# Chapter 6: Status, Trends, and Future Projections of Marine Ecosystems in the US

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# Chapter Contents

## Summary

Marine ecosystems in the United States have undergone substantial and long-lasting change driven by centuries of exploitation and, more recently, by coastal development, pollution, and accelerating climate impacts (1–4). Many marine species—particularly large-bodied animals and migratory species such as sea turtles, salmon, and marine mammals—have declined steeply in abundance and body size (2,5–8). Marine habitats are degraded and reduced in extent, with dramatic declines in wetlands, estuaries, oyster reefs, and coral reefs (9–14). Marine ecosystem decline in the US has resulted in lost livelihoods and cultural experiences and reduced economic, human health, and coastal protection benefits (15–23).

However, some declines in marine ecosystems have been halted and reversed. Strong federal fishery management has reduced unsustainable fishing and enabled substantial stock recovery: 50 stocks have been rebuilt since 2000 (NOAA Fisheries 2024). Conservation measures such as species-specific protections and an assemblage of marine protected areas covering 26% of US waters have resulted in ecological gains (24–26). Habitat restoration efforts for seagrasses, oyster reefs, and salt marshes have demonstrated that ecological functioning can be rebuilt at meaningful scales (27–31). With support from strong management and protection, the US ocean supplies food, supports livelihoods and economies, filters pollutants, protects coastlines, regulates climate, and enhances cultural experiences and human well-being (32–40).

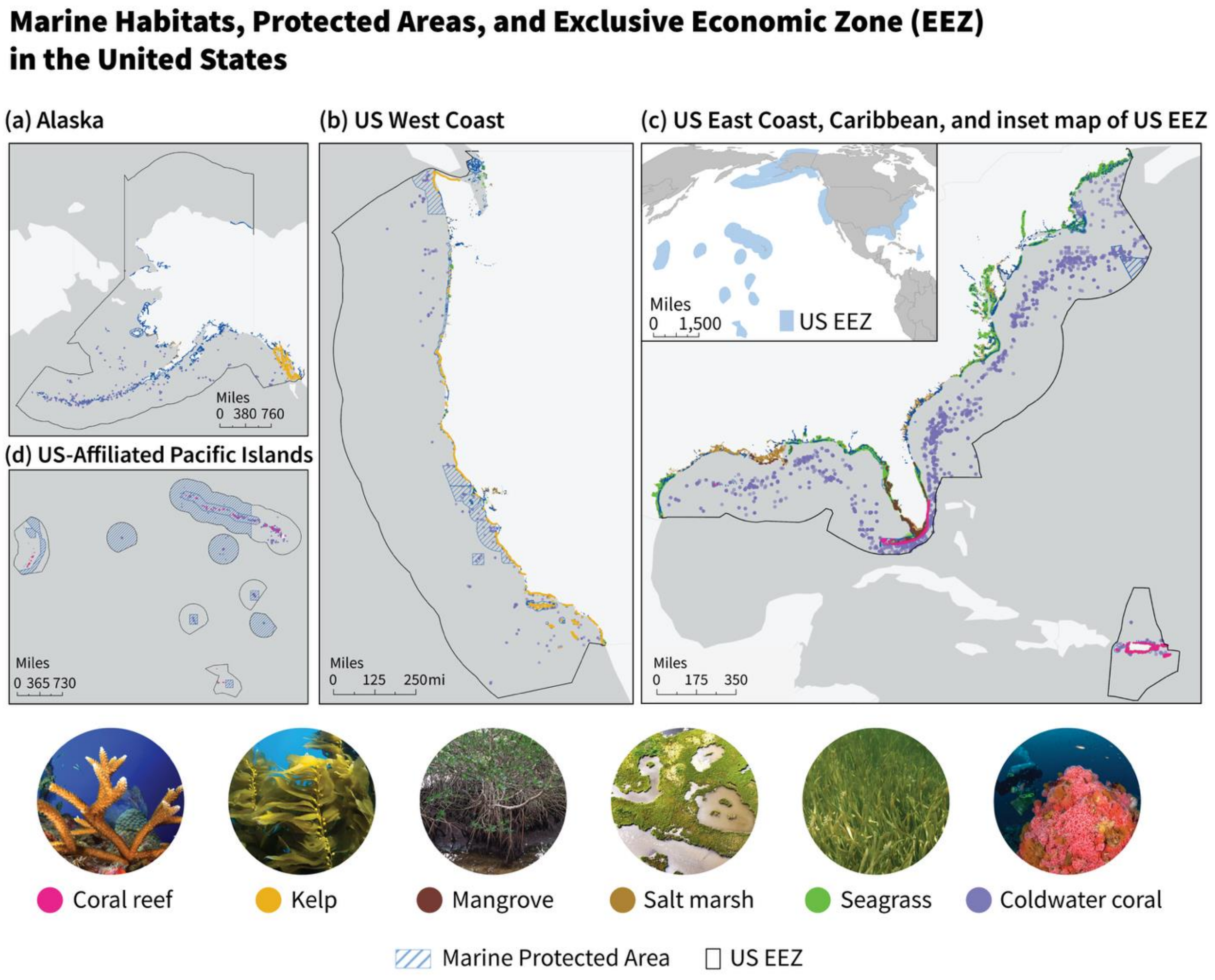
Nevertheless, major challenges persist. Many marine species and habitats are still declining, and some degraded systems show little evidence of recovery even after pressures are reduced (41). Knowledge gaps for many species limit status assessments and management (42). Emerging climate impacts are expected to amplify risks and could push some ecosystems toward irreversible thresholds (43–45). Furthermore, novel threats and weakened protections could create new management challenges (46,47). Sustained investment in science-based management, protection, restoration, and stewardship efforts could help ensure the US ocean's bounty.

## Background

The United States has a vast ocean territory, covering roughly 3.4 million square miles of the Western Atlantic, Arctic, East and West Pacific, and the Gulf of Mexico (Figure 6.1). The surface area of the US **exclusive economic zone** (EEZ, which extends 200 nautical miles from US shores) is one and half times the land mass of all 50 States and territories. This immense area includes numerous ecosystems characterized by broad environmental diversity, which is driven by ocean currents, large-scale wind patterns, freshwater runoff, and seafloor topography. The area is also marked by biological diversity, with distinct **benthic** (seafloor) and **pelagic** (open water) communities ranging from the coastal zone to the deep sea (48–50).

Ecosystems assessed in this chapter include estuaries, coastal wetlands, salt marshes, seagrass meadows, kelp forests, mangrove forests, warm- and coldwater coral reefs, soft-sediment benthic habitats, pelagic ecosystems, and the deep sea. While we use a holistic concept of an ecosystem that bridges interconnected living and nonliving components (51), our focus is on the living components of nature: species, **ecological communities**, and **biogenic habitats** (produced by living organisms) (see Ch. 2: Frameworks). Marine species and habitats are connected with those on land (see Ch. 8: Terrestrial Ecosystems) and in freshwater (see Ch. 7: Inland Waters), highlighting the importance of integrated management.

**Figure 6.1. Marine Habitats, Protected Areas, and the Exclusive Economic Zone in the United States**



**The US exclusive economic zone (EEZ) includes 3.4 million square miles of ocean territory spanning diverse environments.**

*The US EEZ* (52) *includes many important habitats provided by marine species such as tropical coral reefs* (53)*, canopy-forming kelps* (54,55)*, mangroves* (56)*, coldwater corals* (57)*, seagrass* (58)*, and salt marsh* (59)*. Marine protected areas* (60) *help conserve some of these ecosystems. These maps are representative but not exhaustive of all important habitats provided by marine species. Figure original to The Nature Record. Photos (from left to right, all via Flickr except seagrass photo): Staghorn coral at the Florida Keys National Marine Sanctuary (photo credit: Greg McFall/NOAA); giant kelp at Catalina Island, California (photo credit: Ed Bierman [CC BY 2.0]); mangroves on Sanibel Island, Florida (photo credit: justgrimes [CC BY-SA 2.0]); New Jersey salt marsh (photo credit: James Loesch [CC BY 2.0]); seagrass bed near Crystal River, Florida (photo credit: Jennifer McHenry); strawberry anemones on a reef crest at Cordell Bank National Marine Sanctuary (photo credit: Joe Hoyt/NOAA).*

People in the US are connected to marine ecosystems and depend on the resources, **ecosystem services**, and other benefits they provide, including supplying food and supporting livelihoods and economies through fisheries and aquaculture, filtering and assimilating nutrients and pollutants, protecting the coastline from waves and storm surge, regulating climate, and contributing to cultural experiences and spiritual and physical well-being (see KM 6.2). Many benefits have been lost or reduced, particularly from overfishing and coastal development, and existing benefits are threatened by climate change, fishing, mining, oil exploration and extraction, coastal development, and pollution (see KMs 6.1, 6.2). The consequences of ecosystem degradation and species declines could be addressed through marine resource management, conservation, and ecosystem restoration (see KM 6.3, Figure 6.2).

**Figure 6.2. Marine Ecosystem Dynamics, Benefits, and Management**

FIGURE UNDER DEVELOPMENT

**People's relationships to ocean ecosystems in the US affect how they interact with them, the risks they face, the benefits they receive, and their approaches to stewardship, management, and protection.**

*(Figure still under development.) Across the US, people maintain diverse relationships with ocean ecosystems, based on their values, worldviews, and histories with marine and coastal environments. These social drivers affect human activities which can provide benefits but also have negative impacts, including via fishing, habitat damage, climate change, pollution, and recreation. Other negative impacts can be caused by biophysical drivers like invasive species, sea level rise, and ocean acidification. However, social drivers also affect human activities that safeguard marine ecosystems, via stewardship, management, and protection. Recognizing important interconnections between people and marine nature will help ensure future values and benefits to society of marine ecosystems and species, including seafood, economic benefits, recreational opportunities, coastal protection, cultural heritage and experiences, and climate regulation. Tools and approaches to protecting and managing ocean ecosystems, including environmental regulations, marine protected areas, ecosystem restoration, fisheries management, and local stewardship, can help preserve healthy marine ecosystems. Figure original to The Nature Record.*

## Marine Ecosystem Diversity and Biodiversity Hotspots

The ocean is a three-dimensional, dynamic, and constantly moving environment. Many organisms drift freely, forming floating communities of tiny plants and animals called **plankton**. Single-celled **phytoplankton** that take in nutrients directly from the water are the ocean's most significant **primary producers**, a role that on land is carried out by trees. Phytoplankton are rich in nitrogen and grow quickly, serving as an abundant food source for marine animals, including **zooplankton** (small floating invertebrates) and larger animals (61–63). Mixed in with the plankton are the early life stages of many species, dispersing on ocean currents and connecting widely separated coastal ecosystems (64).

Life first began in the ocean, and 39% of **phyla** are found only in the sea, such as **echinoderms** (sea urchins, sea stars) (65). Scientists have described more than 226,000 marine species (66), and many more are undiscovered and uncounted because much of the ocean is unexplored (67). Hotspots of marine biodiversity in the US vary for different kinds of organisms (68,69). Diverse tropical reefs occur around Hawaiʻi, Florida, and US territories in the Caribbean and Pacific (Figure 6.1). The West Coast hosts highly diverse **intertidal** (shoreline) communities, seabird diversity hotspots, and rich communities of fishes, including nearly 100 species of rockfishes (genus *Sebastes*) (70–72). In the deep sea, biodiversity is high around seafloor features (Box 6.1) (73,74). Although biodiversity is commonly higher in coastal areas (69,71), it can also be high in pelagic regions: for example, more fish species have been recorded in the Gulf of Mexico's open ocean than along the coast (75).

### Box 6.1. The Underappreciated Importance of the Deep Sea

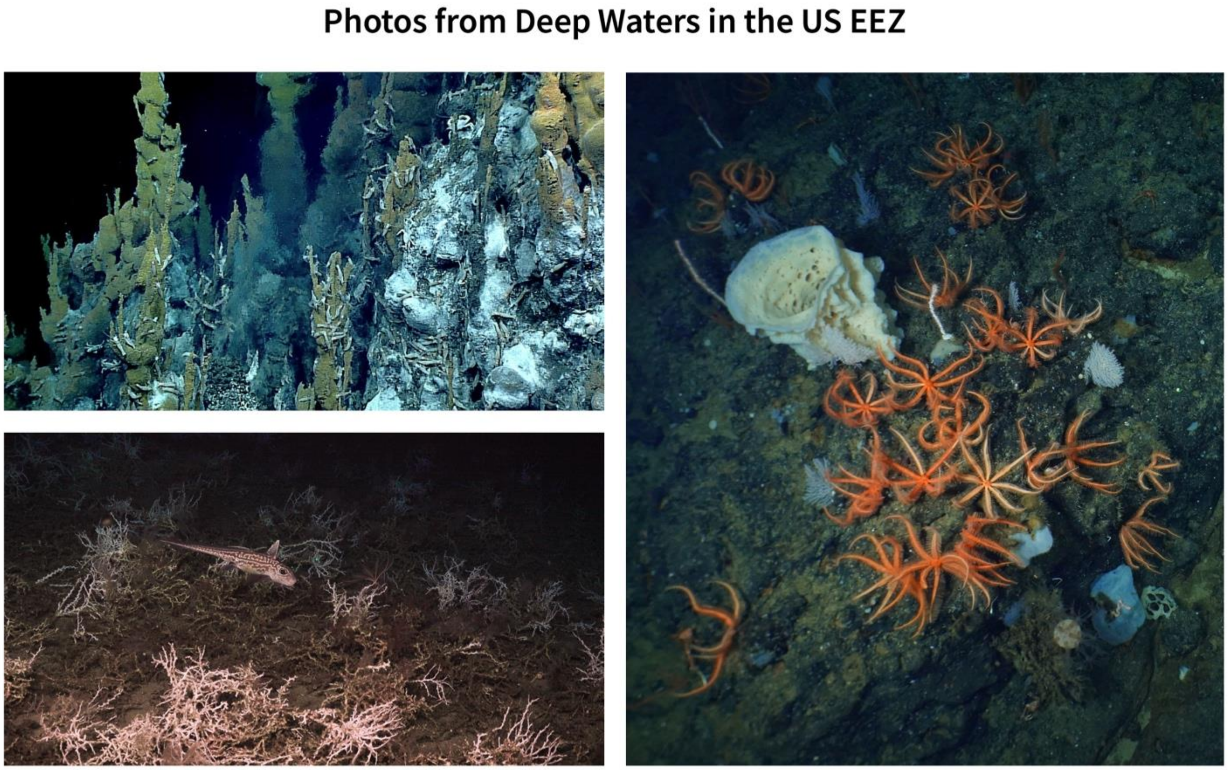
The US exclusive economic zone (EEZ) is 75% deep sea (water depths greater than 650 feet), hosting diverse seafloor features (seamounts, canyons, ridges, abyssal plains), and chemical and biological properties (e.g., **oxygen minimum zones**, **hydrothermal vents**, **methane seeps**, sponge and cold-water coral reefs, and deep trenches). A majority of deep-sea species in the US EEZ remain unseen and undiscovered (67). Diversity surveys have documented high **species richness** in many deep-sea areas of the US EEZ, particularly near islands (e.g., Hawaiʻi) and around seamounts (e.g., New England Seamounts).

Deep-sea corals in the US provide habitat for diverse fish and invertebrate species (Figure 6.3). Over 720 species have been found living with deep corals in the northern and eastern Gulf of Mexico, with species composition depending on depth and geographic location. New discoveries of deep corals, seamounts, and methane seeps regularly result in the discovery of new species and previously unknown animal–microbe relationships (76–79). In 2024, the largest known continuous coldwater coral reef, largely dominated by mounds of the vulnerable coral species *Desmophyllum pertusum* (80), was discovered in the southeast Atlantic extending from southern Florida to South Carolina along the Blake Plateau. This feature (up to 300 miles long and 60 miles wide) covers an area the size of

Vermont and includes nearly 84,000 individual coral mounds that are up to 750 feet high (81).

These deep-sea ecosystems face mounting pressures, including impacts from fishing, threats from emerging activities such as marine carbon dioxide sequestration and deep-sea mining, and the wide-ranging effects of climate change (47,82–85).

**Figure 6.3. Photos from Deep Waters in the US EEZ**



**Deep ocean habitats include diverse and unique marine life, and recent research offers a glimpse into these hidden worlds.**

*(**right**) Brisingid starfish on the San Juan Seamount (from Dive H1841; photo credit: Ocean Exploration Trust, Chief Scientist Lisa Levin). (**top left**) Hydrothermal-vent chimney. In the center of the photo is the vent fluid, which appears as dark smoke due to its high levels of minerals and sulfides; the chimney is crawling with shrimp and crabs (from 2016 Deepwater Exploration of the Marianas; photo credit: NOAA Office of Ocean Exploration and Research). (**bottom left**) A chimera swimming above a coldwater coral reef at a depth of approximately 700 meters on the Blake Plateau (from the Deep SEARCH program funded by the US BOEM, NOAA OE, and USGS; copyright: Woods Hole Oceanographic Institution).*

[END BOX 6.1 HERE]

Hotspots of abundance differ from biodiversity hotspots but are equally important. In high-latitude Alaska ecosystems, summer blooms of phytoplankton support peaks in zooplankton and small fishes that feed huge populations of larger fish, seabirds, and marine mammals such as seals, walrus, and baleen whales. Many species migrate to Alaska from temperate and tropical latitudes, and even from the Southern Hemisphere, to feast. The highly productive **California Current** along the West Coast also supports large populations of marine mammals, including seabirds and migratory baleen whales (71,86). There are other ecosystems, such as **salt marshes**, that have low species diversity but are highly productive and provide important benefits to wildlife and people (87).

### The State of Knowledge and Key Data Gaps

We know much less about US marine ecosystems than about terrestrial ecosystems (88,89). Ocean research involves orders of magnitude greater cost and logistical complexity, particularly in the deep sea and open ocean (42,67,90). Fishery and scientific surveys are overwhelmingly conducted at depths shallower than 100 feet (90), and remote sensing is possible only at depths shallower than 10–20 feet (91). Our knowledge overrepresents near-surface waters and fished habitats. We generally have more scientific knowledge of animals harvested for food (finfishes, **crustaceans**, **bivalves**, and squid) and protected species (marine mammals, sea turtles, seabirds) than for other species, including those at the base of the food web that support ocean ecosystems (small fish, invertebrates, algae, and microbes) (42,68,88,92). Less than half of federally managed fished species and less than 20% of non-federally managed stocks have formal population assessments, known as **stock assessments** (93,94), and population status is known for only a small proportion of marine species. Of the 261 US-managed marine mammal stocks, about 70% have recent population estimates, but less than 20% have estimates of population trends (95–97). Indigenous Knowledge provides different and longer perspectives on aspects of marine nature and could fill some of these data gaps but is often not considered in management (98–101).

## Key Message 6.1: US marine life and ecosystems have been highly altered

*US marine ecosystems and species have declined dramatically compared to a century ago, with overharvesting and habitat degradation causing the largest declines in many areas (virtually certain). Many ecosystems continue to decline as climate change amplifies other pressures (very well established). Continued degradation and loss of marine ecosystems and species are expected in the coming decades based on current trends (very well established), although the exact changes are hard to predict; future conditions could include expansion of some ecosystems and increases of some species (established but incomplete).*

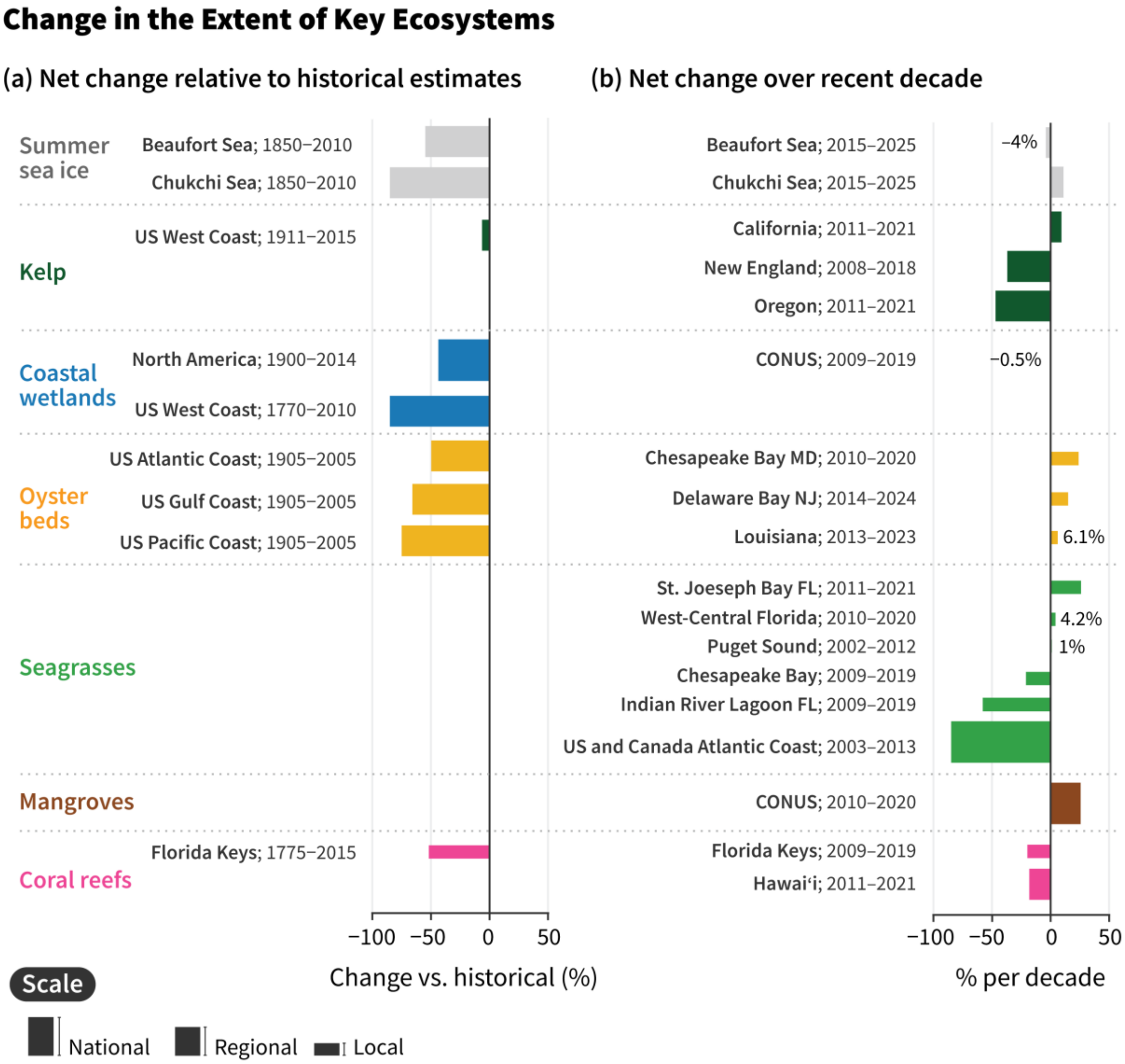
## State of Knowledge 6.1

### Highly Altered Marine Ecosystems

Archaeological evidence shows that fishing reduced the number and size of fish in some areas beginning millennia ago (1,102). Scientific surveys, old nautical charts, and historical photos reveal further declines in recent centuries, especially among large-bodied animals and species like sea turtles and salmon that move between the ocean and land or freshwater (1,2,5,12,103,104).

Many marine ecosystems are defined by **foundation species**, which provide habitat and resources for many other species; examples include tropical and coldwater corals, kelps, seagrasses, mangroves, salt marshes, and oysters. Most of these foundation species have declined nationally and regionally from historical levels primarily as a result of harvest activity, coastal development, and poor water quality, and declines continue despite considerable management and restoration effort and some local successes (Figure 6.4) (9,11,105–111). Losses have been particularly widespread in coastal habitats, notably wetlands, estuaries, and coral reefs (9,10,112). For example, the Florida Reef, the third longest barrier reef in the world, has lost up to 90% coral cover in some locations (14,113,114). Coastal habitats are threatened by their proximity to people, but are also where people interact most with marine nature and derive meaning and value from it (see KM 6.2).

**Figure 6.4. Change in the Extent of Key Ecosystems**



**Many key marine habitats have decreased in extent relative to historical baselines, and many continue to decline.**

*Change in the extent of key habitats is expressed as (**a**) net change relative to historical estimates (percent change)* (14,115–119) *and (**b**) net change over a recent decade (percent change per decade)* (54,120–134). *Bar width is scaled depending on whether the data cover a continental, regional, or local assessment of ecosystem extent. All five habitats for which we have historical data now cover only a fraction of their historical range. Recent change is more variable, with studies in many habitats showing a mix of recovery and continuing decline. Figure original to The Nature Record.*

## Multiple and Compounding Human Impacts on Marine Ecosystems

US marine ecosystems face many connected and interacting threats, including impacts that begin on land and in freshwater systems (see Ch. 7: Inland Waters and Ch. 8: Terrestrial Ecosystems) (4,135). Historically, overharvest and destructive fishing practices were the largest drivers of biodiversity loss in the ocean, followed by habitat degradation from other activities such as coastal development (1,2). Today, climate change has joined habitat loss and degradation as a primary threat to biodiversity, although fishing, pollution (nutrient, toxic, plastic, and noise), altered water quality, and invasive species are also important threats and nearly all ecosystems face cumulative impacts from multiple drivers (2,4,136–139) (see Ch. 9: Drivers and Ch 10: Climate Change). Together, stressors can affect growth, survival, and reproduction of marine species; limit availability of quality habitat; and disrupt interactions among species (140,141). Some fast-growing opportunistic algae and invertebrates are resilient to these pressures and often dominate disturbed sites (142,143). Others are more sensitive, including species that rely on specific or fragile habitat types (7,144–146).

## Depleted and Endangered Species

Although few marine species have been documented as going extinct (2,147), many in the US have dramatically declined. For example, industrial whaling removed an estimated 3 million baleen and sperm whales from the world's ocean, with nearly 1 million harvested in the Northern Hemisphere (8). Following protection through the US Marine Mammal Protection Act and Endangered Species Act (ESA), many whale species have at least partially recovered (148,149). However, species including Rice's whales, North Atlantic right whales, and **southern resident killer whales** are still critically endangered despite being limited almost entirely to US waters (95,96). Harvesting of sea turtles and seabirds was also historically prevalent in the US, reducing populations of many species, though intentional harvest has all but ceased and many species are recovering (150,151).

Currently, more than 100 species of marine mollusks, fishes, mammals, sea turtles, and corals in US waters are protected under the ESA, along with numerous species of birds, reptiles, and crustaceans that spend part or all of their lives in the ocean. Many more species are being considered for future listing (152,153). Recovery efforts for listed species have yielded varying degrees of success (see KM 6.3) (7,151,154).

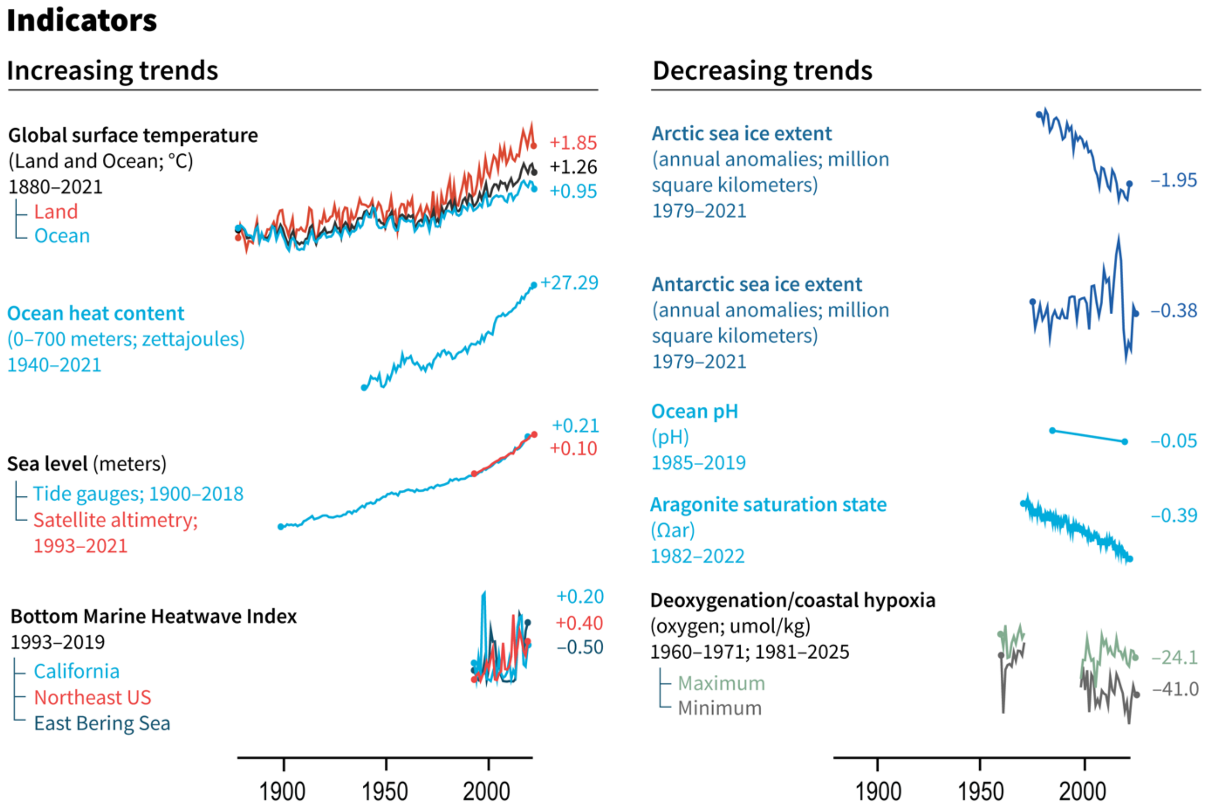
Most fished species in the US are managed using the concept of **maximum sustainable yield** (MSY), which in theory is the largest average amount of fish that can be harvested each year. Currently, **overfishing**, or harvest at rates greater than those associated with MSY, is rare for federally managed fisheries in the US (see KM 6.3) (155). However, even fishing at MSY allows target species biomass to be reduced to approximately 40% of unfished levels (156). That is, even species considered sustainably harvested may have lost up to 60% of their population biomass (157). The status of fished species varies, and several economically, culturally, and ecologically important stocks remain overfished, including Atlantic cod, Pacific sardine, North Pacific blue king crab, South Atlantic red snapper, and Klamath River fall Chinook salmon (155).

Some overfished populations were once highly abundant, and their declines have led to substantial rearrangement of marine food webs and ripple effects on other species (158). For example, four decades of intense fishing on Georges Bank changed the ecosystem from one dominated by cod to one dominated by spiny dogfish, a species that may be hindering the recovery of cod (159,160). Fishing can also harm non-target species and habitats through **bycatch** (catching unintended species in fishing gear) (161) and seafloor damage (162–164). These incidental impacts of fishing can be particularly damaging for slow-growing and late-maturing species (162,165,166).

## Marine Ecosystems in a Changing Climate

Climate change is widely impacting marine systems through marine heat waves, sea level rise, melting sea ice, intensifying storms, altered ocean currents, reduced oxygen levels, and ocean acidification (Figure 6.5; see Ch. 10: Climate Change). These impacts disrupt and often harm marine ecosystems and species (3,136,137,139,167).

**Figure 6.5. Indicators of Change in Ocean Ecosystems**



**Climate change underlies significant trends in key environmental levers that greatly impact marine biodiversity.**

*Climate change impacts marine ecosystems through changes in sea surface temperature, ocean heat content and ocean heat waves, sea level rise, sea ice extent, ocean pH and aragonite saturation state, and low oxygen conditions. Global changes between the start and end of each time series are shown as numerical values to the right of each chart. Global surface temperature, ocean heat content, sea level, sea ice extent, and ocean pH are calculated by fitting each time series with a localized linear regression with a bandwidth of 30 years, as adapted from Marvel et al. 2023* (168). *Bottom marine heatwave index is the annual maximum spatial extent of bottom marine heat wave conditions, as a proportion of each large marine ecosystem (LME) area* (169). *Aragonite saturation state is the globally averaged surface ocean aragonite saturation* (170). *Deoxygenation is the annual minimum and maximum oxygen concentration measured at a constant upwelling density off the coast of Oregon* (171).

Warming and periodic heat waves have substantially reduced sea ice habitat (172) and are driving widespread changes in foundation species, including declines in corals, kelps, and seagrasses (136,173–175). Not all species are declining, however; for example, mangroves are expanding northward in the US at the expense of salt marshes in several regions (176–178). For species living near their limit of heat tolerance, increasing heat waves can result in large-scale mortality. Along the West Coast and Alaska, marine heat waves have caused collapses of numerous fished species including Pacific cod, multiple salmon stocks, and snow crab, in addition to die-offs of seabirds and impacts on whales (179–182). A 2023 marine heat wave and mass coral bleaching event contributed to the decades-long decline of live coral in Florida's reefs and ultimately to the functional extinction of once-dominant acroporid coral species (114).

Marine species are also shifting their geographic and depth distributions in response to warming, generally towards higher latitudes and deeper depths (see Ch 10: Climate Change) (183–185). Along the Northeast coast, ocean warming rates are among the fastest on Earth (186), causing impacts on ocean productivity, biodiversity, species interactions, and fisheries (44,187–190). In the Arctic, changes in temperatures, circulation, sea ice, and other factors are transforming food webs and ecosystem functioning by changing nutrient cycles and primary production and by enabling species from subarctic regions to move into newly accessible habitats (146,191–194).

Range shifts in harvested species create management challenges (195). For example, as species move north, fish like black sea bass and summer flounder have become common off New England where they were once rare (196). Because catch limits are based on past landings, commercial and recreational fishers in New England have limited access to these newly abundant species (197). Meanwhile fishermen in Virginia and North Carolina must travel farther north to harvest these species (189,198). In Alaska's subarctic and arctic seas, climate change has altered the distributions of many species (199,200) and has contributed to collapses of major fisheries for Gulf of Alaska Pacific cod, Bering Sea snow crab, and Western Alaska salmon (201–205).

**Ocean acidification**, the decrease in pH caused by the absorption of excess atmospheric carbon dioxide, can be corrosive to organisms with calcified shells or skeletons such as oysters, scallops, sea urchins, and corals (206). Climate change also results in physical changes, such as altered **upwelling** patterns, that can influence primary productivity and oxygen levels in the ocean (see Ch. 10: Climate Change). For example, the California Current system is a hotspot for nearshore **hypoxia** (low oxygen) due to seasonal upwelling of deep low-oxygen water to shallower depths. The extent of hypoxic areas have been increasing along the West Coast over the past several decades (Figure 6.5) (171). Hypoxic events compress available habitat and can cause species mortality events (207,208).

Lastly, mean sea level has risen across the US coastline over the last century (209,210) (see Ch. 10: Climate Change). As a result, many tidal wetlands are drowning, threatening the health of the plants that resist erosion and help build soil vertically by trapping sediment and producing soil organic matter (211,212). The US experienced a net loss of 0.5% (47 square miles) of tidal marshes from 2009 to 2019, mostly to open water or non-vegetated wetland habitats such as beaches and mudflats (213).

### Marine Ecosystems and Pollution

Pollution—including plastic, chemical, nutrient, sediment, and noise pollution—affects US ocean ecosystems in diverse and complex ways. For example, pollutants bioaccumulate in marine food webs (214). Nutrient pollution—excess nitrogen and phosphorus from agricultural runoff (fertilizers, animal manure), urban stormwater runoff, and wastewater treatment discharges—can drive algal blooms and low-oxygen zones deadly to organisms (Box 6.2) (215,216). Sedimentation, primarily driven by coastal erosion and runoff from construction, development, and agriculture, can alter biogeochemical cycles and smother organisms living in benthic habitats such as seagrass meadows and coral reefs (128,217–219) (see Ch. 9: Drivers). Plastic pollution, a more recent but growing threat, can impact marine species via entanglements and ingestion, including of microplastics, which in turn bioaccumulate in food webs (220–222). Lastly, people produce many different types of noise throughout the ocean, interfering with the natural ability of marine organisms to process sound, a particularly large problem for marine mammals (223).

### Box 6.2. Connections Between Land, Rivers, and Sea: The Gulf of Mexico Dead Zone

The Mississippi–Atchafalaya River Basin system delivers massive amounts of freshwater, sediment, and nutrients to the northern Gulf of Mexico (renamed “Gulf of America” by executive order in 2025) every year. The nitrogen, phosphorus, and silica in this runoff, which is often 5–10 times above natural levels due to agricultural inputs (224), stimulate large phytoplankton blooms that eventually sink and are degraded by bacteria, causing expansive hypoxic or “dead zones” where oxygen levels are too low for marine life (Figure 6.6). These seasonal low-oxygen areas can span nearly 9,000 square miles and are highly correlated with the amount of nitrogen in river runoff (215). The low oxygen levels create a large area that is uninhabitable to fish and invertebrates and can result in die-offs of less mobile species such as worms and urchins that are unable to escape the deadly conditions (215). The dead zone has negative impacts for fisheries because shrimp and finfish move to areas inaccessible to trawlers (225). The response by phytoplankton to nutrient delivery can also lead to the formation of **harmful algal blooms** (HABs) that produce toxins and contribute to the multiplicative stressors impacting animal life and human health in the gulf (226–228).

**Figure 6.6. Gulf of Mexico Dead Zone**

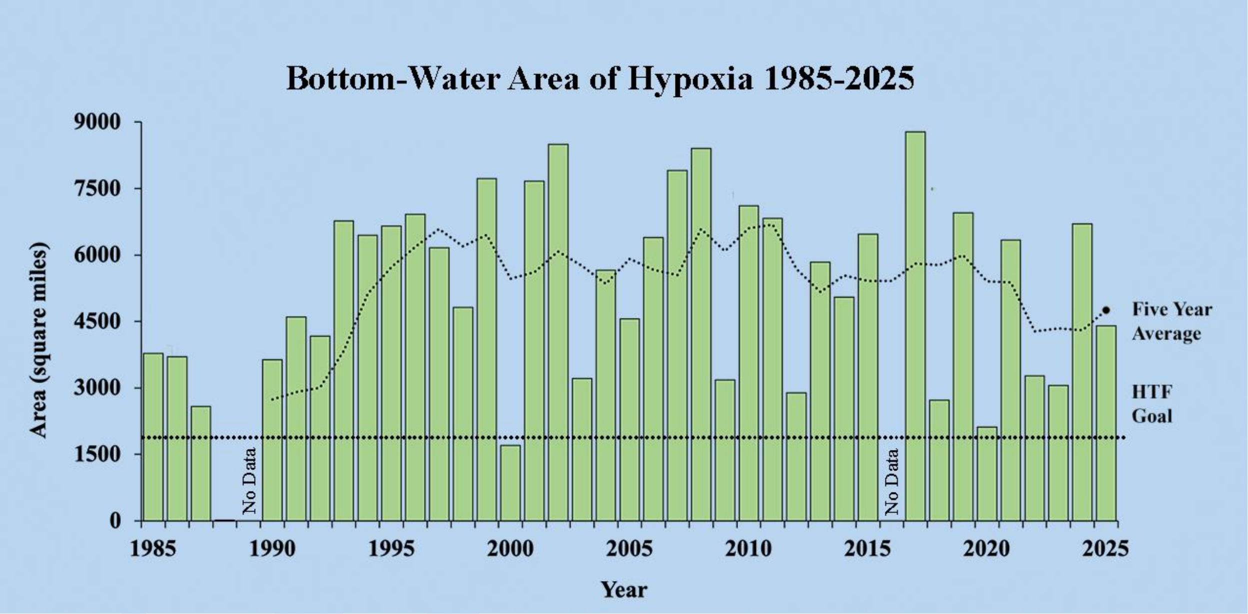
**Low-oxygen waters, also known as a dead zone, covered an area in the gulf approximately the size of Connecticut in the summer of 2025.**

*Map of measured Gulf of Mexico hypoxia zone, July 20–25, 2025. Red area denotes 2 mg/L of oxygen or lower, the level which is considered hypoxic, at the seafloor. Hypoxic waters indicate there is not sufficient oxygen to support marine life. These seasonal conditions occur in the gulf each year as a result of large amounts of nutrients, primarily from agriculture, delivered from the massive watershed of the Mississippi River. (Image credit: LUMCON/LSU)*

The Mississippi River/Gulf of America Hypoxia Task Force is a partnership of federal and state agencies and Tribes established in 1997 with the goal of reducing the size of the gulf hypoxic zone, aiming for a five-year average extent of less than 1,900 square miles by 2035.

Each year, the National Oceanic and Atmospheric Administration (NOAA) supports a research cruise to measure the extent of the dead zone. The five-year average as of 2025 is 4,755 square miles, two-and-half times the target for 2035 (Figure 6.7) (229). Because the main cause is nutrient input from the massive Mississippi River Basin, which drains approximately 65% of US farmland, addressing the issue requires collaboration with land and wetland managers (see Box 7.3 and Box 8.2. The Hypoxia Task Force has called on all states within the watershed to develop comprehensive nutrient-reduction strategies, but several agricultural states including Iowa, Minnesota, and Illinois continue to have large nutrient runoff contributions (230,231). Decisions made by farmers and regulators more than a thousand miles away impact the health of the gulf ecosystem and the coastal communities that depend on it (232).

**Figure 6.7. Change in Size of the Gulf Dead Zone**



**The extent of low-oxygen waters in the gulf has remained high despite a government-led initiative encouraging agricultural states to reduce nutrient loadings into the Mississippi watershed.**

*Long-term size of the hypoxic zone (green bars) measured during ship surveys since 1985, including both the target goal (horizontal black dotted line), established by the Hypoxia Task Force (HTF), and the five-year average measured size (wavy black dotted line). Although the HTF has set an ambitious target to reduce nutrient pollution into the gulf, the hypoxic area is still much larger than the target.* Reprinted from NOAA (233).

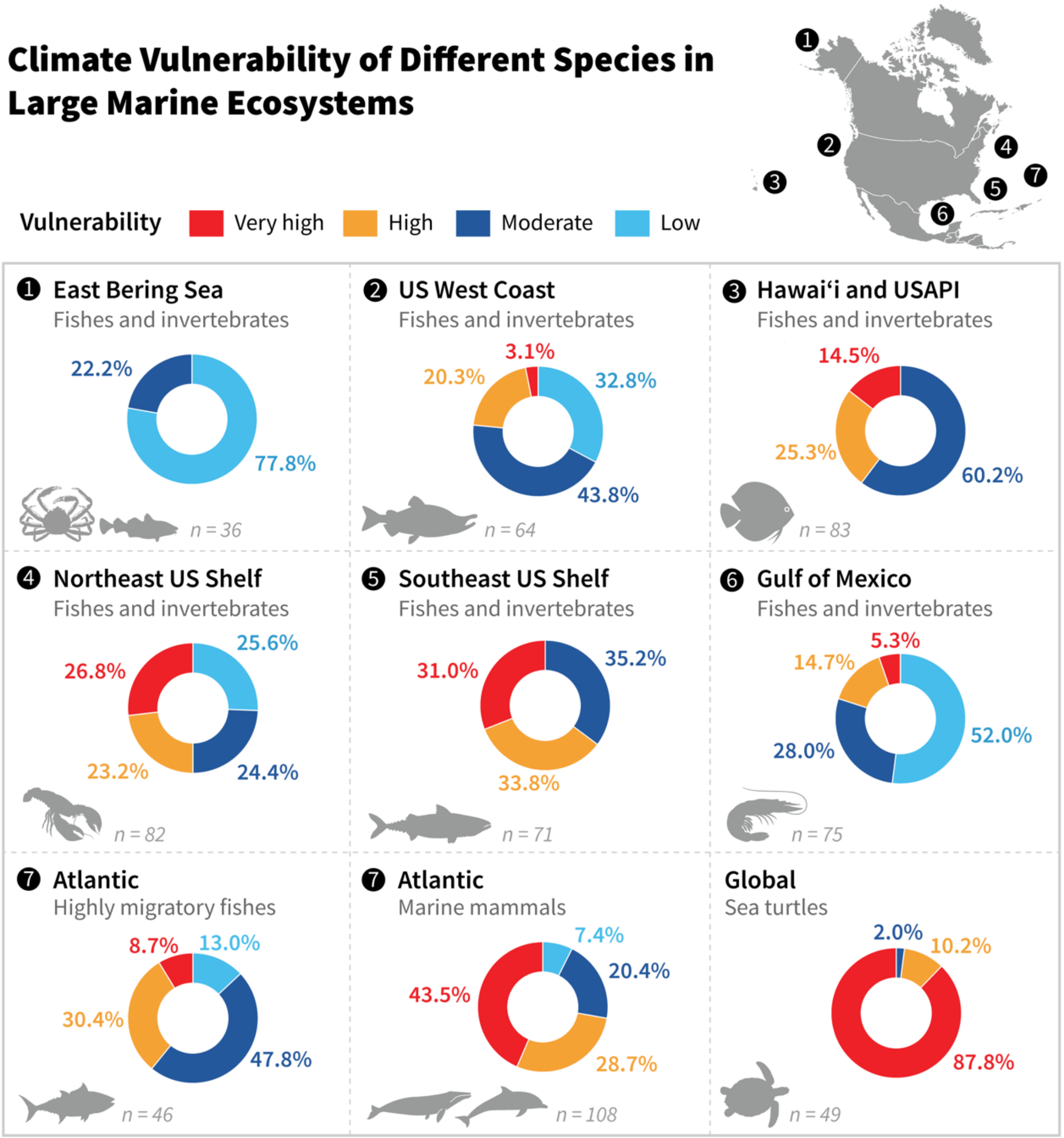
[END BOX 6.2 HERE]

### Uncertain Future Status: Climate Vulnerability

Climate change is expected to be the most important driver of change for marine ecosystems in the future, compounding the impacts of other threats (4,43,234–236) (see Ch 10: Climate Change). Species' distributions will continue to shift, although not all species will decline; some species will emerge as "winners" whose abundance and ecological significance increase (237–240).

Since 2016, NOAA has assessed the future climate **vulnerability** of hundreds of US marine species, based on species' **sensitivity** and **exposure** to climate stressors (Figure 6.8). Nearly all populations examined (93%) are expected to have high or very high climate exposure, with sensitivity to those impacts ranging from low (36% of assessed species) to very high (11%). Regions with lower vulnerability include the Eastern Bering Sea, where projected exposure was low to moderate (241), and the Gulf of Mexico and West Coast, where projected exposures were high to very high but most assessed species had low to moderate sensitivity (242,243). Greater vulnerability was anticipated for systems with relatively high sensitivity and exposure, such as the Pacific Islands and Southeast US shelf (244,245), and for species groups that span multiple ecosystems or are highly dependent upon vulnerable habitats, such as West Coast salmon, Atlantic marine mammals, and sea turtles worldwide (246–248). Species that are vulnerable to climate change are likely to experience declining abundances, shifting distributions, and higher extinction risk in the decades ahead, and ecosystems with a high proportion of vulnerable species could experience major community and trophic reorganization and collapse of important fisheries (43,249–255).

**Figure 6.8. Climate Vulnerability of Different Species in US Large Marine Ecosystems**



**Over the next several decades, nearly all marine species in US waters will experience changes in abundance or distribution because of climate change.**

*NOAA assessment of climate-change vulnerability of subsets of fishes and invertebrates from Hawai'i and the Pacific Territories* (244), *the Eastern Bering Sea* (241), *the West Coast* (243), *the Northeast Shelf* (249), *the Southeast Shelf* (245), *and the Gulf of Mexico* (242); *and for highly migratory fishes of the North Atlantic* (256), *marine mammals of the northwestern Atlantic* (247), *and sea turtles globally* (248). *The majority of populations examined were moderately, highly, or very highly vulnerable to potential climate effects in the coming decades. Vulnerability projections are based on cited assessment authors' analyses of the species' sensitivity and potential exposure to climate change impacts by* *the mid-21st century. Vulnerability categories are low (light blue), moderate (dark blue), high (orange), and very high (red). Figure original to The Nature Record.*

While these NOAA assessments do not cover all US marine regions and species groups, other studies add to our understanding. Arctic ecosystems are experiencing some of the most rapid physical changes on Earth (257), and total animal biomass in the Arctic Ocean is projected to increase strongly this century (43). By the end of the century, corals are predicted to experience severe negative effects of climate change (258,259), with most reef-building coral species at extremely high risk of extinction (260). Reefs with living coral could be gone or incredibly rare throughout the US EEZ, leading to substantial loss of coral-dependent species and the benefits people depend on from healthy reefs (see KM 6.2). For seagrass ecosystems, projected changes given low (SSP1-1.9) and higher (SSP3-7.0) scenarios suggest a redistribution of seagrass by the end of the century, with expansion in the Arctic, losses in lower latitudes, and changes in community composition across latitude (261). Coastal wetlands are also expected to face increasing rates of net loss as sea level rise continues to accelerate (262). While rising atmospheric carbon dioxide levels and plant range shifts can stimulate plant growth and boost wetland elevation gain (177,263), these adjustments will not reverse the long-term decline of coastal wetland area expected under a middle-of-the-road sea level rise scenario (264,265). Tropical and coldwater corals, seagrass, and wetland ecosystems all provide habitat for many other species, from fishes to manatees to birds. They are also important nursery areas for early life stages of species with high cultural or fished importance, including many fish, shark, and crustacean species, and thus declines in these habitats will have cascading impacts (266–272).

### Uncertain Future Status: Increasing Dominance by Harmful Species

US marine ecosystems are increasingly modified by a higher dominance of harmful species. Infectious disease is a growing threat and driver of community change, with many epidemics occurring suddenly, proceeding rapidly, and interacting with climate change. There is no public database of marine pathogen distributions or outbreaks (42), but recent large-scale epidemics affecting important species and biogenic habitats include sea star wasting disease (273), stony coral tissue loss disease (274), eelgrass wasting disease (175,275–277), and urchin ciliate disease (278). Sea star wasting disease caused sudden, widespread mass mortality from Alaska to Mexico (273,279–281), affecting more than 20 sea star species and resulting in the death of millions of sea stars (273,279,280). This included mass die-offs of the predatory sunflower star (*Pycnopodia helianthoides*), which caused herbivorous urchin populations to increase, decimating kelp forests (273,282,283).

Establishment and spread of nonnative species has also been a growing problem. Nonnative species increased in North American coastal waters by 51% between 2000 and 2010 to a total of 450 species (284). Nonnative species often become **invasive**, reaching abundances considerably higher than in their native ranges, with negative impacts on native species and ecosystem health (285). Problematic marine invasive species in the US include Indo-Pacific lionfish, which is now widely established in the western North Atlantic, Gulf of Mexico, and Caribbean (286–288); it is associated with 45–80% declines in the abundance and biomass of native reef fish species in some locations (289,290). Ocean warming often facilitates expansion of invasive species, such as the spread of many invasive pathogens (291) and green crabs, a predator species associated with shellfish fishery declines on the East and West Coasts (292–295).

Outbreaks of nuisance species can also involve native species exceeding historical abundances or distributions, with effects such as fouled fishing gear, altered food webs, negative impacts on recreation and tourism, and even human health concerns. Examples include repeated coastal inundations by the floating seaweed *Sargassum* in parts of the Southeast since 2011 (296), massive blooms and range expansions of free-swimming invertebrates called pyrosomes on the West Coast since the mid-2010s (297,298), and increased frequency of HABs with negative impacts on wildlife, fisheries, human health, and economies (18,216,299–307).

### Description of Evidence Base

Abundant and diverse evidence from ecological surveys, archeological findings, and historical documents indicate it is *virtually certain* that many US marine ecosystems have been substantially altered and key species have declined, especially during the 20th century, particularly as a result of fishing and habitat loss and degradation (1,2,5,7,9,10,12,14,102–104,113,114,144). As once dominant species decline, many empirical studies demonstrate increasing occurrence and abundance of opportunistic and non-native species (142,143,145,146). It is *very well established* based on abundant and consistent empirical data that most marine ecosystems are continuing to deteriorate as climate change adds to other pressures, and numerous modeling and empirical studies make it *very well established* that current trends are expected to continue. (4,44,136,137,146,167,173–175,178–181,187,188,190,191,193,194,308). However, it can be challenging to predict future ecosystem status particularly as regions experience unprecedented ocean conditions, leading to an assessment of *established but incomplete* (44,45,309,310). Outcomes are predicted to vary across species; while many species will continue to decline, others will increase (241–248,291,292).

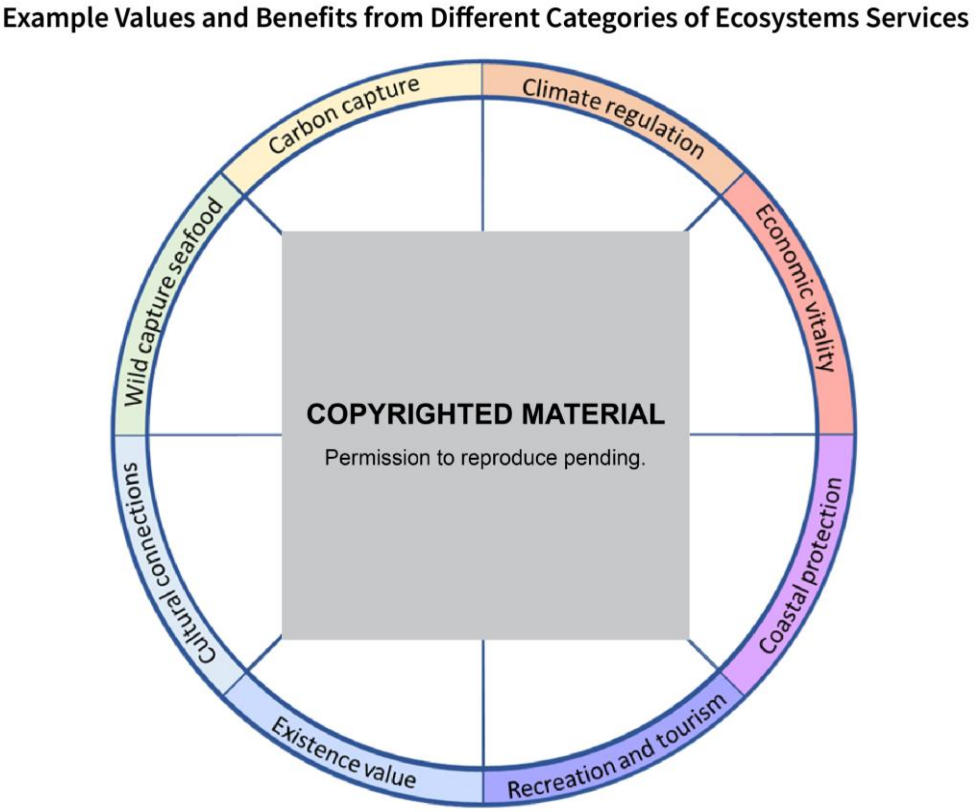
## Key Message 6.2: US marine ecosystems provide crucial economic, human health, climate, and risk-reduction benefits and cultural experiences

*Marine ecosystems benefit people across the US by providing food, jobs, coastal protection, recreation, climate mitigation, and cultural and spiritual connections (virtually certain), in addition to benefits for human health and well-being (established but incomplete). Degradation of marine ecosystems and declines in marine species in the US have resulted in lost benefits, and further losses will occur if marine ecosystems are not effectively managed, protected, and restored (well established). The economic value of* *fisheries, tourism, and protection from flooding and storms makes marine ecosystems vital for coastal communities and the US economy (well established). Noneconomic benefits, such as cultural identity and sense of place, are often stronger in coastal areas than in other types of ecosystems (established but incomplete).*

## State of Knowledge 6.2

Over 129 million people, or almost 40% of the population, live in coastal counties in the US (311). The Nation's coastline extends more than 95,000 miles, and the country has a vast ocean territory (Figure 6.1). Marine species and ecosystems in the US provide a wide range of economic, cultural, human health, climate resilience, and security benefits to people (Figure 6.9) (35,271,312–315). These benefits have been most frequently quantified when they provide direct economic returns, but noneconomic values are also significant. Many benefits depend on abundant populations of marine life and healthy ecosystems; therefore, declines in marine species and ecosystems (see KM 6.1) have resulted in losses of some of these benefits, and further losses are expected with ongoing ecosystem decline (18,22,112,316–318).

**Figure 6.9. Benefits Provided by Marine Ecosystems in the US**



**Marine ecosystems and nature in the US provide people with a range of values and benefits.**

*Illustrative examples of the values, benefits, and relationships that people experience with ocean ecosystems in the US. These benefits from marine nature in the US include food, jobs, coastal protection, recreation, climate mitigation, and cultural and spiritual connections. Degradation of marine ecosystems and declines in marine species could result in the loss of some of these benefits, highlighting the importance of ocean management, protection, restoration, and stewardship. Figure original to The Nature Record (photos in center to be added).*

### Economic Benefits

The US economy benefits from the Nation's vast ocean territory and marine natural resources, which generate revenue, support livelihoods, and provide other benefits with economic value (see Ch. 12: Economy). In 2022, commercial fisheries and the associated seafood industry in the US generated $183.4 billion in sales and $47.2 billion in income (with an additional $74 billion in value-added impacts) and supported 1.6 million full- and part-time jobs (32). Fisheries collapses from overfishing and extreme environmental events (e.g., hurricanes, HABs) have been devastating to fishers, coastal communities, and the broader economy (15,16,319–322). For example, 71 Federal Fishery Resource Disasters were declared from 1989–2020, spanning all US coastal states and territories and resulting in at least $3.2 billion (2019 USD) in revenue loss and an additional $2 billion in Congressional allocations (318).

With wild fisheries landings remaining steady over recent decades, future growth in domestic seafood production could come from **marine aquaculture**—farming seafood in the ocean (323). In 2019, the annual value of marine aquaculture production in the US was estimated at $430.2 million (33), likely an underestimate (324). The industry is growing (324) and diverse, with approximately 65 different marine species farmed in the US since 1970 (324,325). Marine aquaculture has considerable scope for growth (326,327), although may also be constrained by climate impacts. Aquaculture farms in the US have already experienced economic losses from ocean acidification (for shellfish) and HABs (shellfish and finfish) (216,328,329). Furthermore, like all types of food production, aquaculture can have negative environmental impacts (330,331) that must be balanced against its potential benefits (332–335).

US marine waters also support recreational fishing, an activity engaged in by 18.2% of the US population aged six and older (336). Marine anglers took an estimated 201 million fishing trips in 2022 (32). In 2022 recreational fishing supported 691,565 jobs and generated $138 billion in sales, $45.1 billion in income, and $74.9 billion in value-added impacts (32). Recreational harvest equals or exceeds commercial harvest for many marine finfish species, especially along the East Coast and in the Gulf of Mexico (337–339). Declining availability of recreationally fished species, whether from overharvest or other impacts, can result in lost revenues and livelihoods, and future economic benefits are threatened by overfishing, ecosystem degradation, and climate change (340–346).

Ocean-based tourism and non-harvest recreation also provide economic benefits, including activities that are closely connected to nature and marine wildlife—such as whale watching, coastal birding, snorkeling, and diving—as well as those that use the ocean environment but are less dependent on biodiversity, such as boating, swimming, and beachgoing. The estimated annual **gross output** from the marine recreation sector was $225 billion in 2023 (34). Whale watching in the California Channel Islands contributes $14.6 million in **economic output** and $6.0 million in income annually (347). More than half a million visitors went whale watching in Alaska in 2019, supporting more than 1,000 jobs, $37.3 million in labor income, and $103.0 million in economic output (348). Diving and snorkeling on Florida’s coral reefs, including in the Florida Keys National Marine Sanctuary, supports 9,000 to 12,000 jobs and generates as much as $900 million in annual economic output (349,350). Ecosystem degradation can decrease these benefits. For example, HABs in the US have resulted in documented economic losses, including reduced lodging and restaurant expenditures in impacted coastal regions (18,19,343). Future ecosystem degradation and climate change are expected to result in economic losses for some marine recreation and tourism sectors in the US, although anticipated changes vary by location and activity (346,351,352). Lastly, the ocean economy includes sectors, such as shipping, offshore renewable energy, oil and gas extraction, and sand mining, that are not dependent on nature but are important economic drivers and can interact with or conflict with other ocean uses and values.

### Cultural Experiences with Nature

Cultural experiences with nature, which vary strongly based on worldview, depend on the status of nature, the ability of people to access nature, and the meanings and values they associate with those experiences (see Ch. 11: Culture) (35). Cultural experiences associated with marine and coastal ecosystems are not easily assigned economic values and are not systematically considered in management (35,353,354). For example, fishers may sell their catch to friends and neighbors, and transactions through informal networks and other experiences with nature provide additional value by strengthening social connections, fulfilling cultural obligations, and perpetuating traditional foods and diets. These values are often poorly accounted for despite their importance to maintaining coastal community identities and supporting community resilience during disasters (353,355–358).

Cultural experiences are associated with coastal ecosystems more than with other ecosystems (see Ch. 11: Culture). The most frequently studied cultural topics in coastal ecosystems involve sense of place, recreation, and cultural heritage; other important cultural aspects include identity, social cohesion, and spiritual connections. Cultural experiences include teaching your children how to mend a fishing net, learning how to harvest seaweed to ensure it will regrow, giving fish to your neighbor, or sharing in community meals such as the Feast of Seven Fishes, clambakes, crawfish boils, or fa’alavelave (American Sāmoa family gatherings for major life events).

Cultural experiences with nature are shaped by a community’s worldview and its understanding of important relationships with the ocean. Marine management conventions can interfere with these relationships, especially for Indigenous Peoples, who often maintain a reciprocal rather than transactional relationship with nature. For example, in Hawaiʻi endangered sea turtles are ʻaumakua (Native Hawaiian for family or personal gods). When deceased sea turtles are discovered, regulatory prohibitions against handling endangered species and subsequent institutional disposal of the bodies can be seen as disrespectful by people who want to properly honor their ancestors.

Non-Indigenous coastal communities may also have generational histories, cultures, and practices tied to marine nature; these have been less represented in marine management but are starting to be more formally recognized. The Gullah Geechee Cultural Heritage Corridor preserves the unique language and traditions that were developed by descendants of enslaved West and Central Africans on coastal plantations on barrier islands in the Southeast. New Bedford Whaling National Historical Park commemorates the history of the whaling industry central to the New England waterfront.

Declines in the conditions of marine ecosystems have compromised cultural connections with nature. Viewing nature primarily as a commodity with economic value has led to the overharvesting by commercial fisheries that resulted in substantial losses of Indigenous subsistence and ceremonial foods like salmon, herring eggs, and clams (20,21,359–361). Collapses or closures of fisheries because of overharvest or extreme environmental events have threatened the cultural identities and well-being of coastal communities (15,16,320,362). Climate-driven reorganization of marine ecosystems (see KM 6.1) is further challenging the viability of traditional coastal livelihoods. Cultural histories and identities affect how communities adapt or try to maintain cultural connections to nature in the face of climate and other changes (363,364). Commercial fishing experiences that allow visitors to engage in iconic place-based fishing activities—from pulling lobster pots in Maine to serving as commercial fishing crew in Alaska—are emerging as a coastal business strategy, illustrating the power of such experiences even as commercial fishing becomes less viable in these communities (365).

### Human Health and Well-Being Benefits

Nature plays a pivotal but often underappreciated role in supporting human health and well-being (see Ch. 13: Health and Well-Being), and these connections are particularly overlooked for the ocean (36). Marine photosynthesizers contribute half of the oxygen produced on Earth, and ocean ecosystems and species provide or support new medicines, biotechnology, food from fisheries and marine aquaculture, recreation, spiritual value, and inspiration, all of which contribute positively to human health and well-being. The economic benefits described above can also result in communities with better nutrition, lower mortality and disease burden, and better psychological well-being (36).

Seafood from fisheries and marine aquaculture supports good nutrition and helps prevent disease (366,367). Some types of seafood have a smaller environmental footprint than land-based animal proteins (368), making well-managed fisheries and sustainable aquaculture important for both human and planetary health. Marine biodiversity also supports food security and nutrition because diverse aquatic ecosystems tend to produce seafood richer in micronutrients and healthy fats (369). Cultivated algae and seaweeds are used in food and cosmetic products, as a biofuel source, and as crop fertilizers that improve agricultural yields (370). Coastal habitats such as salt marshes and seagrass meadows provide natural filtration that improves water quality and helps protect people from pollutants and pathogens that can accumulate in seafood (371). For example, levels of bacteria in mussels are lower in seagrass than non-seagrass sites near Seattle, indicating that seagrass makes shellfish safer to eat (372). However, these health benefits have to be weighed against health risks of eating seafood contaminated with pollutants such as mercury or microplastics or with pathogens and toxins such those causing ciguatera and paralytic shellfish poisoning—risks that have increased with declining conditions in marine ecosystems (220,306,373–378).

Marine species are also a rich source of new chemical compounds, with uses in medicine and biotechnology. Many marine-derived or -inspired drugs have been approved, with many more in testing, to treat cancer, infections, and other health problems (37). Some discoveries have come from US waters, such as an anti-cancer drug developed from an invertebrate species found among Puerto Rican mangroves (37). Another breakthrough—the light-emitting proteins aequorin and green fluorescent protein from a West Coast jellyfish (*Aequorea victorea*)—has revolutionized biomedical research by making it possible to directly observe biological processes inside living cells (379).

Finally, coastal and marine environments may benefit human health and well-being by building positive emotions and memories, promoting positive social relations, encouraging connectedness to nature, reducing stress, and serving as places to engage in recreation and fitness activities (380–382). Greater exposure to outdoor coastal and ocean spaces can also be associated with benefits for mental health (383,384). All of these health benefits are threatened by marine biodiversity loss and negative human impacts on ocean ecosystems. For example, higher concentrations of microplastics in US coastal waters have been associated with greater risks of diabetes, heart disease, and stroke in nearby communities (385).

### Climate and Risk Reduction Benefits

Ocean ecosystems in the US benefit society by mitigating risks from climate change. The ocean helps regulate temperature increase on the planet by absorbing 90% of excess heat and taking up over 26% of excess carbon dioxide (see Ch. 10: Climate Change). Ocean ecosystems help reduce carbon emissions through expanded ocean-based renewable energy and low-emissions food production (386). Nearshore ecosystems like seagrass meadows, salt marshes, and mangroves are highly efficient at organic carbon sequestration and storage (40). Carbon is also stored in the deep sea, for periods of hundreds if not thousands of years, as organic matter sinks from the open ocean to the seafloor (387).

Coastal wetlands, coral reefs, and other marine ecosystems can mitigate flood risk, reduce storm surge hazards, and attenuate wave energy, resulting in billions of dollars in avoided damages, particularly during major storm events like hurricanes (see Ch. 14: Risk and Security) (22,38,39,388,389). For example, the loss of coastal wetland area between 1996 and 2016 in Florida increased the damages from Hurricane Irma (2017) by $430 million (23). Ongoing loss of coastal wetland area due to sea level rise, development, storm damage and hydrological alteration has greatly increased the vulnerability of coastal populations, and this risk is magnified by the increasing intensity of storms. Other coastal ecosystems, like mangrove forests and coral reefs, can also reduce wave heights and protect shorelines and coastal communities (390–392).

## Description of Evidence Base

Widespread evidence from global, national, and local studies indicates that it is *virtually certain* that marine ecosystems in the US provide a range of benefits to people, including seafood, jobs, recreation, cultural and spiritual connections, climate mitigation, and risk-reduction (32,35,36,40,210,312,315,324,353,357,387,390,391,393,394). Benefits derived from marine nature in the US have been widely assessed in economic terms (32–34), and there are extensive economic data, particularly for commercial and recreational fisheries and aquaculture (32,33,324,395); as a result, it *well established* that marine ecosystems deliver broad economic value. Nationwide value estimates for non-fishing recreational activities are scarce, but local and regional studies highlight their economic relevance (347,349,350,396). Cultural experiences with nature are generally understudied in marine systems (354,397–399), but they appear to be prevalent (see Ch. 11: Culture) and are important for coastal communities, leading to an assessment of *established but incomplete* for these noneconomic benefits and experiences (353,355–358). Connections between ocean ecosystems and human health are also assessed as *established but incomplete*: Although such connections have not been widely studied (36), existing research does suggest important links between the two (37,379,382,383). It is *well established* from numerous global, national, and local studies examining the connections between marine ecosystem condition and benefits to people that declines in marine ecosystems have resulted in lost benefits (15–23) and that ongoing degradation is expected to impact the delivery of benefits in the future (316,400). However, linkages between benefits and ecosystem health are better established for some benefits (e.g., fisheries) (401) than others (e.g., cultural and human health benefits) (402), and more data and common metrics are required to establish a stronger evidence base for the US (403,404).

# Key Message 6.3: Many tools are available to protect and restore marine ecosystems in the US

*Many efforts to conserve, protect, and restore marine systems have been effective (very well established). Such efforts are increasing in the US but often not fast enough to keep pace with losses (well established). Although trade-offs may be necessary, increased investment in conservation and restoration initiatives would help protect the benefits that US communities and economies depend on from these systems (well established).*

## State of Knowledge 6.3

### Efforts to Conserve, Protect, and Restore Marine Species and Ecosystems

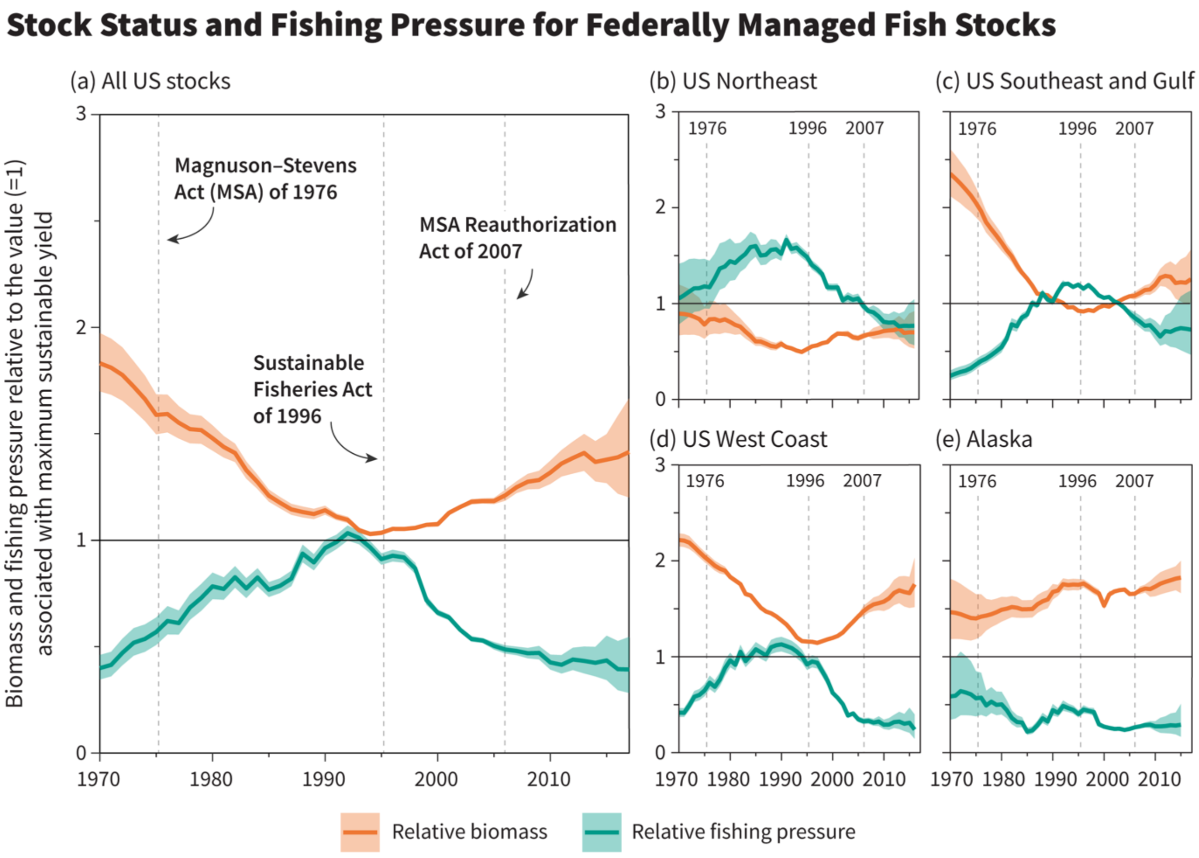
Across the US there are numerous bright spots that highlight how marine species can be protected or recovered (see Ch. 4: Bright Spots). Policy attention at the turn of the century focused on the value of healthy marine ecosystems and the need to preserve these benefits, resulting in important management and policy reform (405,406). Laws that reduce nutrient and organic pollution have improved water quality in many estuaries and coastal regions around the US, fostering recovery of species and habitats (107). Protected areas and species-specific legal protections have helped many depleted populations rebound, including seals, sea lions, whales, sea otters, and sea turtles (151,407–410). Unsustainable fishing has declined sharply, particularly for federally managed fisheries (Box 6.3). As of 2023, only 18% of adequately assessed federally managed fish stocks (47 of 263 stocks) were considered overfished (155), compared to 46% in 1996.

**Box 6.3. US Federally Managed Fisheries as a Management Success Story**

Stronger management of federally managed fisheries (those in the EEZ, usually from 3 to 200 nautical miles offshore) under the Magnuson–Stevens Fishery Conservation and Management Act (MSA) has led to the recovery of many previously overfished stocks (Figure 6.10). Trends in fishing intensity and fish population biomass (i.e., **stock status**) show apparent improvements after the 1996 and 2007 MSA reauthorizations related to management changes. The MSA aims to balance biodiversity protection with the economic and social benefits of fishing. The success of the MSA is clear nationwide and across regions (Figure 6.10), and it has been more successful at meeting conservation goals than many management frameworks in other countries, including the EU Common Fisheries Policy (411).

The recovery of once overfished populations shows that effective management can balance resource use with conservation (412,413). These successes, and the overall performance of US federal fishery management (414), are tied to several key features of the MSA and its reauthorizations (415,416). First, the MSA separates science from policy by requiring evaluation of stock status and uncertainty using the “best scientific information available.” Second, all stocks must have **annual catch limits** (ACLs) that cannot exceed a 50% risk of **overfishing**. Managers use tools such as in-season catch monitoring, trip limits, and **catch shares** to stay within these limits. Third, overfished stocks have mandatory “rebuilding plans” that sharply reduce fishing pressure until the stock recovers to a target population size, which may take years to decades. Between 2000 and 2023, 50 US stocks were declared “rebuilt” (155). Finally, decisions rely on robust fishery-dependent data (e.g., the location, amount, composition of the catch) and fishery-independent monitoring (e.g., scientific trawl surveys). Together, these data streams support regular stock assessments to track stock status relative to reference points and guide rebuilding plans and future ACLs.

**Figure 6.10. Stock Status and Fishing Pressure for Federally Managed Fish Stocks**



**The history of US fisheries shows that scientifically informed management can result in good outcomes for people and nature.**

*Federally managed fish stocks are generally healthy and experiencing sustainable fishing pressure. Since the 1970s, changes in fish population status and the intensity of fishing pressure coincide with significant changes in fisheries management. Orange and green lines show average biomass and average fishing pressure, respectively, relative to the biomass and fishing pressure that would provide maximum sustainable yields (MSY). Shaded regions depict uncertainty related to the uneven representation of stocks across years. Vertical lines show the original Magnuson–Stevens (MSA), 1996 MSA reauthorization,* *and 2007 reauthorization. The horizontal line at 1.0 indicates the values of stock biomass and fishing pressure at maximum sustainable yields. For healthy fish populations and sustainable fisheries, relative fishing pressure should typically be below 1 and relative biomass should be near or above 1. Adapted from Hilborn et al. 2020* (414).

[END BOX 6.3 HERE]

Although many marine ecosystems and habitats have declined (Figure 6.4), several tools and approaches have proven effective at protecting and restoring them, including marine protected areas (MPAs) and habitat restoration. MPAs provide long-term biodiversity and ecosystem conservation by limiting destructive or extractive activities such as dumping or fishing. When well designed, managed, and enforced, they provide benefits including greater reproductive output, higher genetic diversity, bigger and older fish, greater resilience to disturbance, and higher abundances, biomass, and species richness (417,418). MPAs often have the greatest benefits when they have higher levels of protection and prohibit all fishing (417), but some conservation benefits are also possible from MPAs that allow some fishing (419) or from non-MPA conservation areas, such as Indigenous traditional management areas (420).

The US has nearly 1,000 MPAs covering 26% of US waters (Figure 6.1) (24). Most of the MPA area in the US consists of highly protected waters concentrated around Hawaiʻi and US Pacific Island territories; as a result, protected areas do not contain a representative fraction of the biodiversity found in US waters (42). A notable MPA network along the coast of the contiguous US is the California state waters MPA network, which was established and managed under the Marine Life Protection Act (MLPA). This network has resulted in ecological benefits, including higher fish biomass and abundance (25,421,422) and enhanced climate resilience (423–425), although MPAs do not provide blanket protection from climate change impacts (426). The MLPA process is a globally recognized model of MPA planning (427,428) and highlights the importance of well-resourced, science-based, and inclusive management, including efforts to co-manage resources with Tribes (429) and other stakeholders.

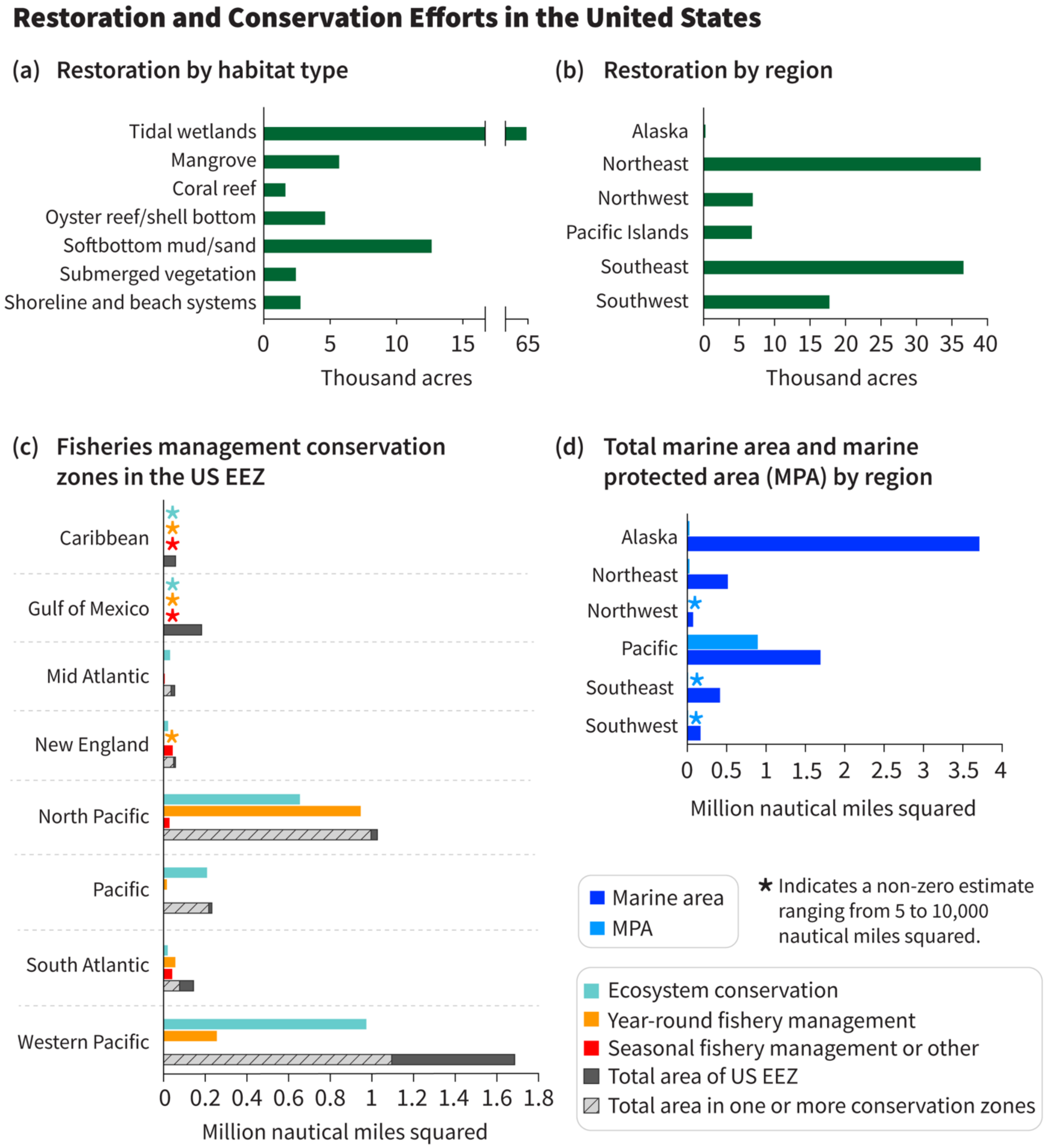
MPAs are not specifically a fisheries management tool: by definition, their primary goal is to conserve biodiversity (430). However, they can provide fisheries benefits. **Spillover effects,** when fish and other organisms move from inside the MPA to unprotected areas outside the boundaries, can increase fishery catch and abundance near MPA borders (431–433). Examples include the spiny lobster fishery in California (433) and the bigeye and yellowfin tuna fishery in Hawaiʻi (26). While not considered MPAs, some fishery management zones (e.g., ecosystem conservation areas and seasonal or year-round fisheries management areas) are designed to address fishery management needs while also yielding conservation benefits (Figure 6.8c).

Restoration projects complement protected areas by aiming to reverse habitat degradation or create new habitat, often focusing on protecting or outplanting (transplanting nursery-grown organisms) foundation species. Over recent decades, restoration has improved estuarine, wetland, and nearshore habitats nationwide (434–436). Some restoration has led to large-scale recoveries: more than 3,600 hectares of seagrass meadows have been reestablished in the Mid-Atlantic states (see Box 4.1) (27) and hard substrate installations have restored giant kelp forests in Southern California (437). More than 1,110 acres of oyster reef have been restored (see Box 4.1), increasing reef structure and oyster biomass (28,29,438). Restored oyster reefs have also improved water quality (439–441), stabilized shorelines (442), and created habitat for other species (440,443). Salt marsh restoration has increased plant cover, sediment stability, and habitat quality (31,444,445), while marsh **living shorelines** have reduced flood risk (393), sequestered carbon (446), and supported coastal resilience (394). There has also been considerable success from reducing the stressors that led to habitat decline, such as improving water quality through reduced nutrient and wastewater inputs and restoring water flow (107,447–449).

Although restoration effort has increased in recent decades, it is dwarfed by the vast expanse of engineered substrates in US coastal waters. While some structures are added specifically to provide habitat, particularly for fishes (450), most are built for navigation, coastal protection, energy production, and aquaculture. This “ocean sprawl” now covers tens of thousands of square miles and continues to grow (451). These unintended habitats can enhance local abundance and connectivity of populations of native species (452,453), but they also an facilitate the spread of non-native species (454).

Together, MPAs, conservation zones within fisheries management areas, and restoration projects have increased the total area receiving some form of protection in US waters, although the extent and level of protection and restoration vary by region (Figure 6.11). Continued progress will depend on sustaining these efforts to ensure that restored and protected areas deliver lasting benefits for people and nature.

**Figure 6.11. Restoration, Fisheries Conservation, and Marine Protection in US Waters**



**Decades of coordinated restoration, conservation, and fisheries management efforts have yielded tangible results for coastal and marine ecosystems.**

*Strong efforts toward expanding restoration, protection and conservation in US waters have resulted in large areas of the US exclusive economic zone (EEZ) that are protected or include restored habitat, although these efforts are uneven across habitat types and* *regions. Restoration efforts are particularly focused on wetlands and mangroves, with more investment along the East Coast than in other geographies. Fisheries management areas that include conservation designations have been widely implemented in Pacific regions of the US EEZ, and Marine Protected Area (MPA) extent is also high in the Pacific, particularly around the Hawaiian Islands and other Pacific territories. Bar graphs show reported habitat restoration projects recorded in the NOAA Fisheries Restoration and Conservation Database (1994–2025) by (**a**) major marine habitat types in US coastal and marine waters, and (**b**) US region; freshwater and terrestrial habitat categories were excluded from analysis. Panel (**c**) shows areas within the US EEZ covered by NOAA Essential Fish Habitat Areas Protected from Fishing and National Marine Fisheries Service Management Areas, with stacked bars representing the portion of total EEZ area covered by one or more fisheries management or conservation designations; totals account for spatial overlap among zone types (455). Panel (**d**) shows total marine area and MPA coverage by US region, where MPAs are formally designated protected areas currently in force (24,417). Units are thousand acres in restoration panels and million nautical miles squared in EEZ and marine area panels. Figure original to The Nature Record.*

### Management Challenges and Failures

While the US has been a global leader in marine conservation and fisheries management, it also faces challenges and instances of management failures. For example, for non-federal fisheries, including state-managed fisheries, only about 20% have reliable stock status estimates, and of those only 16% had an acceptable stock status score (94). Also, many degraded marine ecosystems and depleted species recover very slowly. Atlantic cod abundance remains low decades after the fishery was closed (41), Caribbean and Florida coral reefs have failed to recover once lost (13,14), and kelp forests can flip to persistent urchin barrens that resist recovery (283,456). These examples show how ecosystems can cross thresholds into alternative states that are hard to reverse. Overall, protecting intact nature avoids the high financial costs, long time spans, and uncertain outcomes of restoration (150,457,458).

In some cases, the causes of species or ecosystem decline are well understood, but effective solutions nonetheless remain difficult to implement. For example, the North Atlantic right whale remains critically endangered due to entanglement, ship collisions, and climate-driven changes in prey, despite strong legal protections and intensive research (459). Similar challenges affect southern resident killer whales—a population with fewer than 75 individuals remaining—due to lack of adequate prey, vessel noise, contaminants, and other factors (460–462).

Another challenge is that current conservation approaches and actions frequently involve trade-offs. For example, maintaining coastal wetlands in an era of rising sea levels may require allowing them to migrate landward, but this can come at the expense of other valuable ecosystems such as freshwater wetlands, croplands, and forests, and this process may be impeded by human infrastructure and associated coastal development policies (262,463–465). Neglecting these trade-offs can cause management plans to fail, as occurred with Louisiana's Mid-Barataria sediment diversion project, which was intended to restore rapidly disappearing wetlands. The project was canceled in 2025 after nearly a decade of planning despite the benefits it would bring to inland populations (466,467), largely because it failed to address negative impacts to coastal communities, especially the small-scale shrimp and oyster fisheries that are crucial to local identity and disaster resilience (358).

Marine conservation and restoration actions are increasing but often not fast enough to keep pace with losses. Many US MPAs have low levels of protection and are unlikely to deliver conservation benefits given the scale and intensity of continuing human impacts (24). Restoration cannot succeed when the drivers of decline have not been reduced (436,468,469). Coral restoration in the Florida Keys provides a stark example: vast effort has been spent on restoring *Acropora* species (470), but long-term success has been limited (471), and what little *Acropora* had been successfully restored was lost in a 2023 marine heat wave, along with most wild patches (114). Furthermore, although some restoration efforts are implemented at bay- or landscape-scales, many projects remain too small to offset regional losses and could benefit from more strategic spatial planning (111,458,469,472,473). Finally, the possibility of weakened environmental regulations could further undermine progress toward marine ecosystem protection and recovery (474–476).

### New Management Solutions

Some promising solutions to address the mounting stressors facing marine ecosystems have not yet been tested or implemented at scale. For example, **ecosystem-based management (EBM)**—which emphasizes the complex interactions among species, the environment, and human activities—has many potential benefits for both nature and people (477–479). However, the US mostly manages species and human activities (fishing, transportation, etc.) individually rather than as interacting components (480,481). Further, agencies managing different components of the ecosystem (or impacts originating from other ecosystems including land-based threats; see Box 6.2) often fail to coordinate management. Most US progress toward marine EBM has been on research, planning, and increasing acceptance of EBM, rather than actual management actions (482). Efforts such as the 2010 National Ocean Policy and the 2021 Ocean Policy Committee (established by Congress) to advance coordinated management have made progress, but many aspects of these are now inactive and gaps remain.

**Dynamic ocean management** is another promising approach. Rather than permanently prohibiting human activities like fishing or shipping from specific locations, the location and duration of restrictions are adjusted to reflect the shifting nature of the environment, marine life, and human activity, to achieve conservation goals and while reducing the impacts on human activities that can be caused by fixed closures (483–485). In theory, near-real-time data on ocean conditions and species' habitat use can be provided to managers and the public (486). However, dynamic ocean management has yet to be tested at a large scale and has been formally implemented in only a few cases, such as salmon bycatch avoidance measures in Alaska's walleye pollock fishery (487).

Simpler forms of time-varying management, such as rotational or periodic closures, offer alternatives and have been practiced in some places for centuries (488). These approaches have been successfully applied in US fisheries, including the Atlantic sea scallop fishery (489,490) and the Mid-Atlantic oyster fishery (491), although application to a Hawaiian reef fishery demonstrates that closure periods must be long enough to allow recovery (492). Such approaches may offer immediate strategies for balancing conservation and access to fishing areas (493,494) while more sophisticated dynamic systems are developed.

### Indigenous Management

Indigenous relationships with nature are often reciprocal, with people and nature viewed as one, a perspective that can be at odds with marine management frameworks premised on a separation of people and nature. Indigenous stewardship has resulted in some of the healthiest ecosystems in the country. Indigenous practices, including wild harvesting and sea-farming methods, sustained both the environment and people for millennia (495–497). From this Indigenous perspective, people are a fundamental part of ecosystems and have an obligation to care for the environment that sustains them, and elements of nature are relations or kin. While dominant marine management focuses on maximizing benefits while preventing overharvest, the goal for many Indigenous Peoples is to actively cultivate abundance or "thrivability" for both people and place (20,99,498,499), a difference that has been referred to as taking versus tending (500).

Indigenous stewardship practices are starting to be institutionally recognized and restored, although such governance transitions can face challenges (501). The Indigenous Aquaculture Collaborative is documenting sea gardens based on millennia of place-based knowledge and experience, such as herring egg gardens in Alaska, clam gardens in the Pacific Northwest, and loko iʻa, Native Hawaiian fishponds (495). In these examples, Indigenous practices create conditions that encourage natural reproduction and serve as nursery environments for young animals while producing nutritionally and culturally important marine foods. In other examples, Papahānaumokuākea Marine National Monument was designated in 2010 as the first mixed natural and cultural World Heritage site in the US. The site's management plan is founded on Native Hawaiian cosmology and methods while also aligning with non-Indigenous management needs (502). Similarly, the Chumash Heritage National Marine Sanctuary was designated in 2024 in the first designation process led by an Indigenous group and grounded in Indigenous worldviews.

## Description of Evidence Base

Both fishery-dependent and -independent surveys demonstrate that federally managed fish stocks have adequate biomass and are experiencing sustainable fishing pressure (155,414,415). Furthermore, thanks to numerous studies with consistent results and covering many years, it is *very well established* that some marine populations and habitats are stable or rebounding, following periods of decline, due to active restoration and protection (27–29,107,148–151,407–409,425,434,436,437). However, it is *well established* through extensive empirical evidence and modeling studies that current restoration and protection efforts are inadequate to keep pace with species and habitat declines in the ocean (42,150,458,469,471), particularly for species and ecosystems that are slow to recover from disturbance (13,41,162–164). This evidence suggests the need to increase investment in conservation and restoration to halt or reverse marine ecosystem declines.

## Environmental Justice and Equity Highlights

Marine management in the US typically centers on people and nature as separate concepts, and takes a utilitarian perspective, as reflected in this assessment's focus on nature's benefits and preventing destructive human impacts. However, individuals prioritize various relationships with nature, from fisheries-based livelihoods and working waterfronts to the intrinsic value of healthy seas, which can lead to conflicts over desired management outcomes or preferred approaches (354,359,503).

Management decisions necessarily require trade-offs, which can privilege certain groups or perspectives over others. For example, area-based restrictions on fishing can improve ecosystem health but negatively impact livelihoods of local fishing communities who may have few alternative sources of income (504). As another example, **catch shares** is a fisheries management approach that provides ownership rights for fishing to reduce incentives for overharvest and improve profitability (505–507). However, unless they are carefully designed to include community priorities (506), catch shares can result in a range of social changes, including industry consolidation, non-local ownership, lost livelihood opportunities, and perpetuation of historical participation barriers (505,506,508,509).

Public engagement in natural resource decision-making is now required by many federal and state laws in the US as a way to include broader perspectives. However, processes that meet legal requirements for public engagement are often perceived to result in an unfair distribution of the benefits and burdens of marine management (see Ch. 11: Culture) (354,359,503,510). Further, prolonged conflicts over issues such as sediment diversion projects, managing marine wildlife interactions with fisheries, and MPA implementation indicate a need for more robust public engagement to understand the underlying social, cultural, and political dimensions of these tensions, which may have philosophical and moral underpinnings (358,503,511). Conflicts often emerge between groups with different identities, histories, and relationships with marine management, and existing management frameworks can lead to systematically ignoring less powerful communities.

Indigenous Peoples are particularly disadvantaged by dominant management processes after having already been systematically erased from the landscapes and seascapes central to their identities. Despite the success and benefits of Indigenous stewardship and governance, groups engaging in these practices historically have had difficulty being recognized by the natural resource management institutions that replaced them, other than legal minimums for consultation or treaty rights. Further, species prioritized for cultural functions may not align with those prioritized by marine management (e.g., 512). In some cases, differences can be stark, as in the case of the Pacific lamprey—considered an elder and honored as First Foods in Indigenous ceremonies but seen as trash fish by managers (513). Governance practices that bridge the gap between these different perspectives and consider the philosophical and moral assumptions behind management tradeoffs could help protect nature and all people.

## Emerging Issues

Reliable information on US marine species and habitats and how they are changing is foundational for their management and protection, and science-based management can be highly effective (see KM 6.3). The US ocean faces emerging and interacting challenges amid the rapidly increasing scale of human impacts, combined with the logistical difficulties of observing and working in the ocean. Innovative approaches and new technologies have the potential to greatly expand the scale, resolution, and breadth of marine data and its ability to inform management. However, novel data streams are unlikely to fully replace long-term stock assessments for fisheries management, or to make traditional biodiversity surveys obsolete, at least until new, more synoptic approaches can be validated.

### Emerging Challenges

The US ocean is expected to face growing pressures from climate change and fishing, as well as from emerging activities including **marine carbon dioxide removal** (CDR), deep-sea mining, and increases in offshore infrastructure. Carbon removal methods, seeking to store excess carbon in the ocean, often involve large-scale engineering (see Ch. 10: Climate Change) but have been hindered by limited scientific information to assess efficacy, as well as by low technological readiness and concerns regarding impacts to marine life (46,514,515). Seabed mining for critical minerals (e.g., near American Sāmoa) is being considered by the US, although the financial viability is unproven and the environmental effects could be extremely detrimental to deep sea ecosystems (47,83,84). Finally, infrastructure is being built in the ocean at a rapid pace with the growth of offshore industries, including wind energy, aquaculture, and oil and gas. In some cases, marine infrastructure supports natural habitats and biodiversity (516,517), but its environmental and ecological impacts generally remain uncertain (518,519).

### Emerging Technologies

Developments in **genomics** are revolutionizing the ability to identify species and characterize population structure, family relationships, migratory patterns, and organism health (520–522). Analysis of environmental DNA (**eDNA**), genetic material shed by organisms into the water, can help discover, map, and monitor marine species (523). For example, eDNA can be used to efficiently detect invasive species (524,525) and endangered species (526,527). It also shows promise for estimating species abundance and even biodiversity (528,529), and could help agencies protect human health from harmful algal blooms (530). The biggest limitation of eDNA is the need for comprehensive DNA reference libraries (531). As a result, genetic techniques are complementary to standardized, quantitative surveys but cannot yet substitute for them.

Marine animals are increasingly monitored with acoustic methods that promise to accelerate biodiversity studies of cryptic and hard-to-study marine life, particularly when coupled with artificial intelligence (AI) and machine learning (532). In particular, passive acoustic technologies deploy hydrophones (underwater microphones) that record a wide range of sounds. Sounds that are diagnostic of particular animals can be used to identify where and when they are present (533,534). Broad patterns in biodiversity can also be captured from passive acoustic soundscapes (223).

The growing scope and efficiency of remote sensing techniques, including satellites and drones, is transforming the resolution and availability of data. Along with AI to assist with data processing and interpretation, these advances are improving information: for example, on phytoplankton biomass and productivity (535), as well as on coastal habitats such as mangrove forests, salt marshes, seagrass beds, and oyster and coral reefs (176,536–539). Drones provide higher-resolution data than satellites and can even collect biological samples or deploy tags on animals, providing insights on animal behavior, health, and condition (540). Remote sensing of fishing activity is providing an unprecedented view of the scale and spatial distribution of fishing (541–543), yielding new tools for enforcement of protected areas and other fishing restrictions.

Advances in communications technology are broadening access to knowledge and the scientific process. For example, **telepresence** involves sending high-definition video and audio from remotely operated vehicles at the sea floor through vessels to the internet, enabling ship-to shore interactions. This has also provided the public with real-time online access to deep-sea exploration, video annotation, and virtual reality experiences (544–547). These activities democratize biodiversity discovery and expand public and political science literacy, which are critical to informing regulations and decision-making about resource extraction, pollution, and protections.

Lastly, AI methods such as computer vision have unlocked image and audio analysis at unprecedented scale, allowing automation of organism identification from coral reefs, intertidal zones, and other hard-bottom habitats (548–551), as well as identification of plankton, fish, and other mobile organisms (552,553). Paired with rapid advances in autonomous platforms (e.g., drones and submersibles), these tools are poised to transform assessment of US marine ecosystems across spatial scales and temporal resolutions that would have been unthinkable until recently (554).

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