REELING IN UNCERTAINTY: ADAPTING MARINE FISHERIES MANAGEMENT TO COPE WITH CLIMATE EFFECTS ON OCEAN ECOSYSTEMS

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Physical, chemical, and biological parameters of ocean ecosystems are constantly changing. A variety of scientific research methods demonstrate this unequivocally. To ensure adequate management of resources, fisheries management in the United States is designed to adapt to these ecosystem changes. However, increased uncertainty and unprecedented unidirectional change as a result of climate change are testing our capacity to manage. In light of this challenge, all interested and involved parties must cooperate and play a proactive role in an adaptation effort. Scientists and fishing communities must work together to identify changing conditions and predict future scenarios. Managers must implement flexible regulations that incorporate emerging information. As a society, we must shift our habits to adapt, as humankind has done throughout existence.

Climate change presents a challenge, but also a unique opportunity to revolutionize the U.S. fisheries with dynamic and flexible approaches to management. By exploring the predicted effects of climate change on marine fisheries and the current statutory and regulatory framework, this Article establishes that U.S. fisheries management is well designed to adapt to changing circumstances if involved parties are proactive. The Article proceeds to suggest several emerging methods for managing both fishery resources and the humans that use them that fit well within the current legal framework. The methods analyzed in this Article are no doubt a small sampling of innovations that fishing communities, scientists, and managers are developing. Ultimately, this Article aims to provide a framework for adapting current fisheries management to the environmental changes our planet is currently experiencing.

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I. INTRODUCTION

A quick Internet search for "climate change canary in the coal mine" yields no fewer than twenty different metaphorical canaries.[1] These early warning indicators include frogs, Syria, Australian grape growers, the Marshall Islands, coral reefs, the Arctic, the Purple Finch, national parks, the Pika, and fish. While the idiom is overused, the comparisons are instructive. The long-term averages that compose our global climate are nearly impossible to perceive on a daily basis and the amount of carbon dioxide (CO_2) and heat already absorbed by terrestrial and marine environments is invisible to the naked eye. But those absorbed molecules and shifting averages are changing our environment in subtle yet impactful ways, and we rely on certain "canaries" to tell us that something is amiss. This Article focuses on managing the changes that have allowed experts to characterize marine fish as a "climate canary."

Despite the historical focus on climate change effects to terrestrial systems and the cryosphere,[2] effects on ocean ecosystems present a more immediate and potentially more significant risk.[3] The most significant ocean changes attributed to continued greenhouse gas emissions are the warming of ocean waters and the increased uptake of carbon dioxide by ocean waters leading to ocean acidification. Even small increases in the temperature or acidity of Earth's major water bodies can have significant and far-reaching influence on delicate ocean ecosystems.[4] Due to the complexity of the marine environment, the long-term effects of warming waters and ocean acidification are not completely understood, but current science confirms that changes in the biological, ecological, and chemical infrastructure of the oceans are already occurring.[5] For example, distribution shifts and decreased productivity of marine organisms have already been documented in the Pacific Ocean.[6]

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1 "Canary in the coal mine" is an idiom that alludes to the use of canaries in coal mines as early warning indicators of odorless methane gas. It has become a common phrase to describe something that exhibits the first response to negative change, thereby alerting society to an issue of concern.

2 Cryosphere refers to the "frozen water part of the Earth system" such as glaciers, permafrost, and sea ice at high latitudes. *What is the Cryosphere?*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://perma.cc/6FZ4-6GRB (last visited Feb. 25, 2017).

3 Christophe A.G. Tulou et al., *Climate Change and the Marine Environment*, *in* OCEAN AND COASTAL LAW AND POLICY 571, 571 (Donald C. Baur et al. eds., 2008); s*ee also* Elvira S. Poloczanska et al., *Global Imprint of Climate Change on Marine Life*, 3 NATURE CLIMATE CHANGE 919, 924 (2013) (discussing global warming patterns and effects on marine life); Michael T. Burrows et al., *The Pace of Shifting Climate in Marine and Terrestrial Ecosystems*, 334 SCIENCE 652, 655 (2011) (same).

4 *See infra* Part II.

5 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, FIFTH ASSESSMENT REPORT, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 68 (Christopher B. Field et al. eds., 2014) [hereinafter IPCC 2014].

6 *See, e.g.*, Ashleen J. Benson & Andrew W. Trites, *Ecological Effects of Regime Shifts in the Bering Sea and Eastern North Pacific Ocean*, 3 FISH & FISHERIES 95, 103 (2002) (observing a

Few observe and understand the implications of this change more clearly than fishermen, who are encountering new species in odd places and changes to their usual catch. Much of the time, these changes present a mixture of opportunity and adversity for fishing communities. For example, black sea bass (*Centropristis striata*) are beginning to make an appearance in the Gulf of Maine, far north of their usual range.[7] This new, commercially valuable species presents an opportunity for some fishermen.[8] However, the black sea bass have an appetite for lobster, another commercially important species that is already highly vulnerable to climate change.[9] For many in the region, a solution to this issue is to increase commercial catch of black sea bass, providing new economic revenue and reducing pressure on the already troubled lobster.[10] But the current management approach complicates matters by basing the state-by-state allocation of commercial black sea bass catch quota on historical catch[11] and lacking research surveys north of Massachusetts, where the species appears to be expanding rapidly.[12] This approach can protect fishermen who have historically targeted the species, but has the potential to harm other fishing communities and result in wasteful practices.[13] The lack of research means the viability and stock dynamics of sea bass populations in Maine will remain a mystery until research efforts expand. In the case of the black sea bass, some fishermen's livelihoods are disappearing while others are throwing tons (literally) of dead fish overboard due to a regulatory system that has not kept pace.[14] This narrative of management not keeping up with environmental change is increasingly common in U.S. coastal waters,[15] signaling a need for change.

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complex relationship connecting climate to distribution shifts and productivity changes); Josh A. McGowan et al., *Climate-Ocean Variability and Ecosystem Response in the Northeast Pacific*, 281 SCIENCE 210, 214–15 (1998) (discussing massive reductions in productivity that coincided with warming water temperatures).

7 Christine Burns Rudalevige, *A New Fish for Maine Waters–and Dinner Plates*, PORTLAND PRESS HERALD (Apr. 26, 2015), https://perma.cc/A8AX-X3VP.

8 *Id.*

9 Patrick Whittle, *Fishermen Worry as Black Sea Bass Stake New England Claim*, PHYS.ORG, (Sept. 27, 2015), https://perma.cc/34VU-2ZTC; *see also* Rachel Berman et al., *The Lost Lobsters of Long Island Sound*, RUTGERS RUTGERS SCH. OF ENVTL. & BIOLOGICAL SCIS.: OCEANADAPT (Sept. 3, 2015), https://perma.cc/Q6AG-98LK (discussing the effect of warming waters on lobsters in the Long Island Sound).

10 Whittle, *supra* note 9.

11 KIRBY ROOTES-MURDY, ATL. STATES MARINE FISHERIES COMM'N, 2015 REVIEW OF THE ATLANTIC STATES MARINE FISHERIES COMMISSION FISHERY MANAGEMENT PLAN FOR THE 2014 BLACK SEABASS FISHERY 6–8 tbls.1, 2 & 3 (2015), https://perma.cc/TT52-9QWT.

12 *Id.* at 3–4.

13 Gregory B. Hladky, *Experts Say Wasteful Fishing Regulations Not Keeping Pace with Climate Change*, HARTFORD COURANT (Sept. 6, 2015), https://perma.cc/4YLN-6VTE.

14 *Id.*

15 *See, e.g.*, Press Release, Mid-Atl. Fishery Mgmt. Council, Federal Fishery Management Measures Approved for Blueline Tilefish in the Mid-Atlantic (Apr. 25, 2016), https://perma.cc/YNZ2-J69S (concerning new management measures for blueline tilefish (*Caulolatilus microps*), a species that expanded beyond jurisdiction of the South Atlantic Fishery Management Council).

The United States is fortunate enough to have a robust fisheries governance structure with the capacity to regulate and enforce in most situations, but incorporating adequate and timely science into the management decision process remains an issue. Changing environmental factors—the consequences of which are often difficult to predict and may not be felt until the time to act has already passed—can test the ability of management to adapt and result in unexpected declines in marine biodiversity with attendant effects on coastal communities.[16] Additionally, past and ongoing human alterations of natural systems by overfishing, pollution, and direct damage to marine habitats have undermined the resilience of some marine ecosystems.[17] The combination of impacts from past and ongoing human activities with large-scale and regional environmental climate change present significant risks to commercially important fisheries.[18] The struggle to sustainably manage fishing industries is magnified, making sound management choices in a dynamic and uncertain ocean environment a daunting challenge.[19] As a result, adaptation of U.S. fisheries management to account for these changes is necessary to protect the biodiversity and natural resources in U.S. waters.

To determine the current capacity for adaptation in U.S. fisheries, this Article identifies the major issues that federal fisheries managers now face due to climate change, assesses the primary components of the regulatory system in place, and explores how emerging adaptation mechanisms fit within the system. Part II provides an introduction to how global climate change is associated with changing physical and chemical ocean parameters,

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16 PEW CHARITABLE TR. & OCEAN CONSERVANCY, IT'S A KEEPER: THE LAW THAT'S SAVING AMERICAN FISHERIES: THE MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT 35 (2013), https://perma.cc/3BME-NULZ (noting that fishery managers cannot control events such as shifts in ocean temperature that affect fish valued by fishermen with catch limits, "but they can account for them as part of an overall approach to fishery management. In order to plan and prepare for the consequences of global climate change on the ocean, [managers] need to focus on enhancing ecosystem resilience by building on past restoration successes and habitat protections.").

17 John D. Koehn et al., *Climate Change and Australian Marine and Freshwater Environments, Fishes and Fisheries: Synthesis and Options for Adaptation*, 62 MARINE & FRESHWATER RES. 1148, 1148–49 (2011); IPCC 2014, *supra* note 5, at 459, 516; *see also* D.W. Schindler, *The Cumulative Effects of Climate Warming and Other Human Stresses on Canadian Freshwaters in the New Millennium*, 58 CAN. J. FISHERIES & AQUATIC SCI. 18, 23–24 (2001); Ivan Valiela et al., *Mangrove Forests: One of the World's Threatened Major Tropical Environments*, 51 BIOSCIENCE 807, 810–11 (2001); Scott A. Woolridge, *Water Quality and Coral Bleaching Thresholds: Formalising the Linkage for the Inshore Reefs of the Great Barrier Reef, Australia*, 58 MAR. POLLUTION BULL. 745, 745–48 (2009).

18 IPCC 2014, *supra* note 5, at 68; ORG. FOR ECON. CO-OPERATION & DEV., THE ECONOMICS OF ADAPTING FISHERIES TO CLIMATE CHANGE 23 (2010) [hereinafter OECD ADAPTING FISHERIES TO CLIMATE CHANGE]; Koehn et al., *supra* note 17, at 1148–49; David Fluharty, *Decision-Making and Action Taking: Fisheries Management in a Changing Climate* 8 (Org. for Econ. Co-operation & Dev. Food, Agric. and Fisheries, Paper No. 36), https://perma.cc/KJE4-GGKQ.

19 Fluharty, *supra* note 18, at 8; *see also* OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 21 ("If the ocean changes beyond our historic scientific experience, managers and scientists may have a weakened foundation for making predictions and assessing which management actions to take.").

leading to altered productivity, distribution, and species interactions in marine ecosystems. This is followed in Part III with a background of the underlying legal framework of U.S. federal fisheries management under the Magnuson–Stevens Fishery Conservation and Management Act[20] (MSA or Magnuson–Stevens Act). Because fisheries management is a highly complex topic, this Part focuses on a limited selection of statutory and regulatory components. Finally, Part IV explores six adaptation mechanisms applicable to the federal fisheries management regime that more efficiently incorporate uncertainty and the varying effects of climate change than the status quo. The Article concludes that managers can effectively minimize the detrimental effects of climate change on both fish and human populations that utilize them by increasing the adaptive capacity of the management process and allowing traditionally static features, such as quotas and area closures, to change in response to emerging data.

II. EFFECTS OF A CHANGING CLIMATE ON MARINE CAPTURE FISHERIES

The range of physical, chemical, and biological ocean changes observed and expected to occur due to past, present, and future greenhouse gas emissions is significant. At the most basic level, increased greenhouse gas emissions are correlated with global climatic changes such as increasing atmospheric CO_2 and temperature and increased variability in precipitation and wind patterns. Narrowing the focus to physical and chemical ocean parameters, the role of oceans as a climate regulator is paramount. Oceans function as both regulators of ambient CO_2 by absorbing excess CO_2 from the atmosphere[21] and regulators of global temperature by absorbing heat.[22] As a result, the acidity and temperature of ocean waters are both on the rise.[23] A suite of other related physical and chemical changes—including sea ice reduction, sea level rise, changes in ocean currents, and unidirectional change and increased variability in the salinity and oxygen content of seawater—are also occurring in oceans worldwide.[24]

Widespread consensus exists that marine populations have already begun to respond to these environmental changes in many marine ecosystems.[25] Long-term increases in ocean temperature and associated environmental changes affect the distribution, productivity, and life cycles of

20 16 U.S.C. §§ 1801–1891d (2012).

21 WORLD BANK, TURN DOWN THE HEAT: WHY A 4°C WARMER WORLD MUST BE AVOIDED 11 (2012) https://perma.cc/M3M4-2WKX ("The oceans play a major role as one of the Earth's large CO_2 sinks. As atmospheric CO_2 rises, the oceans absorb additional CO_2 in an attempt to restore the balance between uptake and release at the oceans' surface. They have taken up approximately 25 percent of anthropogenic CO_2 emissions in the period 2000–06.").

22 *See* Tulou et al., *supra* note 3, at 573 (stating that over 80% of the heat retained in earth's atmosphere through the greenhouse effect has been absorbed by the oceans).

23 IPCC 2014, *supra* note 5, at 68–69.

24 *Id.* at 414, 991, 993.

25 McGowan et al., *supra* note 6, at 210.

marine species.[26] Similarly, increasing acidity of ocean waters due to uptake of CO_2 directly affects the productivity and growth of many primary producers and commercially important species.[27] Subsidiary changes such as decreasing oxygen levels and salinity have additional effects on productivity and distribution.[28] Although certain species and regions will experience some positive effects, generally speaking these changes will result in negative trends in fisheries production.[29]

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26 *See*, *e.g.*, IPCC 2014, *supra* note 5, at 68–69. Many studies have recognized that distinguishing between the effects of long-term, climate change-induced warming of ocean waters and natural variations in water temperature is challenging. *See, e.g.*, IPCC 2014, *supra* note 5, at 5; Éva E. Plagányi et al., *Assessing the Adequacy of Current Fisheries Management Under Changing Climate: A Southern Synopsis*, 68 ICES J. MARINE SCI. 1305, 1305 (2011). Natural modes of variability include El Nino Southern Oscillation and Northern Atlantic Oscillation. IPCC 2014, *supra* note 5, at 420. However, studies have concluded that some ecosystem shifts have passed a threshold of natural variability and are the result of anthropogenic warming. David B. Field et al., *Planktonic Foraminifera of the California Current Reflect 20th-Century Warming*, 311 SCIENCE 63, 66 (2006); PAC. FISHERY MGMT. COUNCIL, PACIFIC COAST FISHERY ECOSYSTEM PLAN: FOR THE U.S. PORTION OF THE CALIFORNIA CURRENT LARGE MARINE ECOSYSTEM 142 (2013) [hereinafter PFMC FEP], https://perma.cc/ME5T-T4XV (public review draft).

Additionally, distinguishing between effects of natural variations and permanent warming may not be essential because the effects of natural variations in water temperature can help indicate the sensitivity of marine organisms to the long-term ocean warming of climate change. Lesley Hughes, *Biological Consequences of Global Warming: Is the Signal Already Apparent*, 15 TRENDS ECOLOGY & EVOLUTION 56, 59 (2000). By using the relatively shorter-term temperature shifts as a proxy for the long-term effects of climate change, scientists compensate for the "mismatch between the scales of important atmospheric and oceanographic processes and the spatial and temporal dimensions of biological research programs." McGowan et al., *supra* note 6, at 210. Thus, scientists can look to effects of large interannual—frequently due to warm El Niño and cool La Niña events—and interdecadal sea-surface temperature changes that have occurred over the past century for proof of climate variability effects on marine organisms. *Id.* Although this data is less than ideal and may not accurately predict all the possible future effects of long-term climate variability, potential ecosystem disturbances are detrimental enough that we must heed their projections.

27 JOAN A. KLEYPAS ET AL., IMPACTS OF OCEAN ACIDIFICATION ON CORAL REEFS AND OTHER MARINE CALCIFIERS 1 (2006), https://perma.cc/8LHH-XM3B (explaining that ocean absorption of CO_2 increases acidity of marine waters, resulting in the breakdown of the calcium carbonate skeletons and shells of corals and plankton, essential primary producers in certain marine trophic webs); *see also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 295 box 3.2 (Thomas F. Stocker et al. eds., 2013) ("[Increasing carbonic acid] can affect shell formation for marine animals such as corals, plankton, and shellfish [potentially] affect[ing] fundamental biological and chemical processes of the sea in coming decades."). The increased acidity of oceans threatens the survival of individual species and entire marine ecosystems. COUNCIL ON ENVTL. QUALITY, FINAL RECOMMENDATIONS OF THE INTERAGENCY OCEAN POLICY TASK FORCE 12, 36 (2010) [hereinafter CEQ OCEAN POLICY TASK FORCE] ("[O]cean acidification is expected to have significant and largely negative impacts on the marine food web, ocean ecosystems as a whole, and biological diversity in general."). Significantly, even if emissions are cut, the effects of ocean acidification already occurring may only be reversible through natural processes that will take thousands of years. Press Release, Interacademy Panel on Int'l Issues, Statement on Ocean Acidification (June 2009), https://perma.cc/N5HP-26C5.

28 IPCC 2014, *supra* note 5, at 414.

29 *See* IPCC 2014, *supra* note 5, at 414–16 (analyzing, with varying level of certainty, effects on fisheries and aquaculture as a result of climate change); William W.L. Cheung et al., *Large-*

At the ecosystem level, changes in overall productivity, food-web structure, and community composition are occurring. Effects to primary producers and habitat-forming species are particularly relevant from the ecosystem perspective. Increasing ocean temperatures and acidity affect the productivity of marine ecosystems by reducing the productivity of primary producers[30] and other organisms at the base of the food chain.[31] Expected changes in marine food webs from the variation in productivity of primary producers and consumers will cascade up the food chain, reducing the food available to commercially important fish species.[32]

Climate change also results in alteration to and/or reduction of marine habitat. Water temperature is directly correlated with habitable areas for marine species.[33] With changing water temperatures, mobile species have begun to shift their distribution poleward or to deeper parts of the ocean to remain within their biological limits.[34] Conversely, organisms that are less

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Scale Redistribution of Maximum Fisheries Catch Potential in the Global Ocean Under Climate Change, 16 GLOBAL CHANGE BIOLOGY 24, 31–33 (2010) (projecting catch potential changes of different species of marine fish and invertebrates from 2005 to 2055, suggesting an increase in high-latitude regions and a decrease in the tropics).

30 Primary producers are organisms that create energy from sunlight through the process of photosynthesis and make up the base trophic level of marine food webs, producing ecosystem food that supports the entire marine food chain. NAT'L OCEANIC & ATMOSPHERIC ADMIN., LEARNING OCEAN SCIENCE THROUGH OCEAN EXPLORATION 111 (2011), https://perma.cc/H78N-ZAPK. Increasing temperatures may affect primary producers by affecting essential growth processes such as photosynthesis, respiration, and tissue composition in plants. Hughes, *supra* note 26, at 57–58. Additionally, many primary producers—such as phytoplankton—are calcifiers, meaning that they create their shells and skeletons from calcium carbonate. Tulou et al., *supra* note 3, at 574. Increased acidification negatively affects the calcification process and even small changes in the pH of ocean water will result in a decreased ability to grow shells and skeletons. KLEYPAS ET AL., *supra* note 27, at 5.

31 Primary consumers—organisms further up the food chain but still important prey species—are also affected. For example, reductions in the upwelling of cold, nutrient-rich waters to the surface reduce the amount of food and nutrients available to lower level consumers. Hughes, *supra* note 26, at 59. Off the west coast of the United States, scientists have also suggested a direct causal relationship between declines in zooplankton and an increase in the surface water temperatures of the California Current. *Id.*

32 U. Rashid Sumaila et al., *Climate Change Impacts on the Biophysics and Economics of World Fisheries*, 1 NATURE CLIMATE CHANGE 449, 450 (2011).

33 Lucy Robinson & Amanda Bates, *Marine Species Are on the Move – But What Exactly is A 'Range Shift'?*, RANGE EXTENSION DATABASE & MAPPING PROJECT, https://perma.cc/5H35-JK5P (last visited Feb. 25, 2017) (explaining how the geographic area that different marine species are capable of inhabiting depends partially on ambient temperatures).

34 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, THIRD ASSESSMENT REPORT, CLIMATE CHANGE 2001: IMPACTS, ADAPTATION AND VULNERABILITY 11 (James J. McCarthy et al. eds., 2001). The Intergovernmental Panel on Climate Change (IPCC) has confirmed a correlation between observed changes in marine biological systems and rising water temperatures, as well as related environmental changes. *Id.* at 11–12. Specifically, deviations in the traditional range and abundance of marine organisms have been attributed to climate change. IPCC 2014, *supra* note 5, at 17, 414. The IPCC also projected adverse effects for fisheries as a result of these changes in the distribution and production of fish. *Id.* at 416, 452, 456. Species movement will change ecosystem structures and alter species interactions. *Id.* at 414–15, 461–64. These shifts have been predicted or documented in several areas globally. *See, e.g.*, *National Data*, OCEANADAPT, RUTGERS SCH. OF ENVTL. & BIOLOGICAL SCIS., https://perma.cc/AK8A-EXPR (last visited Feb. 25,

mobile and unable to adapt to unfavorable changes by shifting their distribution will likely experience decreases in productivity and abundance.[35] Increasing temperatures can also directly affect photosynthetic processes and growth rates of biogenic habitat species.[36]

Sea level rise, acidification, and increased frequency of extreme weather are also predicted to effect marine habitats. Sea level rise contributes to losses of coastal wetlands and mangroves[37]—areas recognized as important nursery grounds for commercially and recreationally valuable fish species.[38] Furthermore, ocean acidification and increased water temperatures are exacerbating the bleaching events already occurring in coral reefs[39] that are essential habitat for many economically important species.[40] Changes in temperature and acidity are also leading to an expansion of hypoxic zones (i.e., low oxygen zones) that constrain the habitat of most large marine organisms.[41] Finally, increases in storm frequency lead to direct physical damage to habitats as well as increases in indirect habitat effects, such as sedimentation.[42] The precise ramifications of these changes on habitat vary by depth and latitude.[43]

The productivity and abundance of individual commercially important species are also changing. In addition to the previously discussed indirect effects of reduced ecosystem productivity and habitats, metabolic and growth rates of many commercially important species are directly

2017) (exploring changes in marine species distributions); *see also* Elliott L. Hazen et al., *Predicted Habitat Shifts of Pacific Top Predators in a Changing Climate*, 3 NATURE CLIMATE CHANGE 1, 2–4 (2013) (predicting habitat shifts of Pacific top predators).

35 *See* IPCC 2014, *supra* note 5, at 424.

36 Andrew S. Brierley & Michael J. Kingsford, *Impacts of Climate Change on Marine Organisms and Ecosystems*, 19 CURRENT BIOLOGY R602, R606 tbl.2, R608 (2009); Morgan S. Pratchett et al., *Contribution of Climate Change to Degradation and Loss of Critical Fish Habitats in Australian Marine and Freshwater Environments*, 62 MARINE & FRESHWATER RES. 1062, 1064–65, 1067 (2011).

37 IPCC 2014, *supra* note 5, at 17.

38 *See, e.g.*, William J. Tobias, *Mangrove Habitat as Nursery Grounds for Recreationally Important Fish Species*, 52 GULF & CARIBBEAN FISHERIES INST. PROC. 468, 468–69 (2001); Patrik Rönnbäck, *The Ecological Basis for Economic Value of Seafood Production Supported by Mangrove Ecosystems*, 29 ECOLOGICAL ECON. 235, 236–37, & tbl.1 (1999); Michael W. Beck et al., *The Identification, Conservation, and Management of Estuarine and Marine Nurseries for Fish and Invertebrates*, 51 BIOSCIENCE 633, 633–34 (2001); WORLD BANK, *supra* note 21, at xvi. Notably, the protection of coastal nursery habitat is not likely to be an issue for federal fisheries management, which predominately takes place over 3 miles offshore. *See infra* note 58 and accompanying text. However, consideration of the issue in assessing stock health may be a necessary task for managers.

39 IPCC 2014, *supra* note 5, at 414, 431; *see also* Jacob Silverman et al., *Coral Reefs May Start Dissolving When Atmospheric CO_2 Doubles*, 36 GEOPHYSICAL RES. LETTERS, no. 5, Mar. 2009, L05606 (increasing CO_2 concentrations may lead to the dissolution of ocean coral).

40 *The Importance of Coral Reefs*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://perma.cc/6UJY-JXRB (last visited Feb. 25, 2017).

41 IPCC 2014, *supra* note 5, at 415, 443.

42 Brierley & Kingsford, *supra* note 36, at R602, R606 tbl.2.

43 *Id.*

influenced by temperature, acidity, and weather.[44] The permutation of phenological events—animal life history events that are triggered by climate conditions[45]—contribute to these changes. In marine environments, changes in light or temperature prompt many life events.[46] Life cycle events dependent on day length or light intensity continue to occur on a status quo schedule.[47] However, annual life cycle events dependent on temperature have moved forward in time in response to warming waters.[48] Because the efficient transfer of production to higher trophic levels is dependent on the synchronization of these triggered life cycle events, the mismatch in timing of different life events will alter food-web structures.[49] This alteration may exacerbate and contribute to reductions in productivity and result in the further decline of stocks.[50]

At this point it is important to recognize the need for region-specific assessments of climate effects. Ultimately, the character, range, and intensity of alterations to marine ecosystems attributable to climate change will depend on the species, habitats, human activities, and baseline physical and chemical characteristics of an area.[51] In fact, the effects of climate change on marine fisheries may ultimately bring a mixed bag of positive and negative changes.[52] However, each change, regardless of its nature, will result in alterations in interactions between species, "with consequent feedbacks to local abundance and geographic ranges."[53]

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44 For example, higher temperatures can cause accelerated development and metabolic rates leading to a greater susceptibility to starvation. Koehn et al., *supra* note 17, at 1152. Similarly, some commercially important species such as oyster, crab, and lobster are calcifiers and thus directly affected by increasing acidity. *See, e.g.*, STATE OF ME., FINAL REPORT OF THE COMM'N TO STUDY THE EFFECTS OF COASTAL & OCEAN ACIDIFICATION & ITS EXISTING & POTENTIAL EFFECTS ON SPECIES THAT ARE COMMERCIALLY HARVESTED & GROWN ALONG THE ME. COAST, 126th Leg., 2d Sess., at 4–5 (2015), https://perma.cc/CNM6-EQ89; IPCC 2014, *supra* note 5, at 436; Jason J. Miller et al., *Exposure to Low pH Reduces Survival and Delays Development in Early Life Stages of Dungeness Crab (*Cancer magister*)*, 163 MARINE BIOLOGY 117, 117–18 (2016). Finally, changing weather patterns as a result of climate change have additional effects on metabolic and developmental rates of animals at higher trophic levels. Hughes, *supra* note 26, at 56.

45 *What is Phenology?*, NAT'L WILDLIFE FED'N, https://perma.cc/FT7P-REE2 (last visited Feb. 25, 2017).

46 Martin Edwards & Anthony J. Richardson, *Impact of Climate Change on Marine Pelagic Phenology and Trophic Mismatch*, 430 NATURE 881, 881–83 (2004).

47 *E.g.*, *id.* at 883 (noting that the phenology of diatoms' seasonal cycles have not altered, and are therefore likely dependent on day length or light intensity instead of on temperature).

48 *Id.*

49 *Id.*; *see also* Hughes, *supra* note 26, at 58.

50 Edwards & Richardson, *supra* note 46, at 883.

51 Malin L. Pinsky & Nathan J. Mantua, *Emerging Adaptation Approaches for Climate Ready Fisheries Management*, 27 OCEANOGRAPHY 146, 150–51 tbl.1 (2014).

52 For example, species with an affinity for warmer climates will have a greater range of suitable habitat due to the warming of temperate waters. *See* IPCC 2014, *supra* note 5, at 68. Conversely, species that require cooler waters will retreat further north into cooler waters and ultimately may have no suitable waters left. *See, e.g.*, Hughes, *supra* note 26, at 58.

53 Hughes, *supra* note 26, at 56.

Fishermen are attempting to respond to these changes by altering where and when they fish, as well as what they target.[54] Some of these responses may have negative ecological implications for the sustainability of fisheries, and some responses may be unavailable to fishing communities due to stagnant and outdated regulations.[55] Meanwhile, the health and vulnerability of fish stocks and fishing communities remain in flux.[56] While incorporating climate change issues into management presents difficulties due to the longer time-scale and uncertainty of climate effects, studies show that fishery resources will likely respond to environmental changes on a time-scale relevant to fisheries assessment and management.[57] Therefore, building upon the recent successes of U.S. fisheries management—and protecting natural resources in U.S. waters and the communities that depend on them—will require fishery managers to consider the effects of climate change when making management decisions.

III. THE REGULATORY STRUCTURE OF U.S. FEDERAL FISHERIES MANAGEMENT

The Magnuson–Stevens Act and its accompanying regulatory regime are the primary laws governing the management of fisheries in U.S. federal waters.[58] Originally enacted in 1976,[59] the MSA was intended to promote the domestic fishing industry of the United States and increase federal control over fishery resources within 200 miles of the coast.[60] Through amendments and regulatory change over the past forty years, the MSA's focus has evolved

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54 Pinsky & Mantua, *supra* note 51, at 148.

55 *Id.*

56 Kevern L. Cochrane, *Fisheries Management*, *in* A FISHERY MANAGER'S GUIDEBOOK: MANAGEMENT MEASURES AND THEIR APPLICATION 1, 12–13 (Kevern L. Cochrane ed., 2002), https://perma.cc/93HZ-VPR6.

57 Plagányi et al., *supra* note 26, at 1312–14 & tbl.2.

58 *See* MSA, 16 U.S.C. § 1801(b) (2012). The term "federal waters" refers to all waters between 3 and 200 miles from shore. The Exclusive Economic Zone (EEZ) of the United States—which includes waters along all coasts of the continental U.S., Alaska and Hawaii, and the several U.S. territories in the Pacific and Caribbean—spans an area about 1.7 times the land area of the continental U.S. GLOBAL CHANGE RESEARCH PROGRAM, CLIMATE CHANGE IMPACTS IN THE UNITED STATES 558 (2014), https://perma.cc/W8YN-NBP6. Federal waters do not include waters within 3 miles of the coastline because Congress granted authority to manage resources within 3 miles of shore to coastal states. Submerged Lands Act, 43 U.S.C. § 1301(b) (2012). The Supreme Court of the United States later expanded state waters off the gulf coast of Florida and Texas to approximately nine miles based on historical claims. United States v. Florida, 363 U.S. 121, 129 (1960); United States v. Louisiana, 363 U.S. 1, 64 (1960). An exception to this general rule allows the National Marine Fisheries Service (NMFS) to assert control over a fishery in state waters, if that fishery is engaged in predominately federal waters, is "covered by a fishery management plan implemented under [the MSA]," and the state management—or lack thereof—of the fishery in state waters "will substantially and adversely affect" the federal management scheme. 16 U.S.C. § 1856(b)(1) (2012). State managers are similarly allowed to assert control over a fishery in federal waters when the federal government has asserted no control over the fishery. *Id.* § 1853(a)(3).

59 Fishery Conservation and Management Act of 1976 (Magnuson–Stevens Act), Pub. L. No. 94-265, 90 Stat. 331 (codified as amended at 16 U.S.C. §§ 1801–1891d (2012)).

60 *Id.* § 2(b), 90 Stat. at 332–33 (codified as amended at 16 U.S.C. §1801(b) (2012)).

from expanding domestic fleets and managing the U.S. fishing industry as a business to long-term conservation and responsible use of natural resources.[61]

The essential components of the MSA include a grant of authority to the executive branch, creation of regional management bodies, and a set of guiding principles to govern all fisheries management. The MSA granted the Secretary of Commerce plenary authority over implementation of the law, including oversight authority for the creation of fishery management plans (FMPs).[62] The Secretary has delegated this authority to the National Marine Fisheries Service (NMFS).[63] The MSA also established eight Regional Fishery Management Councils (Councils), tasked with developing and amending the FMPs for each fishery within their respective jurisdictions that requires conservation and management.[64] To guide the creation of FMPs and management of fisheries in the U.S., the MSA outlines several "national standards" and certain required provisions for all FMPs.[65] NMFS has created regulations and advisory guidelines implementing these requirements that

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61 MICHAEL L. WEBER, FROM ABUNDANCE TO SCARCITY: A HISTORY OF U.S. MARINE FISHERIES POLICY 174 (2002). An ecologist described the 1976 Act's definition of optimum yield as "a recipe for achieving heaven or hell, and what is achieved will depend on how the definition is variously interpreted." P.A. Larkin, *An Epitaph for the Concept of Maximum Sustainable Yield*, 106 TRANSACTIONS AM. FISHERIES SOC'Y 1, 9 (1977).

62 16 U.S.C. § 1854(a)(3) (2012). Generally, FMPs are management documents created for a species of fish or group of species that 1) describe the economic and ecological history of the relevant fishery, 2) identify limits on the productivity of the stock, and 3) prevent those limits from being exceeded by including a variety of management measures designed to reduce the impact of human fishing pressures. *Id.* § 1853(a)(1)–(2), (10), (15). In the event that the chosen management measures fail to prevent overfishing, the council must also develop a plan to rebuild the stock. *Id.* § 1853(a)(1). FMPs must also take steps to minimize adverse effects on fishing communities and to protect other aspects of the surrounding ecosystem such as habitat and bycatch. *Id.* § 1853(a)(7), (11), (14).

63 NAT'L OCEANIC & ATMOSPHERIC ADMIN., U.S. DEP'T OF COMMERCE, NEW PRIORITIES FOR THE 21ST CENTURY: NAT'L MARINE FISHERIES SERV. STRATEGIC PLAN 7 (2005) [hereinafter NMFS STRATEGIC PLAN], https://perma.cc/8MED-NTPR. NMFS is part of the National Oceanic and Atmospheric Administration (NOAA), a division of the Department of Commerce. NMFS STRATEGIC PLAN, *supra*, at 1. Other statutes relevant to NMFS's management of living marine resources include the Marine Mammal Protection Act of 1972, 16 U.S.C. §§ 1362–1421(h) (2012), and the Endangered Species Act of 1973, 16 U.S.C. §§ 1531–1544 (2012). NMFS is also known as NOAA Fisheries. *About Us*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://perma.cc/7TZN-TX9X (last visited Feb. 25, 2017).

64 16 U.S.C. § 1852(a)(1), (h)(1) (2012). Council membership includes representatives from each coastal state in the jurisdiction of the relevant Council, a representative of NMFS, citizens appointed to the Council after nomination by a coastal state governor, and nonvoting representatives of several federal agencies. *Id.* § 1852(b)–(c). The vast majority of nominations by the coastal state governors are representatives of the commercial and recreational fishing industries. Thomas A. Okey, *Membership of the Eight Regional Fishery Management Councils in the United States: Are Special Interests Over-Represented?*, 27 MARINE POL'Y 193, 197–98 & figs. 2 & 3 (2003). However, appointments of certain nonindustry interests, such as Native American tribal members or conservationists, are required for some Councils. 16 U.S.C. § 1852(b)(2)(D), (b)(5) (2012). Development of FMPs often leads to the establishment of quotas, research priorities, and other management measures. *See id.* § 1852(h)(6)–(7).

65 16 U.S.C. § 1851(a) (2012).

assist the Councils in developing FMPs.[66] The following sections explore the statutory and regulatory facets of how the MSA and implementing regulations manage several aspects of fisheries: scientific information, fish stocks, ecosystem components, social and economic needs, and scientific uncertainty. This Part also explores how accomplishing many provisions of the law requires a consideration of future environmental change.

A. Utilizing Information: Best Available Science and Essential Fisheries Information

Ongoing changes in ocean ecosystems—even in the absence of climate change and acidification—can render fisheries management ineffective if the underlying science is inaccurate or not current.[67] As a result, the MSA requires the use of the best scientific information available.[68] This requirement has become a common standard for environmental decision making[69] and is in part meant to ensure that every agency decision is objective and is credible.[70] Best available science must form the basis for all conservation and management measures implemented under the MSA.[71] The MSA also requires that FMPs include basic scientific information relating to the socioeconomics of the fishing community, the ecology and biology of the targeted fish species, and essential fish habitat and bycatch.[72] While the best available science standard itself does not explicitly require the Councils or NMFS to conduct their own research when data is incomplete, subsequent interpretations of the standard based on practical need and legislative history have stipulated that NMFS and the Councils do have some responsibility to improve scientific information and reduce uncertainty for future decisions.[73] To this end, NMFS guidelines call for an annual report

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66 50 C.F.R. pt. 600, subpt. D (2015). The portions of these regulations known as the national standard guidelines do not have the force of law. 16 U.S.C. § 1851(b) (2012).

67 OCEAN STUDIES BD., NAT'L RESEARCH COUNCIL, SCIENCE AND ITS ROLE IN THE NATIONAL MARINE FISHERIES SERVICE 4–5 (2002).

68 50 C.F.R. § 600.315(a) (2015).

69 *See, e.g.*, Endangered Species Act of 1973, 16 U.S.C. § 1536(a)(2) (2012) (requiring agencies to use the best scientific data available when evaluating a proposed action's effect on an endangered species); Marine Mammal Protection Act of 1972, 16 U.S.C. § 1371 (2012) (exceptions to the taking moratorium under the Marine Mammal Protection Act may be granted if best available science indicates that taking would have only negligible effects on the species); 36 C.F.R. § 219.3 (2015) (requiring the Forest Service to use the best available science standard in implementing the National Forest Management Act of 1976, 16 U.S.C. §§ 472a, 521b, 1600, 1611–1614 (2012)).

70 Holly Doremus, *The Purposes, Effects, and Future of the Endangered Species Act's Best Available Science Mandate*, 34 ENVTL. L. 397, 418 (2004).

71 16 U.S.C. § 1851(a)(2) (2012).

72 *Id.* § 1853(a)(2), (7), (11), (13).

73 COMM. ON DEFINING BEST SCI. INFO. AVAILABLE FOR FISHERIES MGMT., NAT'L RESEARCH COUNCIL, IMPROVING THE USE OF THE "BEST SCIENTIFIC INFORMATION AVAILABLE" STANDARD IN FISHERIES MANAGEMENT 52 (2004).

summarizing the best available scientific information concerning the past, present, and possible future condition of stocks and marine ecosystems.[74]

Distinct from the best available science standard, several provisions of the MSA require or enable research efforts to update or obtain necessary information. For example, the Councils are required to regularly identify and update research needs for each fishery and submit them to NMFS.[75] Additionally, NMFS and the Councils must establish cooperative research programs and funding mechanisms to address critical information needs.[76] Furthermore, for any new FMPs or FMP amendments, the Councils must specify the scientific data necessary for effective implementation.[77] In sum, managers can use several implicit and explicit requirements of the MSA to gather information and conduct research on the effects of climate change and acidification. And when that research culminates in new and credible best available science, it must form the basis for any new or revised conservation and management measures.

B. Managing the Target Stock: Annual Catch Limits, Rebuilding Plans, and the Evolution of the First National Standard

The first national standard and primary management objective of U.S. fisheries management is to prevent overfishing and rebuild overfished stocks.[78] This standard requires that managers prevent overfishing while achieving optimum yield for each fishery, thereby balancing the maximization of the economic benefits with the importance of long-term conservation.[79] To accomplish this goal and the first national standard, the MSA and NMFS guidance currently require that all FMPs include stock status determination criteria (i.e., objective and measurable criteria for identifying when a stock is overfished or subject to overfishing), management measures to prevent overfishing, annual catch limits and measures that ensure accountability for those catch limits, and—in the event that a stock has become overfished—plans to rebuild the stock as soon as possible.[80]

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74 50 C.F.R. § 600.315(e)(1), (4) (2015).

75 16 U.S.C. § 1852(h)(7) (2012).

76 *Id.* § 1867.

77 *Id.* § 1853(a)(8).

78 *See, e.g.,* 16 U.S.C. §§ 1851(a)(1), 1853(a) (2012). Although the MSA does not explicitly state that conservation concerns are of the highest priority for managers, judicial interpretation of the Act clearly establishes that conservation measures should receive priority over short-term economic interests. *See, e.g.*, Nat. Res. Def. Council v. Nat'l Marine Fisheries Serv., 421 F.3d 872, 879 (9th Cir. 2005); Nat. Res. Def. Council v. Daley, 209 F.3d 747, 753 (D.C. Cir. 2000); *see also* 50 C.F.R. § 600.345(b)(1) (2015) ("Deliberations regarding the importance of fishery resources to affected fishing communities . . . must not compromise the achievement of conservation requirements and goals of the FMP.").

79 16 U.S.C. § 1851(a)(1) (2012).

80 *Id.* §§ 1853(a), 1854(e); 50 C.F.R. § 600.310 (2015).

Stock status determination criteria and catch limits are defined with respect to a series of "reference points."[81] A reference point typically represents a target, limit, or benchmark that indicates the relative productivity of a fish stock or assesses the performance of management in achieving an operational objective.[82] Traditional reference points such as maximum sustainable yield[83] (MSY) have been a major component of federal fisheries management since the MSA's enactment,[84] but emerging data and management tools have resulted in the evolution of a complex analytical framework.[85] This framework has enhanced the level of control and accountability that managers can use to halt declines in U.S. stocks and ensure sustainable harvest.

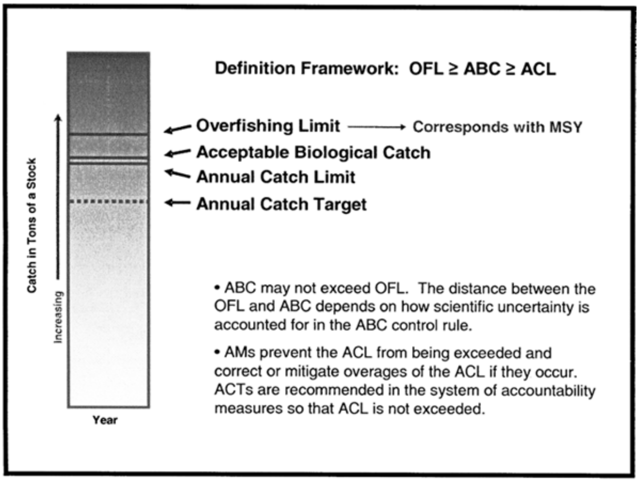

Figure 1.[86]

Within this framework, NMFS guidance outlines the concepts and procedure for using many different reference points. Perhaps the most

81 50 C.F.R. § 600.310(b)(2)(iv) (2015).

82 J.F. Caddy & R. Mahon, *Reference Points for Fisheries Management* 7–8 (Food & Agric. Org. of the U.N. Fisheries, Technical Paper No. 347, 1995), https://perma.cc/Z772-9AAN.

83 MSY is defined as "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets." 50 C.F.R. § 600.310(e)(1)(i)(A) (2015).

84 For example, optimum yield (OY) and MSY were used extensively in federal fisheries management to assess the productivity of stocks and prevent overfishing. PEW CHARITABLE TRUSTS, *supra* note 16, at 12–13. However, the original Magnuson–Stevens Act was "well designed but not watertight," and evolving technology and efficiency in fishing practices resulted in the continued overfishing of major stocks. *Id.* In many fisheries OY was achieved and the National Standard 1 guidelines were satisfied, but many stocks continued to decline and the need for a shift in the parameters of National Standard 1 became increasingly apparent. *Id.* at 12–13.

85 *Id.*

86 Magnuson-Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines, 74 Fed. Reg. 3,178, 3,180 fig.2 (Jan. 16, 2009).

important are annual catch limits (ACLs)—scientifically based quota catch limits that are designed to prevent overfishing.[87] These quotas are paired with management controls to prevent ACLs from being exceeded, termed accountability measures (AMs).[88] Other reference points can inform the setting of ACLs by incorporating aspects of management and scientific uncertainty.[89]

While ACL reference points are management measures that control catch, status determination criteria are informational reference points that are used to define acceptable trends in stock health and fishing activities.[90] These reference points define the point at which a stock is overfished or subject to overfishing.[91] In the event that a stock is overfished based on these criteria, the MSA requires creation of a rebuilding plan that is designed to rebuild the stock within a designated timeframe.[92]

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87 The Act specifies that scientific advice should play a significant role in the process of setting ACLs through the Councils' Scientific and Statistical Committees. 16 U.S.C. § 1852(h)(6) (2012).

88 *Id.* § 1853(a)(15); 50 C.F.R. § 600.310(g)(1) (2015). AMs are an essential component of this scheme and are used to "minimize both the frequency and magnitude of [ACL] overages and correct the problems that caused the overage." *Id.* § 600.310(g)(1). To prevent an ACL from being exceeded, AMs can be proactive and include in-season fishery closures, changes in trip size or bag limits, or scaled reductions in effort if the target catch limit is reached. *Id.* § 600.310(g)(2). To mitigate the effects of an exceeded ACL and prevent future exceedances, AMs can be reactive and include overage payback in the next fishing year. *Id.* § 600.310(g)(3).

89 *See* 50 C.F.R. § 600.310(f)(2) (2015). These additional reference points include elements of the fishery control rule, such as acceptable biological catch and annual catch targets. *Id.* Each reference point provides a slightly different benchmark to inform management and prevent overfishing, and NMFS guidance outlines the relationships between several of them. *See, e.g.*, *id.* § 600.310(e)(2)(i)–(ii) (defining maximum fishing mortality threshold, overfishing limit, and minimum stock size threshold and explaining how these reference points are used to determine overfishing and overfished statuses). Acceptable biological catch is annual level of catch—based on life history, reproductive potential, and vulnerability to overfishing—that reduces the overfishing limit as necessary to account for scientific uncertainties. *Id.* § 600.310(f)(2)–(3). ACLs cannot exceed the determined acceptable biological catch. *Id.* § 600.310(f)(5). Annual catch targets are optional annual numerical catch levels representing the management target of the fishery that accounts for management uncertainty in controlling the actual catch at or below the ACL. *Id.* § 600.310(f)(2)(v). Annual catch targets may be utilized as preemptive accountability measures. *Id.* § 600.310(g)(2).

90 *See id.* § 600.310(e)–(f) (explaining that ACL reference points set limits or target fishing levels, whereas status determination criteria are used to determine if overfishing occurred or if stock is overfished). Examples of status determination criteria include overfishing limits, maximum fishing mortality thresholds, and minimum stock size thresholds. *Id.* § 600.310(e)(2)(i). An overfishing limit is an annual numerical amount of catch that would result in overfishing if exceeded and is often a key element of setting ACLs and monitoring management performance. *Id.* § 600.310(e)–(f); NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, QUESTION AND ANSWERS RELATED TO ANNUAL CATCH LIMITS AND NATIONAL STANDARD 1 GUIDANCE 5 (2011), https://perma.cc/265U-SHWB. Maximum fishing mortality threshold is an alternative criterion for determining overfishing status and minimum stock size threshold is the status measure to determine overfished status. 50 C.F.R. § 600.310(e)(2) (2015).

91 50 C.F.R. § 600.310(e)(2)(i)(A) (2015). Overfished means that the stock biomass is below a critical level while overfishing means that fishing mortality is above a critical level. *Id.* § 600.310(e)(2)(i)(B), (E).

92 MSA, 16 U.S.C. § 1854(e) (2012). Rebuilding must not take longer than 10 years unless the unique biology of a fish species, environmental conditions, or other factors would make it

The implementation of the ACL framework and rebuilding plans has generated positive change in the status of U.S. fisheries. By 2012, amendments for all forty-six federal FMPs to implement ACLs and AMs were completed.[93] The success of these amendments is unequivocal: the cessation of overfishing in 58% of the domestic stocks that were subject to overfishing in 2007, the year the ACL requirement was added to the MSA.[94] To capitalize on this success and maintain positive momentum in the face of climate change and acidification, managers and agency scientists must revisit the process for defining reference points, paying particular attention to those that include consideration of scientific uncertainty and the effect of environmental conditions on stock productivity. Continued monitoring and consideration of changing productivity and distribution in light of climate change and acidification is essential to achieving the first national standard.

C. Protecting Ecosystem Components: Bycatch and Habitat

In the 1990s, awareness of the adverse effect fisheries can have on ecosystem components and deficiencies in related management approaches grew. To remedy these issues, the Sustainable Fisheries Act[95] added provisions to the MSA requiring the Councils to identify adverse effects on habitat and bycatch, and implement measures to minimize those effects.

Several provisions of the MSA—including the ninth national standard—obligate the Councils to gather information on bycatch, and to minimize bycatch and bycatch mortality to the extent practicable.[96] The MSA defines bycatch as fish that are caught but not sold or kept for personal use, including economic discards and regulatory discards.[97] The Councils must gather information on bycatch by instituting a reporting methodology to assess the amount and type of bycatch in each fishery.[98] Finally, every FMP must include measures to minimize bycatch and bycatch mortality.[99]

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impossible to meet that deadline. *Id.* § 1854(e)(4)(A)(ii). Some analysis of economic impact is allowed in determining the appropriate length of time to rebuild a fishery. Nat. Res. Def. Council, Inc. v. Nat'l Marine Fisheries Serv., 421 F.3d 872, 880 (9th Cir. 2005) (explaining that stocks should be rebuilt as quickly as possible but balancing of economic effects of a rebuilding plan can be considered to avoid disastrous short-term consequences for fishing communities).

93 Fisheries of the United States; National Standard 1 Guidelines, 77 Fed. Reg. 26,238, 26,239 (proposed May 3, 2012) (to be codified at 50 C.F.R. pt. 600).

94 NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, STATUS OF STOCKS 2012: ANNUAL REPORT TO CONGRESS ON THE STATUS OF U.S. FISHERIES 6 (2013), https://perma.cc/G3GS-AJ9W.

95 Pub. L. No. 104-297, 110 Stat. 3559 (1996) (codified at 16 U.S.C. §§ 1803, 1861a, 1881–1883, 5107a, 5107b (2012)).

96 16 U.S.C. §§ 1851(a)(9), 1853(a)(11) (2012); 50 C.F.R. § 600.350(b) (2015).

97 16 U.S.C. § 1802(2) (2012). Economic discards are those fish discarded because they are undesirable or lack economic value. *Id.* § 1802(9). Regulatory discards are those fish discarded due to regulations prohibiting their retention or sale. *Id.* § 1802(38). Bycatch does not include "fish released alive under a recreational catch and release fishery management program." *Id.* § 1802(2). Bycatch also does not include marine mammals or seabirds. *Id.* § 1802(12).

98 *Id.* § 1853(a)(11).

99 *Id.*

The MSA also requires the Councils to identify and protect essential fish habitat (EFH).[100] EFH is defined as the "waters and substrate necessary to fish for spawning, breeding feeding or growth to maturity."[101] The MSA requires the Councils to implement measures to minimize the adverse effects of fishing on EFH.[102] In assessing the impact of fishing on EFH, the Councils must consider cumulative impacts on habitat, including the effects of natural stresses, such as climate-based environmental shifts.[103] The MSA also requires the Councils and NMFS to engage in the environmental analysis and decision-making processes of other federal agency actions that may adversely affect EFH.[104]

To minimize adverse effects of fishing on bycatch and habitat, the Councils have broad discretion to adopt a variety of acceptable management measures.[105] For example, a Council may designate spatial or temporal closures where fishing is prohibited or limited to specific fishing gear types.[106] Closures can be strategically placed to protect sensitive habitats, protect species at vulnerable life stages and during important events such as spawning or foraging, or to generally restrict fishing in areas where unacceptable amounts or types of bycatch are likely. Managers can also utilize gear restrictions to minimize impact to habitat or bycatch[107] by minimizing contact with sensitive habitats or reducing the likelihood of catching certain undesirable and/or vulnerable species.[108] Crucially, many of these provisions require ongoing data collection and re-evaluation of management to account for environmental changes and new information,[109]

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100 *Id.* §§ 1853(a)(7), 1855(b).

101 *Id.* § 1802(10).

102 *Id.* § 1853(a)(7). The MSA also requires the consideration of adverse effects to essential fish habitat from other federal agency actions, such as dredging, the construction of bridges and oil platforms, and water quality management. *Id.* § 1855(b); NAT'L MARINE FISHERIES SERV., IMPLEMENTING THE SUSTAINABLE FISHERIES ACT: ACHIEVEMENTS FROM 1996 TO THE PRESENT 15 (2003) [hereinafter NMFS ACHIEVEMENTS FROM 1996 TO THE PRESENT], https://perma.cc/Q2CL-Z8MR. While not addressed in this article, understanding the mechanisms through which certain actions exacerbate climate change or ocean acidification may present another avenue for "adapting" the habitat protection requirements of the MSA.

103 50 C.F.R. § 600.815(a)(5) (2015).

104 16 U.S.C. § 1855(b)(2)–(4) (2012).

105 *Id.* § 1853(b).

106 *Id.* § 1853(b)(2).

107 50 C.F.R. § 600.815(a)(2)(iv)(A) (2015).

108 Examples of bycatch reducing gear restrictions include excluder devices used in trawl nets and increasing mesh size to allow safe passage of smaller species. *See* NMFS ACHIEVEMENTS FROM 1996 TO THE PRESENT, *supra* note 102, at 8. Examples of gear restrictions to reduce habitat effects include anchoring restrictions and required fishing gear modifications. 50 C.F.R. § 600.815(a)(2)(iv)(A) (2015).

109 *See, e.g.*, 16 U.S.C. § 1853(a)(11) (2012) (requiring bycatch reporting methodology to analyze the type and amount of bycatch in the fishery); *id.* § 1853(b)(2)(C) (requiring that area closures are based on best available science and include a procedure and criteria to review the performance and benefits of the closure); 50 C.F.R. § 600.350(d)(4) (2015) (calling for routine monitoring and evaluation of the effectiveness of bycatch management measures). Some examples of future considerations of bycatch and habitat impacts from climate change include: 1) long-term distribution shifts and altered timing of migrations that result in variations in the amount and type of bycatch; 2) changes in productivity resulting in smaller fish that increase

enabling the adaptation of bycatch and habitat measures to future climate change and acidification.

D. Considering the Human Element: Allocation and the Social and Economic Costs of Regulation

Although the MSA focuses on sustainability of natural resources, several provisions require the consideration of the social and economic effects of regulation. U.S. fisheries support livelihoods and provide the food for millions of people,[110] and the eighth national standard recognizes the importance of fishery resources to fishing communities and our economy.[111] Tempered by a standard of practicability, the MSA requires that conservation and management measures take into account the importance of fishery resources to fishing communities in order to minimize adverse economic effects.[112] Although the conservation requirements of the MSA take priority,[113] buy-in from regulated stakeholders is proven to strengthen management outcomes and is essential for long-term success of management.[114] As a result, minimizing adverse effects on fishing

bycatch of fish too small to be retained or sold; and 3) effects of warming and acidification on biogenic habitats, such as coral. *See* discussion *supra* Part II.

110 The United States is among the top five contributors of marine capture fisheries production, with commercial landings of over four million tons, of which 78% is destined for human consumption. NAT'L MARINE FISHERIES SERV., FISHERIES OF THE UNITED STATES 2012 iv (Alan Lowther ed., 2013) [hereinafter FISHERIES 2012]. NMFS has estimated that the entire commercial fishing industry, including seafood processors, wholesalers, and retailers, "generated $103 billion in sales, $44 billion in income and supported 1.5 million jobs in 2006." U.S. REG'L FISHERY MGMT. COUNCILS, OPPORTUNITIES & CHALLENGES 5 (2009), https://perma.cc/67YT-U4AD. Recreational fishing in federal waters—also managed by NMFS and the Councils—accounts for significant additional catch and revenue. *See* FISHERIES 2012, *supra*, at iv.

111 16 U.S.C. § 1851(a)(8) (2012).

112 *Id.*; 50 C.F.R. § 600.345(a) (2015).

113 Litigation regarding the potential conflict between the first and eighth national standards has confirmed that the conservation goals of the MSA take priority. Nat. Res. Def. Council, Inc. v. Daley, 209 F.3d 747, 753 (D.C. Cir. 2000) (finding no conflict between national standards one and eight based on the plain language of the statute and NMFS national standard guidelines). The court found that national standard one's requirement to conserve stocks while achieving optimum yield and national standard eight's requirement to minimize adverse impacts on fishing communities *to the extent practicable* and *consistent with the conservation requirements* of the MSA do not conflict due to the italicized qualifying language. *Id.* (citing 16 U.S.C. §§ 1851(a)(1), (8) (2012)). Similarly, NMFS national standard guidelines state that "[d]eliberations regarding the importance of fishery resources to affected fishing communities . . . must not compromise the achievement of conservation requirements and goals of the FMP." 50 C.F.R. § 600.345(b)(1) (2015).

114 *See, e.g.*, JUDITH A. LAYZER, NATURAL EXPERIMENTS: ECOSYSTEM-BASED MANAGEMENT AND THE ENVIRONMENT 2–3 (2008); U.S. ENVTL. PROT. AGENCY, EPA 841-B-11-001, GETTING IN STEP: ENGAGING STAKEHOLDERS IN YOUR WATERSHED 45 (2nd ed. 2013), https://perma.cc/KR7B-92SW; Lorraine Ridgeway & Carl-Christian Schmidt, *Economic Instruments in OECD Fisheries: Issues and Implementation*, *in* HANDBOOK OF MARINE CONSERVATION AND FISHERIES MANAGEMENT 310, 317 (R. Quentin Grafton et al. eds., 2010); Dean E. Wendt & Richard M. Starr, *Collaborative Research: An Effective Way to Collect Data for Stock Assessments and Evaluate Marine*

communities is an essential consideration when discussing management alternatives. Because necessary regulatory changes may conflict with the expectations and past experiences of fishing communities, stakeholder buy-in is an important aspect of any climate adaptation plan.

The fourth national standard addresses the narrower socioeconomic issue of allocation: who gets to fish and how much do they get to fish.[115] To this end, the MSA prohibits discrimination against residents of different states, and requires fairness and equity in any necessary allocation of fishing privileges.[116] Allocation challenges are likely to arise in the event that a species distribution undergoes a significant shift and restructuring of fishing privileges is necessary to maximize overall benefits.[117] However, even allocation changes that are broadly fair and equitable can be contentious.[118] Formulating engagement plans that set expectations with regards to the effects of climate change and ease community transitions can promote more positive public discourse.

E. Mitigating Uncertainty: Facilitating Flexibility and Contingency Planning

The sixth national standard recognizes the inherent variability in fishery resources and the need for flexible management to protect against uncertainties.[119] The MSA instructs that "[c]onservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches."[120] This requirement calls upon managers to account for the unique uncertainties of each fishery and the potential for unexpected events when making management decisions.[121] NMFS recommends continual data acquisition and analysis to minimize uncertainties, and flexible management regimes to account for contingencies through a range of options.[122] The national standard guidelines recognize climatic conditions as examples of

Protected Areas in California, 1 MARINE AND COASTAL FISHERIES 315, 315 (2009); Kelly Sayce et al., *Beyond Traditional Stakeholder Engagement: Public Participation Roles in California's Statewide Marine Protected Area Planning Process*, 74 OCEAN & COASTAL MGMT. 57, 58 (2013); Mark S. Reed, *Stakeholder Participation for Environmental Management: A Literature Review*, 141 BIOLOGICAL CONSERVATION 2417 (2008); Knut H. Mikalsen & Svein Jentoft, *From User-Groups to Stakeholders? The Public Interest in Fisheries Mgmt.*, 25 MARINE POL'Y 281, 281 (2001); *The U.S. Institute Announces Award Recipients at the ECR2012 Conference*, UDALL FOUND. (May 25, 2012), https://perma.cc/Q57S-RBPR.

115 50 C.F.R. § 600.325(c)(1) (2015).

116 16 U.S.C. § 1851(a)(4) (2012).

117 *See* 50 C.F.R. § 600.325(c)(3)(i)(B) (2015) (allowing for the reallocation of fishing privileges).

118 GEORGE LAPOINTE, NAT'L MARINE FISHERIES SERV., MARINE FISHERY ALLOCATION ISSUES 3, 20 (2012).

119 16 U.S.C. § 1851(a)(6) (2012).

120 *Id.*

121 50 C.F.R. § 600.335(b) (2015).

122 *Id.* § 600.335(c)–(d).

contingencies, thus providing flexibility for managers to gather information and make decisions informed by a consideration of climate change.[123]

One popular method of contingency planning that is absent from the language of the MSA is adaptive management. Nevertheless, NMFS and the Councils are incorporating elements of adaptive management in some areas.[124] In adaptive management, management actions consider uncertainty and data gaps, and are designed such that the results of subsequent management evaluations can fill those data gaps and build understanding of the managed system.[125] This process is iterative and responds to changing conditions and new information. The Councils are most likely to utilize adaptive management in situations where scientific or management uncertainty is high, such as the management of data poor stocks.[126] But in the future, even stocks characterized as data-rich may be subject to a high degree of uncertainty due to climate change and acidification.

Environmental sensitivity has always been an essential consideration in the complex ecosystems and three-dimensional habitats of the ocean. As a result, the U.S. fisheries management regime is well set up to function as a model for how management of natural resources should adapt to a changing climate. Nevertheless, in many ways the current approach is outdated and does not account for our evolving scientific understanding of how environmental conditions are likely to affect marine ecosystems. Neither the MSA nor NMFS regulations explicitly incorporate the effects of climate change on marine ecosystems, and responses to the challenge have emerged slowly and ad hoc in the absence of clear statutory or regulatory guidance. By neglecting to incorporate important factors that are materially changing the circumstances underlying management decisions, fishery managers may fail to ensure sustainability. Thus, fisheries managers must take action to adapt traditional management measures to the effects of climate change.

IV. EXPLORING ADAPTATION MECHANISMS TO MINIMIZE ADVERSE EFFECTS ON MARINE CAPTURE FISHERIES

Much attention is paid to mitigation of climate change, or taking actions to reduce greenhouse gas emissions and avoid climate change.[127] While some actions have been taken to reduce greenhouse gas emissions,[128] the lack of comprehensive global cutbacks in emissions has ensured that many

123 *Id.* § 600.335(d).

124 FISHERIES LEADERSHIP & SUSTAINABILITY FORUM, WEST COAST FORUM 2013: RESPONSIVE AND ADAPTIVE MANAGEMENT STRATEGIES, 6–7 (2013) [hereinafter FISHERIES LEADERSHIP], https://perma.cc/55H5-W8RM.

125 Anne Hayden, *Implementation of the National Ocean Policy: Lessons from New England*, 17 ROGER WILLIAMS U. L. REV. 73, 77 (2012); FISHERIES LEADERSHIP, *supra* note 124, at 4.

126 FISHERIES LEADERSHIP, *supra* note 124, at 13.

127 CHRIS WOLD, DAVID HUNTER & MELISSA POWERS, CLIMATE CHANGE AND THE LAW 62 (2d ed. 2013).

128 *See, e.g.*, *id.* at 68.

consequences of climate change are virtually certain.[129] Adaptation strategies—as opposed to mitigation strategies—are designed to alleviate these unavoidable consequences.[130] In recognition that present and future adaptation actions are necessary, the United States has broadly obligated itself to take steps to adapt to climate change.[131] While development of U.S. adaptation policies has lagged due to the politicized climate debate and the lack of a clear legislative framework,[132] many government agencies and advisory bodies took steps to make adaptation a focus under the Obama Administration.[133] Some of these actions are directly related to adaptation in marine fisheries.[134]

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129 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, FIFTH ASSESSMENT REPORT, CLIMATE CHANGE 2014: SYNTHESIS REPORT 17–19 (Rajendra K. Pachuari et al. eds., 2014).

130 WOLD, HUNTER & POWERS, *supra* note 127, at 113. The United States government, citing the National Research Council, has defined adaptation as the "[a]djustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects." COUNCIL ON ENVTL. QUALITY, PROGRESS REPORT OF THE INTERAGENCY CLIMATE CHANGE ADAPTATION TASK FORCE: RECOMMENDED ACTIONS IN SUPPORT OF A NATIONAL CLIMATE CHANGE ADAPTATION STRATEGY 15 (2010) [hereinafter CEQ PROGRESS REPORT], https://perma.cc/4CUK-KC6Q.

131 For example, as a party to the United Nations Framework Convention on Climate Change (UNFCCC), the United States has accepted commitments to implement and regularly update climate change adaptation measures. United Nations Framework Convention on Climate Change, art. 4(1)(b), May 9, 1992, 1771 U.N.T.S. 107. Fishery stakeholders and managers have also expressed concern and emphasized the need to incorporate climate change effects into fishery management decisions. *Reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act: Oversight Hearing before the H. Comm. on Nat. Res.*, 113th Cong. 8, 12 (2013) (statement of Samuel D. Rauch III, Deputy Assistant Administrator for Regulatory Programs for the National Marine Fisheries Service).

132 Attempts at passing regulatory statutes explicitly addressing climate change effects on ocean ecosystems have stalled at various stages in the legislative process. *See, e.g.*, National Oceans Protection Act, S. 858, 111th Cong. (2009) (assigning responsibility to monitor and respond to climate change to the Council of Ocean Stewardship and a Presidential Panel of Advisors on Oceans and Climate, subsequently referred to committee but not enacted); Lieberman-Warner Climate Security Act of 2007, S. 2191, 110th Cong. (2007) (establishing an Adaptation Fund and require the development of a national strategy for assisting fish, habitats, and ecological processes in adapting to the effects of climate change, however, last under committee consideration in 2008 with no further action taken); Oceans Conservation, Education, and National Strategy for the 21st Century Act, H.R. 2939, 109th Cong. (2005) (initially introduced and under committee consideration in 2005, reintroduced in 2007 and 2009, but repeatedly stalled during committee consideration).

133 *See, e.g.*, Federal Leadership in Environmental, Energy, and Economic Performance, Exec. Order No. 13,514, § 16, 3 C.F.R. at 248, 258 (2010) (creating a Climate Change Adaptation Task Force and requiring agencies to both identify aspects of climate change that are likely to affect the agency's ability to achieve its mission and integrate climate change adaptation planning into their operations, policies, and programs), *revoked by* Planning for Federal Sustainability in the Next Decade, Exec. Order No. 13,693, § 16(b), 80 Fed. Reg. 15,871, 15,880 (Mar. 25, 2015); *see also* CEQ PROGRESS REPORT, *supra* note 130, at 10 (identifying guiding principles for adaptation, including the application of ecosystem-based approaches, continuous evaluation of adaptation performance, and the use of best available science and strong partnerships).

134 *See, e.g.*, CEQ OCEAN POLICY TASK FORCE, *supra* note 27, at 37 (calling for a strategic action plan to address negative impacts of ocean acidification resulting from climate change and alteration in habitats, migratory patterns, and ecosystem structure and function due to

Luckily, the MSA is not grounded in a vision of a stable natural world, as other environmental statutes seem to be.[135] Many aspects of the law already allow for flexibility in the face of new information or environmental change. This Part contemplates several potential adaptation mechanisms—that managers can implement within the current legislative framework—that NMFS and the Councils should consider to ensure continued progress towards meeting the MSA's requirements.

A. Gather and Analyze Information to Assess Potential Effects of Climate Change

Future substantive changes in management strategies will depend on information relating to the response of a given region, stock, or fishery to climate effects. In some cases, management can readily incorporate existing information relating to tolerance to environmental stressors. In others, this information is not available. To mitigate information gaps and prioritize actions, managers can apply methods of assessing climate vulnerability that use existing information to analyze exposure and sensitivity of marine species and communities. To identify and fill information gaps, managers should strive to take advantage of all information-gathering opportunities at their disposal.

The requirement that FMPs contain basic information on the biology of a target fish species is the ideal place to start for the Councils looking to implement adaptation measures in a fishery.[136] Although basic ecological and biological information that federal FMPs must include is not as extensive as that required by certain state laws,[137] the mandate is broad enough to include information useful in assessing the potential effects of climate change on the species. For example, FMPs must include information on the target species' geographic range and habitats that are necessary for spawning, breeding, feeding, or growth to maturity—all of which may change due to climate change.[138] The MSA requirements to prevent overfishing and assess the present and probable future condition of the fishery also likely require some consideration of a species' vulnerability to changing environmental

increasing water temperature); NAT'L FISH, WILDLIFE, & PLANTS CLIMATE ADAPTATION P'SHIP, NATIONAL FISH, WILDLIFE AND PLANTS CLIMATE ADAPTATION STRATEGY 54 (2012), https://perma.cc/HLN2-2PZR (outlining a strategy that calls for new research methods, rapid incorporation of findings into management, increased collaboration across jurisdictions, and a review of laws, regulations, and policies).

135 *See, e.g.*, Elisabeth Long & Eric Biber, *The Wilderness Act and Climate Change Adaptation*, 44 ENVTL. L. 623, 632–33 (2014).

136 *Accord* OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 104 ("Research is the primary tool with which to build an information base to support effective adaptation to climate change.").

137 *See, e.g.*, CAL. FISH & GAME CODE § 7080 (West 2015). California's state marine life management statute explicitly requires an FMPs essential fishery information section to include a discussion of "effects of changing oceanic conditions on the target species." *Id.* § 7080(b).

138 MSA, 16 U.S.C. §§ 1802(10), 1853(a)(7) (2012).

conditions.[139] These required pieces of information can provide an excellent background to begin analyzing climate effects. By using existing data and fishery models, managers can make predictions of species shifts and changes in productivity, resulting in better strategic adaptation and planning of management responses.[140] The practice of predicting future changes will enable managers to make proactive—rather than reactive—management decisions.

Managers can also use existing information to prioritize managed species by their level of vulnerability and facilitate efficient use of limited resources. Determinations of vulnerability can identify when environmental parameters must be included in stock assessments, identify gaps in data and/or the need for increased monitoring, inform management decisions on quotas and rebuilding plans, and identify the need for management actions to reduce vulnerability.[141] Explicitly addressing these issues in Council discussions and FMPs can improve decision making and provide stakeholders with important information.[142] Prioritizing species by vulnerability may also assist decision makers in determining whether directed adaptation (such as the mechanisms outlined in this Article) or passive adaptation (allowing species to naturally adapt to their changing environment without intervention) is more appropriate for a given species.[143] This will be an especially useful exercise for FMPs that manage several species as a fishery management unit.[144] NMFS efforts to assess vulnerability are already underway in some regions,[145] utilizing expert opinions to analyze

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139 *See id.* § 1853(a)(1), (3).

140 Plagányi et al., *supra* note 26, at 1314.

141 Wendy Morrison, Nat'l Oceanic & Atmospheric Admin. Fisheries, Presentation on Assessing the Vulnerability of Fish Stocks to Climate Change at the Marine Fisheries Advisory Committee Meeting (Oct. 2015), https://perma.cc/RDV3-VG7G.

142 ASHLEY L. ERICKSON ET AL., CTR. FOR OCEAN SOLS., INCORPORATING ECOLOGICAL PRINCIPLES INTO CALIFORNIA OCEAN AND COASTAL MANAGEMENT: EXAMPLES FROM PRACTICE 52 (2012), https://perma.cc/L4UJ-VTXA; Ira R. Feldman & Joshua H. Kahan, *Preparing for the Day After Tomorrow: Frameworks for Climate Change Adaptation*, 8 SUSTAINABLE DEV. L. & POL'Y., 2007, at 61, 62.

143 Koehn et al., *supra* note 17, at 1157.

144 The third national standard recommends that individual stocks or interrelated stocks be managed as a unit even when split by political boundaries or biophysical differences. 16 U.S.C. § 1851(a)(3) (2012). These management units can be developed on the basis of biological, geographic, economic, technical, social, or ecological perspectives. 50 C.F.R. § 600.320(d)(1) (2015). For example, the Pacific Fishery Management Council's (PFMC) Coastal Pelagic Species FMP manages several species, two of which are the Pacific sardine (*Sardinops sagax*) and the Northern anchovy (*Engraulis mordax*). PAC. FISHERY MGMT. COUNCIL, COASTAL PELAGIC SPECIES FISHERY MANAGEMENT PLAN 8 (2011) [hereinafter COASTAL PELAGIC SPECIES FMP], https://perma.cc/4QRM-96MZ. These two species have demonstrated diametric responses to changes in ocean temperature, with sardines' productivity increasing with warmer temperatures and anchovies' productivity increasing with colder temperatures. Francisco P. Chavez et al., *From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean*, 299 SCIENCE 217, 217 (2003). In this and similar cases, dramatic effects on future management decisions are likely due to the contradictory responses to ocean temperature.

145 *See, e.g.*, Jonathan A. Hare et al., *A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf*, PLOS ONE, Feb. 3, 2016, e0146756, at 1–2. The NOAA Fisheries Climate Science Strategy calls for climate vulnerability analyses in

relative exposure and sensitivity of each managed species to climate change.[146] NMFS staff are also attempting to characterize the vulnerability of fishing communities, as explored more fully in Part IV.D.

Research analyzing how climate change affects ocean ecosystems is both critical and lagging behind the pace of change. Increased data collection is necessary to fully analyze effects on vulnerable species and develop appropriate management responses. NMFS has characterized many U.S. stocks as data-poor, data-moderate, or data-rich based on technical guidance.[147] For species characterized as data-poor or -moderate, information relevant to determining the effects of climate change is unlikely available. Even for data-rich species, current models and understanding of stock dynamics are based on a concept of equilibrium, and assumptions and conditions that a changing climate may invalidate. And in some cases, theoretical assessments of vulnerability conflict with empirical evidence.[148] Improving both our understanding of the processes that drive variability due to climate change and the means by which managers can apply such knowledge to management decisions requires further research.[149] As a result, research protocols incorporating both academic and industry data on the

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each region for all Living Marine Resources as an immediate action. NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, CLIMATE SCIENCE STRATEGY: HIGHLIGHTS 7 (2015) [hereinafter NOAA FISHERIES CLIMATE SCIENCE STRATEGY], https://perma.cc/SXV7-W3GJ.

146 Jonathan A. Hare et al., *supra* note 145, at 1–2. Exposure refers to how much a species is exposed to changes and variability in temperature, pH, salinity, precipitation, sea-level rise. *Id.* at 6. Sensitivity refers to biological attributes of the species that affect how sensitive the species is to change. *Id.* at 8.

147 V.R. RESTREPO ET AL., NAT'L MARINE FISHERIES SERV., TECHNICAL GUIDANCE ON THE USE OF PRECAUTIONARY APPROACHES TO IMPLEMENTING NATIONAL STANDARD 1 OF THE MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT 22 (1998), https://perma.cc/BAT7-F8SU. Data-poor fisheries are those for which "[r]eliable estimates of MSY-related quantities are unavailable, as are reliable estimates of either current stock size or certain critical life history or fishery parameters. Control rules typically involve parameters such as . . . historical average catch [averages]." *Id.* Data-moderate fisheries are those where:

> Reliable estimates of MSY-related quantities are either unavailable or of limited use due to peculiar life history, poor data contrast, or high recruitment variability, but reliable estimates of current stock size and all critical life history (e.g., growth) and fishery (e.g., selectivity) parameters are available. Control rules typically involve . . . proxies for MSY-related benchmarks.

Id. Finally, data-rich fisheries are those where "[r]eliable estimates of MSY-related quantities and current stock size are available. . . . Stock assessments may be sophisticated, and provide a reasonably complete accounting of uncertainty." *Id.*

148 *See, e.g.*, Hare et al., *supra* note 145, at 22 ("Alewife [(*Alosa pseudoharengus*)] and American Shad [(*Alosa sapidissima*)] have exhibited some of the greatest shifts in distribution in the ecosystem, but the potential for a change in species distribution was low.").

149 PFMC FEP, *supra* note 26, at 142; *see also* ISLAND INST., A CLIMATE OF CHANGE: CLIMATE CHANGE AND NEW ENGLAND FISHERIES 7 (2013) [hereinafter ISLAND INSTITUTE], https://perma.cc/37C5-G8FE (noting that following a single cohort through multiple life stages is necessary to "identify which life history traits make species resilient or susceptible to climate change").

changing range and productivity of fisheries are an essential component of any adaptive management regime.[150]

This is where the MSA data collection requirements and funding mechanisms come into play. Pursuant to the provisions outlined in Part III.A, the Councils and NMFS have the authority—and arguably the duty—to solicit and undertake current and accurate fisheries-independent and -dependent studies focusing on climate change effects. Ongoing efforts to develop fishery ecosystem plans (FEPs) and climate science regional action plans are ideal vehicles through which managers can guide research efforts to determine climate effects on multiple species and the managed ecosystem. FEPs frequently include discussions of the cumulative effects from human activities and environmental shifts, climate change effects on managed species, and possible strategies to integrate ecosystem science into the management process.[151] Regional action plans—regional documents designed to customize and implement NMFS's Climate Science Strategy—are required to contain similar strategies for identifying and filling data gaps specific to climate effects on marine fisheries.[152] Each of these planning documents can also outline cooperative research efforts with other government agencies, states, academia, and industry. Informational resources that exist but remain uncoupled from management decisions in many regions include cooperative fisheries research programs,[153] NOAA's Integrated Ecosystem Assessments,[154] NOAA's Fisheries and the Environment program,[155] the Integrated Ocean Observing System,[156] and new

150 ISLAND INSTITUTE, *supra* note 149, at 6–7.

151 For example, an appendix to the PFMC FEP document outlines an initiative to identify scientific questions and information needs on the longer-term effects of climate change on species managed by the Pacific Council. PFMC FEP, *supra* note 26, app. A at A-3. Through this initial step, the Council aims to "better direct public and private efforts to provide management-relevant science" and assess vulnerability to climate change based on exposure, sensitivity and adaptive capacity. *Id.* at A-21 to -22.

152 NOAA FISHERIES CLIMATE SCIENCE STRATEGY, *supra* note 145, at 19 (2015).

153 For a discussion on how cooperative research with industrial and small-scale fishing communities can align with the MSA's best available science mandate, see Margreta Vellucci, *Fishing for the Truth: Achieving the "Best Available Science" by Forging a Middle Ground Between Mainstream Scientists and Fishermen*, 30 ENVIRONS ENVTL. L & POL'Y J. 275 (2007). Several examples of successful cooperative research programs exist. *See, e.g.*, *Bycatch Avoidance Programs*, UNIV. OF MASS. SCH. FOR MARINE SCI. & TECH., https://perma.cc/XWH8-TZBK (last visited Feb. 25, 2017). Even where cooperative research is not strategically planned, fisheries-dependent data is a strong source of climate-related information for scientists. *See, e.g.*, Jonathan A. Hare & Kenneth W. Able, *Mechanistic Links Between Climate and Fisheries Along the East Coast of the United States: Explaining Population Outbursts of Atlantic Croaker (*Micropogonias undulatus*)*, 16 FISHERIES OCEANOGRAPHY 31 (2007) (using commercial catch data to show that productivity and distribution of Atlantic Croaker are expanding due to warming waters).

154 *Integrated Ecosystem Assessment*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/2WXP-G33W (last visited Feb. 25, 2017).

155 *FATE: Fisheries and the Environment*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/TZY7-R3JC (last visited Feb. 25, 2017).

156 INTEGRATED OCEAN OBSERVING SYS., https://perma.cc/544E-NJRG (last visited Feb. 25, 2017).

regional Ocean Data Portals[157] that gather information from varied sources with the goal of making diverse data sets comparable. Coordination of these programs across jurisdictional boundaries and development of tools that explicitly incorporate this ongoing research into management decisions are important future efforts.

Exploring new methods for using and gathering scientific information is an essential component of adaptation. The several FEPs[158] and regional action plans[159] currently in development should aim to take advantage of all opportunities to assess vulnerability, prioritize managed species, guide public and private research efforts, and incorporate potential effects of climate change into future planning and management decisions. Perhaps the most crucial step in advancing our research and understanding is to recognize the value of these programs and provide funding that enables comprehensive study.[160] While a variety of funding opportunities are available for research,[161] funders or managers should assess the total funding needs for all climate research projects to inform appropriations requests and ensure coordination to avoid duplicative efforts. This understanding—in conjunction with political will, which is admittedly more difficult to achieve—is necessary to ensure the required appropriations. Incorporating vulnerability assessment results and newly gathered information from other research programs into calculations of stock productivity, policies and regulations to protect habitat and vulnerable species, and other necessary management measures will strengthen both the ability of fish species to adapt to climate change and the sustainable use of fishery resources by humans.

B. Incorporate Climate Effects into Stock Assessments, Catch Limits, and Rebuilding Plans

Identifying the safe limits for exploiting a given stock requires complex calculations that incorporate fishery-dependent and -independent data on several factors such as productivity, stock abundance, and reproductive

157 *E.g.*, NE. OCEAN DATA, https://perma.cc/U688-HUAG (last visited Feb. 25, 2017); W. COAST OCEAN DATA PORTAL, https://perma.cc/V6K9-68GV (last visited Feb. 25, 2017).

158 *Fishery Ecosystem Plan*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/YHH8-V5ZU (last visited Feb. 25, 2017).

159 *Regional Action Plans*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/Y773-XVE9 (last visited Feb. 25, 2017).

160 JOINT OCEAN COMM'N INITIATIVE, U.S. OCEAN POLICY REPORT CARD 2012, at 2, 14 (2012), https://perma.cc/U3BF-5NPW ("Ocean management, science, and education programs remain severely underfunded, hindering them from effectively supporting our national security and economic interests and undermining the health of ocean resources."); *see also* JONATHAN A. HARE ET AL., NORTHEAST REGIONAL ACTION PLAN - NOAA FISHERIES CLIMATE SCIENCE STRATEGY 21 (2016), https://perma.cc/3CQ8-DNFC (draft for public comment) (identifying resource limitations as a constraint on research and management).

161 *See, e.g.*, HARE ET AL., *supra* note 160, at 13.

rates.[162] Climate change will have both direct and indirect effects on these factors for many commercially important species altering the calculations underlying several elements of stock assessments and quota management.[163] Specifically, changes in productivity and abundance will effect MSY, status determination criteria, and the level of fishing mortality that a stock can sustainably withstand.[164] While single species stock assessments and catch limits have successfully halted overfishing and led to rebuilding in many cases, ignoring environmental considerations has led to failure in others.[165] Thus, the Councils and NMFS should strive to incorporate observed and predicted effects of climate change into the scientific assessments, harvest controls, and rebuilding plans mandated by the MSA.[166]

The MSA establishes MSY as the basis for fishery management. MSY—or a proxy of MSY—underpins the determinations of stock health, required catch and harvest limits, and the calculation of optimum yield (OY) that represents the long-term management target for each stock.[167] The specification of MSY and OY can account for variabilities in productivity in at least two ways. First, if changes in productivity are unidirectional and quantifiable, a recalculation of MSY may be appropriate. The definition of MSY[168] explicitly calls upon the Councils and NMFS to incorporate prevailing environmental conditions and thus should incorporate current and relevant data relating to climate change effects on the species.[169] Second, in the event that changes in productivity fluctuate (e.g., increased productivity at certain times and in certain areas, decreased productivity in others) or are not quantifiable, increasing the uncertainty buffers inherent in OY may be appropriate.[170] OY is calculated by reducing MSY by any relevant economic, social, or ecological factor.[171] The ecological factors considered in the setting of OY can include predator–prey or competitive interactions and environmental conditions that stress marine organisms.[172] Additionally, the

162 *See Fish Stock Assessment 101 Series*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/MT9K-VV74 (last visited Feb. 25, 2017).

163 *See* discussion *supra* Part II.

164 Koehn et al., *supra* note 17, at 1157.

165 Andrew J. Pershing et al., *Slow Adaptation in the Face of Rapid Warming Leads to Collapse of the Gulf of Maine Cod Fishery*, 350 SCIENCE 809, 809 (2015).

166 A recent study outlines several methods for accounting for climate effects in stock assessments. Pinsky & Mantua, *supra* note 51.

167 MSA, 16 U.S.C. § 1802(33)–(34) (2012).

168 MSY is defined as "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological, environmental conditions and fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets." 50 C.F.R. § 600.310(e)(1)(i)(A) (2015).

169 *Id.* § 600.310(e)(1)(iv) (defining MSY as a long-term average that must be updated as required by long-term environmental or ecological changes).

170 Sarah M. Kutil, Comment, *Scientific Certainty Thresholds in Fisheries Management: A Response to a Changing Climate*, 41 ENVTL. L. 233, 244 (2011) (arguing that uncertainty must be incorporated into the determination of OY and MSY).

171 50 C.F.R. § 600.310(e)(3)(i)(A) (2015).

172 *Id.* § 600.310(e)(3)(iv)(C). Alterations in predator-prey and competitive interactions are likely to result from distribution shifts and the retiming of phenological events. *See* Hughes, *supra* note 26, at 59 fig.2.

Councils can hold a portion of the OY as a reserve to allow for uncertainties in estimates of stock size.[173] Recalculating MSY or increasing the OY buffer to account for climate change effects will further the conservation goals of the MSA.

The setting of catch limits through harvest control rules and the ACL framework can also account for productive variability. Described more fully in Part III.B, the ACL framework includes a series of reference points designed to account for both scientific and management uncertainty to ensure a stock is not overfished.[174] The scientific and management buffers included in setting the ACL framework are another viable option for managers looking to prevent overfishing. The ACL framework also provides an explicit mechanism for incorporating risk and the Council's tolerance of risk in setting catch limits. The Pacific Sardine harvest control rule in the Pacific Fishery Management Council's Coastal Pelagic Species FMP is one example of management that accounts for environmental conditions and risk when setting ACLs.[175] Pacific Sardines exhibit higher productivity in warmer water, and thus the harvest control rule provides for a greater harvest in warm water years, as determined by the average sea-surface temperature from a single monitoring station over a three-year period.[176] Similar mechanisms, rooted in measurements of temperature, pH, or other climate parameters, may add value to the management of other species deemed vulnerable to these changes.

The criteria used to determine whether a stock is overfished or subject to overfishing may also need recalculation based on climate effects. NMFS guidance suggests rooting overfished status determination criteria in MSY, so changes in MSY will necessarily lead to changes in the overfished status

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173 50 C.F.R. § 600.310(e)(3)(v)(H) (2015).

174 For example, acceptable biological catch (ABC) accounts for any aspect of scientific uncertainty identified by a Council. *Id.* § 600.310(f)(2)(ii). Similarly, annual catch targets account for management and enforcement uncertainty in controlling the actual catch. *Id.* § 600.310(f)(2)(v).

175 COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 40.

176 *Id.* Unfortunately, while this rule provides an example of incorporating fluctuating water temperature into stock management, additional science indicated that the control rule as a whole was insufficient to protect the sardine population. *See* Pac. Fishery Mgmt. Council, Council Meeting Decision Summary Document 5 (April 9–14, 2016), https://perma.cc/TWF2-PYKF. The control rule was insufficient in part because the single monitoring station used was not an appropriate indicator of sardine productivity and biomass calculation updates were not updated in a timely manner. *See* FELIPE HURTADO-FERRO & ANDRÉ E. PUNT, REVISED ANALYSES RELATED TO PACIFIC SARDINE HARVEST PARAMETERS 1–2 (2014), https://perma.cc/ZT3K-KFUE; Letter from Geoffrey Shester, Cal. Program Dir., Oceana & Ben Enticknap, Pac. Campaign Manager & Senior Scientist, Oceana, to William Stelle, Reg'l Adm'r, W. Coast Region, Nat'l Oceanic & Atmospheric Admin. Fisheries & Dan Wolford, Chair, Pac. Fishery Mgmt. Council 1, 3–4 (May 29, 2013), https://perma.cc/USN8-Y73C. The Council has since updated the rule to use a more appropriate temperature monitoring station. *See* Pac. Fishery Mgmt. Council, Council Meeting Decision Summary Document 3 (Mar. 8–13, 2014), https://perma.cc/N2S7-T7W4. The health of sardine stock remains at risk, as evidenced by a population crash over the past two years and a subsequent ban on targeted fishing. Lorraine Chow, *Sardine Fishing Banned in Pacific Northwest as Stocks Hit Historic Low*, ECOWATCH (Apr. 12, 2016), https://perma.cc/4GNM-FFLS.

criteria.[177] NMFS guidance also outlines the relationship of status determination criteria to environmental change—suggesting respecification of criteria in the event that the long-term reproductive potential of the stock is compromised by changing environmental conditions.[178] The guidance recognizes that short-term environmental changes that result in fluctuations in the stock, such as El Niño Southern Oscillation conditions, need not lead to revisions to the criteria.[179]

If a fishery is considered overfished, the incorporation of climate change effects into rebuilding plans is essential. Scientists have demonstrated the importance of considering the effects of climate change when making assumptions about recruitment in rebuilding plans.[180] Specifically, the quantity and quality of food available, the relation between the abundance of juvenile fish and sea temperature, and the timing of early life-stages are essential considerations to ensure that rebuilding probabilities and timelines are based on the best available science.[181]

Each aspect of stock management described above is an essential component of sustainable management. All FMPs must include status determination criteria, catch limits, and rebuilding plans when necessary, and the MSA requires the use of best available science in the development of each.[182] Consequently, NMFS and the Councils must incorporate the emerging science of climate change effects into each to continue achieving the conservation requirements of the MSA. Research programs, such as NOAA's Integrated Ecosystem Assessment, are providing information to advance this effort.[183] However, even when research findings make their way into FEP's, the mechanism for incorporating them into stock assessments and catch limits is lacking. The inclusion of environmental conditions into reference point calculations will facilitate a stronger connection, improving scientific certainty in assessments and management approaches, and subsequent ecological outcomes.

C. Protect Ecosystem Components Vulnerable to Environmental Change

The MSA's bycatch and habitat provisions provide several adaptation options to help reduce multiple stressors on vulnerable ecosystem components. Due to changing spatial distributions of bycatch species, climate effects on biogenic habitats, and other potential effects of climate change outlined in Part II, NMFS and the Councils must consider the efficacy of current management at reducing harmful fishing interactions

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177 50 C.F.R. § 600.310(b)(2), (e)(2) (2015).

178 *Id.* § 600.310(e)(2)(iii)(B).

179 *Id.* § 600.310(e)(2)(iii)(A).

180 Carrie A. Holt & André E. Punt, *Incorporating Climate Information into Rebuilding Plans for Overfished Groundfish Species of the U.S. West Coast*, 100 FISHERIES RES. 57, 57–58 (2009).

181 *Id.* at 58.

182 50 C.F.R. § 600.315(a), (d) (2015).

183 INTEGRATED OCEAN OBSERVING SYS., *supra* note 156.

with ecosystem components.[184] The most common mechanism for protecting ecosystem components is by designating areas for special protection, limiting or prohibiting fishing activity within fixed boundaries, and considering the effects of other human interactions.[185] Where these spatial designations protect sessile organisms or habitats, increasing protection from other man-made stressors is essential. Where they protect mobile species, boundaries may need to shift to accommodate changing distributions.

1. Reduce Multiple Stressors on Vulnerable Biogenic Habitats

Council designation and protection of marine habitats will need to account for climate change effects on habitat.[186] As stated previously, temperature, acidity, and oxygen levels are core components of marine habitats. NMFS regulations recognize this, defining EFH to include the associated physical, chemical, and biological properties of aquatic areas.[187] Because temperature, acidity, and oxygen levels fall under the physical and chemical properties of water,[188] a reassessment of EFH designation and other habitat protections may be necessary due to climate change effects.

Protecting habitat from human intervention is a preferred climate adaptation strategy in both terrestrial and marine environments.[189] Scientific literature is replete with recommendations on how habitat reserves can assist species' adaptation to a changing climate.[190] These recommendations include increasing the number of reserves, increasing connectivity between reserves, using predictive models to make decisions on where to situate new reserves, and locating reserves at the poleward boundary of species' ranges.[191] "Sustaining a diversity of healthy populations over time requires conserving a sufficient variety and amount of habitat and building a well-connected network of conservation areas to allow the movement of species

184 *See* discussion *supra* Part II.

185 FOOD & AGRIC. ORG. OF THE U.N., FISHERIES MANAGEMENT: 4. MARINE PROTECTED AREAS AND FISHERIES (supp. 4 2011), https://perma.cc/72WA-D858.

186 Changes in water temperature, sea level, acidity and other impacts of climate change are likely to adversely affect biogenic habitat. *See supra* Part II.

187 50 C.F.R. § 600.10 (2013).

188 *Water Properties and Measurements*, U.S. GEOLOGICAL SURVEY, https://perma.cc/B9X5-5G6W (last visited Feb. 25, 2017) (nothing that temperature as a physical property, while oxygen level and pH are categorized as chemical properties of water).

189 Nicole E. Heller & Erika S. Zavaleta, *Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations*, BIOLOGICAL CONSERVATION, Jan. 2009, at 14, 24–26; Long & Biber, *supra* note 135, at 660.

190 *See* Heller & Zavaleta, *supra* note 189, at 18–23 & tbl.1; *see also* COMM'N FOR ENVTL. COOPERATION, SCIENTIFIC GUIDELINES FOR DESIGNING RESILIENT MARINE PROTECTED AREA NETWORKS IN A CHANGING CLIMATE (R.J. Brock et al. eds., 2012). Commentators also note that protecting habitat that functions as a carbon sink—such as seagrasses—can also function as a mitigation mechanism. *Id.* at 15.

191 Heller & Zavaleta, *supra* note 189, at 18–20 tbl.1; *see also* COMM'N FOR ENVTL. COOPERATION, *supra* note 190.

in response to climate change."[192] Taking these findings into consideration, updated designations of EFH and increased use of area closures may be some of the most effective adaptation measures managers can take.

Recently improved understanding of deep-water corals and their importance as habitat for countless fish species should be an area of focus.[193] Coral reefs are particularly vulnerable to both destructive bottom-tending fishing gears[194] and effects of climate change and acidification.[195] Increasing the number of protected areas or limiting certain destructive fishing gear types in deep-sea coral areas—using either EFH or discretionary protection measures[196]—will protect corals from fishing impacts, assisting their resilience to climate change, and therefore maintaining their role as important fish habitat.[197] For example, in 2015, the New England Fishery Management Council released a draft omnibus amendment to several FMPs that contained deep-sea coral protection measures relying on the MSA's discretionary coral protection authority.[198] While this designation will have some benefits, only the designation of coral as EFH would require consultation for federal agency activities, such as permitting for resource extraction and pollution discharge.[199] The creation of buffer zones around reserves would further protect sensitive areas by accounting for distribution shifts.[200]

2. Embrace Mobile Spatial Management to Minimize Bycatch

The MSA outlines the discretionary use of area closures to provide protection for bycatch species.[201] Most area closures currently in use have static boundaries. This is appropriate when intended to provide broad protection for sessile organisms and habitat. However, many bycatch species are mobile and move geographically depending on season and life stage.[202] Shifting distributions caused by climate change may lead to

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192 NAT'L FISH, WILDLIFE, & PLANTS CLIMATE ADAPTATION P'SHIP, *supra* note 134, at 54.

193 C.M Turley et al., *Corals in Deep-Water: Will the Unseen Hand of Ocean Acidification Destroy Cold-Water Ecosystems*, 26 CORAL REEFS 445, 445 (2007).

194 *Id.*

195 *See* KLEYPAS ET AL., *supra* note 27, at 1; Silverman et al., *supra* note 39, at 1; NAT'L FISH, WILDLIFE, & PLANTS CLIMATE ADAPTATION P'SHIP, *supra* note 134, at 50.

196 MSA, 16 U.S.C. § 1853(b)(2) (2012).

197 *See* NAT'L FISH, WILDLIFE, & PLANTS CLIMATE ADAPTATION P'SHIP, *supra* note 134, at 50; *see also* COMM'N FOR ENVTL. COOPERATION, *supra* note 190, at 10–11, 28.

198 New Eng. Fishery Mgmt. Council, Draft Omnibus Deep-Sea Coral Amendment 7–12 (Nov. 4, 2016), https://perma.cc/U3Q6-HPJW.

199 16 U.S.C. § 1855(b)(1)(D); NMFS ACHIEVEMENTS FROM 1996 TO THE PRESENT, *supra* note 102, at 15–17.

200 Heller & Zavaleta, *supra* note 189, at 18–19 tbl.1, 25.

201 16 U.S.C. § 1853(b)(2) (2012).

202 *See* PAC. FISHERY MGMT. COUNCIL, PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN FOR THE CALIFORNIA, OREGON, AND WASHINGTON GROUNDFISH FISHERY 96 (2011), https://perma.cc/3SVD-2HK6 (implying that identifying a different habitat type for each life stage of each species would be ideal); see also S. Hoyt Peckham et al., *Small-Scale Fisheries Bycatch Jeopardizes Endangered Pacific Loggerhead Turtles*, PLOS ONE, Oct. 17, 2007, e1041, at 1–4 (discussing the effects of bycatch on loggerhead turtles, a migratory species).

alteration or expansion of these seasonal movements. In these cases, management should adjust the boundaries or forsake fixed-boundaries for spatial protections altogether in favor of instruments that are more adaptable to changing locations of sensitive habitats and species.[203] Fortunately, scientists are increasingly able to design mobile area closures that can follow distribution shifts rather than impose a fixed location area closure indefinitely.[204]

The use of management mechanisms that change in space and time in response to changing oceanographic conditions, such as ocean temperature, hold particular promise for adapting to climate driven distribution shifts. These programs—a form of "dynamic ocean management"—are most useful for reducing interactions with vulnerable, highly migratory species such as turtles, sharks, and marine mammals.[205] For example, NOAA's TurtleWatch program provides longline fishermen in Hawai'i with a daily map predicting the location of loggerhead and leatherback turtles based on the known thermal preferences of the turtles and up-to-date sea surface temperature data.[206] Use of the map to avoid areas of predicted sea turtle activity is voluntary by fishermen.[207] Similar voluntary programs for different fisheries are currently in development.[208] With these voluntary programs, incentive to participate is essential. The TurtleWatch program would seem to have high incentive because interactions between the fishery and turtles, both legally protected species, can lead to a closure of the fishery.[209] However, feedback on participation has been mixed.[210]

The most feasible current use of these programs is on a voluntary basis as implementation of such a flexible and dynamic scheme in agency

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203 OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 108; Pinsky & Mantua, *supra* note 51, at 153.

204 Hazen et al., *supra* note 34, at 234 (discussing how accurately scientists can measure and predict migratory species' habitats).

205 Daniel C. Dunn et al., *Dynamic Ocean Management Increases the Efficiency and Efficacy of Fisheries Management*, 113 PNAS 668, 672 (2016).

206 Evan A. Howell et al., *TurtleWatch: A Tool to Aid in the Bycatch Reduction of Loggerhead Turtles* Caretta caretta *in the Hawaii-Based Pelagic Longline Fishery*, 5 ENDANGERED SPECIES RES. 267, 275–76 (2008). For a well-known non-U.S. example that managers incorporated into fishery regulations, see Alistair J. Hobday et al., *Dynamic Spatial Zoning to Manage Southern Bluefin Tuna (*Thunnus maccoyii*) Capture in a Multi-Species Longline Fishery*, 19 FISHERIES OCEANOGRAPHY 243, 245–46 (2010); AUSTL. FISHERIES MGMT. AUTH., EASTERN TUNA AND BILLFISH FISHERY (ETBF): MANAGEMENT ARRANGEMENTS BOOKLET 18–20 (2016), https://perma.cc/UQ4H-SBT4.

207 Howell et al., *supra* note 206, at 276.

208 *See infra* note 219 (discussing experimental permit for the EcoCast program).

209 50 C.F.R. § 665.813(b) (2015). The fishery was closed in 2006 because the fishery met the loggerhead limit. Fisheries Off West Coast States and in the Western Pacific; Hawaii-Based Shallow-Set Longline Fishery, 71 Fed. Reg. 14,416, 14,417 (Mar. 22, 2006).

210 *See* Catherine E. O'Keefe et al., *Evaluating Effectiveness of Time/Area Closures, Quotas/Caps, and Fleet Communications to Reduce Fisheries Bycatch*, 71 ICES J. MARINE SCI. 1286, 1291–93 (2014).

regulations remains untested.[211] Examples already exist of regulatory spatial protections that move seasonally based on temperature-dependent habitat preferences of various species.[212] However, these examples define the area closures with reference to exact geographic coordinates,[213] inhibiting the finer scale and up-to-date movements that are possible with dynamic ocean management. This is because in general, regulatory management decisions are designed to provide certainty to stakeholders and changes must comply with administrative requirements that enable interested stakeholders to provide input.[214] In many cases, these administrative processes take weeks or months to conclude, inhibiting the real-time updates that characterize dynamic ocean management.[215]

To facilitate a regulatory program with more frequent updates based on water temperature, the Councils and NMFS should explore the use of flexible management revision processes as outlined in Part IV.E. Of the examples explored in that Part, the most flexible types of management decisions must be nondiscretionary and subject to preemptive and rigorous environmental and socioeconomic analysis of all possible alternatives and outcomes.[216] Thus, regulatory use of dynamic spatial management may require a substantial amount of empirical evidence of dynamic management's efficacy prior to implementation.[217] Managers can facilitate collection of empirical information by instituting voluntary programs or by placing conditions on experimental fishing permits.[218] Implementation and

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211 For a full review of all global examples of dynamic ocean management see generally Rebecca Lewison et al., *Dynamic Ocean Management: Identifying the Critical Ingredients of Dynamic Approaches to Ocean Resource Management*, 65 BIOSCIENCE 486 (2015).

212 *See, e.g.*, 50 C.F.R. § 223.206(d)(8) (2015) (restricting the use of certain gears in certain areas to protect sea turtles); *see also* Sea Turtle Conservation; Restrictions to Fishing Activities, 67 Fed. Reg. 13,098, 13,098–100 (Mar. 21, 2002) (explaining the scientific rationale for the seasonal spatial closures in 50 C.F.R. § 223.206(d)(8)). Importantly, as waters warm and distributions shift, a mismatch may develop between the current coordinates and the water temperatures with which they are designed to align, further emphasizing the value of a more dynamic approach.

213 *See, e.g.*, 50 C.F.R. § 223.206(d)(8) (2015); *see also id.* § 660.70(p) (allowing in-season adjustments of Rockfish Conservation Areas—as a routine management measure—within previously specified boundaries); *id.* § 660.60(c) (outlining the procedure for routine management measures in the Pacific groundfish fishery).

214 For example, the MSA requires the publication of all FMPs, FMP amendments, and regulations implementing FMPs in the Federal Register for a public comment period. MSA, 16 U.S.C. § 1854(a)–(b) (2012). The MSA also provides for the applicability of the National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321–4370h (2012)—requiring an environmental analysis subject to public notice and comment—to fisheries management decisions. 16 U.S.C. § 1854(i). The Administrative Procedure Act, 5 U.S.C. §§ 551–559, 701–706, 1305, 3105, 3344, 4301, 5335, 5372, 7521 (2012), specifies additional administrative limitations. *Id.* §§ 551–559.

215 *See* 16 U.S.C. § 1854(a)(1) (2012) (providing for a sixty-day comment period for FMPs).

216 *See, e.g.*, COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 13; PAC. FISHERY MGMT. COUNCIL, PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN 53 (2016) [hereinafter PACIFIC COAST GROUNDFISH FMP], https://perma.cc/JM2V-7VJW.

217 One study has already begun to highlight the efficacy of dynamic ocean management. *See* Dunn et al., *supra* note 206, at 670–71.

218 *See, e.g.,* Magnuson-Stevens Fishery Conservation and Management Act; General Provisions for Domestic Fisheries; Application for Exempted Fishing Permit, 81 Fed. Reg.

enforcement of a regulatory dynamic ocean management regime presents additional legal challenges with regards to monitoring and enforcement.[219]

Work needs to continue to maximize efficacy and minimize unintended consequences of dynamic ocean management programs.[220] Additionally, the scientific and technological capacity to model temperature-dependent habitat preferences, collect real-time temperature data, and deliver up-to-date spatial recommendations to stakeholders is not available in all circumstances.[221] Nevertheless, the implementation of dynamic ocean management can both reduce overall restrictions on fishing communities and improve ecological outcomes, especially in light of climate change's effect on spatial distributions.[222] As a result, the concept of dynamic management provides an emerging tool worthy of consideration as an adaptation mechanism.

D. Minimize Adverse Effects on Fishing Communities from Emerging and Disappearing Fisheries and Reallocation

Climate change effects will culminate with the redistribution of costs and benefits for fisheries, but the manner and timing of these effects are unclear. As explored in the previous Parts, adjusting or creating quotas and effort restrictions are essential steps to ensure sustainability in the future. However, policymakers must also take into account social and economic consequences, allocating privileges fairly and considering the effect of regulation on fishing communities.

The MSA requires the fair and equitable distribution of fishing privileges.[223] However, challenges to the very idea of equitable distribution are likely to result from changes in distribution and productivity. Allocation decisions will be particularly contentious if a species range moves out of one Council's jurisdiction and into another.[224] In the event that changes in

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10,593, 10,593–94 (Mar. 1, 2016) (requesting public comment on an experimental fishing permit that would allow fishing for swordfish in a spatial closure designed to protect turtles on condition that the fishermen use the EcoCast model to avoid areas of predicted bycatch).

219 Alistair J. Hobday et al., *Dynamic Ocean Management: Integrating Scientific and Technological Capacity with Law, Policy, and Management*, 33 STAN. ENVTL. L.J. 125, 156–60 (2014).

220 O'Keefe et al., *supra* note 210, at 1291.

221 Hobday et al., *supra* note 219, at 134–42. Managers can use the cooperative research outlined in Part IV.A to create habitat models based on real-time animal movement data facilitating the use of dynamic marine protected areas that adjust to transient oceanic features.

222 Dunn et al., *supra* note 205, at 671–72; Lewison et al., *supra* note 211, at 495.

223 MSA, 16 U.S.C. § 1851(a)(4) (2012). NMFS outlines several factors for the Councils to consider when allocating catch, including fairness and equity, promotion of conservation, avoidance of excessive shares, economic and social consequences of reallocation, dependence on the fishery by present participants, and opportunity for new participants to enter the fishery. 50 C.F.R. § 600.325(c)(3) (2015).

224 Marine species do not recognize political boundaries and frequently inhabit waters under the jurisdiction of two or more Councils. When a fishery extends beyond the geographical area of authority of one Council, the Secretary may designate a single Council to prepare an FMP or

allocation seem appropriate or necessary, the Councils should estimate the benefits and burdens imposed by the reallocation, assess alternatives, and hold a reasoned discussion with stakeholders to ensure fairness and equity.[225]

In the context of adapting fisheries management to climate change, socioeconomic issues will likely arise in the event that reduced catch limits or reallocation are necessary. Many fishermen make business decisions based on their prior informed expectations, and managers may need to consider this when revisiting allocation.[226] For example, fishermen are likely to make decisions about what fishery to invest in and what species to target based on current regulations, market price, and permit, quota and gear costs.[227] If a species alters its distribution, managers and fishermen are confronted with the question of whether to reallocate catch to coincide with the species' new range or have existing fishermen travel much further to catch their target species.[228] In some cases, altered species distribution will result in increasing costs and decreasing profits for fishermen due to new gear purchases or fuel expenses and increased time on the water.[229] In others, fishermen will benefit from new economic opportunities as shifting stock distributions bring commercially valuable species into their local waters.[230] In any scenario, management responses can influence outcomes by enabling or preventing different fishermen from adapting their effort to shifting stock distributions. These changes in distribution will likely amplify as waters continue to warm. Thus, static solutions will be temporary. Managers and the fishing community must exhibit reallocation flexibility to adjust and respond to the continued poleward shifts of fish species.[231]

To begin preparing for these discussions, NMFS and the Councils must develop an awareness of which fisheries and communities are expected to be winners and losers under climate change. This awareness requires an understanding of the direct (e.g., sea level rise, storm surges) and indirect

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call upon several Councils to work together to jointly prepare and FMP. 50 C.F.R. § 600.110 (2015).

225 *Id.* § 600.325(c)(3)(i).

226 W.C. MacKenzie, *An Introduction into the Economics of Fisheries Management* § 1.3.2 (Food & Agric. Org. of the U.N. Fisheries, Technical Paper No. 226, 1983).

227 *Id.* § 1.3.1.

228 *See* ISLAND INSTITUTE, *supra* note 149, at 7. Even if reallocation does not occur, fishermen may abandon a fishery of their own volition if participation becomes economically impractical due to the increased fuel cost and days at sea necessary to travel further.

229 OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 96.

230 *See supra* notes 7–10 and accompanying text.

231 Closely linked fisheries and their corresponding management schemes may provide valuable examples of managing for environmental change. For example, the wetfish fisheries on the west coast—sardine, anchovy, and market squid—are three separate fisheries that fishermen shift between in response to environmental drivers. The flexibility inherent in these fisheries is tied to the gear used, the species opposing responses to water temperature, and a management regime that facilitates shifting effort between and among the individual fisheries. *See* Stacy E. Aguilera et al., *Managing Small-Scale Commercial Fisheries for Adaptive Capacity: Insights from Dynamic Social-Ecological Drivers of Change in Monterey Bay*, PLOS ONE, Mar. 19, 2015, e0118992, at 3.

(e.g., ability to harvest fish) climate effects on coastal communities, as well as the coastal community's ability to adapt. Factors affecting a community's ability to adapt include management constraints and local availability of resources. NMFS efforts to analyze community vulnerability under climate change are underway in some regions.[232] These analyses consider not only the vulnerability of local fishery resources to climate change for each community, but also social factors such as the number of people working in fishery related jobs, community reliance on fisheries revenue, and ability to diversify into other sectors or fisheries.[233] A preliminary study suggests the most vulnerable communities are those that focus fishing effort on species with high vulnerability to climate change and lack species diversity in overall catch.[234] One failure of this study is that the ability of a species to shift their distribution in response to warming waters is a factor that indicates lower vulnerability in the analysis. Thus, the ability of a community to cope with shifting distributions of their target species is largely ignored. Overall, the study demonstrates that different communities are vulnerable for different reasons, and thus one-size-fits-all management or engagement solutions do not exist.[235] As a result, managers will likely deem community- or context-specific solutions a necessity.

NMFS and the Councils should prepare a stakeholder involvement process to prepare for the controversial discussions that will arise. Specifically, the process should encourage the most economically rational and socially acceptable way to reallocate quotas and manage fisheries, and seek to reach consensus among members of the fishing community. The decisions stemming from this process are likely to be within the realm of public interest, more durable, and based on a wider range of perspectives and information. In the event that members of the fishing community deem management or allocation changes necessary and acceptable, the process should also assist fishermen in engaging in a new practice when necessary. Rather than allowing the economic expenditures of fisheries starting from square one, the process should facilitate the transfer and secondhand use of quotas, gear, and knowledge. This type of process will ensure equitable allocation and minimize adverse effects on fishing communities, as required by the national standards of the MSA.

The surf clam (*Spisula solidissima*) fishery in the mid- and north-Atlantic provides one illustration of a fishery for which distribution changes might have significant social and economic consequences. The Atlantic surf clam appears to exhibit declining biomass and a shift in range as a consequence of warming waters.[236] The population has declined in the

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232 Colburn et al., *Indicators of Climate Change and Social Vulnerability in Fishing Dependent Communities Along the Eastern and Gulf Coasts of the United States*, 74 MARINE POL'Y 323, 328 (2016).

233 *Id.*

234 *Id.*

235 *Id.* at 330.

236 Bonnie J. McCay et al., *Human Dimensions of Climate Change and Fisheries in a Coupled System: The Atlantic Surfclam Case*, 68 ICES J. MARINE SCI. 1354, 1356 (2011).

southern part of the fishery's range (Delaware, Maryland, and Virginia), but has remained stable or increased off of New Jersey, New York, and New England.[237] As a result, fishing activities are moving and a surf clam processing plant has relocated from Virginia to New England.[238] Two aspects of this fishery are important for managers to consider if reallocation is necessary. First, surf clam fisherman use hydraulic clam dredges,[239] a gear type with both high capital and operational costs.[240] As a result, the working owner of a dredging rig must catch a certain amount of clams to make a reasonable profit, and any reduction in allowable catch or allocation may impair the economic viability of the fishery.[241] Additionally, the gear is not readily useable to prosecute other fisheries, inhibiting a diversification of fishing that would minimize risk to changes in distribution and allocation. Second, the surf clam fishery has instituted individual transferable fishing quotas (ITQs), a management method that grants individual shareowners a privilege to catch a certain amount of the total allowable catch.[242] ITQs are understood to have both positive and negative aspects[243] that may play out differently depending on how managers and the ITQ shareowners respond to distribution shifts and changes in productivity. Policymakers must fully

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237 *Id.*

238 Malin Pinsky, Opinion, *These Two Changes in the Ocean Are Downright Scary*, MARKETWATCH (Apr. 22, 2016), https://perma.cc/RHH8-PSE8.

239 *Sustainable Fisheries: Atlantic Surfclam and Ocean Quahog*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://perma.cc/7HS8-NZLU (last visited Feb. 25, 2017).

240 J. H. MANNING, CHESAPEAKE BIOLOGICAL LAB., THE MARYLAND SOFT SHELL CLAM INDUSTRY AND ITS EFFECTS ON TIDEWATER RESOURCES 6 (1957), https://perma.cc/C2M4-86FF.

241 *Id.* While the referenced study focused on the soft shell clam industry in Maryland, all fisheries are dependent in catching a certain amount of fish to make a profit.

242 MID-ATL. FISHERY MGMT. COUNCIL ET AL., AMENDMENT #8 FISHERY MANAGEMENT PLAN FOR THE ATLANTIC SURF CLAM AND OCEAN QUAHOG FISHERY 54–56 (1990); *see also* Suzanne Iudicello & Sherry Bosse Lueders, *A Survey of Litigation Over Catch Shares and Groundfish Management in the Pacific Coast and Northeast Multispecies Fisheries*, 46 ENVTL. L. 157, 164–65 (2016) (discussing the implementation ITQs in this fishery).

243 ITQs increase the predictability of catch and profit, leading to capital investment and consolidation of fishing effort and power. As a result, the fishery is characterized by a lean and efficient harvesting sector that may be more amenable to voluntary self-governing and collective agreements about allocation changes in the fishery. McCay et al., *supra* note 236, at 1361–62. However, given that defined quota portions are owned by individuals who may be unwilling to move, they may find themselves stuck with quotas that they cannot fish. And because the total allowable catch for the fishery is still set by the public management body, changing distributions and productivity will affect the future value of ITQ holdings. *Id.* at 1362–63. Additionally, the transition to the ITQ system resulted in the industrialization of the fishery and concentration of shares. *Id.* at 1362. In fact, nearly 25% of the annual quota is owned by a single person. *2016 Initial Surfclam Allocations*, NAT'L OCEANIC & ATMOSPHERIC ADMIN FISHERIES, https://perma.cc/5Q4E-ATRG (last visited Feb. 25, 2017) (showing that nearly 25% of the surfclam quota is owned by two corporations using the same address in Palm Beach Garden, Fla.). A search of public records shows that both corporations are controlled by the same person. The concentration of shares and inability for new participants to enter the fishery results in strong pressure from more powerful members of the industry and restricts the flexibility of fishing community to adapt to climate effects. For additional discussion of the pros and cons of ITQs, see U. Rashid Sumaila, *A Cautionary Note on Individual Transferable Quotas*, 15 ECOLOGY & SOC'Y, no. 3, art. 36 (2010).

consider these characteristics and sensitivities in order to promote cooperative discourse with the fishing community and maximize stakeholder buy-in for management decisions.

Socioeconomic issues are sure to arise due to climate effects. Both the surf clam example explored in this Part and the management of black sea bass mentioned in the Introduction provide important case studies of the lose-lose situations that may arise in the future if we ignore changing conditions. The predicted biological changes, fishery responses, and substantive management changes in these fisheries will affect the bottom line for U.S. fishing communities and the sustainability of resources. While current management efforts facilitate the resolution of many issues, unforeseen difficulties—such as deciding the fate of a fishery targeting a species that has shifted its distribution—may require new engagement processes. These efforts are necessary to promote acceptable and fair decisions that account for the interests of all parties.

E. Increase Adaptive Capacity of Management Regimes to Mitigate Uncertainty

The preceding Parts focus on strategies to incorporate what we already know about climate effects on fisheries. But a major obstacle to continued sustainable fisheries management is the uncertainty of how marine ecosystems will respond to the varying effects of climate change.[244] As circumstances change, even comprehensive scientifically-based management strategies can quickly become ineffectual.[245] As a result, in addition to directly addressing known or predicted changes, managers must also manage uncertainty through procedural strategies that adjust how management decisions are made. This Part highlights the importance of undertaking long-term strategic planning to ensure that management is as adaptive as possible and capable of responding quickly to unforeseen events. Through adaptation of procedural methods, a historically inflexible decision-making process can transition to accommodate what we do not know yet, increasing the adaptive capacity of both fishery managers and participants.[246] This Part will explore three methods of adapting procedural methods: contingency planning, management strategy evaluation, and adaptive management.

244 OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 3.
245 *Id.* at 21.
246 OECD ADAPTING FISHERIES TO CLIMATE CHANGE, *supra* note 18, at 105; *see also* Plagányi et al., *supra* note 26, at 1314 ("Given the difficulties in forecasting such rapid changes, a pragmatic solution resides in formally setting up an actively adaptive feedback cycle."); Pinsky & Mantua, *supra* note 51, at 155 ("Progressive ecosystem changes will require adaptive responses . . . .").

1. Contingency Planning

Decision makers and fishing communities have noted that in many circumstances the current regulatory process is not flexible enough to allow the rapid amendment of FMPs and management approaches[247] in a time frame that is responsive to climate change effects.[248] Contingency planning may remedy this. The NMFS guidelines implementing National Standard 6 state that FMPs should account for contingencies in fisheries and specifically call out climatic conditions as an example of a contingency.[249] NMFS states that these situations require a flexible management regime containing a series of management options that managers can implement quickly when necessary without amending the FMP or its regulations.[250] The FMP should describe the options in detail to ensure that the Council retains its policy-making functions and the public is able to fully understand the triggers and implications of the options during the comment period.[251] The examples contemplated by NMFS in its guidance include criteria that allow managers "to open and close seasons, close fishing grounds, or make other adjustments to management measures."[252] NMFS has released operational guidelines that describe the use of these abbreviated rulemaking methods with reduced administrative requirements.[253] To cope with the uncertain and rapid changes resulting from climate change, the Councils should take full advantage of these rulemaking methods.

Currently, each Council and NMFS regional office interprets these operational guidelines differently and some are better positioned to leverage these tools.[254] For example the Pacific Fishery Management Council uses routine measures[255] and automatic actions[256] to make in-season adjustments in the Groundfish and Coastal Pelagic fisheries.[257] Both routine measures and automatic actions—and other forms of abbreviated rulemaking—are characterized by reduced administrative requirements at the time

247 *See supra* Part IV.C.2 (discussing dynamic ocean management).

248 ISLAND INSTITUTE, *supra* note 149, at 8.

249 50 C.F.R. § 600.335(c)–(d) (2013). As an example, the guidelines contemplate lack of scientific knowledge about the condition of a stock as a variation that would require a reduced level of optimum yield. *Id.* § 600.335(c)(2)(i).

250 *Id.* § 600.335(d).

251 *Id.* § 600.335(d)(1).

252 *Id.* § 600.335(d)(2).

253 NAT'L MARINE FISHERIES SERV., OPERATIONAL GUIDELINES FOR THE MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT FISHERY MANAGEMENT PROCESS, app. 2, at 9 (2015), https://perma.cc/6JX3-K4L2.

254 FISHERIES LEADERSHIP & SUSTAINABILITY FORUM, RESPONSIVENESS IN THE FEDERAL FISHERIES MANAGEMENT PROCESS: USE OF THE CONTINUING AND CONTINGENCY FISHERY MANAGEMENT MECHANISMS ACROSS THE REGIONAL FISHERY MANAGEMENT COUNCILS 5–6 (2013), https://perma.cc/WM37-B7CG.

255 50 C.F.R. § 660.60(c) (2015) (Groundfish); *id.* § 660.517(c) (Coastal Pelagic).

256 *Id.* § 660.60(d) (Groundfish).

257 *See* COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 13–15; PACIFIC COAST GROUNDFISH FMP, *supra* note 216, at 53–56.

management decisions are made.[258] However, automatic measures must be nondiscretionary and subject to preemptive and rigorous environmental and socioeconomic analysis of all possible alternatives and outcomes.[259] Strategic use of these abbreviated rulemaking procedures can result in a flexible management regime characterized by adaptive decision making.

Some fisheries already use these types of strategies through harvest control rules with several different management options framed as conditional statements (i.e., if *ABC* occurs, then *XYZ* is our management response).[260] The benefit of conditional statements in harvest control rules is that they partially or fully eliminate decision-maker discretion at the time a reference point is breached and therefore dispense with the need for lengthy administrative review periods.[261] This decision-making method can also minimize the likelihood of contentious discussions when "triggering events" occur. By preparing contingencies and assessing all alternatives and outcomes of those contingencies ahead of time, managers are able to act quickly and decisively when a fishery reaches a predefined state. The application of these flexibility mechanisms is possible in several aspects of management, but their effectiveness often depends significantly on the timely collection and assessment of data, which is limited by agency capacity.[262] Sunset provisions provide an additional nuance to the use of conditional statements by identifying a particular reference point or event that indicates when a given conditional statement is no longer applicable or effective.

A flexible regime characterized by conditional statements and sunset provisions could result in more rapid management responses to changing conditions than the typical management revision process, which generally takes the form of framework adjustments or amendments.[263] While framework adjustments have more flexibility than FMP amendments, many limitations exist. For instance, in-season adjustments are usually limited to certain measures.[264] Moreover, the framework process still requires notice and comment, and several Council meetings to analyze alternatives and

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258 COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 13–14; PACIFIC COAST GROUNDFISH FMP, *supra* note 216, at 53–54.

259 COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 13.

260 WORLD WILDLIFE FUND, FISHING WITHIN LIMITS (2012), https://perma.cc/LJ2F-CKVK. An example conditional statement is: "if the fishery stock level falls below the target level, then the level of fishing must be reduced by 20%." *Id.*

261 COASTAL PELAGIC SPECIES FMP, *supra* note 144, at 13.

262 PACIFIC COAST GROUNDFISH FMP, *supra* note 216, at 45.

263 *See, e.g.*, 50 C.F.R. § 648.41 (2015) (framework process for NEFMC management of Atlantic Salmon (*Salmo salar*)); *id.* § 648.25 (framework process for MAFMC management of Atlantic Mackerel (*Scomber scombrus*), squid (*Dorytheuthis pealeii* or *Illex illecebrosus*), and butterfish (*Peprilus triacanthus*)). A framework adjustment is an "abbreviated administrative procedure that may be used in certain situations to modify or update an FMP without completing the full amendment process." Oceana v. Locke, 831 F. Supp. 2d 95, 104 (D.D.C. 2011).

264 *See, e.g.*, 50 C.F.R. § 648.41(a) (2015) (limiting in-season adjustments to two very specific management actions).

public sentiment.[265] As a result, implementation of framework adjustments can take several months.[266] Framework adjustments provide supplemental value in the event that no contingency is prepared to address certain unforeseen changes, but strategic contingency planning is preferable for managing adaptively.

2. Management Strategy Evaluation

Methods of evaluating different proposed management strategies can supplement the contingency planning process by evaluating tradeoffs of different management choices under varying environmental conditions. Management strategy evaluation (MSE) is a simulation technique that allows such an evaluation for control rules that set allowable catch. Through MSE, managers use models to simulate the full management cycle—from data collection, to stock assessment, to setting catch limits, to predicting catch in the fishery—all of which feeds back into data collection.[267] This full cycle simulation allows managers to test how altering any assumption, or multiple assumptions, affects management outcomes.[268] An important aspect of MSE is the involvement of stakeholders in defining management objectives and the overall management approach, creating a cooperative management atmosphere and reducing both ecological and socioeconomic risks.[269] Challenges to implementing such an approach include the associated significant up-front costs[270] and identifying and coordinating with diffuse stakeholder groups or in fisheries with a history of mistrust between managers and fishing communities.[271]

Managers have traditionally used MSEs to determine the extent to which a single approach to setting allowable catch meets multiple management objectives and is robust to uncertainty.[272] Expanding MSE simulations to test responses to changing environmental conditions can enable managers to identify multiple appropriate management strategies for multiple future scenarios in which the extent of predicted changes and ecosystem responses are uncertain. Managers can incorporate these future scenarios and their paired, appropriate management strategies into conditional statements. While only one of the predicted future scenarios will

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265 *E.g.*, *id.* § 648.25 (2015).

266 *See* JOSH EAGLE ET AL., TAKING STOCK OF THE REGIONAL FISHERY MANAGEMENT COUNCILS 35–36 (2003).

267 André E. Punt et al., *Management Strategy Evaluation: Best Practices*, 17 FISH & FISHERIES 303, 306 (2016); Daniel S. Holland, *Management Strategy Evaluation and Management Procedures* 19–20 & fig.1 (Org. for Econ. Co-operation & Dev. Food, Agriculture & Fisheries, Working Paper No. 25, 2010), https://perma.cc/9V5G-GDKF.

268 Holland, *supra* note 267, at 19–20.

269 *Id.* at 21.

270 *Id.* at 22.

271 *E.g.*, Priscilla Weeks, *Language and "Limited Entry": The Formation of Texas Shrimping Policy*, *in* STATE AND COMMUNITY IN FISHERIES MANAGEMENT: POWER, POLICY AND PRACTICE 103, 111 (E. Paul Durrenberger & Thomas D. King eds., 2000) (discussing the mistrust between Texas shrimpers and the relevant regulatory agency).

272 *Id.* at 19–21.

occur in real-life at any given time, the variety of MSE supported conditional statements will ensure that the management regime is prepared for most possible scenarios. Sunset provisions in the MSE can stipulate for reevaluation of the scenario approaches based on a set timeline, the discovery of new information, or externalities not accounted for.

3. Adaptive Management

A final component of long-term strategic planning is the use of adaptive management strategies to address uncertainty. Designing "adaptive" management mechanisms is relatively straightforward in theory: as long as decision making, monitoring, and assessment are linked and form a closed loop, management can be considered adaptive.[273] However, the innovation of true adaptive management requires a more explicit strategy for designing management options as experiments and incorporating learning into the monitoring and assessment processes.[274] This occurs on two timescales—long-term strategic planning, and annual implementation and monitoring.[275] In the climate context, adaptive management can benefit managers by enabling the direct confrontation of uncertainty and quick alterations in regulatory approaches in response to changing conditions and new information. The long-term processes should recognize predictions and uncertainty as they relate to the broader climate context, allowing managers to identify necessary additional information, design management strategies that will gather that information, and designate where and how collected information will feed into future decisions.

Adaptive management provides the planning framework within which managers can implement MSE, conditional statements, and dynamic management strategies. Specifically, the long-term strategic planning phase can initially involve the selection of a harvest strategy based on the MSE simulation and iteratively consist of revising the MSE models and inputs based on new learning over time. The annual implementation phase—and finer scale decision making—involves the application of prespecified conditional statements and dynamic management strategies using empirical data to implement decision rules. Information gathered from annual monitoring is fed back into the long-term strategic planning process at the appropriate time.

While few real-world examples exist of such a strategic and adaptive management approach, implementation of Australia's Commonwealth Fisheries Harvest Strategy Policy provides the inspiration for this model. That Policy provides for the use of MSE as the preferred approach for

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273 *See* BYRON K. WILLIAMS ET AL., U.S. DEP'T OF THE INTERIOR, ADAPTIVE MANAGEMENT: THE U.S. DEPARTMENT OF THE INTERIOR TECHNICAL GUIDE 1, 5 (2009) (describing iterations of monitoring, evaluation, and adjustment).

274 *Id.* at 1.

275 Josh Eagle et al., *Domestic Fishery Management*, *in* OCEAN AND COASTAL LAW AND POLICY 305, 308 (Donald C. Baur et al. eds., 2d ed. 2015).

setting and iteratively revising harvest strategies.[276] Periodic adjustments to harvest strategies are called for when necessary to incorporate changes to understanding of a fisheries status, external drivers that increase risk to the fishery, or clear evidence exists that the current harvest strategy is not working.[277] This policy also calls for the use of data collection and indicators to implement the chosen harvest strategy on an annual basis.[278] The Pacific Fisheries Management Council is currently attempting to develop a similar procedure for groundfish rebuilding plans.[279]

Managers should aim to increase the level of adaptability in management in any way possible to mitigate uncertainty in climate effects. The procedural requirements of the MSA, as well as the National Environmental Policy Act[280] and Administrative Procedure Act,[281] will certainly limit progress in this area. But long-term strategic planning and the implementation of conditional statements and nondiscretionary measures as contemplated by NMFS operational guidelines can help facilitate the change. Explicit adaptive management processes can provide a framework for strategic planning, but the presence of dynamic scientific advice linked to management triggers can be a form of adaptive management even without a more formal process. Regardless of the approach taken, expanding the ability of management to rapidly respond to effects of climate change will maximize the prospects of the continuing sustainable management of fisheries.

V. CONCLUSION

U.S. fisheries management has taken great strides towards sustainability over the past 30 years.[282] However, a suite of biological, chemical, and physical changes in the oceans pose serious threats to sustainable fisheries management and the accomplishments of Congress,

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276 AUSTL. DEP'T OF AGRIC., FISHERIES, & FORESTRY, COMMONWEALTH FISHERIES HARVEST STRATEGY: POLICY AND GUIDELINES 7, 48–50 (2007).

277 *Id. at* 7, 50–51.

278 *Id.* at 2, 15–17.

279 Draft Summary Minutes, Sci. & Statistical Comm., Pac. Fishery Mgmt. Council 10–11 (June 11–12, 2015), https://perma.cc/QC49-EZ2S.

280 National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321–4370h (2012).

281 Administrative Procedure Act, 5 U.S.C. §§ 551–559, 701–706, 1305, 3105, 3344, 4301, 5335, 5372, 7521 (2012).

282 *See, e.g.*, Fisheries of the United States; National Standard 1 Guidelines, 77 Fed. Reg. 26,238, 26,239 (May 3, 2012) ("From 2007 to 2012, the 46 Federal FMPs have been amended to implement ACLs and AMs to end and prevent overfishing."); Josh Eagle et al., *supra* note 275, at 321 ("The evolution of fisheries law has resulted in, if not the end of overfishing, material improvements in the proportion of species classified as overfished or undergoing overfishing."); J.R. Beddington et al., *Current Problems in the Management of Marine Fisheries*, 316 SCIENCE 1713, 1715 (2007) (explaining that of several countries surveyed, only the United States had seen an improvement in the number of overfished stocks); PEW CHARITABLE TR., *supra* note 16, at 17 ("Since the establishment of annual catch limits and accountability measures for nearly all federally managed fisheries in the United States, the evidence is mounting that we are on the way to ending overfishing and rebuilding and sustaining fishery populations.").

NMFS, and the Councils. Absent a new approach, harm to ecosystem health, livelihoods, and food security is likely. The variety of environmental changes occurring in the oceans will influence many of the biophysical processes that underlie management decisions, and even today remain poorly understood. Elevated action is necessary to maintain progress towards sustainable fisheries.

This Article concludes that despite the significant uncertainty of climate effects, the current fisheries management regime provides managers with the flexibility to utilize many emerging tools to assist both marine species and fishing communities in their adaptation efforts. Although the history of the MSA is rooted in economic interests, the current text and implementation of the MSA focuses on the use of science-based management that incorporates uncertainty, risk, and environmental change in a number of important ways. Focusing on a selection of national standards and core requirements in the Magnuson–Stevens Act, this Article concludes that the complexity and uncertainty inherent in ocean ecosystems necessitated a flexible and precautionary regulatory regime to ensure sustainable fishing.

These components of the MSA allow for emerging tools to adapt to climate change. Ongoing research is a core component of fisheries and ocean ecosystem management. While funding and coordination remain concerns, managers have a number of programs at their disposal to increase understanding of how marine communities and ecosystems respond to changing environmental conditions. This information can feed into many aspects of management including adjusting how many fish can be caught, protecting sensitive habitats or species from interaction with fisheries, and facilitating our shift towards more holistic management of ocean ecosystems. Tools to tie new information directly to management decisions are also emerging, enabling the much sought after connection between knowledge and action, science and policy. Considering the social and economic costs of adaptation is an additional component of a climate adaptation strategy. Fisheries provide jobs, livelihoods, and a way of life for thousands of Americans who are the first to experience the environmental changes this article outlines. Considering and protecting their interests to the extent possible requires renewed understanding of community reliance on fishing activity. Finally, broader scale uptake and use of the management innovations, developed to reduce uncertainty over time, will become critical as we enter a future with no analog.

Future Council decisions that incorporate elements of these adaptation strategies would be broadly consistent with the MSA's ten national standards and other core requirements. However, their ultimate success or failure will depend on implementation and enforcement by NMFS and the Councils, including the collection of new and relevant scientific data. Funding, agency capacity, and stakeholder buy-in will present challenges, but many suggested adaptation mechanisms are designed to alleviate and resolve these limitations to the extent possible. For example, a shift towards cooperative research and climate specific stakeholder engagement can expand agency capacity and ensure stakeholder support for management decisions. Additionally, facilitating rapid management responses through alternative contingency plans based on a range of predictions from past and ongoing climatic research will mitigate the lack of definitive science. Most importantly, an adaptive governance structure must explicitly recognize uncertainty and reject any measure that assumes a static ecosystem. Regulatory adaptation and flexibility in response to new uncertainties can help clear the already murky waters and ensure the continued vitality of U.S. marine capture fisheries.