24. Oceans and Marine Resources

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Key Messages

1. **The rise in ocean temperature over the last century will persist into the future, with continued large impacts on climate, ocean circulation, chemistry, and ecosystems.**
2. **The ocean currently absorbs about a quarter of human-caused carbon dioxide emissions to the atmosphere, leading to ocean acidification that will alter marine ecosystems in dramatic yet uncertain ways.**
3. **Significant habitat loss will continue to occur due to climate change, in particular for Arctic and coral reef ecosystems, while expansions of habitat in other areas and for other species will occur. These changes will consequently alter the distribution, abundance, and productivity of many marine species.**
4. **Rising sea surface temperatures have been linked with increasing levels and ranges of diseases of humans and marine life, such as corals, abalones, oysters, fishes, and marine mammals.**
5. **Altered environmental conditions due to climate change will affect, in both positive and negative ways, human uses of the ocean, including transportation, resource use and extraction, leisure and tourism activities and industries, in nearshore and offshore areas. Many marine activities are designed based on historical conditions. Thus, climate changes that result in conditions substantially different from recent history may significantly increase costs to businesses as well as disrupt public access and enjoyment of ocean areas.**
6. **In response to observed and projected climate impacts, some existing ocean policies, practices, and management efforts are incorporating climate-change impacts. These initiatives, such as increasing the resilience of built infrastructure or natural marine ecosystems, can serve as a model for other efforts and ultimately enable people and communities to adapt to changing ocean conditions.**

As a nation, we depend on the oceans for seafood, recreation and tourism, cultural heritage, transportation of goods, and, increasingly, energy and other critical resources. The U.S. Exclusive Economic Zone extends 200 nautical miles seaward from the coasts, spanning an area about 1.7 times the land area of the continental U.S. and encompassing waters along the U.S. East, West, and Gulf coasts, around Alaska and Hawaii, and including the U.S. territories in the Pacific and Caribbean. This vast region is host to a rich diversity of marine plants and animals and a wide range of ecosystems, from tropical coral reefs to sea ice-covered polar waters in the Arctic.

Oceans support vibrant economies and coastal communities with numerous businesses and jobs. More than 160 million people live in the coastal watershed counties of the U.S., and population in this zone is expected to grow in the future. The oceans help regulate climate, absorb carbon dioxide (an important greenhouse, or heat-trapping, gas), and strongly influence weather patterns far into the continental interior. Ocean issues touch all of us in direct and indirect ways (NMFS 2011; NOC 2012; NRC 2010b; U.S.Commission on Ocean Policy 2004).

Changing climate conditions are already affecting these valuable marine ecosystems and the array of resources and services we derive from the sea. Some climate trends, such as rising seawater temperatures and ocean acidification, are common across much of the coastal areas and open ocean worldwide. The biological responses to climate change often vary from region to region, depending on the different combinations of species, habitats, and other attributes of local systems. Data records for the ocean are often shorter and less complete than those on land, and in many cases it is still difficult to discern long-term ocean trends from natural variability (Doney et al. 2012).

Rising Ocean Temperatures

The rise in ocean temperature over the last century will persist into the future, with continued large impacts on climate, ocean circulation, chemistry, and ecosystems.

Cores from corals, and other indirect temperature measurements, indicate the recent rapid increase of ocean temperature is the greatest that has occurred in at least the past millennium and can only be reproduced by climate models with the inclusion of manmade sources of heat-trapping gas emissions (Jansen et al. 2007; Jungclaus et al. 2010; Mann et al. 2008; Oppo et al. 2009). The ocean is a critical reservoir for heat within Earth’s climate system, and because of seawater’s large heat capacity, small changes in ocean temperature reflect large changes in ocean heat storage. Direct measurement of ocean temperatures shows warming beginning in about 1970 down to at least 2300 feet, with stronger warming near the surface leading to increased thermal stratification of the water column (Levitus et al. 2009; Levitus et al. 2012). Sea surface temperatures in the North Atlantic and Pacific, including near U.S. coasts, have also increased since 1900 (Deser et al. 2010; Smith et al. 2008). In conjunction with a warming climate, the extent and thickness of Arctic sea ice has decreased rapidly over the past four decades (Comiso 2011; Rothrock et al. 2008; Walsh and Chapman 2001). Models that best match historical trends project seasonally ice-free northern waters by the 2030s (Stroeve et al. 2007; Stroeve et al. 2012; Wang and Overland 2012).

Ocean Warming

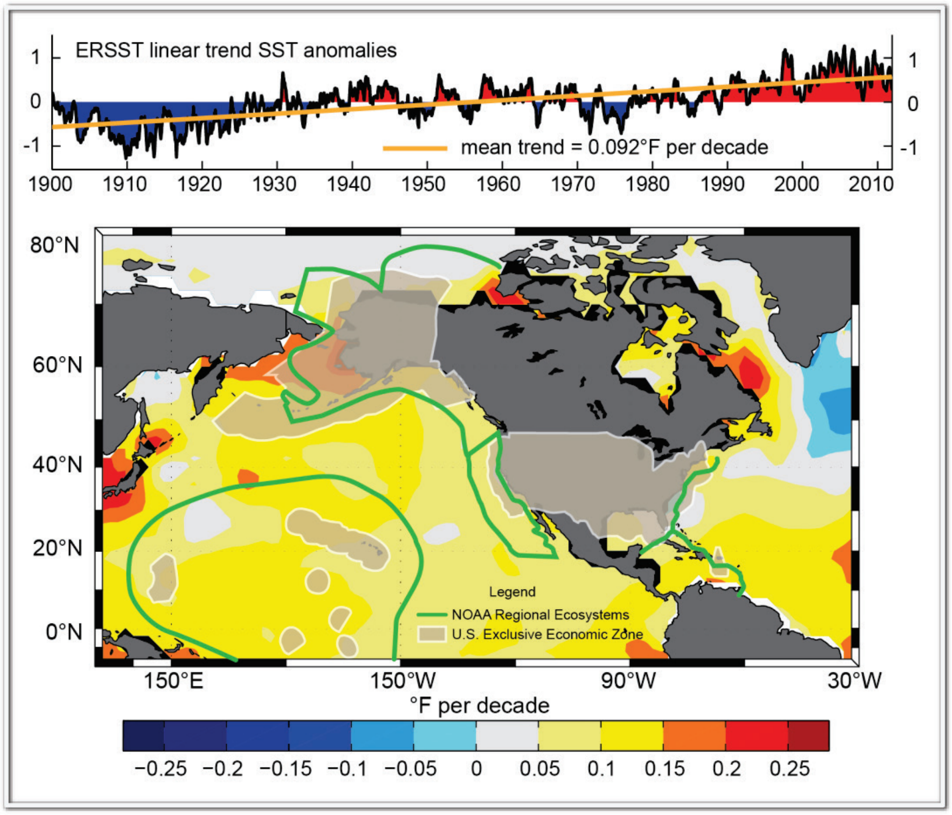

Figure 24.1: Ocean Warming

Caption: The average sea surface temperature (SST, upper panel) for the ocean surrounding the U.S. and its territories (the area covered by the map in the lower panel) has increased by more than 0.9°F over the past century. There is significant variation from place to place, with the ocean off the coast of Alaska, for example, warming far more rapidly than other areas (lower panel). The shading on the map denotes U.S. land territory and the regions where the U.S. has rights over the exploration and use of marine resources, as defined by the U.S. Exclusive Economic Zone (EEZ). Green lines denote the boundaries of the National Oceanic and Atmospheric Administration (NOAA) Regional Ecosystems, which often extend beyond the EEZ. Warming of the upper ocean is reducing the biological productivity of tropical and subtropical (poleward of the tropics) oceans. This can affect the food web, resulting in changes for fisheries and other important human activities that depend on ocean productivity. Adapted from (Chavez et al. 2011).

Climate-driven warming reduces vertical mixing that brings nutrients up from deeper water with potential impacts on biological productivity. Warming and altered ocean circulation are also expected to reduce the supply of oxygen to deeper waters, leading to expected future expansion of sub-surface low-oxygen zones (Keeling et al. 2010; Stramma et al. 2008). Both reduced nutrients at the surface and reduced oxygen at depth have the potential to change ocean productivity (Chavez et al. 2011). Satellite observations indicate that warming of the upper ocean leads to reductions in the biological productivity of tropical and subtropical (poleward of the tropics) oceans and expansion of the area of surface waters with very low plankton biomass (Behrenfeld et al. 2006; Polovina et al. 2008). Ecosystem models suggest that the same patterns of change will occur due to surface warming over this century, perhaps also increasing productivity near the poles (Polovina et al. 2011; Steinacher et al. 2010). These changes can affect ecosystems at multiple levels of the food web, with consequent changes for fisheries and other important human activities that depend on ocean productivity (Doney et al. 2012; Sumaila et al. 2011).

Other changes in the physical and chemical properties of the ocean are also underway due to climate change. These include rising sea level (Church and White 2011a), changes in upper ocean salinity (including reduced salinity of Arctic surface waters) resulting from changed inputs of freshwater and losses from evaporation, increases in wave height from changes in wind speed, and changes in oxygen content at various depths – changes that will affect marine ecosystems and human uses of the ocean in the coming years (Doney et al. 2012).

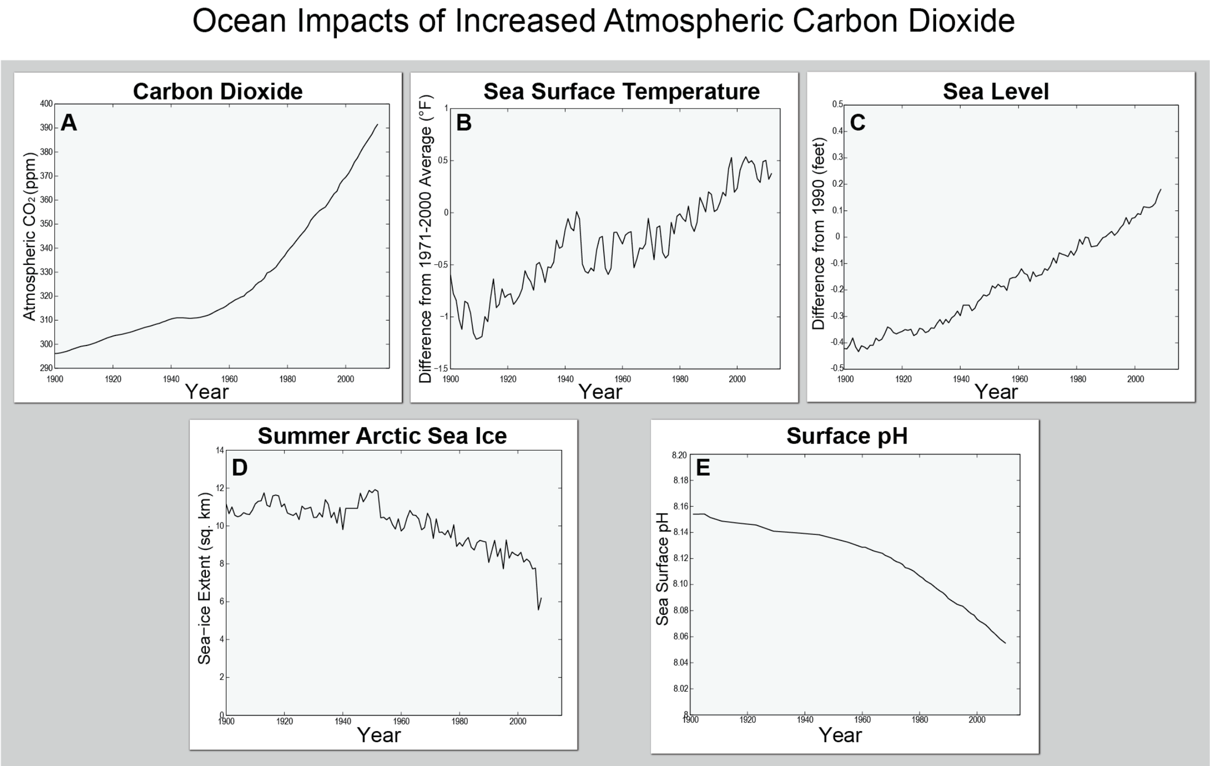

Figure 24.2: Ocean Impacts of Increased Atmospheric Carbon Dioxide

Caption: As heat-trapping gases, primarily carbon dioxide (CO_2) (panel A), have increased over the past decades, not only has air temperature increased worldwide, but so has the temperature of the surface ocean (panel B). The increased ocean temperature, combined with melting of glaciers and ice sheets on land, is leading to higher sea levels (panel C). Increased air and ocean temperatures are also causing the continued, dramatic decline in Arctic sea ice during the summer (panel D). In addition to these climate effects of increased CO_2, the ocean is becoming more acidic as increased atmospheric CO_2 dissolves into the ocean (panel E). (Sources: Adapted from SST: CSIRO 2012; NCDC 2012; Smith et al. 2008) CO_2: (Etheridge 2010; Tans and Keeling 2012), and NOAA NCDC, SLR: (CSIRO 2012) and(Church and White 2011) , pH: (Doney et al. 2012), and Sea Ice: (University of Illinois 2012)

While the global pattern is clear, there is considerable variability in regional and local manifestation of the effects of climate change, because oceanographic conditions are not uniform and are strongly influenced by natural climate fluctuations. Interactions with processes in the atmosphere and on land, such as rainfall patterns and runoff, also vary by region and are strongly influenced by natural climate fluctuations, resulting in additional local variation in the observed effects in the ocean.

Ocean Acidification Alters Marine Ecosystems

The ocean currently absorbs about a quarter of human-caused carbon dioxide emissions to the atmosphere, leading to ocean acidification that will alter marine ecosystems in dramatic yet uncertain ways.

Atmospheric CO_2 has risen by about 40% above preindustrial levels (MacFarling Meure et al. 2006; Tans and Keeling 2012). The ocean absorbs some of the human-caused emissions of carbon dioxide, thereby changing seawater chemistry, decreasing pH (that is, making seawater more acidic) (NRC 2010b; Sabine et al. 1999) (see also Ch. 2: Our Changing Climate, Key Message 11). Regional differences in ocean pH occur as a result of variability in other regional or local conditions as noted above (Feely et al. 2008). Ocean acidification will continue in the future due to the basic physics of the interaction of atmospheric carbon dioxide and ocean water. More acidic waters create repercussions along the marine food chain. For example, calcium carbonate is a skeletal component of a wide variety of organisms in the oceans, including corals. Decreased seawater pH makes it more difficult for these living things to form and maintain calcium carbonate shells and skeletal components, resulting in alterations in marine ecosystems that will become more severe as present-day trends in acidification continue or accelerate (Cooley et al. 2009; Doney et al. 2009; Riebesell et al. 2007). Tropical corals may be particularly susceptible to the combination of ocean acidification and ocean warming, which would threaten the rich and biologically diverse coral reef habitats.

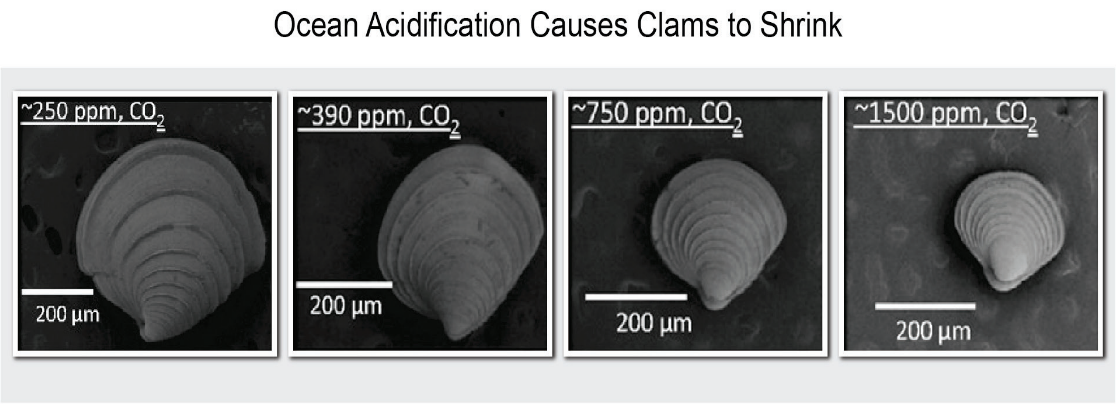

Figure 24.3: Ocean Acidification Causes Clams to Shrink

Caption: The 36-day-old clams in the photos are a single species, *Mercenaria mercenaria*, grown under varying levels of carbon dioxide (CO_2) in the air. CO_2 is absorbed from the air by ocean water, acidifying the water and thus reducing the ability of the clam to grow its shell. As seen in the photos, the clams (measured in microns) become progressively smaller as CO_2 levels rise. Current atmospheric CO_2 concentration is approximately 390 parts per million, which is the level in the second photo from the left, showing that these commercially important animals have already been affected by changes in CO_2 levels since the preindustrial era, when concentration was about 250 parts per million. (Figure source: Talmage and Gobler 2010)

Eighty percent of seafood consumed in the U.S. is imported, and more than half of the imported seafood comes from aquaculture (fish and shellfish farming) (NMFS 2011). Increased ocean acidification, low-oxygen events, and rising temperatures are already affecting shellfish aquaculture operations. Higher temperatures are predicted to increase aquaculture potential in poleward regions, but decrease it in the tropics (De Silva and Soto 2009). Acidification, however, will likely reduce growth and survival of shellfish stocks in all regions (Doney et al. 2009).

Box: The Impacts of Ocean Acidification on the West Coast Aquaculture Industry

Ocean acidification has already changed the way shellfish farmers on the West Coast conduct business. For oyster growers, the practical effect of the lowering pH of ocean water has not only been to make the water more acidic, but also more corrosive to young shellfish raised in aquaculture facilities. Growers at Whiskey Creek Hatchery, located in Oregon’s Netarts Bay, found that low pH seawater during spawning reduced growth in mid-stage larval (juvenile) Pacific oysters (Barton et al. 2012). Hatcheries in Washington State have also experienced losses of spat (oyster larvae that have attached to a surface and begun to develop a shell) due to water quality issues that include other human-caused effects like dredging and pollution (Feely et al. 2010). Facilities like the Taylor Shellfish Farms hatchery on Hood Canal have changed their production techniques to respond to increasing acidification in Puget Sound.

These impacts highlight two changing aspects in regional ocean chemistry: 1) existing natural variation may interact with human-caused change to produce unanticipated results for shellforming marine life, especially in coastal regions (Waldbusser et al. 2011); and 2) as a result, there is an increasing need for information about water chemistry conditions through the use of sensor networks. In the case of Whiskey Creek, instruments installed in collaboration with ocean scientists created an "early warning" system that allows oyster growers to choose the time they take water into the hatchery from the coast. This allows them to avoid the lower-pH water related to upwelling and the commensurate loss of productivity in the hatchery.

From a biological perspective, these kinds of preventative measures can help produce higher-quality oysters. Studies on native Olympia oysters (*Ostrea lurida*) show that there is a "carry-over" effect of acidified water – oysters exposed to low pH conditions while juveniles continue to grow slower in later life stages (Hettinger et al. in press). Research on some oysters species such as Pacific oyster (*Crassostrea gigas*), the commercially important species in U.S. west coast aquaculture, shows that specially selected strains can be more resistant to acidification (Parker et al. 2012).

Overall, economically important species such as oysters, mussels, and sea urchins are highly vulnerable to changes in ocean conditions brought on by climate change. Sea temperature and acidification are expected to increase; the acidity of surface seawater is projected to increase by almost a factor of two by the end of this century. Some important cultured species may all be influenced in developing stages, during fertilization, and as adults (Gibson et al. 2011), resulting in lower productivity. Action groups, such as the California Current Acidification Network (C-CAN), are working to address the needs of the shellfish industry – both wild and aquaculture-based fisheries – in the face of ocean change. These efforts bring scientists from across disciplines together with aquaculturists, fishermen, the "ocean observing" community, and state and federal decision-makers to ensure a concerted, standardized, and cost-effective approach to gaining new understanding of the impact of acidification on ecosystems and the economy.

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Habitat Loss Affects Marine Life

Significant habitat loss will continue to occur due to climate change, in particular for Arctic and coral reef ecosystems, while expansions of habitat in other areas and for other species will occur. These changes will consequently alter the distribution, abundance, and productivity of many marine species.

Species have responded to climate change in part by shifting where they live (Chen et al. 2011; Parmesan 2006). Such range shifts result in ecosystem changes, including the relationships between species and their connection to habitat, because different species adapt to changing conditions in different ways. This means that ocean ecosystems are changing in complex ways, with accompanying changes in ecosystem functions (such as nutrient cycling, productivity of species, and predator-prey relationships). Overall habitat extent is expected to change as well, though the degree of range migration will depend upon the life history of particular species. For example, reduction in seasonal sea ice cover and warmer surface temperatures may open up new habitat in polar regions for some important fish species, such as cod, herring, and pollock (Loeng et al. 2005) However, continued presence of cold bottom-water temperatures on the Alaskan Continental shelf could limit northward migration into the northern Bering Sea and Chukchi Sea

(Sigler et al. 2011). In addition, warming may cause reductions in the abundances of some species, such as pollock, in the their current ranges in the Bering Sea (Mueter et al. 2011). For other ice-dependent species, including several marine mammals such as polar bears and harp seals, the loss of their critical habitat will result in population declines (Moore and Huntington 2008; Wassmann 2011). These changes will result in changing interactions among species with consequences that are difficult to predict.

Climate-change impacts such as ocean temperature increases can profoundly affect production of natural stocks of fish by changing growth, reproduction, survival, and other critical characteristics of fish stocks and ecosystems. Fish stocks are moving poleward and to deeper water (Dulvy et al. 2008; Mueter and Litzow 2008; Murawski 1993; Nye et al. 2009; Perry et al. 2005), and productivity of fisheries is predicted to decline in the lower 48 states, while increasing in parts of Alaska (Cheung et al. 2009). Costs of fishing are predicted to increase as fisheries transition to new species and as processing plants and fishing jobs shift poleward (Sumaila et al. 2011). The cumulative impact of such changes will be highly variable on regional scales because of the combination of factors – some acting in opposite directions. Some areas will benefit from range expansions of valuable species or increases in productivity, while others will suffer as species move away from previously productive areas.

Coral Reef Ecosystem Collapse

Recent research indicates that 75% of the world's coral reefs are threatened due to the interactive effects of climate change and local sources of stress, such as overfishing, nutrient pollution, and disease (Burke et al. 2011; Dudgeon et al. 2010; Hoegh-Guldberg et al. 2007; Hughes et al. 2010). In Florida, all reefs are rated as threatened, with significant impacts on valuable ecosystem services they provide (Mumby and Steneck 2011). Caribbean coral cover has decreased from 50% to only 10%, an 80% reduction, in less than three decades (Gardner et al. 2003). These declines have in turn led to a flattening of the three dimensional structure and a decrease in the capacity of coral reefs to provide shelter and other resources for other reef-dependent species of fish and invertebrates (Alvarez-Filip et al. 2009).

The symbiosis between coral and its associated algae partner is destroyed by higher than usual temperatures and results in a condition where the coral is still alive, but devoid of all its color (bleaching). Bleached corals can later die or become infected with disease (Miller et al. 2009; Weil et al. 2009). Thus high temperature events alone can kill large stretches of coral reef. Evidence suggests that relatively pristine reefs with fewer human impacts and intact fish and associated invertebrates are more resilient to coral bleaching and disease (Sandin et al. 2008).

Figure 24.4: Warming Seas Are a Double-blow to Corals

Caption: A colony of star coral (*Montastraea faveolata)* off the southwest coast of Puerto Rico, estimated to be about 500 years old, exemplifies the effect of rising water temperatures. Increasing diseases due to warming waters (A) were followed by such high temperatures that bleaching, or loss of symbiotic micro-algae from coral occurred (B), followed by more disease (C) that finally killed the colony (D). (Photo credit: Ernesto Weil)

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Rising Temperatures Linked to Diseases

Rising sea surface temperatures have been linked with increasing levels and ranges of diseases of humans and marine life, such as corals, abalones, oysters, fishes, and marine mammals.

There has been a significant increase in reported incidences of disease in corals, urchins, mollusks, marine mammals, turtles, and echinoderms over the last several decades (Ward and Lafferty 2004). The complexity of the host/environment/pathogen interaction makes it challenging to separate climate warming from the myriad of other causes facilitating increased diseased outbreaks in the ocean. However, three categories of disease-causing pathogens are unequivocally related with warming oceans.

Firstly, warmer winters due to climate change can increase the overwinter survival and growth rates of pathogens (Harvell et al. 2009). A disease-causing parasite in oysters that proliferates at high water temperatures and high salinities has spread northward up the eastern seaboard as water temperatures warmed during the 1990s (Cook et al. 1998; Ford 1996). Growth rates of coral-disease lesions increased with winter and summer warming from 1996-2006 (Weil et al. 2009). Winter warming in the Arctic is resulting in increased incidence of a salmon disease in the Bering Sea, and is now thought to be a cause of a 57% decline of Yukon Chinook salmon (Zuray et al. 2012).

Secondly, increasing disease outbreaks of ecologically important species like coral, eelgrass, and abalone have been linked spatially with rising temperature anomalies. The spectacular biodiversity of tropical coral reefs is particularly vulnerable to warming, because the corals that form the foundational reef structure live very near their upper thermal limits. The increasing frequency of record hot temperatures has caused widespread coral bleaching (Eakin et al. 2010) and disease outbreaks (Bruno et al. 2007)), and is a principle factor contributing to the endangered status of a third of the world's reef-building corals (Carpenter et al. 2008). In the Chesapeake Bay, eelgrass died out almost completely during the record-hot summers of 2005 and 2010 (Moore and Jarvis 2008), and the California black abalone has been driven to the edge of extinction by a combination of warming water and a bacterial disease (Altstatt et al. 1996; Neumann et al. 2010).

Thirdly, there is evidence that increased water temperature is responsible for the enhanced survival and growth of certain marine bacteria that make humans sick (Baker-Austin et al. 2012). Warm seasonal expansion of *Vibrio parahaemolyticus*, a pathogenic bacterial species, is responsible for human illnesses associated with oysters harvested from the Gulf of Mexico (Martinez-Urtaza et al. 2010) and northern Europe (Baker-Austin et al. 2012). *Vibrio vulnificus*, which is responsible for the overwhelming majority of reported seafood-related deaths in the U.S. (Oliver and Kaper 2007), is also a significant and growing source of potentially fatal wound infections associated with recreational swimming, fishing-related cuts, and seafood handling, and is most frequently found in water with a temperature above 68°F (Martinez-Urtaza et al. 2010; Oliver and Kaper 2007; Scallan et al. 2011; Weis et al. 2011).

There has also been a significant increase in reported incidences of disease in urchins, mollusks, marine mammals, turtles, and echinoderms (a group of some 70,000 marine species including sea stars, sea urchins, and sand dollars) over the last several decades (Bates et al. 2010; Bruno et al. 2007; Eakin et al. 2010; Harvell et al. 2009; Staehli et al. 2009). Increasing disease outbreaks affecting ecologically important species, which provide critical habitat for other species such as corals (Boyett et al. 2007; Bruno et al. 2007; Ward et al. 2007), algae (Case et al. 2011) and eelgrass (Hughes et al. 2002), have been linked with rising temperatures. Disease increases mortality and can reduce abundance for affected populations as well as fundamentally change ecosystems by changing habitat or species relationships. For example, loss of eelgrass beds due to disease can reduce critical nursery habitat for several species of commercially important fish (Hughes et al. 2002).

Impacts of Marine-related Climate Change

Altered environmental conditions due to climate change will affect, in both positive and negative ways, human uses of the ocean, including transportation, resource use and extraction, leisure and tourism activities and industries, in nearshore and offshore areas. Many marine activities are designed based on historical conditions. Thus, climate changes that result in conditions substantially different from recent history may significantly increase costs to businesses as well as disrupt public access and enjoyment of ocean areas.

Climate change will affect maritime security, transportation, and governance. Recently, discussion has expanded to include the growing security, transportation, and governance dimensions of global climate change. For example, according to some researchers, the Arctic region "could slide into a new era featuring jurisdictional conflicts, increasingly severe clashes over the extraction of natural resources, and the emergence of a new 'great game' among the global powers" (Berkman and Young 2009). National security concerns and threats to national sovereignty have also been a recent focus of attention (Borgerson 2008; Campbell et al. 2007; Lackenbauer 2011). With sea ice receding in the Arctic as a result of rising temperatures, global shipping patterns are already changing and will continue to change considerably in the decades to come (Berkman and Young 2009; Cressey 2007; Khon et al. 2010; Stewart et al. 2007).

Resource use for fisheries, aquaculture, energy production, and other activities in ocean areas will also need to adjust to changing conditions. Aside from the movement of living resources, discussed above, changing ocean and weather conditions make any activities at sea that much more difficult to plan, design, and operate.

In the U.S., the tourism industry also plays a large economic role in ocean services. Nationally in 2010, 2.8% of gross domestic product, 7.52 million jobs, and $1.11 trillion in travel and recreational total sales are supported by tourism (OTTI 2011a, 2011b). In addition, in 2009-2010, nine of the top ten states and U.S. territories and seven of the top ten cities visited by overseas travelers were coastal, including the Great Lakes (OTTI 2011a, 2011b). Changes in the location and distribution of marine resources such as fish, healthy reefs, and marine mammals due to climate change will affect the recreational industries and all people that depend on reliable access to these resources in predictable locales. For example, as fish species shift poleward or to deeper waters (Cheung et al. 2011; Nye et al. 2009), these fish may be less accessible to recreational fishermen. Similarly, new weather conditions differing from the historical pattern, and extreme events such as typhoons and hurricanes, mean that the public will not be able to count on recent experience in planning leisure and tourism activities (Moreno and Becken 2009; Scott et al. 2004; Yu et al. 2009). Climate impacts such as changes in wind patterns and wave heights, and more intense storm events will pose a challenge for tourism, boating, recreational fishing, diving, and snorkeling, all of which rely on highly predictable comfortable water and air temperatures and calm waters (Moreno and Becken 2009; Scott et al. 2004). As weather patterns change, and air and sea surface temperatures rise, preferred locations for recreation and tourism also may change. In addition, infrastructure such as marinas, marine supply stores, boardwalks, hotels, and restaurants that support leisure activities and tourism will be negatively affected by sea level rise. They may also be impacted by increased storm intensity, changing wave heights

(Scott et al. 2004; Yu et al. 2009), and other expected effects of a changing climate; these impacts will vary significantly by region (IPCC 2012).

Initiatives Serve as a Model

In response to observed and projected climate impacts, some existing ocean policies, practices, and management efforts are incorporating climate-change impacts. These initiatives, such as increasing the resilience of built infrastructure or natural marine ecosystems, can serve as a model for other efforts and ultimately enable people and communities to adapt to changing ocean conditions.

Climate considerations can be integrated into planning, restoration, design of marine protected areas, fisheries management, and aquaculture practices to enhance ocean resilience and adaptive capacity. Many existing sustainable-use strategies, such as ending overfishing, establishing protected areas, and conserving habitat, are known to increase resilience. Analyses of fishery management and climate scenarios suggest that adjustments to harvest regimes (especially reducing harvest rates of over-exploited species) can improve catch stability under more uncertain and changing climate conditions. These actions could have a greater effect on biological and economic performance in fisheries than impacts due to warming over the next 25 years (Eide 2008; Ianelli et al. 2011; Perry et al. 2010). The stability of international ocean and fisheries treaties, particularly those covering commercially exploited and critical species, might be threatened as the ocean changes (Garcia and Rosenberg 2010).

New 5-year strategies for addressing flooding, shoreline erosion, and coastal storms have been developed by most coastal states under their Coastal Zone Management Act programs (NRC 2010a). Many of these plans are explicitly taking into account future climate scenarios as part of their adaptation initiatives. The North Pacific Fishery Management Council and NOAA have chosen to delay opening the U.S. fisheries in the Arctic Sea pending greater understanding of the changing productivity of these potential fishing grounds as they become increasingly ice-free. Private shellfish aquaculture operations are changing their business plans to adapt to ocean acidification (Barton et al. 2012; Feely et al. 2010). These changes include monitoring and altering the timing of spat settlement dependent on climate change induced conditions, as well as seeking alternative, acid-resistant strains for culturing.

Additionally, there is promise in using restoration of key habitats to provide a broad suite of benefits that can reduce climate impacts, with relatively little ongoing maintenance costs. For example, if in addition to sea level rise, an oyster reef or mangrove restoration strategy also included fish habitat benefits for commercial and recreational uses and coastal protection services, the benefits to surrounding communities could multiply quickly. Coral-reef-based tourism can be more resilient to climate change impacts through protection and restoration, as well as reduction of pollution and other habitat-destroying activities. Developing alternative livelihood options as part of adaptation strategies for marine food producing sectors can help reduce economic and social impacts of a changing climate.

Box: Climate Impacts on New England Fisheries

Fishing in New England has been associated with bottom-dwelling fish for more than 400 years, and is a central part of the region's cultural identity and social fabric. Atlantic halibut, cod, haddock, flounders, hakes, pollock, plaice, and soles are included under the term "groundfish." The fishery is pursued by both small boats (less than 50 feet long) that are typically at sea for less than a day, and by large boats (longer than 50 feet) that fish for a day to a week at a time. These vessels use home ports in more than 100 coastal communities from Maine to New Jersey and land more than $700 million in fish and shellfish at the dock each year (NOAA NMFS 2009). Captains and crew are often second- or third-generation fishermen who have learned the trade from their families.

From 1982-2006, sea surface temperature in the coastal waters of the Northeast warmed by close to twice the global rate of warming over this period (Belkin 2009). Long-term monitoring of bottom-dwelling fish communities in New England revealed that the abundance of warm-water species increased, while cool-water species decreased (Collie 2008; Nye et al. 2009). A recent study suggests that many species in this community have shifted their geographic distributions northwards by up to 200 miles since 1968, though substantial variability among species also exists (Nye et al. 2009). The northward shifts of these species are reflected in the fishery as well: landings and landed value of these species have shifted towards northern states such as Massachusetts and Maine, while southern states have seen declines.

The economic and social impacts of these changes depend in large part on the response of the fishing communities in the region (McCay et al. 2011). Communities have a range of strategies for coping with the inherent uncertainty and variability of fishing, including diversification among species and livelihoods, but climate change imposes both increased variability and sustained change that may push these fishermen beyond their ability to cope (Adger et al. 2009). Larger fishing boats can follow the fish to a certain extent as they shift northward, while smaller inshore boats will be more likely to leave fishing or switch to new species (Adger et al. 2009). Long-term viability of fisheries in the region may ultimately depend on a transition to new species that have shifted from regions further south (Sumaila et al. 2011).

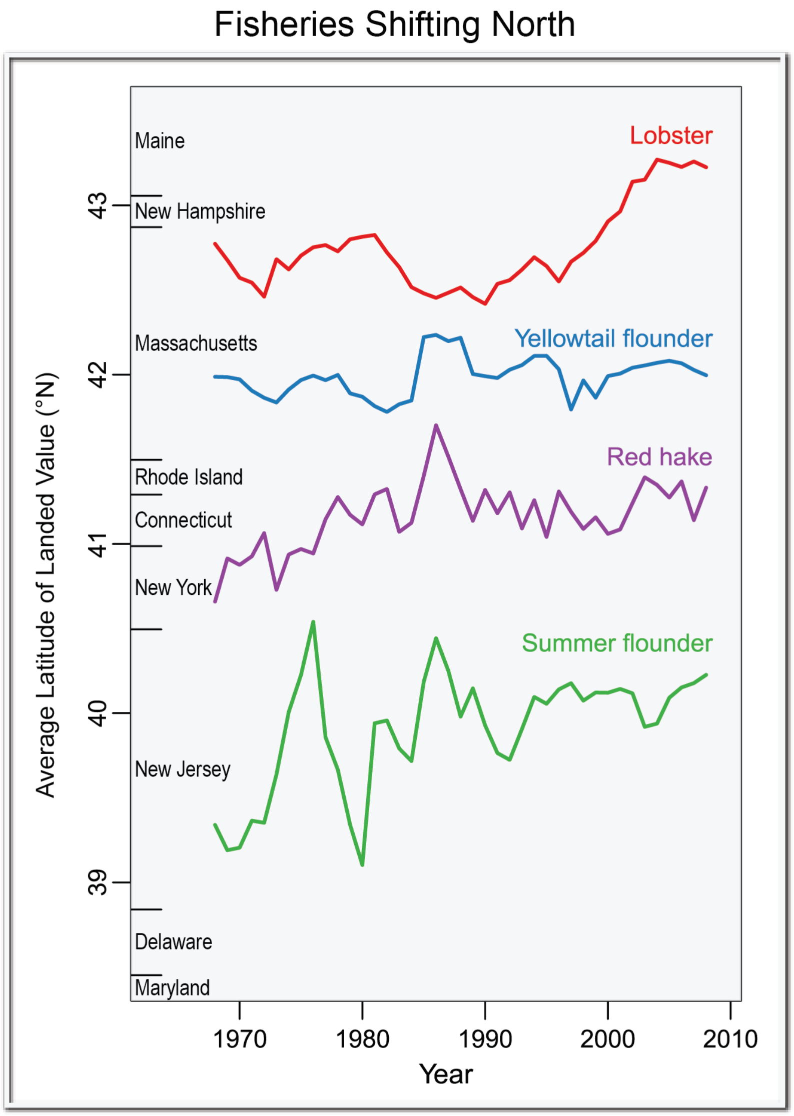

Figure 24.5: Fisheries Shifting North

Caption: Ocean species are shifting northward along U.S. coastlines as ocean temperatures have risen. As a result, over the past 40 years more northern ports have gradually increased their landings of four marine species compared to the earlier pattern of landed value. While some species move north out of an area, other species move in from the south. This kind of information can inform decisions about how to adapt to climate change. Such adaptations take time and have costs, as local knowledge and equipment are geared to the species that have long been present in an area. (Figure Source: adapted by M. Pinsky based on Griffis and Howard 2012)

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Traceable Accounts

Key Message Process: A central component of the assessment process was the Oceans and Marine Resources Climate assessment workshop that was held in January 23-24, 2012 at NOAA in Silver Springs, MD, and simultaneously, via webex, at NOAA in Seattle, WA, with nearly 30 participants participating a series of scoping presentations and breakout sessions that began the process leading to a foundational Technical Input Report (TIR) report entitled "Oceans and Marine Resources in a Changing Climate: Technical Input to the 2013 National Climate Assessment." (Griffis and Howard 2012). The report, consisting of nearly 220 pages of text organized into 7 sections with numerous subsection and more than 1200 references, was assembled by 122 authors representing a wide range of inputs including governmental agencies, NGOs, tribes and other entities.

The chapter author team engaged in multiple technical discussions via teleconferences that permitted a careful review of the foundational TIR (Griffis and Howard 2012) and of approximately 25 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. The Chapter Author Team met at Conservation International in Arlington, VA on 3-4 May, 2012 for expert deliberation of draft key messages by the authors wherein each message was defended before the entire author team before this key message was selected for inclusion in the Report; these discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities".

Key message #1/6	**The rise in ocean temperature over the last century will persist into the future with continued large impacts on climate, ocean circulation, chemistry, and ecosystems.**
Description of evidence base	The key message is supported by extensive evidence documented in Sections 2 and 3 of the Oceans Technical Input (Griffis and Howard 2012) and in the additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Relevant and recent peer-reviewed publications (Jansen et al. 2007; Jungclaus et al. 2010; Levitus et al. 2009; Levitus et al. 2012; Mann et al. 2008), including many others that are cited therein, describe evidence that ocean temperature has risen over the past century. This evidence base includes direct and indirect temperature measurements, paleoclimate records, and modeling results. There are also many relevant and recent peer-reviewed publications describing physical and chemical ocean properties that are underway due to climate change (Chavez et al. 2011; Comiso 2011; Rothrock et al. 2008).
New information and remaining uncertainties	Important new information since the last assessment includes the latest update to the Levitus et al. (2012) atlas. There is accumulating new information on all of these points with regard to physical and chemical changes in the ocean and resultant impacts on ecosystem. Both measurements and model results are continuing to sharpen the picture. A significant area of uncertain remains with regard to the region by region impacts of warming, acidification and associated changes in the oceans. Regional and local conditions mean that there is far from uniform impacts around the US coasts and internationally. Forecasting of regional changes are still an area of very active area of research though the overall patterns for some features is now clear. Large-scale and recurring climate phenomena (El Niño, the Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation, etc.) cause dramatic changes in biological productivity and ecosystem structure and make it difficult to discern

	climate-driven trends. Current time series of biological productivity are restricted to a handful of sites around the globe and to a few decades, and satellite time series are even shorter, beginning in 1997. Attempts to overcome these limitations suggest a decline of 1% per year over the past century have been widely debated (Chavez et al. 2011). However, the few in-situ time series mostly indicate increases in biological productivity over the past 20 years but with clear links to regional changes in climate (Chavez et al. 2011).
Assessment of confidence based on evidence	Confidence that the ocean is warming, acidifying, and sea level is rising is **very high**. Changes in other physical and chemical properties such as wave heights and oxygen minimums and salinity are of **medium** confidence. For ecosystem changes, there is **high** confidence that these are occurring, though the details of these changes are highly variable.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: Please see KM #1 for a detailed description of process.

Key message #2/6	**The ocean currently absorbs about a quarter of human-caused carbon dioxide emissions to the atmosphere, leading to ocean acidification that will alter marine ecosystems in dramatic yet uncertain ways.**
Description of evidence base	The key message is supported by extensive evidence documented in the Oceans Technical Input (Griffis and Howard 2012) and additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Key message #11 in Chapter 2, Climate Change Science, and its traceable Account also provides evidence for ocean acidification. Numerous references demonstrate the declining acidity around the world (Feely et al. 2008; NRC 2010b) all confirm the recent trend. There is a rapid growth in peer-reviewed publications describing how ocean acidification will impact ecosystems (Cooley et al. 2009; Doney et al. 2009), but to date evidence is largely based on studies of calcification rather than growth, reproduction and survival of organisms. For these latter effects available evidence is from laboratory studies in low pH conditions, rather than in situ observations.
New information and remaining uncertainties	The interplay of environmental stressors may result in 'surprises' where the synergistic impacts may be more deleterious or more beneficial than expected and create complexities in terms of how to predict the outcome of the interplay of stressors on marine ecosystems. Many, but not all calcifying species, are affected in laboratory studies by increased acidity, but how those responses will cascade through ecosystems and foodwebs is still uncertain. Although studies are underway to expand understanding of ocean acidification on all aspects of organismal physiology, much remains to be learned.
Assessment of confidence based on evidence	Confidence is **very high** that carbon dioxide emissions to the atmosphere are causing ocean acidification, and high that this will alter marine ecosystems. The nature of those alterations is unclear however and predictions of most specific ecosystem changes have **low** confidence at present.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: Please see KM #1 for a detailed description of process.

Key message #3/6	**Significant habitat loss will continue to occur due to climate change, in particular for Arctic and coral reef ecosystems, while expansions of habitat in other areas and for other species will occur. These changes will consequently alter the distribution, abundance, and productivity of many marine species.**
Description of evidence base	The key message is supported by extensive evidence documented in the Oceans Technical Input (Griffis and Howard 2012) and additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Many peer-reviewed publications (Burke et al. 2011; Dudgeon et al. 2010; Hoegh-Guldberg et al. 2007; Hughes et al. 2002) describe global change induced threats to coral reefs. There are also many relevant and recent peer-reviewed publications (Cheung et al. 2011; Dulvy et al. 2008; Mueter and Litzow 2008; Murawski 1993; Nye et al. 2009; Perry et al. 2005) discussing impacts of climate induced habitat change on marine species and resources.
New information and remaining uncertainties	Regional and local variation is, again a major component of the remaining uncertainties. Different areas, habitats and species are responding differently and have very different adaptive capacities. Those species that are motile will certainly respond differently, or at least at a different rate, by changing distribution and migration patterns compared to species such as corals. Although it is clear that some fish stocks are moving poleward and to deeper water, how far they will move and whether most species will move remains unclear. A key uncertainty is the extent to which various areas will benefit from range expansions of valuable species or increases in productivity, while others will suffer as species move away from previously productive areas. The loss of critical habitat due to climate change will result in changes in species interactions that are difficult to predict.
Assessment of confidence based on evidence	There is **very high** confidence that habitat and ecosystems are changing, but that change is not unidirectional by any means. Distribution, abundance, and productivity changes are species and location dependent and may be increasing or decreasing in a complex pattern.

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Key Message Process: Please see KM #1 for a detailed description of process.

Key message #4/6	**Rising sea surface temperatures have been linked with increasing levels and ranges of diseases of humans and marine life such as corals, abalones, oysters, fishes, and marine mammals.**
Description of evidence base	The key message is supported by extensive evidence in the Oceans Technical Input (Griffis and Howard 2012) and additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. As noted in the chapter, the references document increased levels and ranges of disease coincident with rising temperatures.
New information and remaining uncertainties	The complexity of the host, environment, pathogen interaction makes it challenging to separate climate warming from other causes of disease outbreaks in the ocean.
Assessment of confidence based on evidence	There is **high** confidence that disease outbreaks and levels are increasing. Again there is substantial local to regional variation but the overall pattern seems consistent.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 24: Ocean and Marine Resources

Key Message Process: Please see KM #1 for a detailed description of process.

Key message #5/6	**Altered environmental conditions due to climate change will affect, in both positive and negative ways, human uses of the ocean, including transportation, resource use and extraction, leisure and tourism activities and industries, in nearshore and offshore areas. Many marine activities are designed based on historical conditions. Thus, climate changes that result in conditions substantially different from recent history may significantly increase costs to businesses as well as disrupt public access and enjoyment of ocean areas.**
Description of evidence base	The key message is supported by extensive evidence documented in the Oceans Technical Input (Griffis and Howard 2012) and additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Many peer-reviewed publications describe the predicted impacts of climate change on tourism and recreation industries and their associated infrastructure (Moreno and Becken 2009; Scott et al. 2004; Yu et al. 2009).
New information and remaining uncertainties	Given the complexity of leisure and tourism activities, there are large uncertainties in impacts in specific locals or for individual activities. Some businesses and communities may be able to adapt rapidly, others less so. Infrastructure impacts of climate change will also be an important part of the ability of business, communities and the public to adapt.
Assessment of confidence based on evidence	As with many other impacts of climate change, the evidence that change is occurring is very strong but the resultant impacts are still uncertain. For leisure and tourism there is suggestive evidence of changes and only **medium** confidence on the effects of the ongoing changes in ocean conditions.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
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Key Message Process: Please see KM #1 for a detailed description of process.

Key message #6/6	**In response to observed and projected climate impacts, some existing ocean policies, practices, and management efforts are incorporating climate-change impacts. These initiatives, such as increasing the resilience of built infrastructure or natural marine ecosystems, can serve as a model for other efforts and ultimately enable people and communities to adapt to changing ocean conditions.**
Description of evidence base	The key message is supported by extensive evidence documented in the Oceans Technical Input (Griffis and Howard 2012) and additional Technical Input reports received as part of the Federal Register Notice solicitation for public input, as well as stakeholder engagement leading up to drafting the chapter. Scenarios suggest that adjustments to fish harvest regimes can improve catch stability under increased climate variability. These actions could have a greater effect on biological and economic performance in fisheries than impacts due to warming over the next 25 years (Eide 2008; Ianelli et al. 2011; Perry et al. 2010).
New information and remaining uncertainties	Efforts are underway to enhance the development and deployment of science in support of adaptation, to improve understanding and awareness of climate-related risks, and to enhance analytic capacity to translate understanding into planning and management activities. While critical knowledge gaps exist, there is a wealth of climate- and ocean-related science pertinent to adaptation. Including such resources as listed in the technical report.
Assessment of confidence based on evidence	There is **high** confidence that adaptation planning can help mitigate the impacts of changing ocean conditions. But there is much work to be done to craft local solutions to the set of emerging issues in ocean and coastal areas.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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