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SPECIAL FEATURE (REVIEW)

Marine ecosystem services: Ecological, socioeconomic and cultural sustainability

Fish and fisheries in hot water: What is happening and how do we adapt?

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Abstract

Rapid climate changes are currently driving substantial reorganizations of marine ecosystems around the world. A key question is how these changes will alter the provision of ecosystem services from the ocean, particularly from fisheries. To answer this question, we need to understand not only the ecological dynamics of marine systems, but also human adaptation and feedbacks between humans and the rest of the natural world. In this review, we outline what we have learned from research primarily in continental shelf ecosystems and fishing communities of North America. Key findings are that marine animals are highly sensitive to warming and are responding quickly to changes in water temperature, and that such changes are often happening faster than similar processes on land. Changes in species distributions and productivity are having substantial impacts on fisheries, including through changing catch compositions and longer distances traveled for fishing trips. Conflicts over access to fisheries have also emerged as species distributions are no longer aligned with regulations or catch allocations. These changes in the coupled natural-human system have reduced the value of ecosystem services from some fisheries and risk doing so even more in the future. Going forward, substantial opportunities for more effective fisheries management and operations, marine conservation, and marine spatial planning are likely possible through greater consideration of climate information over time-scales from years to decades.

KEYWORDS

climate change, coupled social–ecological systems, fisheries, marine spatial planning, species distributions

1 | INTRODUCTION

We are at a fascinating and—to many—concerning moment in the history of the ocean, with rapid environmental changes driving substantial reorganizations of marine ecosystems around the world. As a result of human greenhouse gas emissions, ocean surface temperatures have risen 0.7°C and $p\mathrm{CO}_2$ concentrations have increased, with cascading effects on stratification, primary productivity, circulation, oxygen concentrations, carbonate chemistry, and more (Hartmann, Klein Tank, Rusticucci, et al., 2013; Rhein, Rintoul, Aoki, et al., 2013). At the same time the ocean has become a site of unprecedented investment and development, which will shape and be shaped by climate change. We also know that marine ecosystems provide a wide range of ecosystem services, from food to cultural practices to recreation to climate regulation and more (Guerry et al., 2012). A key question is how this provision of services will change in the face of climate change. To answer this question, though, we need to understand not only the ecological dynamics of marine systems, but also human adaptation and feedbacks between humans and the rest of the natural world.

In this review, we outline what we have learned from research primarily in continental shelf ecosystems and fishing communities of North America about the ecological responses to changing ocean temperatures, their implications for capture fisheries, and what these changes mean for effective climate adaptation going forward. Capture fisheries are only one of many sources of marine ecosystem services, and yet their tight coupling to ecosystem dynamics make them a leading indicator of broader dynamics.

2 | MARINE ANIMAL RESPONSES TO WARMING

To understand organismal responses to temperature changes, it can be useful to think in terms of a thermal performance curve that displays relative fitness of an organism as a function of temperature (Sinclair et al., 2016). These curves generally reveal minimum and maximum temperatures at which organisms can function, despite the challenges and complexity of compiling and interpreting these curves across different stages of organismal development, thermal history, and other factors (Sunday et al., 2019). These curves can be broad or narrow, and the difference between the minimum and maximum is called the thermal tolerance breadth (Sunday, Bates, & Dulvy, 2011). Organisms with broad thermal performance curves are called eurytherms, while those with narrow curves are called stenotherms (Somero, 2010).

Synthesis of thermal tolerance breadth data across marine and terrestrial ectotherms reveals that marine animals on average have narrower tolerance breadth than do terrestrial species by about 10°C (Figure 1) (Sunday et al., 2011, 2014). Examples include the Antarctic fish *Lepidonotothen nudifrons* that can tolerate only an 11°C range of temperatures in the lab, whereas its terrestrial neighbor, the sub-Antarctic caterpillar (*Pringleophaga marioni*), can tolerate a 45°C range. Across latitudes, both marine and terrestrial tolerance breadth is narrow at the equator, but on land, breadth increases towards the poles. In the ocean, breadth increases only to mid-latitudes before declining towards the poles (Figure 1).

For understanding vulnerability to warming, however, it is more useful to examine the difference between an organism's maximum experienced body temperature and its upper thermal limit. This difference is called the thermal safety margin. On land, thermal safety margins are narrowest at mid-latitudes, close to where the hottest hourly temperatures are found (Pinsky, Eikeset, McCauley, Payne, & Sunday, 2019). In the ocean, the narrowest safety margins are at the equator. Of more consequence, however, is that marine thermal safety margins are narrower than those on land across all latitudes, suggesting that marine species are more sensitive to warming temperatures than are ectotherms on land (Pinsky et al., 2019).

These differences in sensitivity of individual organisms also scale up to differences in how species respond to changing temperatures. Records of species occurrences and biomass through time at the scale of continents provide an opportunity to address this question. For example, bottom trawl surveys on the continental shelves of

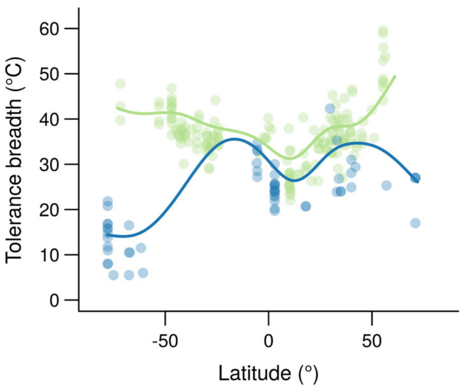

FIGURE 1 Thermal tolerance breadth across latitudes in marine (blue) and terrestrial (green) ectothermic animals, based on data in Sunday et al. (2011, 2014) [Color figure can be viewed at wileyonlinelibrary.com]

North America cover a wide range of marine ecosystems, from sub-Arctic to sub-tropical across two oceans and catch a wide range of species, including cod, lobster, and whelks. These surveys have revealed that American lobster (*Homarus americanus*) in the northeast U.S. were centered around 40.5°N in 1968, but shifted northeast at 70 km/decade to 42.5°N by 2008 (Pinsky, Worm, Fogarty, Sarmiento, & Levin, 2013). Across all surveyed species in the northeast United States, the average was a northeastward shift of 20 km/decade (Pinsky et al., 2013). The trawl surveys also reveal a wide variety of rates and directions that species have shifted, from rapidly northward like lobster, to rapidly southward for squid (*Doryteuthis pealeii*), to few changes at all for others. The variety of shifts observed in the ocean mirror similar patterns reported on land (La Sorte & Jetz, 2012; Moritz et al., 2008). Many explanations for this variety have emphasized the idiosyncratic nature of each species response to changing environment (La Sorte & Jetz, 2012; Moritz et al., 2008; Walther, 2010), suggesting that understanding the variation may be quite difficult.

However, there may be other and potentially simpler explanations as well, one of which is the idea of climate velocity. If one imagines a temperature gradient, one can draw an isotherm (line of equal temperature) as a line across that gradient. Then, as the gradient warms, the isotherm moves with a particular speed and direction that can be expressed in terms of km/decade. This combination of speed and direction is what we call climate velocity (Loarie et al., 2009). Spatial gradients in ocean temperatures are especially weak, which means that climate velocities are especially rapid in the ocean. Climate velocities are upwards of 200 km per decade in some locations (Burrows et al., 2011). Examination of observed species shifts in the trawl data reveals that marine species roughly follow climate velocities (Pinsky et al., 2013). Species do not follow climate velocities perfectly, as is to be expected given the large number of factors that influence species distributions. However, close to 40% of the variation in the rate and direction of observed shifts across taxa and regions can be explained by climate velocity. Calculations of the degree to which marine taxa lag behind climate velocities also suggests that they do not, on average, lag behind (Pinsky et al., 2013). There is some evidence from North America that slow-growing species are slightly more likely to lag behind (Pinsky et al., 2013), plus other evidence from Australia that specialists, species with small range sizes, and species with low mobility are more likely to lag behind (Sunday et al., 2015). The evidence of little lag in the ocean, however, contrasts, most strongly with the abundant evidence for lags on land, from small mammals to butterflies, plants, trees, and birds (Bertrand et al., 2011; Chen, Hill, Ohlemüller, Roy, & Thomas,2011; Devictor et al., 2012; La Sorte & Jetz, 2012; Zhu, Woodall, & Clark, 2012).

Not only is there evidence that marine species are in general keeping up with climate velocities over decades, but other evidence suggests they respond to short-term variation in temperatures as well. Atlantic moonfish (*Selene setapinnis*), for example, have higher biomass in the southeast United States after a warm winter and lower biomass after a cold winter (Morley, Batt, & Pinsky, 2017). Other species in the southeast United States have positive (pink shrimp *Farfantepenaeus duorarum*) or negative (smooth dogfish *Mustelus canis*) responses to warm winters. Across the full assemblage of species, the direction and magnitude of response is explained by the temperature preference of each species. Warm-water species respond positively to warm winters, while cold-water species respond negatively (Morley et al., 2017). These responses are apparent in the spring immediately following the winter, and spring biomass is actually more correlated to winter temperatures than to spring temperatures, suggesting an especially important role of winter in setting the community structure in this region (Morley et al., 2017).

Despite general responses, the ecological mechanisms underlying each species' response can be quite different. The greater biomass of star drum (*Stellifer lanceolatus*) after a warm winter, for example, appears to result from low mortality of young-of-the-year fish that shelter in estuaries (and high mortality in cold winters). In contrast, low biomass of smooth dogfish in the spring after a warm winter appears to result from their early migration north and out of the region.

In addition, warming interacts strongly with other environmental factors, including food availability and oxygen (Brett, 1971; Deutsch, Ferrel, Seibel, Portner, & Huey, 2015). Metabolic rates increase with temperature, driving an increased demand for oxygen and food. Both food limitation and reduced oxygen concentrations therefore cause a reduction in upper thermal limits. Overall global declines in ocean productivity with warming (Stock, Dunne, & John, 2014), though with substantial regional variation, suggest that thermal limitations may often intensify in the future. However, predator–prey interactions are also changing as species ranges shift at different rates and in different directions (Selden, Batt, Saba, & Pinsky, 2018), suggesting that food availability will differ by species.

Overall, the picture emerging is that marine animals are highly sensitive to warming and are responding quickly to changes in water temperature. Marine species are more sensitive to temperature change and also responding faster to temperature change than are species on land. The relatively fewer barriers to colonization and the smaller thermal safety margins in the ocean likely explains the faster response.

3 | IMPACTS ON FISHERIES AND PEOPLE

The rapid changes in species distributions and abundances described in the previous section are also, in many cases, having profound impacts on fisheries and people. At a broad level, changes in population growth rate directly impact the natural-capital wealth represented by any given economically important population. This link exists because the rate of change of a stock (the growth rate) influences the future benefits from the stock (Fenichel et al., 2016). Faster-growing fish populations have a greater imputed asset price per unit, all else being equal. Accounting for these changes in economic terms, however, remains an important research area.

To understand how fisheries adapt to warming waters, the northeast United States provides a fascinating microcosm. Fishing makes an important contribution to the economic health and vitality of coastal communities throughout the region. Vulnerability of these communities to climate change takes many forms, ranging from sea level rise and its effects on fisheries infrastructure to impacts on the mix of species sought by fishers in different ports (Colburn et al., 2016; Hare et al., 2016). Assessment of community dependence on climate-sensitive species reveals stark differences in risk to social and economic well-being (Colburn et al., 2016; Rogers et al., 2019). However, the climate vulnerability of coastal communities as a result of dependence on species sensitive to climate change is ranked consistently high from Virginia to Cape Cod (Colburn et al., 2016). Colburn et al. (2016) further observed that species diversity in landings was uniformly low from Massachusetts through Maine, indicating a weak portfolio structure. Between-port differences in landed species diversity was more pronounced in much of the Mid-Atlantic Bight, with a mix of low and moderate diversity fisheries and a very modest number of high diversity fisheries. Deliberate attempts to strengthen the portfolios held in all vulnerable coastal fishing communities could be beneficial as a hedge against climate change.

Even in the absence of any governmental efforts, substantial bottom-up adaptation by commercial fishing communities is apparent (Young et al., 2019). In terms of fishing fleet practices, these actions generally fall into four categories: traveling further to fish, switching to operate out of new ports, switching to catch new species, or leaving fishing altogether. The degree to which fishers can or wish to pursue different adaptation options is influenced by regulations, economic incentives, infrastructure, local ecological knowledge, and technology, but regulations have had a particularly large influence on the spatial movements of commercial fishers (Dubik et al., 2019; Pinsky & Fogarty, 2012; Young et al., 2019).

Red hake, for example, have shifted rapidly north over the last four decades, moving from the Mid-Atlantic Bight up into New England. The mean latitude of red hake landings has also shifted north substantially over this period of time, but can be divided into two distinct periods. From the late 1960s until the late 1980s, the fishery shifted north in time with the fish, but starting in the 1990s, red hake continued shifting north while the fishery stayed centered further south (Pinsky & Fogarty, 2012). Because of efforts to protect other species, the small-mesh nets used by the red hake fishery are excluded from large portions of this northern region. This fact, along with relatively few markets for the fish, appears to explain why the fishery has not continued moving north. Overall, the red hake fishery has shifted north 75% slower than has the fish, a pattern that also appears in other fisheries in the region, including lobster, summer flounder, and yellowtail flounder (Pinsky & Fogarty, 2012).

Changes in regulations can also motivate new movements of commercial fishers. For example, Cunningham et al. (2016) found that New England fishers moved south into the mid-Atlantic fishery because of the ability to “bank” fishing opportunities in the New England sector system. This change was unrelated to climate change, but highlights the importance of regulations and institutions for aligning fishers with fish.

The adaptations of fishers to the effects of climate change are also strongly influenced by property rights—as well as regulations—as shown in the northeast United States surfclam fishery (McCay, Brandt, & Creed, 2011). The surfclam fisheries use individual transferable rights in shares of annual quotas. This system has sharply decreased the numbers of vessels and quota owners, allowing for greater efficiencies not only in harvesting but also in cooperative research and in management policy deliberation about new approaches to a rapidly changing system. In the surfclam fisheries, both boats and processing plants relocated substantially further north after clam beds off Delaware, Maryland, and Virginia experienced a loss of productivity associated with high temperatures (McCay et al., 2011). It is worth noting that some of the adaptations in fishing fleet behavior described here, such as changes in fishing location, can be rapid, and also in many cases both flexible and reversible. However, changes in shoreside infrastructure, such as closure or relocation of processing plants, are much slower and much harder to change once initiated.

More detailed insights into changes in fisher behavior are available from trip reports, which have been filed for most commercial fishing trips in the northeast United States since 1996 (DePiper, 2014). Each report records the location and length of the fishing trip, the amount of each species caught, and the gear used. The data are self-reported, but audits suggest that the data are reliable enough for aggregate analysis (DePiper, 2014). Aggregating by peer groups of vessels from the same port using similar gear not only resonates with fishers who share environmental knowledge and adaptation strategies (St. Martin & Hall-Arber, 2008) but also provides a scalable unit of analysis for documenting peer group responses to environmental change (St. Martin, Olson, Levin, & Poe, 2017).

For example, Young et al. (2019) examined the mobilities and catch compositions of such "communities at sea" throughout the Northeast. The case of large trawl boats from Beaufort, North Carolina, illustrates one of the many adaptation issues faced by fishers from these communities. The Beaufort fleet used to fish, on average, off North Carolina in 1996 (Figure 2). Average fishing locations moved northward in subsequent years until fishing was centered 500 km further north off New Jersey by 2014 (Figure 2) (Young et al., 2019). Fishing trips can be 1,000 km round trip (or more) and involve burning substantial diesel fuel. The boats primarily catch a flatfish called summer flounder (*Paralichthys dentatus*), and summer flounder are now more abundant off New Jersey than they are off North Carolina. For a variety of reasons related to recovery from overfishing and warming waters, summer flounder are found further north now than they were a couple decades ago (Bell, Richardson, Hare, Lynch, & Fratantoni, 2015; Nye, Link, Hare, & Overholtz, 2009).

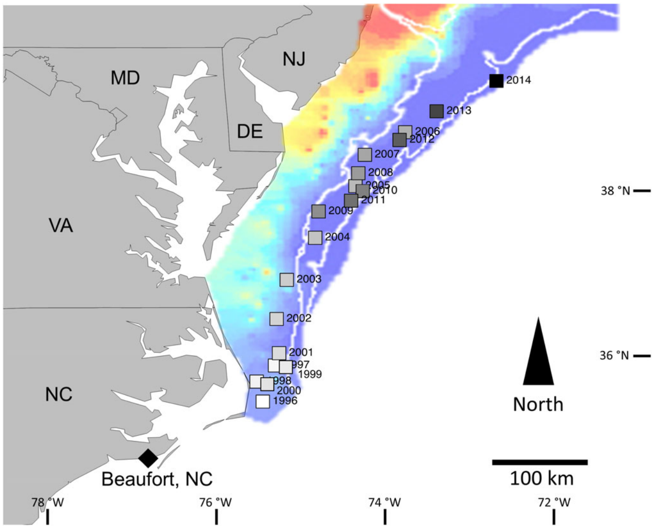

FIGURE 2 Locations over time of the center of fishing trips for large trawlers (>65 ft.) from Beaufort, North Carolina, as recorded in Vessel Trip Reports. The colors represent biomass density (red is high, blue is low) of summer flounder (*Paralichthys dentatus*) from spring bottom trawl surveys in 2014. Data from Young et al. (2019) and from http://oceanadapt.rutgers.edu [Color figure can be viewed at wileyonlinelibrary.com]

Catch portfolios also appear to be an important factor mediating fishing fleet responses to climate change. For example, the Beaufort boats appear to be highly specialized (Young et al., 2019). The fishers catch primarily summer flounder, and so they have chosen to move when summer flounder do. On the other hand, certain other fisheries are quite diversified. Just like a stock portfolio, diversified fishing portfolios also appear less exposed to risks, such as from climate change. Across dozens of fishing communities in the northeast United States, diversified fishing communities have not moved fishing locations as much as more specialized communities (Young et al., 2019). These movement patterns are most visible among communities of large boats (e.g., more than 65 ft.), which are more mobile than small fishing boat communities. Specialized small boat fishing communities, however, were more likely to shrink in size to less than three participating boats, while communities catching a more diversified portfolio were more likely to retain more than three boats (Young et al., 2019). Three boats is the minimum size at which privacy requirements allow tracking of communities. It is worth noting as well that interactions among distinct fisheries are becoming increasingly important (Fuller, Samhouri, Stoll, Levin, & Watson, 2017).

Important questions, however, concern why fishermen in Beaufort do not fish for other species, and why fishing boats in New Jersey do not catch more summer flounder, since they would have lower travel costs. One major factor is the set of regulations governing summer flounder catch: each state has a proportional allocation of summer flounder that it can land each year, and that allocation was set based on the summer flounder distribution in the 1980s (Dubik et al., 2019). That distribution was much further south than it is now, and the allocation has not been updated as the species has moved. The New Jersey share is relatively limited, so boats with New Jersey permits aren't allowed to catch more. Instead, fishing boats from North Carolina permits find it profitable to travel to catch the fish. In addition, some fishers from New Jersey, Rhode Island, and others states have found it profitable to buy North Carolina permits as a way to access the fishery, which requires them to offload their catch in North Carolina even if they catch the fish further north.

The accumulation of individual aggravations has led to organized, collective action within fisheries. For example, in response to their constituents, 16 members of Congress wrote a letter in 2016 to the U.S. Secretary of Commerce complaining about summer flounder management (Courtney et al., 2016). Perhaps more dramatically, the Secretary of Commerce overruled fisheries managers in 2017 and allowed recreational fishing regulations in New Jersey that had been deemed scientifically insufficient for preventing overfishing (Parker, 2017). New Jersey had requested less conservative regulations partly on the grounds that summer flounder were abundant in state waters, even though such regulations would likely exceed the limited catch allocation to the state. The less strict regulations in effect increased the New Jersey allocation.

An important picture emerging is that, in addition to the challenges faced by local communities, regional fisheries face particular problems from climate change when they are pushed across political boundaries. These may be boundaries among states, as in the summer flounder case, or among nations as in the case of Northeast Atlantic mackerel (*Scomber scombrus*). Mackerel shifted from European Union (EU) waters into Icelandic waters in a shift linked to temperature and prey (Spijkers & Boonstra, 2017). Iceland started fishing for mackerel unilaterally and could not agree with the EU on a joint management plan. The combined fishing pressure was above the recommended catch, and Iceland and the EU still aren't cooperating. In fact, Iceland dropped its bid to join the EU, in part over fisheries issues.

While much of the focus so far has been on impacts to commercial fisheries, recreational fishers can also be impacted by changing climate and changing fish populations. Recreational fisheries directly impact substantially more people than do commercial fisheries (Arlinghaus et al., 2019). One finding is that recreational fishers often prefer fishing in warmer weather (Mendelsohn & Markowski, 2004), which suggests that a warmer climate could increase demand for recreational fishing opportunities and potentially intensify existing conflicts with the commercial sector (Abbott, 2015). Such intensification could add to existing conflicts over the spatial mismatch of allocations and fish availability.

Shifting species are already disrupting economies and politics from community to national levels. It may be surprising that these impacts are already visible, but the broader point that natural resources are vital to social and economic wellbeing across scales should not be a surprise, nor should it any longer be a surprise that adaptation to changing conditions will be increasingly challenging and often contentious. Climate change adds a new dimension to such dynamics because now the foundations of economies are on the move without regard for state and national boundaries. Going forward, climate change projections suggest that more than 70 countries around the world are likely to gain new transboundary fisheries like mackerel by 2100 (Pinsky et al., 2018). A future with less warming and lower greenhouse gas emissions, however, would also have fewer chances for conflicts over transboundary fisheries (Pinsky et al., 2018).

4 | POTENTIAL FOR ADAPTATION IN FISHERIES MANAGEMENT, CONSERVATION, AND SPATIAL PLANNING

With fish moving, fisheries adapting bottom-up, and conflicts emerging, it becomes relevant to ask if and how fisheries management, marine conservation, and other marine spatial planning (MSP) efforts can adapt to more effectively manage and conserve marine resources (Lindegren & Brander, 2018). Management, conservation, and planning decisions are made over a range of timescales (Tommasi et al., 2017), from annual or multi-annual decisions about reference points, catch limits, and spatial regulations, to decade-scale decisions about how to manage emerging fisheries or how to spatially allocate different ocean uses (Gissi, Fraschetti, & Micheli, 2019). Investment decisions within the fishing and offshore energy industries are also often made over decade-scale time horizons. Over decades and longer, decisions are made about how to interact with stakeholders or how to structure cooperation among management organizations. Lubchenco, Cerny-Chipman, Reimer, and Levin (2016) show that there is great potential in modifying individual or collective incentives. Powerful mechanisms that work if well-designed can include rights-based or secure-access fisheries, ecosystem-service accounting that emphasizes conservation benefits, and the modification of social norms. Marine reserves are another tool that can aid the sustainability of stocks.

Increasingly, the information for more adaptive decision-making is becoming available, and modeling techniques are expanding to treat the interaction between ecological and social systems (Tekwa, Fenichel, Levin, & Pinsky, 2019). Stock assessments have long provided critical information about biomass, while newer resources have become useful for understanding species distributions and recent changes in distribution. OceanAdapt (http://oceanadapt.rutgers.edu) is one example that displays animated maps online for more than 500 marine species around North America, while Redmap is a similar effort in Australia that includes citizen observations (http://www.redmap.org.au/). For informing longer-term decisions over decades, climate change projections have been used to project future spatial habitat distributions for many species (Cheung et al., 2009; Molinos et al., 2015; Morley et al., 2018).

The question then becomes how managers and policymakers can use such information, with emerging fisheries as one key area. For example, blueline tilefish (*Caulolatilus microps*) appeared north of Cape Hatteras, North Carolina, in a region where the fishery was unregulated. Only a decade or so later were emergency regulations implemented (Pinsky et al., 2018). Jonah crab (*Cancer borealis*), also an unregulated fishery at first, represented a valuable alternative target for lobster fishing communities in southern New England after lobster declined substantially with warming waters. With warning that such fisheries may emerge, pre-emptive management plans can set conservative catch and bycatch limits for species whose populations are otherwise too small to attract attention, allowing those populations to grow when environmental conditions improve. Letting these populations grow is also the economically optimal solution, since faster growing populations can more quickly support a productive fishery (Moberg, Pinsky, & Fenichel, 2019).

Another area for climate adaptation is in cooperative management across political boundaries for species likely to cross those boundaries (Pinsky et al., 2018). Sharing data and science can be an important step towards building trust and a shared understanding of ecosystem changes. Beyond that, tradeable permits/quota or dynamic allocation systems can make the allocation system more adaptable in the face of shifting species distributions (Aqorau, Bell, & Kittinger, 2018). Side payments can also be useful for incentivizing cooperation among stakeholders (Miller, Munro, Sumaila, & Cheung, 2013). All of these solutions require improved coordination of management among countries, however, which will likely be easier for countries already coordinating extensively on such issues and more difficult for countries with more limited diplomatic exchange.

Over the longer term, a key area for integrating climate change projections will be in MSP. Current MSP efforts rarely consider climate change, and yet plans are typically designed to remain in place for decades. In other words, over the time-scales at which climate impacts will become substantial (Gissi et al., 2019). Shifts in species distributions are likely to change the locations that are most valuable for fisheries, for recreation, and for conservation, but are unlikely to have much or any impact on offshore energy development, shipping lanes, and other ocean uses. These differences in spatial shifts can create new conflicts among uses that are not currently considered. Whether marine spatial plans can be made robust to climate impact—such as by designing use and conservation areas in networks across gradients of temperature and other climate axes—remains to be tested.

Finally, fishers and communities can adapt their behaviors and businesses, particularly when armed with knowledge of probable reconfigurations of species available on the fishing grounds they visit (Rogers et al., 2019). Communities may pursue novel collective adaptation strategies such as Community Supported Fishing (CSF) and other initiatives designed to enhance connections between fishers, consumers, and a concern for environmental well-being (Campbell, Boucquey, Stoll, Coppola, & Smith, 2014; Snyder & St Martin, 2015). While CSFs vary considerably (Bolton, Dubik, Stoll, & Basurto, 2016), most CSFs help to diversify fisheries and reduce dependencies on single species. The new proximate markets they create are also likely to be more flexible and responsive to environmental change (Stoll, Dubik, & Campbell, 2015).

5 | CONCLUSION

Marine species and fishing communities have long adapted and responded to climate variability over timescales from seasons to centuries, and yet the changes occurring now are happening faster and more dramatically as a result of climate change. Research to date reveals that marine animals are highly sensitive to warming and are responding quickly and often predictably to changes in ocean temperatures, particularly through changes in spatial distribution. These changes have been faster than has been observed on land. In response, fishers and entire fleets are moving to new locations, catching new species, or facing the challenges of lost fishing opportunities and livelihoods locally and regionally. Movements of fisheries across political boundaries are particularly challenging and have led to conflict in many cases. Adaptation to these changes within fisheries management and communities, within conservation efforts, and within MSP, however, is possible and is likely needed to greater degrees than observed to date if we are to continue meeting societal goals for ecosystem services from the sea.

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