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ISSUE BRIEF

CLIMATE CHANGE AND FISHERIES: MODERNIZING FISHERIES SCIENCE FOR CLIMATE RESILIENCE

Robust science is the foundation of U.S. fisheries management. It is what allows managers to avoid overfishing, maintain stable and sustainable fisheries, provide domestically produced seafood, and protect our ocean ecosystems. Yet the pace and scale of climate change is challenging fisheries science by undermining traditional methods and fundamental assumptions—and in turn threatening to undo decades of work rebuilding our nation's fishery populations and managing them sustainably.

These challenges can be overcome with investments in scientific infrastructure and in research that provides decision makers with the climate-informed advice they need for sustainable fisheries management. Only by jump-starting climate-informed fisheries science will we be able to ensure that U.S. fisheries are managed on the basis of science and sustainability into the future, that fisheries remain economic engines in our coastal communities, and that we continue to produce environmentally sound seafood.

Fishing has been an engine of our country's economy and a cultural mainstay for Indigenous communities for centuries.[1] Fisheries even played a role in U.S. history: Atlantic cod provided protein for a growing population and fueled international trade, leaving such a legacy in New England that the fish is featured on several state flags.[2] Similarly, in Alaska, fisheries were the first major industry and provided a significant motivation for the push toward statehood.[3]

Today U.S. fisheries remain a significant economic driver. Fisheries can also produce a sustainable food source with multiple health benefits.[4]

Marine fisheries are the world's last major wild food systems. From subsistence fishing to waterfronts busy with commercial fishing fleets, fish define the rhythms of life for millions of Americans.[5]

Commercial fishing boats in Portland, Maine.

FISHERIES MANAGEMENT DEPENDS ON SCIENCE

The success of U.S. fisheries management stems in part from the strength of the nation's fisheries science. The 1996 and 2006 amendments to the Magnuson–Stevens Fishery Conservation and Management Act have successfully safeguarded our marine life, ending chronic overfishing and rebuilding 47 depleted fisheries over the past two decades.[6]

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National Fisheries Management Scientists sampling and measuring fish.

To manage a fish population successfully, managers must have some idea of how many fish are in the ocean and how quickly they grow and reproduce.[7] This is the fundamental information used to estimate how many fish can be safely caught without jeopardizing the population and the fisheries that depend on it. How precise this knowledge must be depends on how intensively managers intend to exploit the fish population. In industrialized nations like the United States, managers often pursue high exploitation levels (see box, "More Fishing Means More Science"). This leaves relatively little room for error, so effective fisheries management tends to be a data-intensive process.[8]

U.S. fishery managers rely on scientists for estimates of the size and condition of fish populations. These estimates are based on in-the-water fish counts or surveys and a range of biological information, all of which is integrated into a mathematical model called a stock assessment.[12] Stock assessments provide a snapshot of the status of a given fish population as well as recommendations for safe catch levels and projections of future population trends, assuming certain ocean conditions and population responses to those changes.

Fisheries science is never perfect, and population estimates and catch limit recommendations always carry some degree of uncertainty. But fundamentally, good science

MORE FISHING MEANS MORE SCIENCE

Fundamentally, the more fish you want to harvest from a managed stock, the more accurate and precise the science must be.

For managers to target the "maximum sustainable yield" for a population, scientists must determine how many fish can be removed from the population without jeopardizing its ability to replenish itself. This is a difficult question to answer precisely, and doing so requires gathering a large amount of information on the species' biology and life history, as well as accurate data on historical catches and relative indicators of abundance over time.[9]

By contrast, if managers aim for a slightly lower yield, the demands on scientists are reduced.[10] Backing away from the threshold of overfishing means the information they provide can be less precise, because managers need only to be in the right ballpark in order to maintain sustainability for the fish stock.[11]

allows managers to make good decisions. When scientists can estimate the size and productivity of a fish population accurately, managers are able to set sustainable catch limits that ensure the long-term health of the stock. By contrast, if scientific information on a fish stock is imprecise or uncertain, managers may inadvertently allow overfishing or forgo possible yield that could be safely harvested.

Science provides the blueprint for sustainable fisheries management and therefore is critical for maintaining healthy fisheries and fishing-dependent coastal communities.

CLIMATE CHANGE IS DISRUPTING FISHERIES SCIENCE

As the earth warms, the oceans are absorbing a tremendous amount of heat (Figure 1).[13] As ocean temperatures rise, circulation patterns are changing as a result, leaving us with warmer waters, altered currents and seasonal cycles and more extreme events like marine heat waves.[14] More carbon dioxide also is dissolving into the oceans, slowly making them more acidic.[15] Ocean creatures are responding to these changes in their surroundings in a number of ways, many of which affect the information and assumptions used in developing stock assessments and management advice and challenge effective fisheries management.

RANGE SHIFT: Many fish populations are moving poleward and offshore as they seek to remain within their preferred thermal tolerances.[16] Other populations are expanding or contracting their historical geographic ranges. The movement is dramatic in some cases, with marine life fleeing northward at rates up to six times faster than their land-based counterparts to stay in areas with their preferred ocean temperatures.[17] It is also widespread in many areas—such as off the U.S. East Coast, where more than 70 percent of commercially valuable fish species have moved northward or into deeper waters in recent decades.[18]

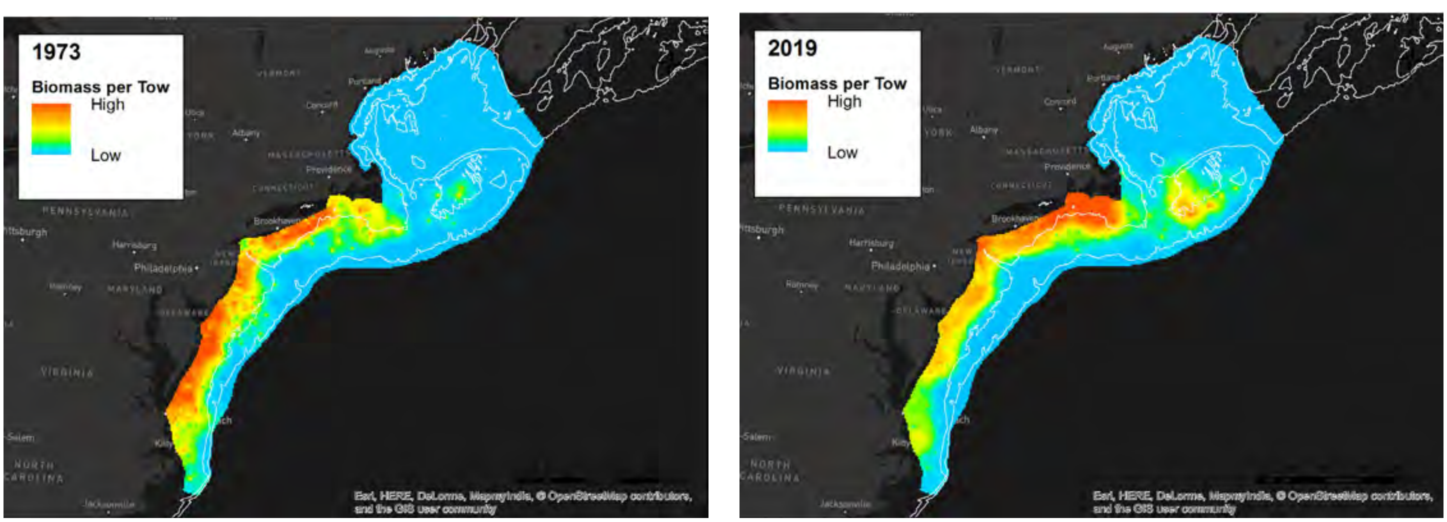
For example, summer flounder were once abundant off North Carolina but are now commonly found off New Jersey and New York instead, hundreds of miles north (Figure 2).[19] American lobster populations appear to be abandoning their southerly grounds, and lobster fisheries may no longer be viable south of Cape Cod due to changed ocean conditions.[20] The Atlantic black sea bass population in turn is expanding, potentially taking over habitat from other retreating species.[21]

A basic premise of fisheries surveys is that stock distribution is relatively static and unchanging relative to a survey's spatial coverage; this assumption allows scientists to infer abundance trends from their observations (see box, "Surveying Fish Populations").[22] However, today's range changes can pose problems for fisheries science, especially when stocks shift in areas that are not routinely surveyed. The patterns of these geographic shifts are difficult to infer from surveys' current survey spatial coverage.

ALTERED STOCK STRUCTURE: The way a fish population is arranged in space and time—known as stock structure—can affect how that population responds to fishing.[23] With climate change, fisheries science must consider stock structure as dynamic, not fixed, and evaluate the effect of changing stock structure on population dynamics and management.

Some stocks are essentially a single, well-mixed unit, and a fish caught in one location can be thought of as fungible with any other fish in the population. Other stocks appear to be divided into subunits, each of which may have independent dynamics and must be considered separately.[24] It can be important to get stock structure right in fisheries modeling; certain structures may cause the overall population to be more or less resilient to fishing pressure, and structure may also determine tipping points or other unexpected responses from a population.[25]

Figure 2: The distribution of Summer flounder biomass in 1973 and 2019



Climate change, however, is driving changes in fish stock structure by splitting populations apart or joining them together. As a consequence, scientists can no longer assume that stock structure is static, and past research and inferences may need to be reevaluated.[26] Moreover, given the rapid pace of change, it can be difficult to find clear evidence supporting new stock structure assumptions. These issues around stock structure can lead to elevated uncertainty in population estimates and harvest recommendations.[27]

CHANGES IN PRODUCTIVITY AND BEHAVIOR: Climate change introduces further uncertainty by changing fish stocks' biological processes and behavior relative to their historical baselines. When modeling a fish stock, scientists estimate various biological characteristics like juvenile survival and "recruitment" into the population, size or age at maturity, and natural mortality, based on past studies of the species or a similar one.[28] The general assumption is that these parameters are variable from year to year but do not change in a uniform direction over time—meaning, for example, that an Atlantic codfish today will grow at the same rate at which a codfish grew in the 1980s.[29]

Climate change, however, is rapidly altering the growth and productivity of our fish stocks.[30] With changing ocean conditions, some species are growing faster, and others slower, than they used to.[31] Some species are producing more successful young ("recruits") per spawning adult, and others fewer, than they used to.[32] Myriad changes to biological processes are being seen, driven by new environmental conditions—from altered temperature and water chemistry to changed prey availability and predation patterns.[33]

These biological changes can increase uncertainty in fisheries science. Biological parameters often strongly affect the outcome of a stock assessment model.[34] Shifts in existing model parameters resulting from climate change can reduce a model's usefulness—sometimes even to the point where the model outputs are too uncertain to be used in management.

COMPETING USES OF THE OCEAN: Another way that climate change will affect fisheries science is through competing ocean uses, such as offshore wind energy developments. Some areas of the ocean may become unusable for fishermen as well as for scientists conducting fishery surveys. Fish populations may

SURVEYING FISH POPULATIONS

Every year scientists head out to survey our nation's coastal waters, creating a record of fish abundance over time that is invaluable for stock assessments.

While the details of each survey vary, scientists always follow a consistent sampling pattern across the designated area. Scientists also always use consistent fishing gear when conducting the survey, such as a specific configuration for bottom-trawl nets.

By maintaining the same practices year in and year out, scientists are able to draw conclusions from the changes that they see over time. For example, if over a number of years or decades Atlantic cod show up in trawl survey nets with declining frequency, it may indicate that the cod population is dwindling. These survey data have provided strong evidence for the effect of climate change on fish distribution.

Northeast trawl survey.

respond in different ways to new infrastructure in the water and to altered fishing patterns. Further, reduced access to surveys and other research may make these changes difficult to observe.

FAILING TO ADAPT FISHERIES SCIENCE POSES A SERIOUS RISK TO U.S. FISHERIES

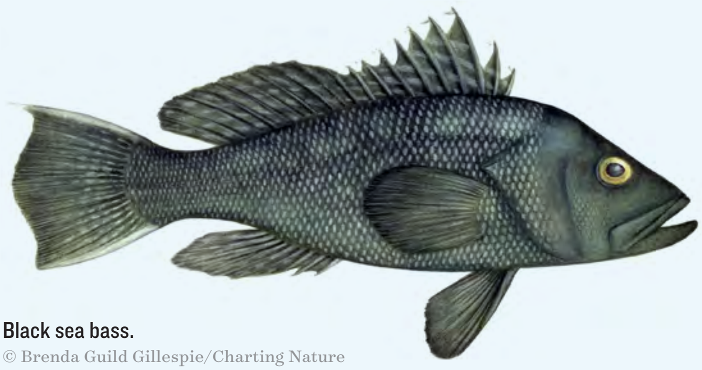
Because climate change is affecting ocean conditions, fish populations, and our assumptions of how species will respond to changes, federal scientists are struggling to execute their core mandate of modeling fish populations and setting sustainable catch levels.

As discussed above, climate-related issues are sometimes rendering stock assessment models unusable. When this happens, scientists and managers are left scrambling for backup sources of information, as occurred with black sea bass (discussed in one of our case studies, below). Even when a stock assessment is used for management, climate change can reduce the accuracy of its projections and create subsequent problems, as with Atlantic mackerel (another of our case studies).

More generally, the current approaches to providing science-based advice for fisheries management often rest on assumptions of past conditions which may no longer be accurate. In essence, information gaps about changing ocean conditions and fishes' response to them are causing an increased risk of incorrect catch limit recommendations.[35]

Inaccurate science can result in overfishing and can undermine rebuilding plans, putting at risk decades of hard work to sustainably manage our fish stocks—and potentially harming the coastal communities that depend on fishing.[36] Outdated science also undermines trust in the management system, as illustrated by the black sea bass case study, and can make managers vulnerable to political pressure.

NMFS scientists utilize fisheries and oceanographic data to conduct regular stock assessments.



Black sea bass.

© Brenda Guild Gillespie/Charting Nature

Atlantic mackerel.

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BLACK SEA BASS: CLIMATE-DRIVEN STOCK DYNAMICS THROW OFF THE SCIENCE

Black sea bass (*Centropristis striata*) is a prized target species for anglers and commercial fishermen on the East Coast. In 2012, just as evidence of climate impacts on fish populations was starting to accumulate, the Mid-Atlantic black sea bass stock assessment was rejected in peer review—meaning that independent scientists who reviewed the work recommended not using it for management purposes.[37]

While the details are complex, the overall issue was that the north and south ends of the Mid-Atlantic black sea bass stock appeared to be behaving differently from each other. At the northern end of its range, black sea bass was expanding rapidly, while at the southern stock boundary it was not.[38] The stock assessment model struggled to reconcile these differing trends, and as a result scientists had to shelve the model and fall back on earlier and simpler methods for calculating catch limits.[39]

This created a problem for managers, as fishermen perceived the resulting catch limits as flawed. Fishing industry participants argued that the black sea bass catch limits put in place after the 2012 assessment cycle were "punitive and based on bad information" and that "faith in the management system is being lost."[40]

By the next black sea bass stock assessment, in 2016, scientists were able to resolve the climate-related issues by structuring their model with two subunits, and the assessment passed peer review.[41] That said, it is not clear whether trust in the management system was restored fully; industry participants continued to assert that "if a new stock assessment had been available earlier, management measures could have been updated . . . and non-compliance [in the fishery] would be less of an issue."[42]

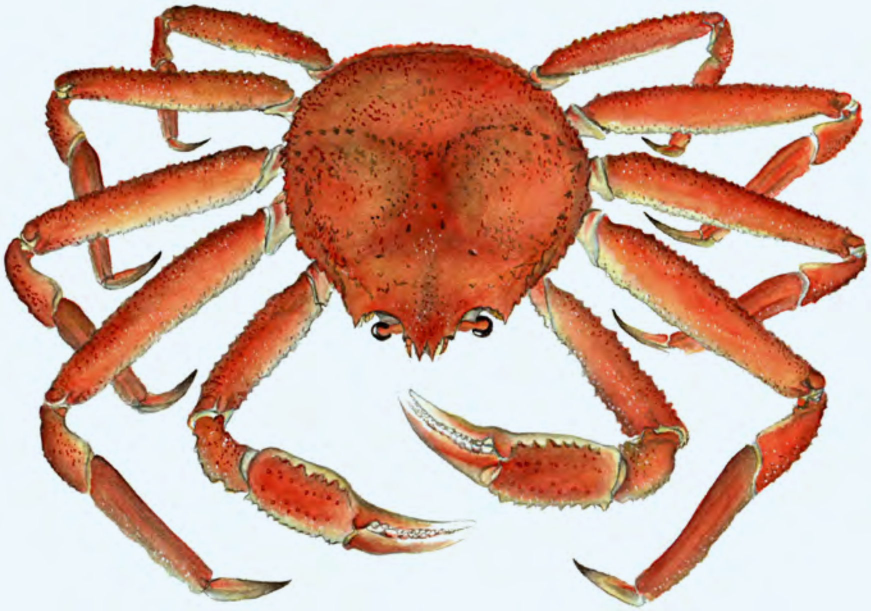
Managers have also had a difficult time addressing the expansion of the black sea bass populations.[43] State-specific quotas are based on historical distribution of landings. Surveys clearly show an expansion, but shifting quota from one state to another has proved challenging.

ATLANTIC MACKEREL: DECLINING PRODUCTIVITY FORCES A REBUILDING DO-OVER

Even if a stock assessment correctly reflects the current stock status, climate change can undermine its usefulness to managers. For example, Atlantic mackerel (*Scomber scombrus*) was assessed in 2017 and declared overfished, meaning that the population had dropped to the point where it needed to be rebuilt.[44] The assessment included a new index of abundance that was developed jointly by U.S. and Canadian scientists, and it provided projections for what the Atlantic mackerel population would look like in upcoming years.[45] Managers relied on these projections to adopt a rebuilding plan for the stock, reducing catch and aiming to rebuild mackerel fishery within five years.[46]

Four years later, however, when the next stock assessment came out, it became clear that Atlantic mackerel was not bouncing back as expected.[47] In fact, it turned out that managers had significantly overshot the actual safe harvest amount and that the stock was still being subjected to overfishing.[48]

How did this happen? After further analysis, scientists concluded that the stock had experienced a significant decline in recruitment in recent years—meaning Atlantic mackerel was simply less productive than it used to be.[49] Managers had to discard the original rebuilding plan, close the fishery temporarily, and prepare a new rebuilding plan that accounted for the now less-productive state of Atlantic mackerel.[50] The result was further disruption for industry, as well as substantial management costs.



Snow crab.

SNOW CRAB: CLIMATE-RELATED MORTALITY THROWS OFF POPULATION FORECASTS

Snow crab (*Chionoecetes opilio)* is an important target species for American crabbers in the Bering Sea. Crab is the third highest value fishery in Alaska; in 2019 there were 47 million pounds of landings worth $226 million.[51] The eastern Bering Sea crab fishery operates on the basis of regular stock assessments; scientists use results from the annual eastern Bering Sea trawl survey to estimate the number of snow crabs in the water and set safe catch limits.[52]

In 2015, scientists noticed a large year class—or cohort—of young snow crabs starting to show up in survey gear.[53] There were more young snow crabs than had ever been observed before, setting up projections of a large fishery harvest in subsequent years when those crabs matured. The record-breaking year class was tracked through 2018 and 2019, and despite a modest reduction in size as time passed, the snow crab stock assessment still projected a large fishery harvest when the cohort matured to catchable age.[54]

In 2021, however, when the record-breaking cohort should have been mature and harvestable, scientists unexpectedly found the snow crab population had dropped to very low levels. They concluded that the large year class had "disappeared from the eastern Bering Sea shelf before reaching commercial size."[55] Fishery quotas had to be cut by nearly 90 percent, and in combination with other crab closures, the eastern Bering Sea crab industry now is facing more than $200 million in revenue reductions for the year.[56] With biomass at historic lows, the stock was declared overfished, and managers are beginning to prepare a rebuilding plan.[57] Due to continued low population numbers, the snow crab fishery was closed in the fall of 2022.

While the magnitude of the snow crab collapse is clear, scientists are still investigating the causes. It appears that several years of low winter ice coverage affected the "cold pool" that typically exists at the bottom of the Bering Sea and deters predator species like Pacific cod and walleye pollock from entering the region.[58] With warmer bottom waters, cod and pollock appear to have moved into the Bering Sea and may have devoured thousands of young crabs in the process.[59] Warmer water temperatures may have contributed to the disappearing cohort more directly as well. Because snow crab prefer cold bottom water, scientists have speculated that some may have migrated off the continental shelf to deeper and colder waters, thereby disappearing from the trawl survey, which covers only shallower shelf waters.[60] Warmer water also increases the metabolic needs of crabs, meaning that they must eat more to stay alive, so it is also possible that large numbers of snow crabs simply starved to death.[61]

Under climate change, many U.S. fish populations are behaving differently. Traditional assumptions of stability—in temperature, ocean conditions, predation, and spatial distribution, for example—are being upended. Scientists' jobs are now harder because they must monitor conditions more carefully, investigate causal mechanisms and drivers, and make forecasts in a more complex and chaotic system.

SOLUTIONS ARE WITHIN REACH

These challenges can be overcome with reasonable investments in our nation's fisheries science infrastructure. Fully funding the National Oceanic and Atmospheric Administration's (NOAA) recently launched Climate, Ecosystems, and Fisheries Initiative (discussed below) and enhancing NMFS's on-the-water observation are essential to modernizing the U.S. fisheries science system and providing decision makers with the information they need to sustain fisheries in a changing climate.

Invest in 21st-Century Methods by Supporting the Climate, Ecosystems, and Fisheries Initiative

Fisheries science is currently insufficiently funded to meet the mandates of the Magnuson–Stevens Act, and the impacts of climate change exacerbate the situation. Fisheries scientists will need expanded resources to better anticipate and respond to the effects of climate change on species, ecosystems, and fisheries.

Accurately predicting future conditions, assessing risks, and identifying best fishery management strategies means using state-of-the-art climate models to provide robust projections of likely ocean conditions at regional and subregional scales relevant for fisheries management. It also means using these robust projections to create scenarios of likely future ecosystem and fisheries conditions to help evaluate the best fisheries management strategies for resilience and adaptation to climate change.

Investment in species-specific laboratory research is essential to help scientists connect the projected changes in ocean physical conditions with likely changes in species, ecosystems, and ultimately fisheries and fishing communities. Finally, scientists must develop decision support tools, like risk assessments and management strategy evaluations (see box, "Scenario Planning and Management Strategy Evaluation"), to help managers make the best use of climate projections and examine different management approaches in light of the anticipated changes in our oceans.

Fortunately, NOAA recently launched a Climate, Ecosystems, and Fisheries Initiative to modernize U.S. fisheries science.[62] Based on prior successful efforts in Alaska, NOAA scientists are building out regional models to project future ocean conditions and associated impacts on species, ecosystems, and fishing communities.[63] At the same time, the agency is scaling up its capacity for decision support tools to enable rigorous analysis of different management approaches in light of climate change. The Climate, Ecosystems, and Fisheries Initiative will develop the end-to-end system needed to assess risks and identify best fishery management strategies for rapidly changing climate and ocean conditions. The initiative is integrated across the agency, bringing in scientists from different disciplines and line offices and leveraging existing research and expertise. Importantly, the Climate, Ecosystems, and Fisheries Initiative also includes a human dimension, as scientists are examining fishing community vulnerability and analyzing how these communities can adapt to climate change.

National Marine Fisheries Service research vessel.

SCENARIO PLANNING AND MANAGEMENT STRATEGY EVALUATION

Scenario planning is the process of outlining potential future fish population scenarios and the appropriate management responses. Both are developed by stakeholders with input from scientists with a variety of expertise.

Management strategy evaluation (MSE) is the process of quantitatively analyzing different management approaches to determine how well they perform under current or expected future conditions.[64] MSE may take the form of simulation modeling but also can include other types of structured analysis. The general notion is to compare different approaches for managing a fishery—essentially pretesting them—before selecting one.[65]

In the MSE process, scientists work with managers and stakeholders to define the goals of management, which may include yield, economic returns, ecosystem health, or community stability, among other things. Scientists then sketch out a rough model of the fishery system and apply various management strategies to that model fishery—things like catch limits, area-based management, gear requirements, and so forth. They then see how well each management strategy performs and provide the results to decision makers.

MSE is a particularly useful tool for fishery management in the face of climate change, as it can help managers make decisions in spite of imperfect information.[66] Under climate change, the future is unlikely to look exactly like the past, so MSEs can and should be used to evaluate which approaches to managing a fishery will be useful to a range of possible future conditions.[67]

The Climate, Ecosystems, and Fisheries Initiative will deliver critical infrastructure for our nation's fisheries management system and should be fully funded at approximately $60 million. This is less than 1 percent of the agency's overall $7 billion budget and should be provided as soon as possible. The agency's 2022 *Blue Book* report states that this investment "will establish a nationwide ocean modeling and decision support system that provides decision-makers with climate-informed advice on changing ocean conditions, impacts on marine resources, and best management strategies to reduce impacts and increase economic resilience."[68] This a critical investment to maintain the integrity of our nation's commercial and recreational fisheries, which support more than $350 billion in economic activity and 1.8 million jobs annually.[69]

Scientists conduct oceanographic sampling to better understand water conditions.

Enhanced On-The-Water Observation

U.S. fisheries science infrastructure must also update its observation and monitoring systems. Because the oceans are changing, scientists must be able to track developments on the water in real time, from newly arriving species to marine heat waves and algal blooms. In addition, it is critical to maintain usable information on population abundance, recruitment, and biological processes. As previously noted, climate change is driving many species to shift their ranges and is altering species' biological processes; lacking a broad vision of in-the-water dynamics, these changes can undermine survey data sets and prior biological studies.

To keep pace with the changing oceans, NOAA's fishery-independent surveys must be reviewed and redesigned. In some cases, it may be necessary to expand coverage to match species' shifted ranges. In other cases, timing or survey methods may have to be adjusted to reflect species' new behavior. And in still other cases, surveys may need to be restructured to avoid wind turbines or other offshore uses. In a few cases, entirely new surveys may need to be initiated to sample new species and areas, including around large-scale wind energy developments. Biological sampling programs must also be reviewed to ensure their effectiveness in light of shifting species distributions and altered biological processes.

To help meet these needs, NOAA can and should expand its use of cooperative research with fishing industry partners, building on successful examples such as the West Coast trawl survey and the Gulf of Maine longline survey (see box, "Cooperative Fishery Surveys"). Cooperative research allows NOAA to expand surveying capacity beyond its small number of "white ships." It also brings industry members into the scientific process, which helps build understanding and collaborative relationships across partners in the management system. NOAA also can and should pursue other ways to gather observational data efficiently, such as through use of autonomous or remotely operated vehicles, acoustic monitoring, and environmental DNA, as well as build out analytical infrastructure to integrate the collected data into fisheries science products. And NOAA should continue its approach of working with other agencies to track and mitigate the impacts of offshore infrastructure like wind energy on fisheries data-gathering.[70]

COOPERATIVE FISHERY SURVEYS

Involving fishermen in scientific surveys is a good idea. Not only does it build trust and understanding, but it also leverages fishermen's knowledge and capacity to help collect scientific information. In a few regions, NOAA has designed cooperative fishery surveys that directly rely on fishermen and fishing vessels.

To conduct the West Coast bottom trawl survey, for example, NOAA charters a handful of trawl vessels each year.[71] Fishermen outfit their boats with a specified gear configuration, and scientists work with them to identify sampling locations in U.S. waters from the Canadian to the Mexican border. Vessels carry instruments to measure net position, location, and an array of oceanographic information like temperature and salinity. NOAA scientists and volunteers ride along on the survey trips to count, sort, measure, and take biological samples from the fish hauled up.[72] The cooperative arrangement allows NOAA to tap into existing fishery capacity, rather than using the relatively expensive NOAA white ships, and also provides reliable income for industry partners.

For the Gulf of Maine longline survey, NOAA takes a similar approach, chartering fishing industry vessels twice a year to help survey rocky and otherwise difficult-to-access areas of the seafloor off the East Coast.[73] Boats are configured with fishing gear and scientific equipment, and scientists work closely with industry members to measure the catch and take samples for future biological study.[74]

These cooperative surveys are generally regarded as a success by both fishermen and scientists, and NOAA should build on the cooperative model going forward.

Even with increased use of efficient approaches like cooperative research and advanced sampling technologies, however, NOAA will need a substantial increase in funding to upgrade its observational surveying, sampling, and analysis capabilities. Observational programs are key to successful fisheries science and management, and Congress should invest in this work to ensure fisheries remain sustainable. Specifically, in NOAA's budget fisheries surveys and assessments should be increased by at least $25 million, in order to modernize and update the agency's observational programs in light of climate change.

© NOAA

Scientists classify and measure fish collected by a trawl survey.

LOOKING FORWARD

Our nation's valuable fisheries are at an inflection point. We can maintain the status quo for our fisheries science infrastructure, allowing methods and data collection to be overwhelmed by climate change, and end up with uncertain and risky scientific advice, politically driven fisheries management, and the high likelihood of unsustainable harvesting. Or we can wisely invest in upgrading our scientific infrastructure to ensure climate-informed fisheries management that supports resilience, adaptation, and sustainability in the face of changing climate and oceans.

By supporting the Climate, Ecosystems, and Fisheries Initiative to identify climate-ready fishery management strategies and overhauling our observational programs, we have a chance to build resilience and ensure that fisheries continue to be economic engines in our coastal communities and provide healthy food into the future.

ENDNOTES

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