

ISSUE BRIEF

# CLIMATE CHANGE AND FISHERIES: MANAGING FOR RESILIENCE

Climate change is rapidly altering our oceans. As the marine environment grows warmer, more acidic, and lower in oxygen, the impacts on marine life have been dramatic, including on the fish populations that support our productive fisheries. Some fish stocks are moving away from their former habitats to stay within their preferred temperature conditions. Others that are less able to move or adapt are declining altogether. Changing ocean conditions, more frequent extreme weather events, changes in prey availability, and disrupted reproductive cycles will make it more difficult for some fish stocks to thrive or maintain their numbers. In many cases, climate change is imposing new stressors on fish populations that are already stressed by fishing activities.

This period of upheaval will cause instabilities in the marine ecosystems that support our rich fisheries. This will lead to social and economic disruptions in fishing communities as they lose historical resources.

In the face of this rapid environmental change, maintaining or increasing fish population resilience will be critical for securing sustainable fisheries. Fish population resilience is the ability of a fish stock to remain viable and persist over time in the face of environmental variation and change. Fishing activity tends to reduce the resilience of fish populations by eliminating older age classes and decreasing genetic variation. The combined effects of climate change and fishing pressure can generate harmful synergies that pose an unacceptable risk to a fishery. Climate change can cause previously sustainable management strategies to fail, and fishing pressure can make it more difficult for fish populations to withstand or adapt to climate change. But with more attention to attributes that enhance resilience, these risks can be reduced.

This issue brief describes approaches and potential policies to better integrate population resilience into fisheries management, with the goal of maintaining viable fish stocks and healthy fisheries into the future. Note that population



Sunrise over fishing boats moored in Thomsen Harbor in Sitka, Baranof Island, Alaska.

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resilience is different from ecosystem resilience, which refers to the ability of an entire ecosystem to resist, recover from, or adapt to disturbances and changes.<sup>1</sup> Population resilience focuses solely on a population of organisms—fish, in this case. This policy brief focuses on the federal fisheries management framework of the Magnuson–Stevens Fishery Conservation and Management Act.

## RESILIENCE IN FISH POPULATIONS

Resilience generally means the ability of a system to maintain or return to a stable state or set of characteristics in the face of disturbance.<sup>2</sup> Scientists recognize different components of resilience, such as the resistance of a system to disturbance, the system's likelihood of recovery from disturbance, and the rate of recovery following the disturbance.<sup>3</sup> Ecologists measure resilience with various metrics such as resistance—or the amount of change following disturbance—the speed at which the population recovers to its original state, and variability in population size over time.<sup>4</sup>

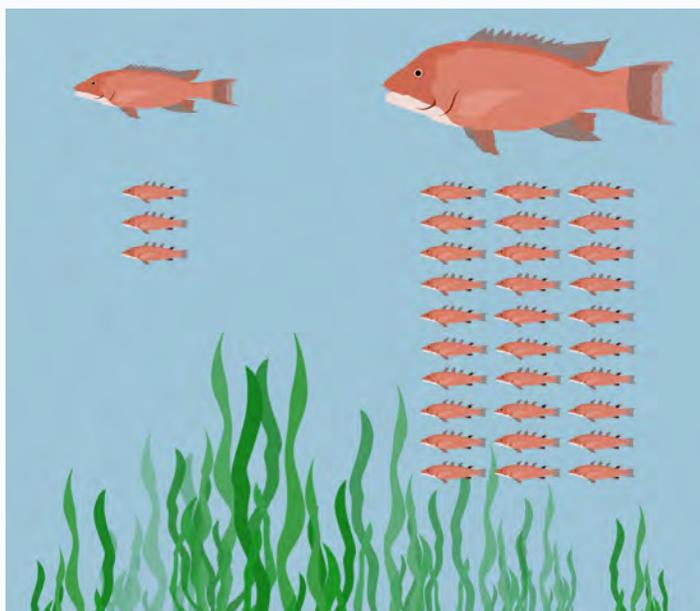
There are several concrete characteristics of populations that tend to support resilience in a population, including large population sizes, intact age structure, genetic and phenotypic variation, and broad geographic distribution.

### LARGE POPULATION SIZE

Overall biomass or abundance level is important to population resilience. Larger populations generally maintain greater genetic diversity.<sup>5</sup> They also are more likely to have diverse responses to environmental variation—whether these responses result from fish of different age groups, genotypes, phenotypes, or physical locations, as discussed below. Populations containing a diversity of individuals are more resilient to climate and other human-related disturbances because in such a system, there is a higher chance that at least some individuals will survive and reproduce. This is known as the “portfolio effect,” a term borrowed from investors who diversify their holdings to buffer against market swings.

### AGE STRUCTURE—INCLUDING BIG, OLD, FERTILE FEMALES

An intact or well-distributed age structure tends to help populations resist or recover from disturbances. Older spawning fish—sometimes referred to as “big, old, fertile females”—are likely to have more and higher-quality babies.<sup>6</sup>

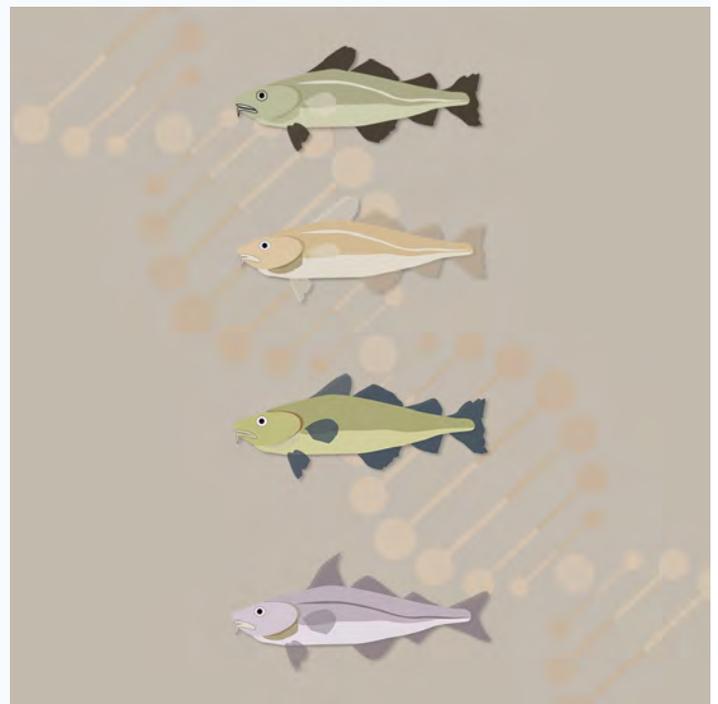


An illustration showing the increase in reproductive capacity of adult female sheephead as they age and grow larger.

Also, older fish can spawn at different times, which can diversify the population's reproductive effort and help ensure success in the face of varying environmental conditions.<sup>7</sup> Finally, each age class in a population has encountered, and succeeded under different environmental conditions. Having cohorts of three-, five-, and seven-year-old fish, for example, guarantees that there are more “environmental histories” in the population, and this can provide a buffer to environmental fluctuations, stabilizing fishery productivity over time.<sup>8</sup>

### GENETIC AND PHENOTYPIC DIVERSITY

Genetic diversity, which is the variation in genes underlying traits, increases the probability that a population will be able to adapt to environmental changes over time.<sup>9</sup> Phenotypic diversity refers to the variety of observable traits that individuals in the population display and encompasses everything from size and morphology to behavior. A wide range of phenotypes can help a population weather environmental changes, as some may be less affected by a change or disturbance than others.<sup>10</sup>



An illustration of the different colorations of cod against a background of DNA, representing biodiversity among fish.

### BIOLOGICAL VARIATION: A SOURCE OF RESILIENCE

**GENOTYPE:** The set of genes carried by an individual in a species. Genetic diversity within a population refers to the range of differences across the genotypes of individuals in the same population.

**PHENOTYPE:** An observable characteristic about an individual in a species, such as coloration, growth rate, size and age at maturity, or spawning patterns. A phenotype is determined by genes and the environment's influence on those genes. Phenotypic diversity is a measure of the variation of phenotypes within a population.

## SPATIAL STRUCTURE AND CONNECTIVITY

Meta-populations, made up of spatially separated but reproductively connected populations, can help buffer the impacts of disturbances on the overall population by providing diverse responses to environmental variation or helping to replenish populations that have suffered declines.<sup>11</sup> A large geographic range also can promote resilience and tends to be associated further with phenotypic and genetic diversity.<sup>12</sup>

## CLIMATE CHANGE INCREASES THE NEED FOR POPULATION RESILIENCE

The natural environment is not static, and to persist, fish populations have always had to be resilient (see text box, “Variation: Cycles, Variance, and Unidirectional Change,” below). Climate change, however, dramatically raises the stakes for population resilience. Greenhouse gas emissions are causing persistent, unidirectional changes in ocean temperature, oxygen level, salinity, pH, circulation patterns, primary productivity, ecosystem structure, and trophic interactions, among other things.<sup>13</sup> Climate change also is leading to an increased frequency and severity of extreme weather events, such as marine heat waves.<sup>14</sup> While the effects of climate change will vary widely across regions and

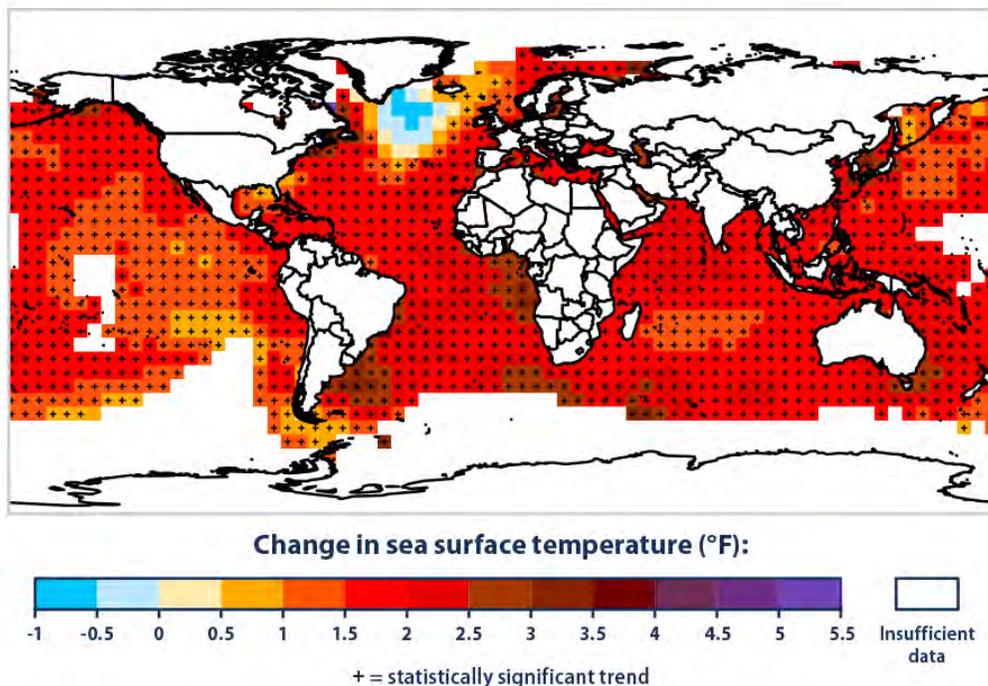
species—and in some cases may even enhance population growth—climate change generally is bringing increased environmental disturbance and change to which fish populations must recover and adapt in order to persist.

## CYCLES, VARIATION, AND UNIDIRECTIONAL CHANGE

Earth’s climate naturally changes in cycles spanning decades to millennia due to irregularities in its orbit, changes in incoming solar radiation, and ocean and atmospheric circulation patterns, among other things. These cyclical changes operate at the global to regional scales, driving observable, large-scale trends in environmental conditions.<sup>15</sup> At a smaller scale, any given location on Earth (including the oceans) will experience some variation in conditions from one year to the next due to the complexity of the overall climate system.<sup>16</sup> This kind of interannual variation is superimposed on the cyclical changes that operate at regional and global scales.

Cyclical change and background variation are nondirectional forms of environmental change. In other words, over the long term they do not trend in one particular direction (e.g., steadily warmer or steadily cooler). By contrast, climate change is a directional change globally: Human greenhouse gas emissions are driving a steady and progressive increase in global temperatures.<sup>17</sup>

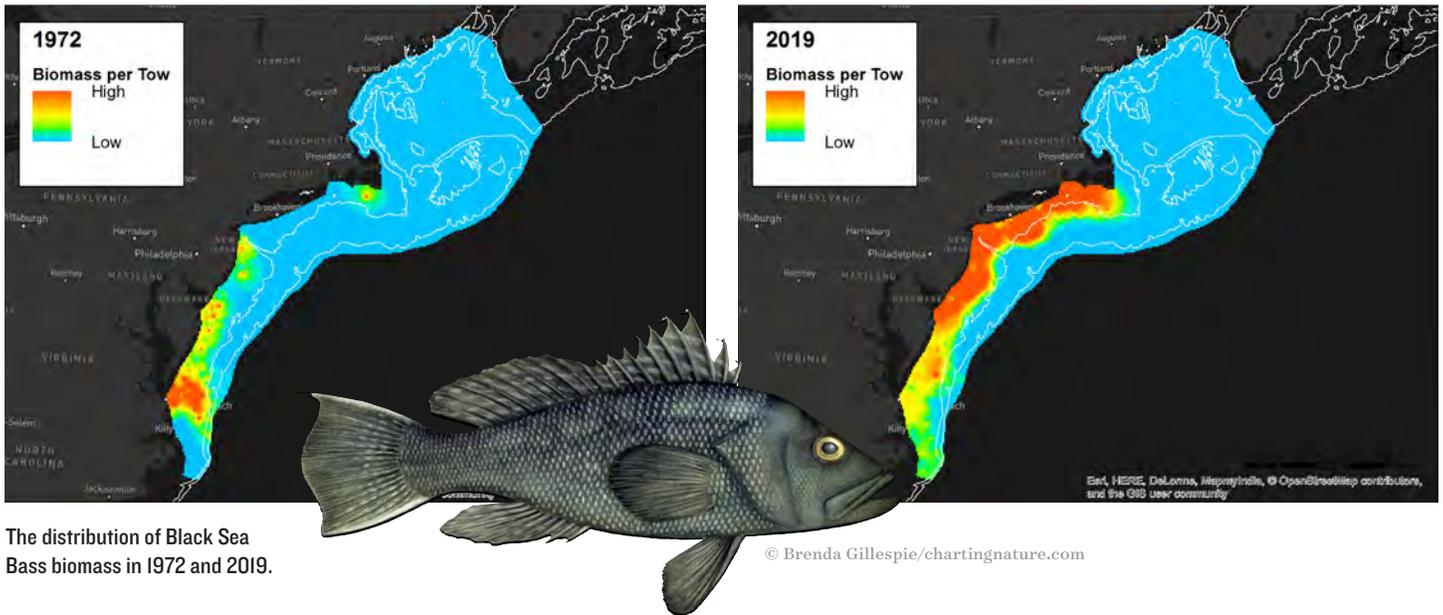
Change in Sea Surface Temperature, 1901–2020



Data sources:

- IPCC (Intergovernmental Panel on Climate Change). 2013. Climate change 2013: The physical science basis. Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge, United Kingdom: Cambridge University Press. [www.ipcc.ch/report/ar5/wg1](http://www.ipcc.ch/report/ar5/wg1).
- NOAA (National Oceanic and Atmospheric Administration). 2021. NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp). Accessed March 2021. [www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp](http://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp).

For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at [www.epa.gov/climate-indicators](http://www.epa.gov/climate-indicators).



The distribution of Black Sea Bass biomass in 1972 and 2019.

© Brenda Gillespie/chartingnature.com

The geographic ranges of fish populations are already shifting as a result of warming ocean temperatures; fish are moving poleward and farther offshore as they try to stay within the thermal conditions for which they are adapted.<sup>18</sup> This geographical change can put populations under a great deal of pressure: It can require them to chart new seasonal migration routes; change habitats; and feed and spawn under conditions with altered timing, new currents, and potentially new predators or prey species. Genetic and phenotypic diversity is crucial for fish populations' ability to thrive and adapt during these transitions.<sup>19</sup> Abundance also becomes critically important, as reproduction and growth rates may be altered in the transition and the population may have to withstand a period of reduced productivity.<sup>20</sup>

Whether our fish populations are able to succeed in the face of climate change will depend on their resilience. Robust populations with greater phenotypic and genetic diversity will exhibit a range of responses to environmental change and will therefore be more likely to remain viable over time.<sup>21</sup> Fish populations with degraded resilience, by contrast, will be more likely to experience reproductive failures, population decline, range fragmentation, and even local extinction.

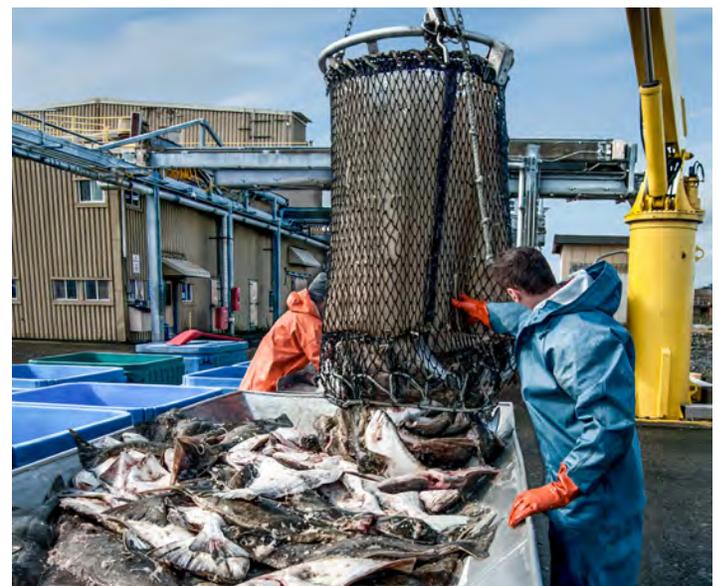
### FISHING CAN REDUCE POPULATION RESILIENCE

Recurring harvest can lead to significant changes in a natural population of fish. Fishing activity selects for specific individuals within a population—usually relatively large adults—and removes them at what is often a high rate compared with natural mortality.<sup>22</sup> In some cases, fishing can remove over half of the adults in a population every year.<sup>23</sup> This repeated removal of selected individuals can alter a population in many ways that tend to reduce its resilience.

**Age Structure:** Harvested populations tend to have truncated age structures, with the older age classes either eliminated or significantly reduced.<sup>24</sup> Larger, older fish generally are more fecund, have higher-quality offspring and longer and more flexible spawning seasons, and are

better able to migrate to suitable habitats. Loss of these fish can result in reduced reproductive potential and increased fluctuations in abundance for a population, as well as diminish diversity in the form of older individuals.<sup>25</sup>

**Genetic and Phenotypic Diversity:** The persistent removal of individuals from a population can act as a selection pressure and lead to permanent loss of genetic or phenotypic variability within the population.<sup>26</sup> Phenotypic characteristics like size or age at maturity, growth rate, or maximum size tend to show reduced diversity in harvested populations.<sup>27</sup> Narrowed phenotypic diversity from fishing can limit a population's ability to spread risk across multiple phenotypes, which is an important element of resilience.<sup>28</sup> And reduced genetic diversity as a result of selective pressure from fishing can curtail a population's ability to adapt over time—perhaps the most critical element of resilience in the long run.<sup>29</sup>



Fresh caught halibut being unloaded from a fishing boat in Alaska.

**Behavioral Changes:** Through repeated harvesting that changes the genetic makeup of a fish population, fishing can alter foraging and reproductive behavior.<sup>30</sup> In one laboratory study, repeated harvesting of fast-growing individuals induced changes in the willingness of Atlantic silversides to forage and in their response to predation, reducing the capacity of the population to reproduce and recover.<sup>31</sup> Behavioral changes induced by fishing can affect the resilience of a population, through altered population dynamics or increased vulnerability to external threats or stressors.

**Spatial Structure and Connectivity:** Fishing pressure can alter a population's spatial structure in a number of ways, including range contraction or reduced connectivity across the population's range.<sup>32</sup> Atlantic cod in the Gulf of Maine provide an example: Scientists have learned that the population historically had a complex spatial structure, with a number of distinct subpopulations, but some of those subunits have likely been extirpated due to fishing mortality.<sup>33</sup> Because spatial complexity can provide an important buffering function for populations, exploited fish populations with altered spatial structures may be weakened in their ability to recover from and adapt to environmental change.<sup>34</sup>

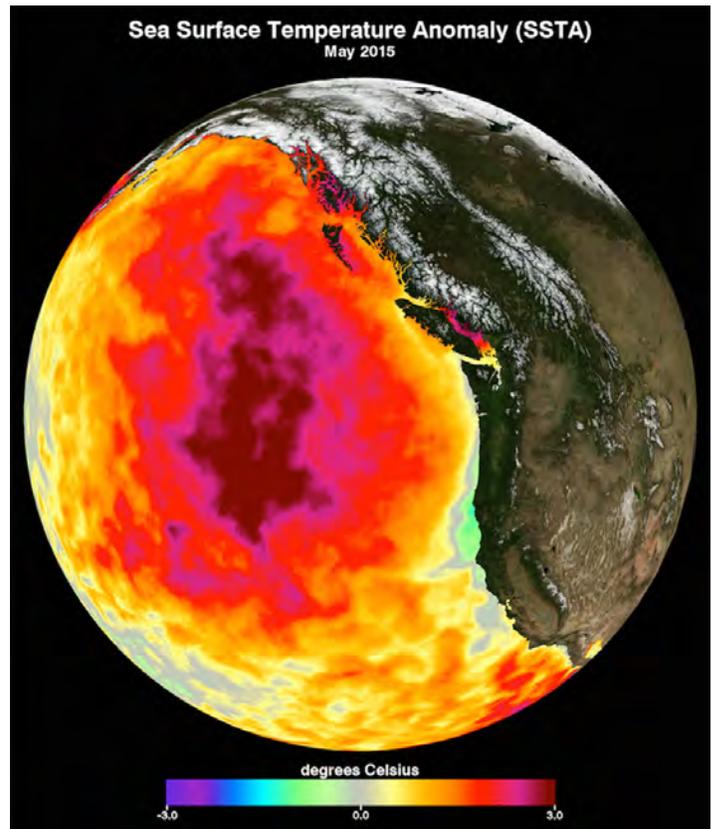
Overall, the changes induced in a fish population by fishing tend to make it harder for that population to resist or recover from disturbances or adapt to environmental change.<sup>35</sup>

## FAILURES WHEN CLIMATE CHANGE IS COMBINED WITH FISHING PRESSURE

Because climate change is dramatically increasing the pace and intensity of environmental variation, exploited fish stocks face an increasing risk of population declines.<sup>36</sup> There are many ways this can occur, given the breadth of impacts that both fishing and climate change can have on a population.

In some cases, managers who implement strategies to ensure fishery sustainability may inadvertently allow overfishing because environmental change is not being taken into account. Fish populations encountering strong climate change impacts may be more vulnerable to fishing pressure and may be driven to collapse with what were previously sustainable levels of fishing mortality.<sup>37</sup> As one recent scientific study noted, "The more quickly the environment shifts, the less harvesting it takes to drive the population extinct."<sup>38</sup> This type of breakdown has occurred in the past and is likely to occur more frequently in the future under climate change.

In other cases, a population will need to shift its geographic range in order to stay within its preferred thermal envelope (or other form of habitat such as salinity or oxygen availability). Fishing pressure can inhibit colonization and range expansion when fishermen accidentally catch—or begin to target—fish as they move into an area.<sup>39</sup> As a result, fishing pressure can inhibit the ability of a population to shift its range, which in turn may result in a fish stock being effectively left behind by shifting ocean conditions.<sup>40</sup> Such a population, pushed beyond its ability to adjust, will decline, as reduced rates of growth and reproduction fail to keep pace with mortality.



A data image of planet earth showing the monthly average sea temperature in the north Pacific Ocean for May 2015.

In addition to range shift, fish populations can adapt to changing conditions through evolutionary processes. Climate change will strain their thermal, oxygen, and pH tolerances, thereby imposing a strong selective pressure. Because fishing mortality can reduce genetic and phenotypic diversity, it may reduce the ability of some stocks to adapt to new conditions.<sup>41</sup> As with the stocks unable to shift range, these populations will slide into decline over time as they lose their viability.

Climate change and fishing pressure each pose significant challenges to fish populations; when combined their impacts are multiplied. In some cases, these synergistic impacts could cause long-term or permanent harm to U.S. fishery resources, like the collapses of North Atlantic cod populations in the mid to late 20th century.

## CAREFUL MANAGEMENT CAN HELP EXPLOITED POPULATIONS STAY RESILIENT

To protect population resilience, scientists have identified three broad management strategies: maintain large fish populations, promote balanced age distributions, and preserve phenotypic and spatial diversity.

As discussed above, maintaining large fish populations is important both because abundance directly affects a population's ability to withstand disturbance and because a large population size can increase genetic and phenotypic diversity.<sup>42</sup> Maintaining fish population abundance is the primary goal of traditional fisheries management. Climate



A school of fish swimming over an eelgrass bed in Channel Islands National Marine Sanctuary, California.

change simply makes it more important to keep managed fish populations at healthy levels and to rebuild those whose numbers have dropped too low. Managers as a result may want to consider accelerated reductions to fishing mortality for rebuilding stocks, ongoing modest fishing mortality reductions for healthy stocks, or the adoption of guidelines (or harvest control rules) that allow quick response to changing environmental conditions—all of which are consistent with the current federal fisheries management framework.<sup>43</sup>

Maintaining a balanced age structure can be approached in a number of ways, including through fishing gear modification, size or slot limits, or protected areas.<sup>44</sup> By modifying gear, fishermen can increase the selectivity of their harvest, avoiding specific size classes of fish. However, this solution is fishery-specific, and its viability depends on practical factors like spatial patterns of age classes, gear escape mechanisms, and so forth. Slot limits work by permitting harvest of only medium-size fish and can be effective in fisheries where catch and release is an option (i.e., where post-capture



Alaska Fisheries Science Center (AFSC) scientist Chris Wilson holding a 38 inch ruler above a massive shorttraker rockfish caught off Unalaska Island, Alaska, and delivered to the Fisheries Monitoring and Analysis Division (FMA) Wet Laboratory.

mortality is low), like lobster and crab fisheries or sometimes recreational fisheries.<sup>45</sup> Protected or closed areas can be difficult to establish but are regarded by some scientists as the most effective strategy to preserve large, old individuals within a population, particularly demersal species with high site fidelity.<sup>46</sup> Large, old individuals have great value in the population because they can diversify reproductive patterns and increase overall productivity, laying abundant, high-quality eggs that spill beyond the boundaries of the protected area.<sup>47</sup>

Attempts to manage phenotypic diversity depend on the ability to identify distinct characteristics or subpopulations within a population and manage them separately. For example, if a population contains subcomponents with different spawning locations and times, as is the case with some salmonids, this can enable more fine-grained management.<sup>48</sup> When the differences are difficult to observe directly, genetic information can help to identify subcomponents within a population, as has been done with Atlantic herring.<sup>49</sup>

## TRADITIONAL FISHERIES MANAGEMENT: FOCUS ON BIOMASS

Western fisheries management historically focuses on biomass or abundance as the primary metric of stock health. Stock assessments are used to evaluate the quantity of fish in the water and determine an amount of biomass that can be sustainably removed by the fishery. Removals are regulated via total allowable catch limits, and biomass levels are maintained, if necessary, through rebuilding procedures that temporarily reduce catch.<sup>50</sup>

Many of the characteristics necessary for population resilience, like phenotypic and genetic diversity, are simply ignored. Some resilience characteristics, like foraging or reproductive behavior, may be analyzed through academic or government research, but the information is rarely incorporated into stock assessments or management. Characteristics like age structure may be incorporated into stock assessments, but even then they have no direct impact on management except insofar as they influence the eventual estimates of biomass, productivity, and allowable catch.

Traditional fisheries management essentially relies on a simplified approach to resilience, assuming that a population will have a relatively high resilience so long as its biomass is maintained at a relatively high level. The problem is that while a large population size is indeed important for resilience, it is not always sufficient on its own; things like balanced age structure, population structure across the seascape, and phenotypic diversity play critical roles too. Moreover, in practice, managers may struggle to actually maintain biomass at desired levels.<sup>51</sup> As a result, traditional fisheries management has run into problems with resilience in the past.

Once phenotypic diversity is identified, management generally consists of time- and/or area-based measures. Time and area closures can be designed around life events, like spawning closures that encompass a wide range of spawning times. Area-based management also can be used to ensure that a population is protected across distinct environmental regimes or conditions, to maintain both phenotypic and genetic diversity.<sup>52</sup> And in the context of shifting stocks, area management also can include range-margin policies like prohibiting fishing at the outer edges of a population's range to preserve any diversity that exists in trailing or leading-edge populations.<sup>53</sup>

## POLICY RECOMMENDATIONS

Fishery managers and policymakers can take tangible steps now to protect the resilience of our nation's managed fish populations. We provide several recommendations for actions that fishery managers and the federal fisheries agency can take under their existing authority, as well as recommendations for changes to the federal law to drive needed reforms.

### FISHERY MANAGERS: START CONSIDERING AND MANAGING FOR POPULATION RESILIENCE

The first movers in federal fishery management under the Magnuson-Stevens Fishery Conservation and Management Act are the eight Regional Fishery Management Councils.<sup>54</sup> The councils make the year-in, year-out management decisions about how much to catch, when and where fishing can take place, what gear can be used, and more. They have a range of staff and advisers including Scientific and Statistical Committees (SSCs), as well as support from the National Marine Fisheries Service (NMFS).

With climate change already upon us, the councils can and should launch concerted efforts to evaluate the population resilience characteristics of the managed stocks in their regions. This work can be done under current law and with existing information.

Specifically, the councils should ask their scientific advisers and NMFS for all available quantitative and qualitative information on age structure, genetic and phenotypic diversity, spatial structure and connectivity, and a synthesis of what that information implies about the resilience of managed stocks. They further should review how climate change is affecting the fish stocks in their regions—are they undergoing range shift, responding to changed chemistry or ocean currents, showing evidence of new food web dynamics, or experiencing other changes? Councils should ask NMFS and their SSCs which resilience characteristics are going to be most important for each of their managed stocks.

After reviewing the information, the councils should work with their scientific advisers and NMFS to develop ways to manage stocks for population resilience. This will be an iterative process that takes time, and it will depend on the specifics of the situation. But with engagement and attention from managers it is possible. It also need not require an overwhelming amount of work: Councils can start by focusing first on the most climate-vulnerable species in their regions (see text box, “Climate Vulnerability,” below) using NMFS's available climate vulnerability assessments.

### CLIMATE VULNERABILITY

Definitions vary, but climate vulnerability generally can be thought of as the likelihood of a population being adversely affected by climate change.<sup>55</sup> More specifically, scientists often look at two different components of vulnerability: a population's exposure to climate-related stresses, and its sensitivity to those stresses.<sup>56</sup>

Recently NMFS has developed a peer-reviewed methodology for quantifying the climate vulnerability of marine species, using the exposure + sensitivity approach.<sup>57</sup> The agency has applied this methodology to produce regional assessments of climate vulnerability for managed species in the Northeast, Alaska, and the West Coast.<sup>58</sup> These assessments can and should be used to prioritize management efforts.

### NMFS: PROVIDE GUIDANCE AND SUPPORT ON MANAGING FOR POPULATION RESILIENCE

As the federal agency charged with interpreting and implementing the Magnuson-Stevens Act, NMFS can take several key steps to promote population resilience under current law.

First, the agency should clarify that the Magnuson-Stevens Act already requires fish stocks to be managed for population resilience. The central provision of the act, National Standard 1, requires managers to avoid overfishing and “achiev[e], on a continuing basis, the optimum yield” from each fishery.<sup>59</sup> The ongoing and long-term nature of this mandate necessitates that fish stocks be managed for population resilience, because a fish stock with degraded resilience will eventually fail in the face of environmental change. Phrased differently, it is not reasonable to assume that fish stocks with degraded population resilience will be able to provide optimum yield “on a continuing basis.”



A commercial fishing boat in New Bedford outer harbor, Massachusetts.

© Daniel Logan/Dreamstime



A commercial fishing boat in New Bedford outer harbor, Massachusetts.

Second, NMFS should develop guidance to help the Fishery Management Councils evaluate and manage for population resilience. NMFS has taken initial steps with vulnerability assessments and technical memoranda; however, further guidance is needed at an applied level for councils and regional offices to actually operationalize management approaches.<sup>60</sup> Specifically, the agency should develop methods and approaches for evaluating the population resilience of a managed fish stock, using existing information such as age, size, growth patterns, exploitation and depletion levels, spatial information, and any genetic or phenotypic information that may be available. Then NMFS should set forth a range of management options for improving population resilience. The key is to build approaches and management options flexibly around available information, rather than design idealized concepts that may be difficult to implement given imperfect information.

Third, NMFS should provide resources and staff to assist the councils in assessing the resilience of their managed stocks and applying resilience concepts to management. National guidance will require implementation at the regional level, and NMFS will need to assist the councils with both funding and staffing to translate guidance concepts into applied, stock-based management policies. Staff and funding also will be critical in helping the councils initially evaluate the resilience of their managed stocks—that is, get the lay of the land at the outset so they can improve upon current management conditions.

While not the focus of this issue brief, it should also be noted that ecosystem-based fisheries management (EBFM) is a critical part of promoting resilient fish populations. EBFM is an integrated approach that considers and accounts for interactions of managed fisheries with other species and promotes resilience at the ecosystem level.<sup>61</sup> NMFS should ramp up implementation of EBFM by reinvigorating management under existing policy tools, such as the EBFM Policy Road Map and Regional Action Plans.<sup>62</sup>

## CONGRESS: CONSIDER AMENDING THE LAW TO PROMOTE POPULATION RESILIENCE

While the Magnuson–Stevens Act already implicitly relates to the concept of population resilience, Congress should consider amending the law to explicitly address the issue and center it in the fisheries management framework. Doing so would underscore the urgency of promoting and restoring population resilience and keeping our nation’s fish stocks sustainable in the face of climate change. There are a few ways Congress could do this.

**Add a Broad Mandate for Resilience:** An important starting point would be to add an explicit mandate for population resilience to the law, complementing the implicit mandate that already exists in National Standard 1. An explicit mandate could take any of several forms, but one approach would be to add population resilience to the Fishery Management Plan (FMP) requirements found in Section 303 of the act. A new subsection could be added to Section 303 with a mandate on population resilience, or resilience could be added to the core requirement for “conservation and management” in Section 303(a)(1)(A).<sup>63</sup> This latter approach, included in legislation introduced in the 117th Congress, has the advantage of making resilience an explicit requirement while still giving the councils and NMFS flexibility in how to approach the issue.<sup>64</sup>

**Require NMFS to Issue Guidance on Resilience:** Enacting a broad mandate for fish stock resilience likely would spur NMFS to issue guidance, but if Congress wanted to be certain, it could instruct the agency to do so. This approach is used regularly in the Magnuson–Stevens Act context and could be a way for Congress to show its interest in and intention to promote population resilience.<sup>65</sup>

**Provide Scientific Advice to the Councils on Promoting Resilience:** Another effective building block of resilience-oriented management would be to require the SSCs to provide scientific information and advice to their councils on the resilience of managed fish stocks in the region. This could be done by adding population resilience to the list of topics in Section 302(g)(1)(B), which sets forth the subjects about which SSCs must provide advice to the councils.<sup>66</sup> If more detail were needed, Congress could specify the level of granularity (e.g., on a stock-by-stock basis) or the frequency with which such advice must be given (e.g., each time a new stock assessment is completed), or it could provide more detailed instructions on the type of analysis to be completed and provided to the councils (e.g., examining the impact of fishing mortality on the stock’s resilience characteristics and comparing this with the impacts of climate change on the stock). In general, providing usable and specific information on population resilience would help the councils make management decisions that promote resilience.

**Add Population Resilience to the Act’s Findings, Purposes, and Policy:** The Magnuson–Stevens Act starts with a recitation of Congress’s findings, purposes, and policy with respect to marine fisheries management.<sup>67</sup> This section

of the act could be amended to state a clear congressional policy to restore and protect population resilience for all managed stocks, and a finding that such management is urgently needed in light of climate change. While amending the act's findings, purposes, and policy section does not change the operative management framework, it does serve to raise awareness and make clear that NMFS and the councils should be paying attention to population resilience.

**Require Specific Actions to Address Resilience:** A more concrete approach would be to provide one or more direct requirements for NMFS or the councils to take certain management actions. These could include monitoring and restoring age structure, using annual catch limits to promote resilience, or using time/area management practices and protected areas. If Congress were to provide direct requirements like these, it would need to consider which stocks the requirements would apply to (e.g., all managed stocks or only the most climate-vulnerable ones) and how the requirements would be implemented, given existing information levels and management structures in the different regions.

## CONCLUSION

To keep pace with a rapidly changing ocean and secure healthy fisheries into the future, we must acknowledge fishery population resilience as a foundational component of fishery management. Long an important concept in ecology, resilience should increasingly inform on-the-water management efforts given the stressors associated with climate change. Moving beyond the Magnuson–Stevens Act framework's emphasis on fishery biomass, managers already have authority to place additional emphasis on promoting resilience, such as by maintaining large fish populations, promoting balanced age distributions, and preserving phenotypic and spatial diversity. Additional resources and technical guidance will be required, however, to operationalize resilience-focused management strategies across fisheries and regions. The councils, NMFS, and policymakers in Congress must each give prompt attention to promoting resilience as part of climate-ready fisheries management.

## Endnotes

- 1 See, for example, Donald A. Falk, Andrew C. Watts, and Andrea E. Thode, "Scaling Ecological Resilience," *Frontiers in Ecology and Evolution* 7, a275 (2019): 2–3, <https://www.frontiersin.org/articles/10.3389/fevo.2019.00275/full>.
- 2 Simon A. Levin and Jane Lubchenco, "Resilience, Robustness, and Marine Ecosystem-Based Management," *BioScience* 58, no. 1 (2008): 27–32, <https://academic.oup.com/bioscience/article/58/1/27/233362>; C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics* 4 (1973): 1–23, <https://www.annualreviews.org/doi/abs/10.1146/annurev.es.04.110173.000245>.
- 3 Dave Hodgson, Jenni L. McDonald, and David J. Hosken, "What Do You Mean, 'Resilient'?", *Trends in Ecology & Evolution* 30, no. 9 (2015): 503–506, <https://www.sciencedirect.com/science/article/pii/S0169534715001627>; Stuart L. Pimm, "The Complexity and Stability of Ecosystems," *Nature* 307 (1984): 321–26, <https://www.nature.com/articles/307321a0>.
- 4 Hodgson, McDonald, and Hoskin, "What Do You Mean, 'Resilient'?"
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- 63 16 U.S.C. § 1853(a)(1)(A).
- 64 Sustaining America’s Fisheries for the Future Act of 2021, H.R. 4690, 117th Cong. § 102(a)(1).
- 65 16 U.S.C. § 1851(b) (National Standard Guidelines); 16 U.S.C. § 1881a(c)(3) (guidelines for information confidentiality); 16 U.S.C. § 1855(b)(1)(A) (guidelines regarding Essential Fish Habitat); 16 U.S.C. § 1852(j)(5) (procedures regarding financial disclosures); 16 U.S.C. § 1856(c)(1)(C) (reporting procedures for foreign fishing); 16 U.S.C. § 1853a(c)(6)(D)(ii) (procedures for certain referenda); 16 U.S.C. § 1855(a)(2) (guidelines for implementing List of Fisheries); 16 U.S.C. § 1867(e) (guidelines for cooperative research); 16 U.S.C. § 1881b(a) (guidelines for fisheries observers).
- 66 See 16 U.S.C. § 1852(g)(1)(B). This approach was taken in recently introduced legislation. See H.R. 4690 § 505(b).
- 67 See 16 U.S.C. § 1801.