National Fish, Wildlife and Plants Climate Adaptation Strategy

Marine Ecosystems

Photo: NOAA

Disclaimer

The information in this Marine Ecosystems Background Paper was developed by the Marine Technical Team of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*), and was used as source material for the full *Strategy* document. It was informally reviewed by a group of experts selected by the Team. While not an official report, this Marine Ecosystems Background Paper is available as an additional resource that provides more detailed information regarding climate change impacts, adaptation strategies, and actions for U.S. marine ecosystems and the species they support. These papers have been edited by the Management Team for length, style, and content, and the Management Team accepts responsibility for any omissions or errors.

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Introduction

Over the past decade, there have been increasing calls for action by government and non-governmental entities to better understand and address the impacts of climate change on natural resources and the communities that depend on them. These calls helped lay the foundation for development of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*).

In 2009, Congress asked the Council on Environmental Quality (CEQ) and the Department of the Interior (DOI) to develop a national, government-wide climate adaptation strategy for fish, wildlife, plants, and related ecological processes. This request was included in the Fiscal Year 2010 Department of the Interior, Environment and Related Agencies Appropriations Act Conference Report. The U.S. Fish and Wildlife Service (FWS) and CEQ then invited the National Oceanic and Atmospheric Administration (NOAA) and state wildlife agencies, with the New York State Division of Fish, Wildlife, and Marine Resources as their lead representative, to co-lead the development of the *Strategy*.

A Steering Committee was established to lead this effort and it includes representatives from 16 federal agencies with management authorities for fish, wildlife, plants, or habitat as well as representatives from five state fish and wildlife agencies and two tribal commissions. The Steering Committee charged a small Management Team including representatives of the FWS, NOAA, Association of Fish and Wildlife Agencies (representing the states) and Great Lakes Indian Fish and Wildlife Commission to oversee the day-to-day development of the *Strategy*.

In March of 2011, the Management Team invited more than 90 natural resource professionals (both researchers and managers) from federal, state, and tribal agencies to form five Technical Teams centered around a major ecosystem type. These teams, which were co-chaired by federal, state, and I most instances, tribal representatives, worked over the next eight months to provide technical information on climate change impacts and to collectively develop the strategies and actions for adapting to climate change. The five ecosystem technical teams are: Inland Waters, Coastal, Marine, Forests, and a fifth team comprising four ecosystems: Grasslands, Shrublands, Deserts, and Arctic Tundra.

This Background Paper focuses on marine systems, including information about these systems, existing stressors, impacts from climate change, and several case studies highlighting particular impacts or adaptation efforts. Information from this Background Paper informed discussion of marine impacts and adaptation measures in the full *Strategy*, and was used to develop the Goals, Strategies, and Actions presented in that document and repeated here. This Background Paper is intended to provide additional background information and technical details relevant to marine systems, and to summarize those approaches most relevant to managers of these areas and the species they support. Some of the material presented herein overlaps with that for other ecosystem types, particularly regarding cross-cutting issues.

The ultimate goal of the *Strategy* is to inspire and enable natural resource professionals, legislators, and other decision makers to take action to adapt to a changing climate. Those actions are vital to preserving the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides. The *Strategy* explains the challenges ahead and offers a guide to sensible actions that can be taken now, in spite of uncertainties over the precise impacts of climate change on living resources. It further provides guidance on longer-term actions most likely to promote natural resource adaptation to climate change. The *Strategy* also describes mechanisms to foster collaboration among all levels of government, conservation organizations, and private landowners.

Federal, state, and tribal governments and conservation partners are encouraged to look for areas of overlap between this Background Paper, the *Strategy* itself, and other planning and implementation efforts. These groups are also encouraged to identify new efforts that are being planned by their respective agencies or organizations and to work collaboratively to reduce the impacts of climate change on marine fish, wildlife, and plants.

Marine Ecosystem Description


Photo: AFWA

Marine ecosystems are the largest systems on the planet, covering over 70 percent of the Earth's surface and constituting over 99 percent of the living space on the planet (area x depth). These vast ecosystems are composed of many different habitats which extend from the nearshore regions to continental shelves and the deep ocean. They are home to millions of species and provide food, income, protection, and many other vital ecosystem services to billions of people around the world. For the purposes of this report, the marine ecosystems under U.S. jurisdiction generally extend from the shore to 200 miles seaward (Figure 1, see Appendix for figures). This area is generally referred to as the U.S. exclusive economic zone (EEZ) and spans 3.4 million square nautical miles of ocean. It is the largest EEZ in the world encompassing 1.7 times the land area of the continental United States. It is divided into 11 different large marine ecosystems (LMEs) (Figure 1) based on unique physical, chemical, and biological features of these regions.

Diversity of Marine Fish, Wildlife, and Plant Resources:

Marine ecosystems can be broadly characterized as aquatic or pelagic habitat, and bottom or benthic habitat (Figure 2). Within the pelagic environment, the waters are divided into the neritic province, which includes the water above the continental shelf, and the oceanic province, which includes all the open waters beyond the continental shelf. The high nutrient levels of the neritic province—resulting from riverine runoff and coastal/deep ocean upwelling—distinguish this province from the oceanic. The upper portion of both the neritic and oceanic waters—the epipelagic zone—is where photosynthesis occurs; it is roughly equivalent to the photic zone. Below this zone lie the mesopelagic, ranging between 650 and 3300 feet, the bathypelagic, from 3300 feet to 2.5 miles, and the abyssal pelagic, which encompasses the deepest parts of the oceans from 2.5 miles to the recesses of the deep-sea trenches.

The benthic environment also is divided into different zones (Figure 2). The supralittoral is above the high-tide mark and is usually not under water. The littoral, or intertidal, zone ranges from the high-tide mark (the maximum elevation of the tide) to the low-tide mark. The sublittoral is the environment beyond the low-tide mark and is often used to refer to substrata of the continental shelf, which reaches depths of between 500 and 1000 feet. Sediments of the continental shelf generally originate from the land, particularly in the form of riverine runoff, and include clay, silt, and sand. Beyond the continental shelf is the bathyal zone, which occurs at depths of 500 feet to 2.5 miles and includes the descending continental slope and rise. The abyssal zone (between 2.5 and 3.7 miles) represents a substantial portion of the oceans. The deepest region of the oceans (greater than 3.7 miles) is the hadal zone of the deep-sea trenches. Sediments of the deep sea primarily originate from a rain of dead marine organisms and their wastes.

These ecosystems host species ranging from microscopic planktonic organisms that comprise the base of the marine food web (i.e., bacteria, phytoplankton, and zooplankton) through kelp (*Pueraria montana*) and eel grass (*Zostera marina*) beds to a wide range of invertebrates (e.g., corals, crustaceans, mollusks) and vertebrates (e.g., fish, turtles, birds, and marine mammals) (Figure 3, Table 1). Marine organisms are not distributed evenly throughout the oceans. Variations in characteristics of the marine environment create different habitats and influence what types of organisms will inhabit them. The availability of nutrients, light, water depth, temperature, oceanographic energetics (waves and/or currents), sedimentation rates, proximity to land, and topography all affect marine habitats. Light availability is a key factor in species distribution and is used to describe different zones including the photic zone where these is light and the aphotic zone, an area of inky darkness that occupies most of the ocean (Figure 2). The actual depth of these zones depends on local conditions such as cloud cover, water clarity (turbidity), and mixing by the winds and tides. Marine organisms are particularly abundant in the photic zone, especially the upper or euphotic portion; however, many organisms vertically migrate across zones.

Ecosystem Products and Services:

The diversity and productivity of marine ecosystems are also important to human survival in providing ecosystem services. The services these systems provide include:

- Food, jobs, and income from the harvest of fish and shellfish;
- Marine products that serve as animal feed, fertilizers for crops, additives in foods (i.e., alginate for ice-cream) and marine pharmaceuticals (i.e., those derived from sponges, marine worms, sharks, soft corals, and other marine taxa for use in medical trials[1];
- Coastline protection from coral reefs and kelp forests that reduce wave action and erosion;
- Recreation and relaxation from interactions with ocean ecosystems; and
- Cultural identity and spiritual values to coastal communities, as well as many tribes and indigenous people whose ties to the water and the species living there are integral to their histories and way of life.

Linkages to Other Systems:

Marine systems are connected to all other ecosystems, but they have particularly substantial linkages to two other systems considered in the *Strategy* —the Coastal, and the Inland Waters systems. Numerous marine species inhabit these systems during parts of their life cycles. Also, many of the climate and non-climate stressors that need to be addressed to successfully manage marine species in a changing climate are stressors that impact multiple systems. Therefore, some of the actions identified in the *Strategy* need to be implemented across multiple systems.

Many Fish, Wildlife, and Plants Cross Ecosystems:

Species that live in both the coastal and marine systems during their lifecycles include the range of species from invertebrates to fish to seabirds. Diadromous fish rely upon inland waters for important freshwater habitat used for spawning (e.g., salmon, striped bass, sturgeon, etc.) or maturing (e.g., American eel (*Anguilla rostrata*)). Other marine fishes require coastal waters and estuaries as nursery areas. Seabirds, turtles, and some marine mammals use coastal lands for rest and reproduction. Even without considering the added pressure of climate change, many of these species are at risk of extinction due to factors including habitat loss, present or past direct harvest, and mortality as bycatch in fisheries. Habitats that are linked across these two systems include sandy beaches, estuaries, mangroves, seagrass beds, and coral reefs. For example, mangroves serve as nurseries for some reef fish that hatch in seagrass beds and live in coral reefs later in life (Mumby 2006).

[1] http://oceansandhumanhealth.noaa.gov/documents/

Impacts of Climate Change on Marine Systems

A number of reviews of the impacts of climate change on marine systems in U.S. waters are available (IPCC 2001, AR4 2007, Kennedy et al. 2002, Heinz Center 2008, Maclean and Wilson 2011). European and Canadian reviews are also available (Anadón et al. 2007, Lemmon et al. 2008, Herr and Galland 2009). Marine ecosystems are also impacted by a range of non-climate stressors such as fishing and pollution that may affect the ability of marine species and habitats to adapt to climate change, and may in turn be exacerbated in a changing climate. There are also a variety of resources available on the impacts of these non-climate stressors on marine ecosystems. The following is a summary of available information on current and projected impacts of climate change on marine ecosystems, also summarized in Table 1.

Table 1: Expected Climate Change Impacts on Marine Ecosystems (USGCRP 2009 and IPCC AR4 2007)

Major Changes Associated With Increasing Levels of GHGs	Major Impact on Marine Systems
Ocean acidification:	Negative impacts on corals, shellfish, and other species (particularly early life stages and organisms at base of food chains), changes in biogeochemical processes that may reduce the ability of the ocean to absorb excess $CO_{2,}$ creating a positive feedback to climate change
Increased temperatures:	Mass mortalities of corals and other species, changes in organism phenology, distribution, growth and mortality rates, changes in timing and magnitude of primary and secondary productivity, spread of diseases and invasive species
Melting ice:	Changes in timing, magnitude of primary productivity and fish productivity. Loss of habitats critical to foraging and reproduction of ice-dependent species
Rising sea levels:	Inundation of coastal marshes, loss of marine bird nesting habitat, erosion, saltwater intrusion affects early life history stages of many marine species
Changing currents:	Changes in phenology, dispersal, distribution and growth rates of fish stocks and other species, changes in timing and magnitude of primary and secondary productivity, changes in spread of diseases and invasive species
Changing stratification:	Changes in nutrient distributions in water column and timing and magnitude of primary and secondary productivity, altered predator-prey interactions
Changing precipitation patterns:	Changes in salinity, nutrient and sediment flow to coastal waters affects near-shore productivity and early life stages of many marine species, especially those who use freshwater and estuarine habitat for part of their life cycle
Drying conditions/drought:	Increased salinity, changes in nutrient and sediment flow to coastal waters affects near-shore productivity and early life stages of many marine species (particularly anadromous species)
More extreme rain/weather events:	Reduced salinity, changes nutrient and sediment flow to coastal waters affects near-shore productivity and early life stages of many marine species (particularly anadromous species)

Marine systems and taxa (Table 1) respond physically, chemically, and biologically to changes and variability that are occurring on both global and regional scales (Figure 4, Table 2). Anthropogenic (human induced) climate change is caused by an increase in greenhouse gases (carbon dioxide (CO_2), methane, water vapor, etc) in the atmosphere that leads to an increase in global temperatures. In marine systems, the two primary responses to these climate changes are 1) increases in ocean temperatures (and many associated physical changes discussed below) and 2) absorption of atmospheric CO_2, leading to ocean acidification. Human activities that occur in the marine environment or are dependent on marine species can exacerbate (increase) or ameliorate (lessen) the impacts of climate change on fish, wildlife, and plants. It is around these activities that adaptation strategies can be developed.

ARCTIC SEABIRDS

Changes in climate – both regime shifts and long-term climate change – have affected Arctic seabirds and the marine ecosystems upon which they depend. There is clear evidence that Arctic seabird numbers fluctuate in response to climate variability, and increasing evidence that populations are responding to climate change. The proximate cause of population effects is changes in prey distribution, abundance, and phenology due to changes in sea surface temperatures and ocean circulation. Studies have shown effects on foraging distributions of little auks (Alle alle) across the Greenland Sea related to sea temperature; prey shortages for least auklets (*Aethia pusilla*) in the Pribilof Islands related to high sea temperatures; possible range expansion of the razorbill (*Alca torda*) in the Canadian Arctic in response to range expansion of favored prey; documented breeding phenology shifts in little auks and black-legged kittiwakes (*Rissa tridactyla*) in Svalbard that were related to air and sea surface temperature changes; breeding phenology shifts in kittiwakes over a 32-year period on the Pribilof Islands related to sea ice concentration and sea surface temperature; and climate-related mismatch of prey availability and timing of breeding in thick-billed murres (*Uria lomvia*) at a colony in northern Hudson Bay, Canada.

Climate change is likely to have continued and increasing effects on the distribution and abundance of Arctic seabirds in the future through mechanisms such as altering prey distribution and abundance through long-term shifts in ecosystem regimes; affecting the timing of the spring primary production bloom associated with receding sea ice; and mismatching prey availability and timing of breeding. Direct effects of increased air and sea temperatures may cause thermal stress, especially for breeding birds, and potentially resulting in northward movement of species distributions. In addition, an increase in the number and intensity of storms increase might lead to increased mortality.

To date, a number of nearshore and coastal Marine Protected Areas have been established in the Arctic specifically to protect seabird breeding colonies and their associated foraging areas. Such areas include, for example, the Akpait and Qaqulluit National Wildlife Areas on Baffin Island in Canada; bird cliffs within the Hornstrandir Nature Reserve in Iceland; 15 bird sanctuaries in the Svalbard Archipelago of Norway; and the five units of the Alaska Maritime National Wildlife Refuge in the United States. Many other protected areas have seabird nesting colonies including the gigantic Northeast Greenland National Park and the Franz Josef Land wildlife reserve in Russia, which is 62 percent marine.

Changes in Ocean Temperature:

Surface waters of the oceans are gradually warming. The Intergovernmental Panel on Climate Change (IPCC AR4 2007) reported that between 1961 and 2003, global ocean temperatures rose by 0.2 °C, with much greater localized ocean temperature changes observed by some researchers (e.g., 0.8 °C in Monterey Bay, CA during 1931-33 to 1993-1996 (Sagarin et al. 2009)). There is also a correlation between warming trends in the deeper ocean and sea surface temperature, suggesting that surface trends are also predictive of shifts in whole-ocean temperature budgets (IPCC AR4 2007). Such warming has several collateral consequences including sea level rise, increases in storm frequency and intensity, increased stratification of the water column, and changes in ocean circulation. As water warms, it expands, and the ocean surface rises. That is, most of the excess heat in the ocean, and the associated thermal expansion, is currently in a surface layer less than 1000 feet deep. Over time, this heat will diffuse downward to greater depths, increasing expansion and triggering further increases in sea level. Additional sea level rise is caused by the melting of inland glaciers and continental ice sheets, including those associated with Greenland and Antarctica. Melting of sea ice and sea bed permafrost is also a consequence of atmospheric and ocean warming, and impacts to species of this melting will produce associated physical (including increased stratification in the water column), chemical, and biological changes. Melting sea ice is also changing transportation routes, oil and gas exploration and extraction, fishing, and tourism in the Arctic, which could also impact the fish, wildlife, and plants in this region.

Ocean warming also impacts weather events. Warming sea temperatures boost the energy available to germinate and intensify hurricanes and typhoons. While it is unclear if the frequency of these storms is affected by climate change, their intensity is expected to increase as sea surface temperatures rise (IPCC AR4 2007). With ongoing warming of the atmosphere and the ocean, key water masses and the processes they control could undergo major changes. Surface ocean currents are driven by wind. A change in the intensity and location of winds (e.g., the Westerlies moving northward in the Atlantic) will cause changes in surface ocean circulation. Currents are also distinguished by their temperature and salinity properties.

Thermohaline circulation, which is driven by temperature and salinity gradients, can be significantly affected by the warming climate and could slow the circulation of cold or salty deep ocean currents in the Atlantic and Pacific Oceans. These large scale changes in circulation could have more localized impacts such as increased ocean stratification (and the associated hindrances to vertical water movement) and alterations to upwelling and coastal productivity.

WEST COAST OYSTER PRODUCTION

In 2007 and 2008, two of the three major West Coast oyster hatcheries discovered that their Pacific oyster larvae were dying. It did not happen all the time, so researchers set out to understand why. Was something wrong in the water pumped from the sea into the hatcheries? By testing the water, researchers discovered a telltale pattern. The larvae died only when upwelling off the coast brought deep, cold water to the surface—and into the hatcheries (Feely et al. 2008). This cold water was low in calcium carbonate, the basic material in oyster shells. Without enough dissolved calcium carbonate (in a form known as aragonite), the oyster larvae struggled to survive.

The finding pointed to the ultimate culprit—the same rising CO_2 levels in the atmosphere that cause climate change. When CO_2 concentrations increase in the air, the ocean absorbs more CO_2. That increases the acidity of the water. Higher acidity (lower pH), in turn, means that the water cannot hold as much dissolved calcium carbonate. Compounding the issue is the fact that cold water, like that found on the bottom of the ocean, cannot dissolve as much calcium carbonate as warmer water can. Thus, the acidic cold water that is churned up during upwelling is especially harmful to the oyster larvae.

The hatcheries figured out ways around the problem. One of them measured concentrations of dissolved CO_2 in the seawater and pumped in water only when it was above a pH level of 7.75 (typically late in the day after plankton had lowered water CO_2 levels through photosynthesis). The other hatchery moved its intake from deep to shallow water.

But these steps do not solve the larger, far more significant problem—the increasing acidification of the oceans. Over the last six years, the difficulties faced by the hatcheries in rearing Pacific oyster larvae have been paralleled by poor supplies of naturally produced seed oysters in Willapa Bay, Washington—the most important oyster-producing bay on the West Coast. Acidification is already having a serious effect on the West Coast's

$80 million per year oyster industry, which employs thousands of people in economically depressed coastal communities (PCSGA 2010). If the acidification of the oceans is the cause, then the problem will just get worse. Not just oysters will be at risk, but also the basic food webs in the oceans because so many species use calcium carbonate to build shells and skeletons.

Ocean Acidification:

The oceans act as a buffer to changes in atmospheric CO_2 providing a sink for one-fourth of all anthropogenic CO_2 emissions (Sabine et al. 2004; IPCC AR4 2007; Le Quéré et al. 2009). In the past, it was believed that the oceans would offset the effects of greenhouse gas emissions by absorbing CO_2 (Orr et al. 2005, Fabry and Balch 2010). It is now understood that while absorption of CO_2 by the ocean slows the atmospheric greenhouse effect, CO_2 reacts with seawater to fundamentally change the chemical environment in which living marine resources reside. These changes include not only a reduction in pH (hence the term “ocean acidification”) but also changes in the availability of a range of chemical compounds many of which are tightly linked with biological processes (i.e., productivity, respiration, calcification). The geochemical processes driving pH changes are predictable, but the feedbacks between these geochemical processes and marine organisms are not fully understood, such that impacts on marine biodiversity and ecosystems remain difficult to predict. A doubling of the atmospheric CO_2 concentration, which could occur within the next 50 years, would cause a rapid change in marine chemistry and may, in the worse case scenario, lead to mass extinction events not seen for 65 million years (McLeod et al. 2008). Even the most optimistic predictions of future atmospheric CO_2 concentrations (e.g. an increase to approximately 450 parts per million) could be high enough to cause coral reefs to no longer be sustainable (Hoegh-Guldberg et al. 2007, Veron et al. 2009), bivalve reefs to slow or even stop developing, and large areas of polar waters to become corrosive to shells of some key marine species. Effects at lower trophic levels (e.g., phytoplankton) will have cascading impacts on higher trophic levels as food web dynamics are impacted by reduced primary production.

Impacts on Marine Ecosystems:

These physical and chemical changes in the marine environment will directly impact the biological functions of the species occupying these systems. Thus, as changes occur in ocean temperature or pH, one can expect changes in nutrient availability, biological productivity, reproductive success, the timing of biological processes (e.g., spawning), biogeography, migrations, community structure, predator-prey relationships, and entire biomes. For example:

- Temperature changes in marine ecosystems will affect ecological processes such as productivity, species interactions, and even toxicity of compounds found in marine systems (Schiedek et al. 2007).
- Species are adapted to specific ranges of environmental temperatures. As temperatures change, species can respond by: 1) migrating poleward or deeper; 2) reducing their climate niche within the existing range; 3) evolve; or 4) go extinct (Mueter and Litzow 2008, Cheung et al. 2009, Nye et al. 2009, Overholtz et al. 2011), creating new combinations of species that will interact in unpredictable ways. Changes in ocean circulation patterns will change larval dispersal patterns and the geographic distributions of marine species (Block et al. 2011). Between 2000 and 2100, warming in the North Pacific is projected to result in a 30 percent increase in the area of the subtropical biome, while areas of the equatorial upwelling and temperate biomes will decrease by 28 percent and 34 percent, respectively (Polovina et al. 2010).

- Altered patterns of wind and water circulation in the ocean environment will influence the vertical movement of ocean waters (i.e., upwelling and downwelling). This coupled with increased stratification of the water column resulting from changes in salinity and water temperature will change the availability of essential nutrients and oxygen to marine organisms throughout the water column.
- Warming of both air and ocean temperatures has resulted in the loss of Arctic sea ice. Retreat of sea ice has resulted in the loss of habitat for marine mammals such as ice seals and polar bears (*Ursus maritimus*) which are adapted to live on or engage in some activities on the ice. Variation in the spatial extent of sea ice and timing of the spring retreat has strong effects on the productivity of the Bering Sea ecosystem. For example, the timing of the spring phytoplankton bloom is directly tied to the location of the sea ice edge over the Bering Sea shelf (Stabeno et al 2001).
- Increased ocean acidification will directly and indirectly impact physiological and biological processes of marine organisms such as growth, development, and reproduction (Le Quesne and Pinnegar 2011).

Species can respond to gradual changes in the climate over long time scales of years to decades to centuries and adapt biologically to new conditions. A primary concern for fish, wildlife, and plants and their ecosystems is the rapid rate of change currently observed and the fundamental changes in mean ecosystem state to which these organisms have adapted. While many species can respond to changing conditions over long time frames (decades or longer) the current rate of change is likely too fast for many species to respond to and biologically adapt.

KELP FOREST COMMUNITIES

The Channel Islands of southern California are frequently praised as the “Galapagos of North America” for their beauty, biological diversity, and recreational value. Forests of Giant kelp (*Laminariales*) provide habitat to over 1,000 species of marine fishes and invertebrates. To address concerns over declines in marine species, the California Fish and Game Commission established a network of no-take marine protected areas (MPAs) in state waters in and adjacent to Channel Islands National Park and National Marine Sanctuary in 2003, after four years of civic engagement and scientific and socio-economic analyses. In 2006 and 2007, NOAA extended the MPAs into deeper, adjacent federal waters of the National Marine Sanctuary (80 percent of park and sanctuary waters remain open to recreational and commercial fisheries). Long-term ecological monitoring began at Channel Islands National Park in 1982. Research and monitoring by the U.S. Geological Survey, NOAA, National Park Service, California Department of Fish and Game, University of California, non-governmental organizations and others under the Partnership for Interdisciplinary Studies of Coastal Oceans have greatly expanded scientific understanding of the restorative effects of these new MPAs.

Comparative monitoring of areas inside and outside of MPAs has demonstrated increases in size and abundance of several fish species. Moreover, recovery of certain key species is maintaining optimal conditions for growth and recovery of kelp. Spiny lobster (*Panulirus interruptus*) and sheephead (*Semicossyphus pulcher*), which are popular commercial and recreational target species, are also important predators of urchins, which in turn graze on kelp in rocky habitats. Protecting lobsters and sheephead in these reserves has helped to maintain top-down predator control of urchins that have overpopulated and overgrazed kelp forest habitats and transformed many areas into urchin barrens. In addition to increasing size and abundance of several fish species, studies have shown that kelp abundances have increased at much greater proportions inside than outside of these MPAs (CA DFG 2008). The Channel Islands MPAs and others created by the state of California through the Marine Life Protection Act, offer a promising adaptation strategy for reducing non-climate stressors on kelp forest ecosystems and enhancing their ability to recover from climate-induced disturbances such as El Nino Southern Oscillation (ENSO) events. Large storms and warm water from the 1983 ENSO event caused profound impacts on near-shore communities, including complete loss of kelp from many areas.

Regional changes are more relevant to understanding ecological responses to climate change than are global averages (Walther et al. 2002). Impacts of climate change should therefore not only be studied on ocean basin scales, but also at regional and local scales by downscaling global climate models (Stock et al. 2010) complimented with empirical observation, monitoring, and experiments.

Impacts of Non-Climate Stressors:

The impacts of climate change on species can be made worse when combined with the impacts of non-climate stressors. The National Center for Ecological Analysis and Synthesis has mapped[2] and published (Halpern et al. 2008) stressors resulting from human activities on marine ecosystems worldwide. Major non-climate stressors include habitat loss or modification, anthropogenic noise, harmful algal blooms,[3] fishing (Hilborn et al. 2003, Pauly et al. 2005, Mora et al. 2009, Worm et al. 2009, Murawski 2010, Branch et al. In Press); agricultural, industrial, and household activities producing nutrient and contaminant enrichment and introduce debris in coastal waters (Carpenter et al. 1998, Cloern 2001, Anderson et al. 2002); energy/mineral exploration and extraction (Paine et al. 1996); and a variety of marine hazards related to human activities (e.g. Crain et al. 2008). Stresses from these sources have the potential to exacerbate the effect of climate change. Alternatively, reducing the impacts of these stressors (in association with climate change) presents a management opportunity to moderate the effect of climate change on marine systems and species, while efforts continue to reduce green house gas emissions.

Vulnerable Habitats and Species:

Climate change has the potential to affect a wide variety of marine habitats (Table 2). Within these habitats individual species show a varied response to climate change, and our current knowledge of these responses can be characterized in three ways: species currently known to exhibit negative responses; species anticipated to be affected negatively within the foreseeable future; and species for which either a positive or neutral response is anticipated.

A well-documented example of taxa responding to ocean climate change is marine fish species. Shifts of fish stocks to higher latitudes and deeper depths as a physiological or behavioral response to higher temperatures have been observed in many ecosystems (Mueter and Litzow 2008, Cheung et al. 2009, Nye et al. 2009, Overholtz et al. 2011). One obvious repercussion of these shifts is that fishermen will have to travel further and spend more time catching the fish that were historically easier to catch because they were in closer proximity and at shallower depths. While it is true that as some commercial stocks shift northward, others may take their place, fishers will still have to undertake the costly task of updating infrastructure to effectively harvest the changing mixture of fish stocks. Fishery agencies will also have to update domestic and international regulatory measures to conform to these new stock boundaries.

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[2] http://www.nceas.ucsb.edu/globalmarine

[3] http://www.cop.noaa.gov/stressors/extremeevents/hab/current/CC_habs.aspx

Another well-studied example is shallow water coral reefs. Perhaps the most obvious effect of a changing climate on coral reefs is the “bleaching” associated with increased water temperatures and ultraviolet (UV) irradiance which can cause mortality. Even if a coral survives a bleaching event there is a greater risk of disease and reduced reproduction over the next season. Ocean acidification has been demonstrated to impact coral and shellfish reef growth, reproduction, and structural integrity and taken together these impacts could result in loss of coral reefs in many areas in the near future (Veron et al. 2009). Indeed, the listing of elkhorn (*Acropora palmate*) and staghorn (*Acropora cervicornis*) corals as “threatened species” under the U.S. Endangered Species Act (ESA) was because the major threats (i.e., disease, hurricanes, and elevated sea surface temperature) are severe, unpredictable, and likely to increase in the future.

CORAL REEF BLEACHING


Photo: NOAA/Eakin

Coral reefs are one the most productive ecosystems on Earth. At the heart of the coral reef’s success is a symbiotic relationship between coral and microscopic algae within the living coral. The coral provides the nutrients that the algae need to capture CO_2 through photosynthesis. The algae, in turn, provide coral with the carbon they need to build their skeletons—and thus, the reef itself.

A changing climate is threatening this symbiotic relationship and the whole coral reef ecosystem. When sea temperatures rise too much, the coral expel their alage, a process called bleaching (since the coral become whiter without their symbionts). In 2005, up to 90 percent of shallow-water corals in the British Virgin Islands bleached in response to increased water temperatures (Wilkinson and Souter 2008). Bleaching has profound effects on corals and the loss of the symbionts can ultimately cause the bleached coral to starve to death.

Bleaching isn’t the only threat to coral. Rapid increases in the atmospheric CO_2 concentration, and thus, ocean acidification, may be the final insult to these ecosystems. The absorption of atmospheric CO_2 by the world’s oceans contributes to chemical reactions which ultimately reduce the amount of carbonate making it unavailable to coral to build their skeletons (Hoegh-Guldberg et al. 2007).

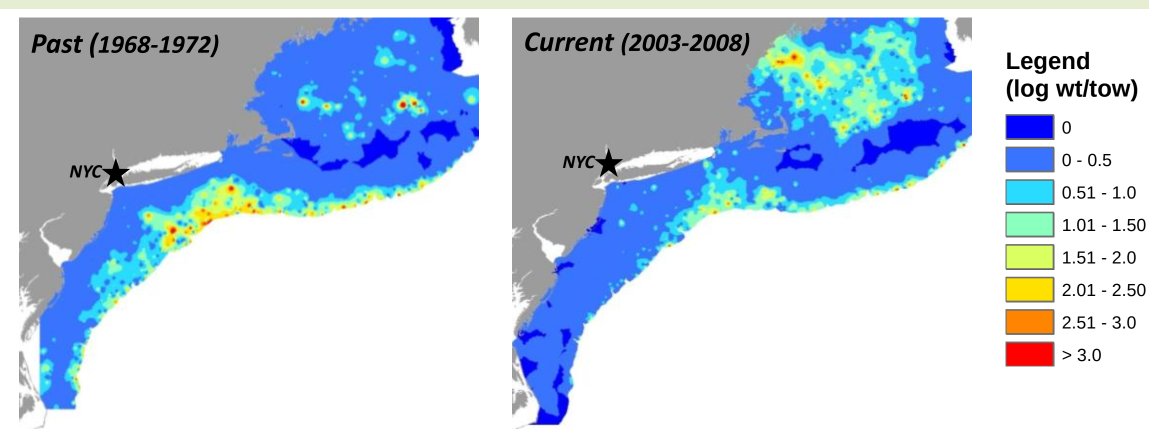
An effort is underway to try to protect coral reefs by making them more resilient to climate change. The Nature Conservancy has started a Reef Resilience program, working in the Florida Keys in partnership with the State of Florida, NOAA, and Australia’s Great Barrier Reef Marine Park Authority, to understand the non-climate factors that adversely affect coral reefs such as damage from charter and private vessels and improper erosion control. The hope is that by reducing these non-climate stressors, the coral will be better able to resist being bleached when sea temperatures increase. A related approach, being studied by scientists at the University of Miami, Australia Institute of Marine Science, and elsewhere, is actively inoculating corals with algal symbionts that are resistant to higher water temperatures.

Climate projections of fish stocks and fisheries in the future predict that changes will continue. In a study coupling climate models to an Atlantic cod (*Gadus morhua*) population model, Fogarty et al. (2008) showed that the maximum sustainable yield of cod could decrease by 50 percent by the end of the century in response to climate change. In a similar study, Atlantic croaker (*Micropogonias undulates*) is projected to expand northwards, have the population increase, and have the maximum sustainable yield increase (Hare et al. 2010). Studies linking fish population models to climate models have been conducted in other regions (Hollowed et al. 2009) and in general, these projections suggest that in a given region, some fishery stocks will benefit from climate change, while others will be harmed.

SHIFTING SPATIAL DISTRIBUTIONS OF U.S. FISH STOCKS

The United States is fortunate to have several multispecies fish monitoring programs in its large marine ecosystems where the abundance and location of important fish and macroinvertebrate species are consistently documented each year. Without these long time series of data, shifts in spatial distribution of U.S. fish stocks would never have been detected. Several studies using these data have found large distributional shifts in marine fish in the California Current Ecosystem (Hsieh et al. 2008), Bering Sea (Mueter and Litzow 2008), and the Northeast United States (Nye et al. 2009).

In the Northeast, two-thirds of 36 examined fish stocks shifted northward and/or to deeper depths over a 40-year time period in response to consistently warm waters (Nye et al. 2009). The figure below shows the past and present spatial distribution of a commercially important fish species, silver hake, as an example of shifts that have been observed in this area. Surf clams in this area also suffered higher mortality in recent warm years and are now found only at deeper depths (Weinberg 2005). Similarly, in the Bering Sea, fish have moved northward as sea ice cover is reduced and the amount of cold water from melting sea ice is reduced (Mueter and Litzow 2008). In both cases, fishers have to travel further and set their nets to deeper depths, increasing the costs associated with fishing. In both ecosystems, fish stocks are shifting closer to the borders of neighboring Canada and Russia, requiring coordinating monitoring and assessment of key stocks. In the California ecosystem, shifts in spatial distribution were more dramatic in species that were heavily fished (Hsieh et al. 2008). Combined, these studies stress the importance in preventing overfishing in healthy stocks to enhance recovery of those at low abundance such that these shifts in spatial distribution and the resilience of these species will not be exacerbated by climate change.



Silver hake distribution in the past as compared to its present distribution (Nye et al. 2011).

Climate change is also predicted to affect a number of other species in the foreseeable future. This is particularly true for Arctic species, where shrinking ice cover reduces habitat and increases adult and juvenile mortality in some species. In 2005, the International Union for Conservation of Nature (IUCN)

Polar Bear Specialist Group reviewed the status of polar bears using the IUCN Red List categories and criteria. The group concluded that the Red List classification of the polar bear should be upgraded from Least Concern to Vulnerable based on the likelihood of a predicted decline in the total global polar bear population of more than 30 percent within the next 35 to 50 years. Similarly in 2008, the United States classified the polar bear as a "threatened species" under the ESA because of a projected decline in abundance. The main cause of this projected decline in polar bear numbers is malnutrition and reduced survival resulting from the projected loss of sea ice habitat required by polar bears and their prey (e.g., ring seals (*Pusa hispida*)). If current warming trends continue unabated, polar bears will be vulnerable to extinction within the next century.

Some species may, however, benefit from climate change. For example, the recovery of bleaching corals may be positively affected in those locations where sea surface winds increase, thus resulting in increased upwelling of cooler deep ocean waters and less penetration of UV light through the water column. However, this benefit may be at least partially offset in some cases by an increase in primary productivity and the concomitant change in community composition (Bakun 1990); the fact that bleaching events are becoming much more frequent; and if hurricanes grow in intensity, they can also be very physically destructive to reefs. Other examples include range expansion and potential population growth of Atlantic croaker, submerged aquatic vegetation benefiting from higher CO_2 levels, and some warmer water marine fishes growing bigger/faster. These may, however, all be initial positive benefits which may, at a later date, be overwhelmed by other climate stressors (e.g., thermal changes).

Ultimately, virtually all marine species will be affected by climate change and ocean acidification. The most vulnerable are those with narrow environmental tolerances, specialized habitat requirements, dependency on a specific environmental trigger or on interspecific interactions which are likely to be disrupted by climate change, or have a poor ability to disperse to a new or more suitable range. Species with these traits will be even more vulnerable if they have a small population, a low reproductive rate, long generation times, low genetic diversity, and are threatened by other human activities.

Climate Adaptation Strategies and Actions for Marine Systems

The *Strategy* identifies seven primary Goals to help fish, wildlife, plants and ecosystems cope with the impacts of climate change. As discussed in the Introduction, these Goals were developed collectively by diverse teams of federal, state, and tribal technical experts, based on existing research and understanding regarding the needs of fish, wildlife and plants in the face of climate change. Each Goal identifies a set of initial Strategies and Actions that should be taken or initiated over the next five to ten years.

Actions listed here were derived from those Technical Team submissions determined to be most applicable to marine systems. Numbers that correspond to the full *Strategy* document are designated by *Strategy* (S) and the Action number (e.g., 1.1.1).

GOAL 1: Conserve habitat to support healthy fish, wildlife and plant populations and ecosystem functions in a changing climate.

Strategy 1.1: Identify areas for an ecologically-connected network of terrestrial, freshwater, coastal, and marine conservation areas that are likely to be resilient to climate change and to support a broad range of fish, wildlife, and plants under changed conditions.

Actions:

— A: Identify and map high priority marine areas for conservation using information on species distributions (current and projected), habitat classification and geophysical settings (including areas of rapid change and slow change). (**S 1.1.1**)

— B: Identify and prioritize for consideration marine areas currently experiencing rapid climate impacts (e.g., Arctic, tropical reef ecosystems). (**S 1.1.2**)

— C: Establish and maintain a comprehensive, inter-jurisdictional inventory of current conservation areas and candidate high priority conservation areas in order to coordinate future conservation efforts. (**S 1.1.4**)

— D: Assess current Marine Managed Areas (MMA) for value in protecting against and/or building resilience to climate change impacts on the local, regional, national and international level, and identify important gaps.

— E: Create geo-referenced depiction of the current U.S. MMAs compatible with the Multipurpose Marine Cadastre, and the National Information Management System under development for Coastal and Marine Spatial Planning.

Strategy 1.2: Secure appropriate conservation status on areas identified in Action 1.1.1 to complete an ecologically-connected network of public and private conservation areas that will be resilient to climate change and support a broad range of species under changed conditions.

Actions:

— A: Conserve areas identified in Action 1.1.1 that provide high-priority habitats under current climate conditions and are likely to be resilient to climate change and/or support a broad array of species in the future. (**S 1.2.1**)

— B: Build redundancy into the network of conservation areas by protecting multiple examples of the range of priority areas identified in Action 1.1.1. (**S 1.2.3**)

— C: Identify other marine spatial management tools besides MMAs that are useful for addressing climate change impacts and ensure wide distribution to managers of the type, authority for and best application of each type.

Strategy 1.3: Restore habitat features where necessary and practicable to maintain ecosystem function and processes and resiliency to climate change.

Actions:

- A: Develop and implement restoration protocols and techniques that promote marine ecosystem resilience and facilitate adaptation under a range of possible future conditions. (**S 1.3.1**)
- B: Restore degraded habitats as appropriate to support diversity of species assemblages and ecosystem structure and function. (**S 1.3.2**)
- C: Restore or enhance areas that will provide essential habitat and ecosystem services during ecosystem transitions under a changing climate. (**S 1.3.3**)

Strategy 1.4: Conserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.

Actions:

- A: Assess and prioritize critical connectivity gaps and needs across current marine conservation areas. (**S 1.4.2**)
- B: Assess and take steps to reduce risks of facilitating movement of undesirable non-native species, pests, and pathogens. (**S 1.4.4**)
- C: Identify and protect habitats important for maintaining connectivity and supporting robust populations of marine species including areas likely to serve as refugia in a changing climate.

GOAL 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.

Strategy 2.1: Update current or develop new species, habitat, and land and water management plans, programs and practices to consider climate change and support adaptation.

Actions:

- A: Incorporate climate change considerations into existing and new management plans and practices using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, and scenario planning. (**S 2.1.1**)
- B: Develop and implement best management practices to support habitat resilience in a changing climate. (**S 2.1.2**)
- C: Identify species and habitats particularly vulnerable to transition under climate change and develop management strategies and approaches for adaptation. (**S 2.1.3**)

Strategy 2.2: Develop and apply species-specific management approaches to address critical climate change impacts where necessary.

Actions:

- A: Use vulnerability and risk assessments to design and implement management actions at species to ecosystem scales. (**S 2.2.1**)
- B: Develop criteria and guidelines for the use of translocation, assisted migration, and captive breeding as climate adaptation strategies. (**S 2.2.2**)
- C: Where appropriate, actively manage populations of vulnerable species as part of fisheries, protected species or other management activities to maintain biodiversity, human use, and other ecological functions. (**S 2.2.3**)

Strategy 2.3: Conserve genetic diversity by protecting diverse populations and genetic material across the full range of species occurrences.

Actions:

— A: Identify, protect and maintain areas/sources of genetic diversity among marine species across ranges of target species.
— B: Develop and implement approaches for assessing and maximizing the genetic diversity of species. (**S 2.3.1**)
— C: Develop protocols for use of propagation techniques to rebuild abundance and genetic diversity for particularly at-risk species. (**S 2.3.3**)

ADAPTATION STRATEGIES FOR SALMON

Photo: AFWA

Salmon are a valuable group of species with high commercial, cultural, recreational and ecological value. As a cold-water dependent species, their health, migrations, distribution, and performance is affected by stream flow and water temperature. Therefore, declining stream flows and summer temperature increases predicted with climate change may have wide ranging impacts. To assess potential effects on salmon, future climate conditions were modeled in Washington State, including simulations of stream flow and summertime stream temperatures (Mantua et al. 2009). Modeled results showed widespread and large increases in air and stream temperature with the largest changes projected for watersheds in Eastern Washington. These changes will be detrimental to salmon, but there are management steps that can be taken to reduce climate change impacts and improve habitat conditions for salmon.

Mantua et al. (2009) highlighted "an urgent need for mapping existing and potential thermal and hydrological refugia in order to prioritize habitat protection and restoration efforts." Once high priority watersheds have been identified, they recommended adaptation strategies to ameliorate increasing stream flow or temperatures, including:

- reducing out-of-stream water withdrawals during periods of high temperature and low stream flow;
- restoring floodplain functions that recharge aquifers;
- protecting undercut banks and deep stratified pools;
- restoring vegetation in riparian zones;
- protecting and enhancing in-stream flows in summer;
- strategic cold-water releases from large storage reservoirs during summer; and
- reconnection of watersheds to cooler, protected headwater reaches by removing barriers to upstream fish passage.

Strategies that conserve cold-water habitats are already being implemented as part of restoration efforts for salmon listed under the ESA. For example, removal of two aging dams on the Elwha River in Washington State will restore passage of salmon to more than 60 miles of high elevation, cold-water habitat in Olympic National Park. This is one action in a larger strategy to increase salmon resilience by reconnecting high elevation habitats that have been blocked by dams, which increases salmon life history diversity and resilience by providing fish access to a high-diversity of habitat types (Waples et al. 2009). A second example is the Columbia Basin Water Transactions Program, which uses a variety of strategies to reduce water withdrawals during low flow periods, including water rights acquisition, leases, or other water conservation actions. Such actions will reduce the effects of declining stream flows and rising stream temperatures as a result of climate change, and as well as help reduce other stresses on salmon populations. Finally, restoration of riparian zones is often used to help reduce summer stream temperatures, which not only partly protects streams against rising temperatures but also restores many other riparian functions including reducing sediment and pesticide delivery to streams, and inputs of leaf litter and large logs that support stream food webs and create habitat diversity. Many of these riparian restoration efforts are currently funded through the USDA Conservation Reserve Enhancement Program or through NOAA's Pacific Coastal Salmon Recovery fund.

GOAL 3: Enhance capacity for effective management in a changing climate.

Strategy 3.1: Increase the climate change awareness and capacity of natural resource managers and enhance their professional capacity to design, implement, and evaluate fish, wildlife, and plant adaptation programs.

Actions:

— A: Build on existing needs assessments to identify gaps in climate change knowledge and technical capacity among natural resource professionals. (**S 3.1.1**)

— B: Develop training on the use of existing and emerging tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, decision support tools, and adaptive management). (**S 3.1.3**)

— C: Support and enhance web-based clearinghouses of information and tools on climate change impacts and adaptation strategies in marine and coastal ecosystems. (**S 3.1.6**)

— D: Develop regional downscaling of Global Climate models to conduct vulnerability assessments of marine living marine resources.

— E: Evaluate the effectiveness of adaptation strategies by explicitly incorporating mechanisms of change into policies.

Strategy 3.2: Facilitate a coordinated response to climate change at landscape, regional, national, and international scales across state, federal, and tribal natural resource agencies and private conservation organizations.

Actions:

— A: Use regional venues such as Regional Fishery Management Councils, Regional Ocean Partnerships, Landscape Conservation Cooperatives to collaborate across jurisdictions and develop marine conservation goals and seascape scale plans capable of sustaining marine resources at desired levels. (**S 3.2.1**)

— B: Collaborate with tribal governments and native peoples to integrate traditional ecological knowledge and principles into climate adaptation plans and decision-making. (**S 3.2.4**)

— C: Engage with international neighbors, including Canada, Mexico, Russia, and nations in the Caribbean Basin, Arctic Circle, and Pacific Ocean to help adapt to and mitigate climate change impacts in shared trans-boundary areas and for common migratory species. (**S 3.2.5**)

Strategy 3.3: Review existing federal, state and tribal legal, regulatory and policy frameworks that provide the jurisdictional framework for conservation of fish, wildlife, and plants to identify opportunities to improve, where appropriate, their utility to address climate change impacts.

Actions:

— A: Review existing legal, regulatory and policy frameworks that govern protection and restoration of habitats and ecosystem services and identify opportunities to improve, where appropriate, their utility to address climate change impacts. (**S 3.3.1**)

— B: Continue the ongoing work of the Joint State Federal Task Force on Endangered Species Act (ESA) Policy to ensure that policies guiding implementation of the ESA provide appropriate flexibility to address climate change impacts on listed fish, wildlife and plants and to integrate the efforts of federal, state, and tribal agencies to conserve listed species. (**S 3.3.6**)

Strategy 3.4: Optimize use of existing fish, wildlife, and plant conservation funding sources to design, deliver, and evaluate climate adaptation programs.

Actions:

— A: Prioritize funding for land and water protection programs that incorporate climate change considerations. (**S 3.4.1**)

— B: Review existing federal, state, and tribal grant programs and revise as necessary to support funding of climate change adaptation and include climate change considerations in the evaluation and ranking process of grant selection and awards. (**S 3.4.2**)

— C: Collaborate with state and tribal agencies and private conservation partners to sustain authorization and appropriations for the State and Tribal Wildlife Grants Program and include climate change criteria in grant review process. (**S 3.4.3**)

GOAL 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.

Strategy 4.1: Support, coordinate, and where necessary develop distributed but integrated inventory, monitoring, observation, and information systems to detect and describe climate impacts on fish, wildlife, plants, and ecosystems.

Actions:

— A: Develop consensus standards and protocols that enable multi-partner use and data discovery, as well as interoperability of databases and analysis tools related to fish, wildlife, and plant observation, inventory, and monitoring. (**S 4.1.2**)

— B: Strengthen and expand efforts to support integrated observations on climate change impacts on ocean habitats and living marine resources.

— C: Develop sentinel site networks to provide integrated early warning and tracking of climate change impacts on marine habitats and living marine resources for decision makers.

— D: Collaborate with the National Phenology Network to facilitate monitoring of phenology and create an analogous National Population Network to catalog the changes in distribution and abundance of fish, wildlife, and plants that have been identified as most vulnerable to climate change. (**S 4.1.9**)

Strategy 4.2: Identify, develop, and employ decision support tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, strategic habitat conservation approaches, and adaptive management evaluation systems) via dialogue with scientists, managers (of natural resources and other sectors), and stakeholders.

Actions:

— A: Develop regional downscaling of Global Climate models to conduct vulnerability assessments of marine living marine resources (**S 4.2.1**)

— B: Engage scientists, resource managers, and stakeholders in climate change scenario planning processes, including identification of a set of plausible future scenarios associated with climate phenomena likely to significantly impact fish, wildlife, and plants. (**S 4.2.2**)

— C: Conduct risk assessments to identify key climate change hazards and assess potential consequences for fish, wildlife and plants.

— D: Conduct vulnerability and risk assessments for priority marine species (threatened and endangered species, species of greatest conservation need, species of socioeconomic and cultural significance). (**S 4.2.4**)

— E: Use observation, information, assessment, and decision support systems to monitor and determine the effectiveness of specific management actions to analyze the potential for maladaptation and adapt management approaches appropriately. (**S 4.2.8**)

GOAL 5: Increase knowledge and information on impacts and responses of fish, wildlife and plants to a changing climate.

Strategy 5.1: Identify knowledge gaps and define research priorities via a collaborative process among federal, state, and tribal resource managers and research scientists working with the National Science Foundation (NSF), USGCRP, National Climate Assessment (NCA), USDA Extension, Cooperative Ecosystem Study Units (CESUs), Climate Science Centers (CSCs), LCCs, Migratory Bird Joint Ventures (JVs), and Regional Integrated Sciences and Assessments (RISAs).

Actions:

— A: Increase coordination and communication between resource managers and researchers through existing forums (e.g., NSF, USGCRP, NCA, USDA, CESUs, CSCs, LCCs, JVs, RISAs, and others) to ensure research is connected to management needs. (**S 5.1.1**)

— B: Bring managers and scientists together to prioritize research needs that address resource management objectives under climate change. (**S 5.1.2**)

Strategy 5.2: Conduct research into ecological aspects of climate change, including likely impacts and the adaptive capacity of species, communities and ecosystems, working through existing partnerships or new collaborations as needed (e.g., USGCRP, NCA, CSCs, RISAs, and others).

Actions:

— A: Produce regional to subregional projections of future climate change impacts on physical, chemical, and biological conditions for U.S. marine ecosystems. (**S 5.2.1**)

— B: Support basic research on life histories and food web dynamics of marine fish, wildlife, and plants to increase understanding of how species are likely to respond to changing climate conditions and identify survival thresholds. (**S 5.2.2**)

— C: Accelerate research on establishing the value of ecosystem services and identify potential impacts (e.g., loss of pollution abatement) from climate change. (**S 5.2.4**)

— D: Increase research on early life histories, food web dynamics, and other species interactions to better understand implications of climate change on ecological interrelationships among marine dependent fish, wildlife, and plants.

Strategy 5.3: Advance understanding of climate change impacts and species and ecosystem responses through modeling.

Actions:

— A: Define the suite of physical and biological variables and ecological processes for which predictive models are needed via a collaborative process among state, federal, and tribal resource managers, scientists, and model developers. (**S 5.3.1**)

— B: Develop climate sensitive growth and yield models for marine species to ensure long-term sustainability of marine species and habitats. (**S 5.3.3**)

— C: Develop models to provide predictions of physical atmospheric and oceanographic climate changes for the marine waters of the EEZ.

GOAL 6: Increase awareness and motivate action to safeguard fish, wildlife and plants in a changing climate.

Strategy 6.1: Increase public awareness and understanding of climate impacts to natural resources and ecosystem services and the principles of climate adaptation at regionally- and culturally-appropriate scales.

Strategy 6.2: Engage the public through targeted education and outreach efforts and stewardship opportunities.

Strategy 6.3: Coordinate climate change communication efforts across jurisdictions.

— A: Develop and implement communication efforts between NOAA and DOI to increase awareness of the impacts and responses to climate change in marine ecosystems. (**S 6.3.1**)

GOAL 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.

Strategy 7.1: Slow and reverse habitat loss and fragmentation.

Actions:

— A: Work with fisheries managers and other marine resource users to identify shared interests and potential conflicts in reducing and reversing habitat fragmentation and loss through comprehensive planning and zoning. (**S 7.1.1**)

— B: Bridge the gap between ecosystem conservation and economics, and consider market-based incentives that encourage conservation and rehabilitation of marine ecosystems for the full range of ecosystem services. (**S 7.1.6**)

Strategy 7.2: Slow, mitigate, and reverse where feasible ecosystem degradation from anthropogenic sources through land/ocean-use planning, water resource planning, pollution abatement, and the implementation of best management practices.

Actions:

— A: Work with local and regional land-use, water resource, and coastal and marine spatial planners to identify potentially conflicting needs and opportunities to minimize ecosystem degradation resulting from development and land and water use. (**S 7.2.1**)

— B: Work with ocean-use planners to identify potentially conflicting needs and opportunities to minimize marine ecosystem degradation resulting from development and ocean-use change.

Strategy 7.3: Use, evaluate, and as necessary, improve existing programs to prevent, control, and eradicate invasive species and manage pathogens.

Actions:

- A: Employ a multiple barriers approach to detect and contain incoming and established invasive species, including monitoring at points of origin and points of entry for shipments of goods and materials into the United States and for trans-shipment within the country. Utilize education, regulation, and risk management tools (e.g., the Hazard Analysis and Critical Control Point process) to address. (**S 7.3.1**)
- B: Apply integrated management practices, share innovative control methodologies, and take corrective actions when necessary to manage fish, wildlife, and plant diseases and invasives. (**S 7.3.7**)
- C: Avoid use of potentially invasive species in aquaculture and other areas.

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Appendix

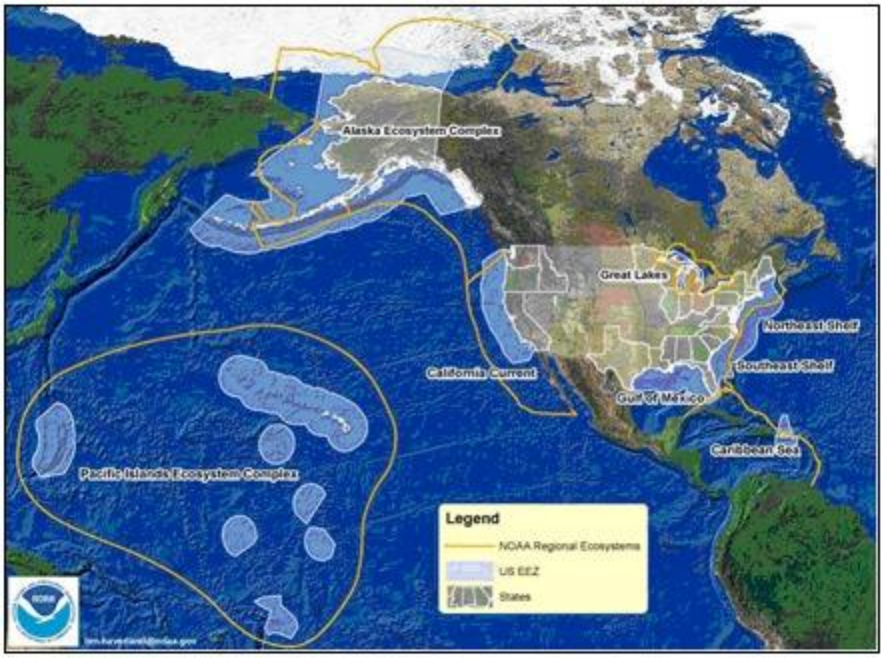

Figure 1. Marine ecosystems considered by the Marine Technical Team

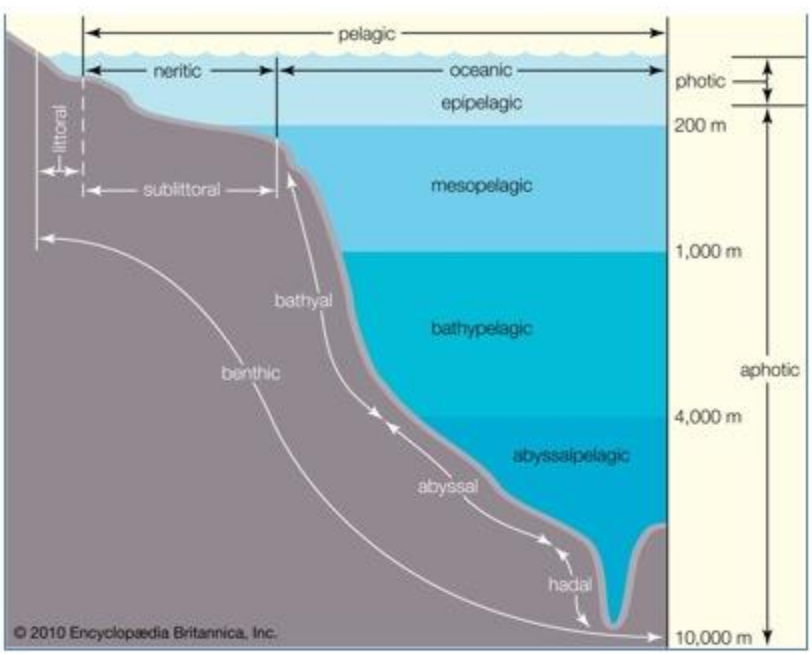

Figure 2. Major marine habitats considered by the Marine Technical Team.

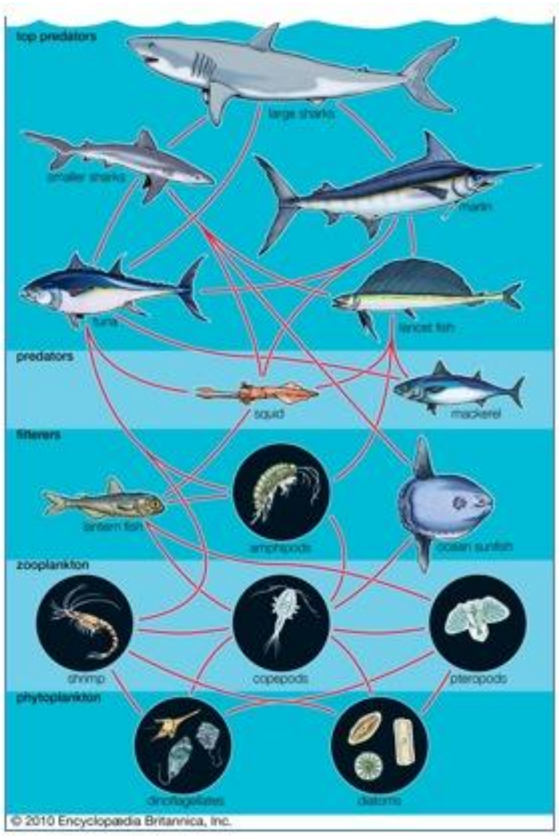

Figure 3. Examples of major marine taxa.

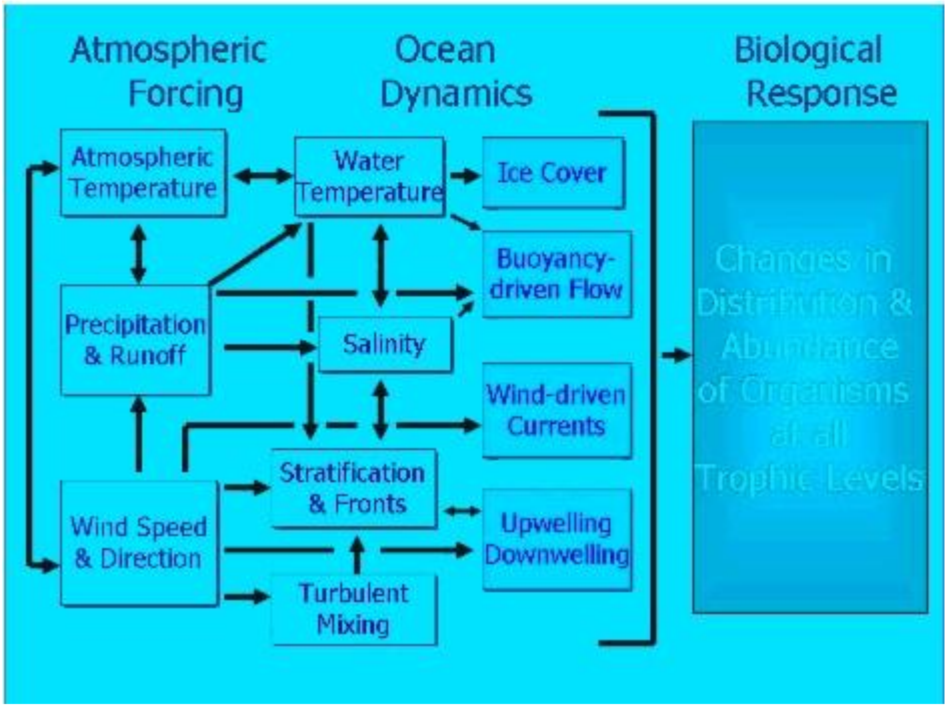

Figure 4. Interactive pathways between changes in atmospheric forcing, ocean dynamics, and biological response in production processes. Changes in atmospheric temperature, precipitation, and winds will affect stratification, buoyancy-driven flows, upwelling and downwelling, sea ice and other factors. These will potentially affect production at all trophic levels. (ICES 2011, redrawn from Glantz 1990)

Table 1. Matrix showing areas of common (C) or rare (R) occurrence of living marine resources in different habitat components of marine ecosystems. Blank cells are areas where these resources are not expected to occur.

Living Marine Resources			Habitat													
			Pelagic Region			Benthic Region										
						Continental Shelf Zone				Continental Slope Zone			Abysssal Zone			
			Epipelagic zone	Mesopelagic zone	Bathypelagic zone	General	Submerged aquatic vegetation	Shallow coral reefs	Salt domes	General	Canyons	Cold seeps	General	Deep coral forests	Sea mounts	Thermal vents
Protista		Phytoplankton	C			C										
		Macroalgae					C									
		Other						C						C	C	C
Plantae		Vascular plants					C									
Animalia	Invertebrate	Cnidaria	C	R	R	C	C	C	R	R	R	R	R	C	R	R
		Molluscs	C	C	R	C	C	C	R	C	C	R	R	R	R	R
		Annelids				C	C	C	R	C	C	R	R	R	R	R
		Echinoderms				C	C	C	R	C	C	R	R	R	R	R
		Arthropods	C	C	R	C	C	C	R	C	C	R	R	R	R	R
	Vertebrates	Pisces	C	C	R	C	C	C	R	C	C	R	R	R	R	
		Reptilia	C			C	C	C								
		Aves	C			C	R	R								
		Mammalia	C	R		C	C	R			R					

Table 2. Matrix showing areas of potential impacts of climate change on marine ecosystem.

Stressor			Habitat														
			Pelagic Region				Benthic Region										
			Shelf	Oceanic			Continental Shelf				Continental Slope Zone			Abysssal			
Climate	Atmospheric change	Oceanic effect - 1st order	Epipelagic zone	Epipelagic zone	Mesopelagic zone	Bathypelagic zone	General	Submerged aquatic vegetation	Shallow coral reefs	Salt domes	General	Canyons	Cold seeps	General	Deep sea coral reefs	Sea mounts	Thermal vents
	Air Chemistry	Ocean acidification (OA)															
		Dissolved oxygen (DO)															
		Biogeomchemistry															
	Temperature	Ocean warming (SST and deeper)															
		Ice melting															
	Precipitation (increased river flow)	Salinity															
		Flushing of rivers and estuaries															
	Pressure gradients decreased (lighter winds)	Wind driven currents															
		Reduced mixing															
	Pressure gradients increased (stronger winds)	Upwelling															
		Wind driven currents															
		Deep mixing															
		Storminess															
		Wind pattern density gradient															

Stressor			Habitat														
			Pelagic Region				Benthic Region										
			Shelf	Oceanic			Continental Shelf				Continental Slope Zone			Abysssal			
Climate	Atmospheric change	Oceanic effect - 1st order	Epipelagic zone	Epipelagic zone	Mesopelagic zone	Bathypelagic zone	General	Submerged aquatic vegetation	Shallow coral reefs	Salt domes	General	Canyons	Cold seeps	General	Deep sea coral reefs	Sea mounts	Thermal vents
Climate		Gyres															
Climate	Light frequency	Solar irradiance															
Climate	Light frequency	Increased UV penetration															
Climate	Decadal variability in atmospheric change	Wind driven currents and gyres															
NonClimate	Extraction	Fishing															
NonClimate	Extraction	Mining															
NonClimate	Extraction	Energy															
NonClimate	Extraction	Nonconsumptive															
NonClimate	Energy production	Thermal discharge															
NonClimate	Energy production	Sea water intake/use															
NonClimate	Energy production	Radiation															
NonClimate	Energy production	Other pollution															
NonClimate	Pollution	Land based															
NonClimate	Pollution	Atmospheric deposition															
NonClimate	Pollution	Marine debris															
NonClimate	Hazards	Marine transportation															
NonClimate	Hazards	Man-made disasters															
NonClimate	Hazards	Invasives															

Stressor			Habitat														
			Pelagic Region				Benthic Region										
			Shelf	Oceanic			Continental Shelf				Continental Slope Zone			Abysssal			
Climate	Atmospheric change	Oceanic effect - 1st order	Epipelagic zone	Epipelagic zone	Mesopelagic zone	Bathypelagic zone	General	Submerged aquatic vegetation	Shallow coral reefs	Salt domes	General	Canyons	Cold seeps	General	Deep sea coral reefs	Sea mounts	Thermal vents
		Natural (disease?)															

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