financial tools and economic/policy approaches have been successful in promoting fisheries management changes towards greater sustainability?
6. Have any interventions to enhance resilience in X fishery been proposed, researched? If so, which ones?
7. Given current sustainability trends you see in X fishery, how do you see the market for X evolving (esp. geographical shifts in major sourcing areas)?
8. What seafood market signals incentivize or reinforce sustainable fisheries management presently? Which market influences have a negative impact?
9. Who are the key actors to engage to promote/encourage policy and management changes to enhance resilience in X fishery?
10. Give interviewee a chance to describe their background and experience with X fishery (fisheries) under discussion.

Interviewees

(listed in alphabetical order by last name)

Enrique Alonso, Sustainable Fisheries Partnership (Chile)

Merrick Burden, Environmental Defense Fund (USA)

Lovasoa Cedrique, Blue Ventures (Madagascar)

Erica Cunningham, Environmental Defense Fund (Humboldt Current)

Paula Ezcurra, Climate Science Alliance (USA-Mexico)

Tim Fitzgerald, Environmental Defense Fund (USA)

Renato Gozzer, Sustainable Fisheries Partnership (Peru)

Tom Grasso, Environmental Defense Fund (USA)

Rodrigo Guijon, Wildlife Conservation Society (Chile)

Kristin Kleisner, Environmental Defense Fund (USA)

Nykol Jara, Wildlife Conservation Society (Chile)

Fiorenza Micheli, Stanford University (USA)

Jenny Oates, Blue Ventures (UK)

Gonzalo Olea, Pesca Sustentable (Chile)

Laura Rodriguez, Environmental Defense Fund (Latin America)

Indah Rufiati, Blue Ventures (Indonesia)

Jorge Torre, COBI (Mexico)

Amy Hudson Weaver, Niparajá (Mexico)

Appendix B. SET domains, factors, subfactors

Table B1. Social, ecological, technological domains, factors, and subfactors used to evaluate climate resilience in WFF priority fisheries

Domain	Factor	Subfactors
Social	Governance	Established system for responsibility, authority, decision-making
	Social Capital	Stakeholder coordination, inclusion and equity, agency
	Economic Context	Access to credit, incentives for sustainability, livelihood diversity
Ecological	Species Traits	Physiological, behavioral, life history traits
	Ecosystem Traits	Environmental conditions that affect stock vulnerability
	Compounding Stressors	Non-climate stressors that affect stock vulnerability
Technological	Knowledge Systems	Fishery performance data, environmental data
	Management Practices	Input controls, output controls, adaptive management
	Infrastructure and Capacity	Gear selectivity, management and supply chain efficiency

Supporting literature

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Appendix C. Summary findings on fisheries archetypes

Table C1. Climate vulnerabilities and potential interventions for general archetypes and themes in climate-resilient fisheries

Theme/ Archetype	Example fishery	Key climate vulnerabilities	Key SET domain vulnerabilities	Potential resilience interventions
Stocks move across jurisdictions; new or changing species interactions	Jumbo flying squid, Alaska cod and pollock, Mexico finfish	Warming, fluctuating environmental conditions	● Species and/or ecosystem traits (e.g., prey species) are sensitive to changing env conditions ● Lack of sufficiently coordinated governance ● Inadequate incorporation of env drivers of fishery performance	● Cross-jurisdictional governance and management ● Early warning systems based on shared data, assessments, and monitoring; harvest controls incorporating environmental drivers ● Market incentives, access to capital and infrastructure for diversified species harvest ● Shared catch, profits
Stock abundance decline due to environmental stressors	Chile crabs, Indo blue swimming crabs, Gulf of Alaska cod, Mexico finfish	Warming, acidification, habitat degradation	● Species and/or ecosystem traits are sensitive to changing env conditions ● Inadequate incorporation of env drivers of fishery performance ● Inadequate management practices to adaptively manage fisheries in response to climate-driven changes	● Early warning systems consisting of harvest controls, adaptive management incorporating environmental drivers ● Identification of climate/fishing refugia ● Livelihood diversification

Complex, opaque international supply chains based on vulnerable sources	Global octopus	Warming, habitat degradation	• Weak, uncoordinated governance • Highly fluid supply (multiple species from many locations to major markets) diminishes potential sustainability incentives • Inadequate harvest rules for supply species • Inadequate management practices to adaptively manage fisheries in response to climate-driven changes	• Development of transparent, inclusive, participatory decision-making activities • Early warning systems consisting of harvest controls, adaptive management incorporating environmental drivers • Climate vulnerability assessments for source species • Identification of climate/fishing refugia • Large consumer markets drive sustainability in supply chain
Climate effects on already well-managed fisheries	Gulf of Alaska cod	Warming reduces juvenile survival, thus stock abundance	• Inadequate management practices to adaptively manage fisheries in response to climate-driven changes • Sustainability incentives do not incorporate climate resilience considerations • Inequitable vulnerability among stakeholders in highly capitalized fishery	• Incorporate climate change and climate resilience into sustainability incentives • Parametric insurance schemes

Appendix D. Supporting information for fishery-specific resilience evaluations

Access supporting information (AppxC_WFF-fisheries-climate-resilience-evals.xlsx):
https://drive.google.com/file/d/1CSsl3ZCVdDDcbq1ksLq5fws33MdxkLMg/view?usp=sharing