Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

GREATER FARALLONES & CORDELL BANK NATIONAL MARINE SANCTUARIES

CORDELL BANK

CONDITION REPORT

2009–2021

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator

National Ocean Service
Nicole LeBoeuf, Assistant Administrator

Office of National Marine Sanctuaries
John Armor, Director

Cover photo: Cordell Bank is a vibrant rocky reef abundant with invertebrate life that supports a diversity of fish species, like rockfish. Photo: Clinton Bauder/Bay Area Underwater Explorers

Suggested citation:

Office of National Marine Sanctuaries (2023). Cordell Bank National Marine Sanctuary condition report: 2009–2021. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

Table of Contents

Authors

Cordell Bank National Marine Sanctuary

Lead author: Danielle Lipski

Contributing authors, in alphabetical order:

Michael Carver

Lilli Ferguson

Kaitlin Graiff

Rachel Pound

Jennifer Stock

Monisha Sugla

Office of National Marine Sanctuaries

Lead author: Kathy Broughton

Contributing authors, in alphabetical order:

Jack Eynon

Stephen R. Gittings, Ph.D.

Danielle Schwarzmann, Ph.D.

National Centers for Coastal Ocean Science

Contributing authors, in alphabetical order:

Sarah Hile

Ayman Mabrouk, Ph.D.

Office of National Marine Sanctuaries

The Office of National Marine Sanctuaries (ONMS), part of the National Oceanic and Atmospheric Administration (NOAA), serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 15 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sanctuaries range in size from less than one square mile to more than 582,000 square miles and serve as natural classrooms, are cherished recreational spots, and are home to valuable commercial industries.

Cordell Bank National Marine Sanctuary

Cordell Bank National Marine Sanctuary (CBNMS) is a productive marine ecosystem off the coast of northern California. The sanctuary is entirely offshore, with its southernmost boundary located 42 miles north of San Francisco, its eastern boundary six miles from shore, and its western boundary 30 miles from shore. In total, the sanctuary protects an area of 1,286 square miles. The centerpiece of the sanctuary is Cordell Bank, a four-and-a-half mile by nine-and-a-half mile rocky undersea feature located 22 miles west of the Point Reyes headlands. The bank sits at the edge of the continental shelf and rises abruptly from the soft sediments of the shelf to within 115 feet of the ocean surface. Other significant features of the sanctuary include Bodega Canyon, deep slope habitat, and the continental shelf. The combination of ocean conditions and undersea topography creates a rich and diverse marine community in the sanctuary. The prevailing California Current flows southward along the coast, and annual upwelling of nutrient-rich deep ocean water supports the sanctuary's rich biological community of fishes, invertebrates, marine mammals, and seabirds.

Framework for Condition Reports

Condition reports are used by NOAA to assess the condition and trends of national marine sanctuary resources and ecosystem services. These reports provide a standardized summary of resources in NOAA's sanctuaries, driving forces and pressures on those resources, and current conditions and trends for resources and ecosystem services. These reports also describe existing management responses to pressures that threaten the integrity of the marine environment. Condition reports include information on the status and trends of water quality, habitat, living resources, maritime heritage resources, and the human activities that affect them. They present responses to a set of questions posed to all sanctuaries (Appendix A). The reports also rate the status and trends of ecosystem services (Appendix B). Resource and ecosystem service status are assigned ratings ranging from good to poor, and the timelines used for comparison vary from topic to topic. Trends in the status of resources and ecosystem services are also reported, and unless otherwise specified, are generally based on observed changes in status since the prior condition report.

Sanctuary condition reports are structured around two frameworks: 1) a series of questions posed to all national marine sanctuaries; and 2) a management-logic model called the Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response (DPSER) framework (detailed below). The questions are derived from a conceptual, generic model of a marine ecosystem. The DPSER framework defines the structure of condition reports.

Although the National Marine Sanctuary System's 15 national marine sanctuaries and two marine national monuments are diverse in many ways, including size, location, and resources, condition reports allow ONMS to consistently analyze the status and trends of resources and ecosystem services in each site's ecosystem to inform place-based management. To that end, each unit in the sanctuary system is asked to answer the same set of questions, located in Appendix A and Appendix B. Additional details on the evolution of the condition report process are below.

DPSER Framework

In 2019, ONMS began restructuring sanctuary condition reports based on a model that describes the interactions between driving societal forces (Driving forces), resulting threats (Pressures), their influence on resource conditions (State), the impact to derived societal benefits (Ecosystem services), and management responses (Response) to control or improve them. The DPSER framework recognizes that human activities, the primary target of management actions, are linked to demographic, economic, social, and/or institutional values and conditions (collectively called drivers). Changes in these drivers affect the nature and level of pressures placed on both natural and heritage resources, which determines their condition (e.g., the quality of natural resources or aesthetic value). This, in turn, affects the availability of benefits that humans receive from the resources (ecosystem services[1]), which prompts targeted management responses intended to prevent, reduce, or mitigate undesirable changes (see Figure FCR.1).

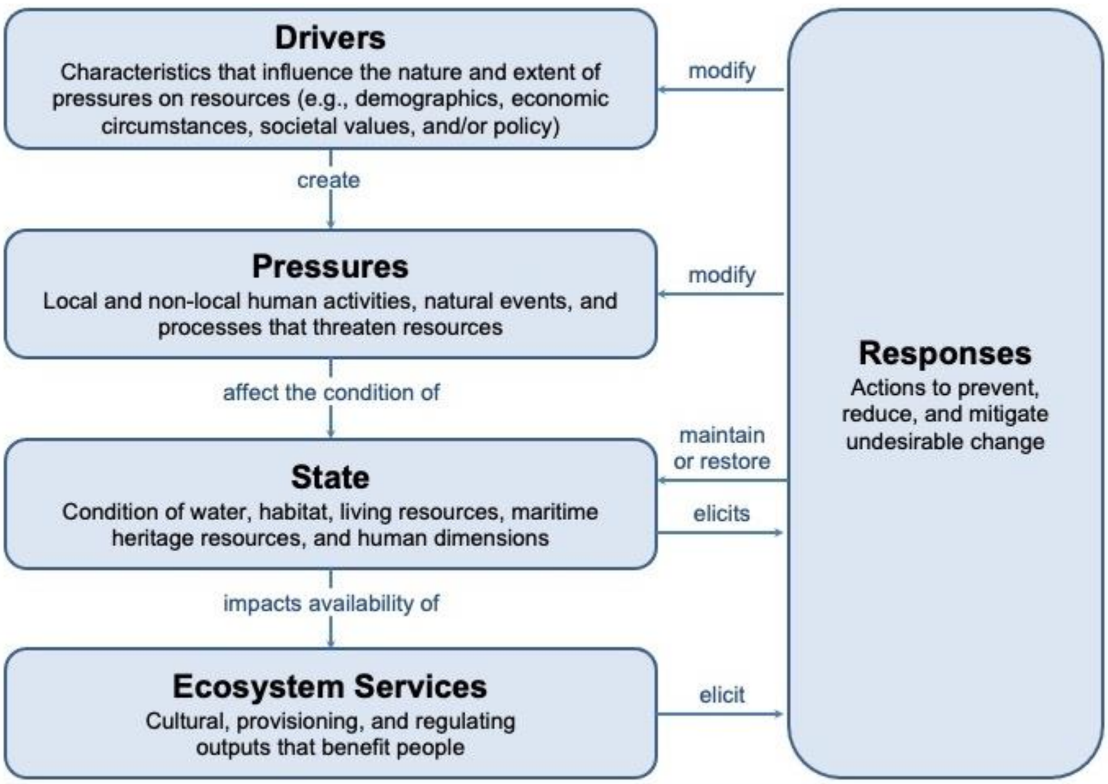


Figure FCR.1. This diagram of the DPSER framework illustrates the functional connections between components and the targets of management responses designed to modify driving forces, pressures, and resource conditions. Image: NOAA

[1] For the purposes of this report, ecosystem services are defined as benefits that humans desire from the environment (e.g., recreation, food). They are what link humans to ecosystems, can be goods (e.g., food) or services (e.g., coastal protection), are valued to varying degrees by various types of users, and can be regulated directly by the environment or managed by controlling human activities or ecosystem components (e.g., restoring habitats). Whether or not specific services are rendered can be evaluated directly or indirectly based on attributes of the natural ecosystem that people care about. For example, recreational scuba divers care about water clarity and visibility in coral reef ecosystems. These are attributes that can be measured and factored into status and trend ratings to assess ecosystem services.

About This Report

The purpose of a condition report is to use the best available science and most recent data to assess the status and trends of various parts of the sanctuary's ecosystem. The first condition report for CBNMS was released in 2009 (Office of National Marine Sanctuaries [ONMS], 2009); ratings from that report are provided in Appendix D. Since the last condition report, CBNMS expanded in 2015 and in 2021 the staff merged with Greater Farallones National Marine Sanctuary to form one joint management unit to administer the two sanctuaries. This updated condition report marks a second comprehensive description of the status and trends of sanctuary resources and ecosystem services. The findings in this condition report document status and trends in water quality, habitat, living resources, maritime heritage resources, and ecosystem services from 2009–2021, unless otherwise noted. The report helps identify gaps in current monitoring efforts, as well as causal factors that may require monitoring and potential remediation through management actions in coming years. The data presented will not only enable sanctuary resource managers and stakeholders to acknowledge and have a shared perspective on prior changes in resource status, but will also inform management efforts to address challenges stemming from pressures, such as increasing coastal populations and climate change.

The findings in this condition report will provide critical support for identifying high-priority sanctuary management actions and will specifically help to shape updates to the CBNMS management plan. The management plan helps guide future work and resource allocation decisions at CBNMS by describing strategies and activities designed to address priority issues and advance core sanctuary programs. The next update to the sanctuary management plan will begin in 2024, building on the 2014 management plan, which contains a number of actions to address issues and concerns (ONMS, 2014a). The process will involve significant public input, agency consultation, and environmental compliance work, and, depending on the complexity of actions proposed, may take one to three years to complete.

The State of Resources section of this document reports the status and trends of water quality, habitat, living resources, and maritime heritage resources from 2009–2021, unless otherwise noted. The State of Ecosystem Services section includes an assessment of human benefits derived from commercial harvest, consumptive and non-consumptive recreation, science, education, heritage, and sense of place within the sanctuary.

In order to rate the status and trends of resources, human activities, and ecosystem services, sanctuary staff consulted with a group of non-ONMS experts familiar with resources, activities, and services in the sanctuary (Appendix C). These experts also had knowledge of previous and current scientific efforts in the sanctuary. Evaluations of status and trends were based on the interpretation of quantitative and, when necessary, qualitative assessments, as well as observations of scientists, managers, and users.

Two other important changes to the condition report process since 2008 should be noted. First, in response to feedback provided to ONMS, the process used to generate the current condition report is more quantitatively robust and repeatable. This was achieved by using the NOAA Integrated Ecosystem Assessment framework (National Oceanic and Atmospheric

Administration [NOAA], 2020a), which takes a literature-based approach to developing indicators for key components of the ecosystem. Status and trend assessments can then be made for the selected indicators over time. This approach ensures that, whenever possible, the expert community has quantitative data representative of core ecosystem components available to them as they contribute to assessment ratings. These indicators continue to be tracked over time, and updated time series data can be used in subsequent assessments.

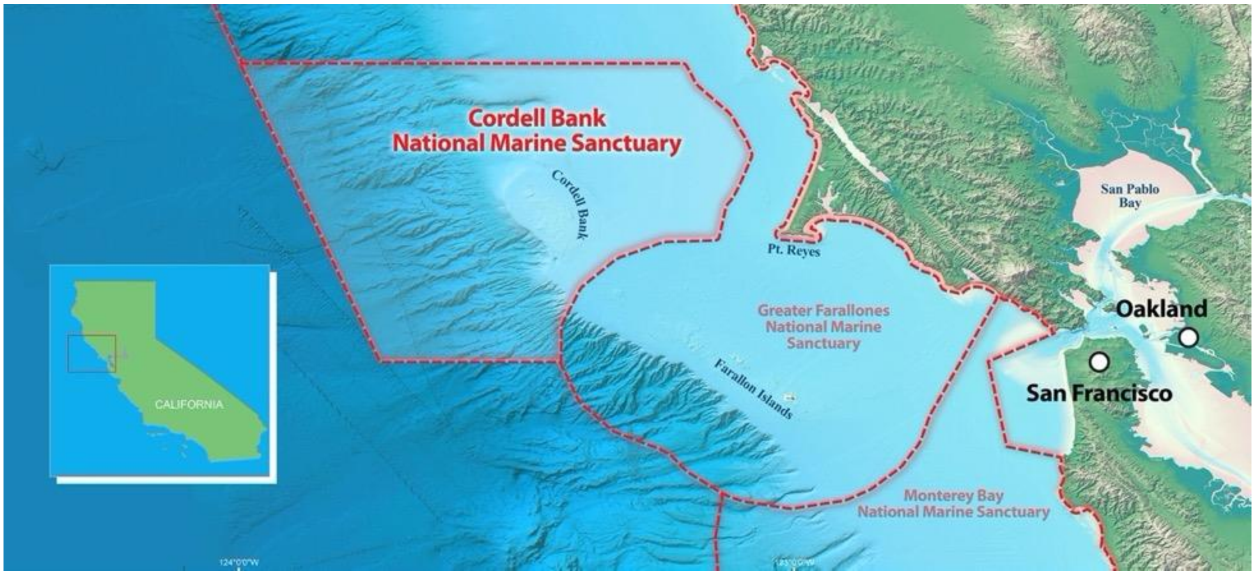
The second improvement pertains to communication of confidence, which was not done in a consistent way in earlier reports. Determination of confidence is now based on an evaluation of the quality and quantity of data used to determine the rating (e.g., peer-reviewed literature, expert opinion) and the level of agreement among experts (Appendix C). The new approach allows for a consistent and standardized characterization of confidence. The symbols used for status and trend ratings have been modified to depict levels of confidence as judged by the expert panel.

This condition report meets the aforementioned standardized format and framework prescribed for all ONMS condition reports. To the extent possible, authors have attempted to make each section’s narrative consistent and comparable in terms of content, detail, and length; however, it is important to understand that each section contains different types and amounts of information given the realities and confines of data sets and expert opinions that were available during this process. Finally, ratings reflect the collective interpretation of sanctuary staff and outside experts based on their knowledge and perception of local conditions. When the group could not agree on a rating, sanctuary staff determined the final rating with an acknowledgement of the differences in opinion noted in the report. The interpretation, ratings, and text in this condition report are final and the responsibility of ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report. This report has been peer reviewed and complies with the White House Office of Management and Budget's peer review standards, as outlined in the Final Information Quality Bulletin for Peer Review (White House Office of Management and Budget, 2004).

Executive Summary

Cordell Bank National Marine Sanctuary (CBNMS) was designated in 1989 and expanded to its current size of 1,286 square miles in 2015. The sanctuary is entirely offshore, with its southern boundary located 42 miles north of San Francisco, eastern boundary located six miles from shore, and western boundary located 30 miles from shore. Seafloor features, such as the rocky Cordell Bank, deep Bodega Canyon, steep slope, and continental shelf habitats, combined with significant upwelling ocean conditions, create an extremely productive marine environment in CBNMS, with an array of species that contribute to the sanctuary's unique biodiversity.

This condition report used the best available information to assess the status and trends of the sanctuary's resources and ecosystem services. The report is structured around a Drivers-Pressures-State-Ecosystem Services-Response model. The report provides a comprehensive update of the status and trends of sanctuary resources from 2009 to 2021, covering the broad categories of water quality, habitat, living resources, and maritime heritage resources. The report also includes the first evaluation of the status and trends of ecosystem services—the ways humans derive benefits from different ecosystem attributes that they care about for their lives, lifestyles, and livelihoods.



Cordell Bank National Marine Sanctuary is 1,286 square miles and is located entirely offshore of the coast of Marin and Sonoma counties in California. Map: NOAA

Pressures on the Sanctuary

The primary pressures identified for CBNMS included climate change and ocean acidification, fishing, vessel activity, and marine debris. Climate change has affected all aspects of the sanctuary, including, but not limited to, water quality, species abundance and distribution, human activities, and ecosystem services. The climate-related pressures of greatest concern are ocean temperatures, upwelling patterns, ocean acidification, and deoxygenation and hypoxia. Some of the greatest challenges related to climate change include marine heatwaves, harmful algal blooms, hypoxic events, and ocean acidification.

Commercial and recreational fishing in CBNMS contribute to the local economy, support jobs, and provide food, but also impact sanctuary habitats and species through harvest, bycatch, seafloor impacts, lost gear, and wildlife entanglement.

Dungeness crab are an economically vital species and are vulnerable to climate-related changes in the ocean. Photo: A. Trigg/NOAA

Vessel impacts include discharge of oil and sewage; wildlife disturbance, including ship strikes on whales and other species; and air and water pollution via exhaust gas emissions.

Marine debris in the ocean is a known and growing threat to marine life and biological diversity, even in remote offshore locations like CBNMS, where it has been found in all habitats. In addition to altering the structure of habitats within CBNMS, lost or discarded fishing gear can continue to catch and kill marine life for years.

Deep-sea corals and other invertebrates can grow on rocky seafloor features, but marine debris can inhibit this growth. Photo: Ocean Exploration Trust/NOAA

Status and Trends of Sanctuary Resources

The condition report rates the status and trends of water quality, habitat, living resources, and ecosystem services. Overall, CBNMS had good water quality throughout the assessment period, as it is not affected by some of the issues present in coastal sanctuaries, such as land-based runoff and point source pollution. For example, there was no information to suggest eutrophication has occurred in CBNMS, and water quality risks to human health, such as poor water quality affecting water access, have not been an issue.

Water Quality

Climate change has affected water quality in CBNMS. The marine heatwave from 2014–2016 resulted in unprecedented extreme conditions. In addition, during the last 10 years, the sanctuary experienced high variability between cold and warm conditions. These anomalies appear to have been more extreme and longer in duration compared to previous events. The 2014–2016 marine heatwave caused significant increases in temperature at the sea surface and at depth. However, the localized upwelling that occurs in CBNMS appeared to offer some buffering and protection from extreme temperatures in the region. Extensive harmful algal blooms during the 2014–2016 marine heatwave caused crabs and shellfish to be unsafe to eat, impacting fisheries, and there were some indications that harmful algal bloom frequency and duration may be worsening over time. The 2014–2016 marine heatwave caused habitat compression, which forces suitable habitat for forage species and their predators to be concentrated closer to shore instead of distributed over the continental shelf and shelf break. These climate impacts have had repercussions to habitat, living resources, and ecosystem services.

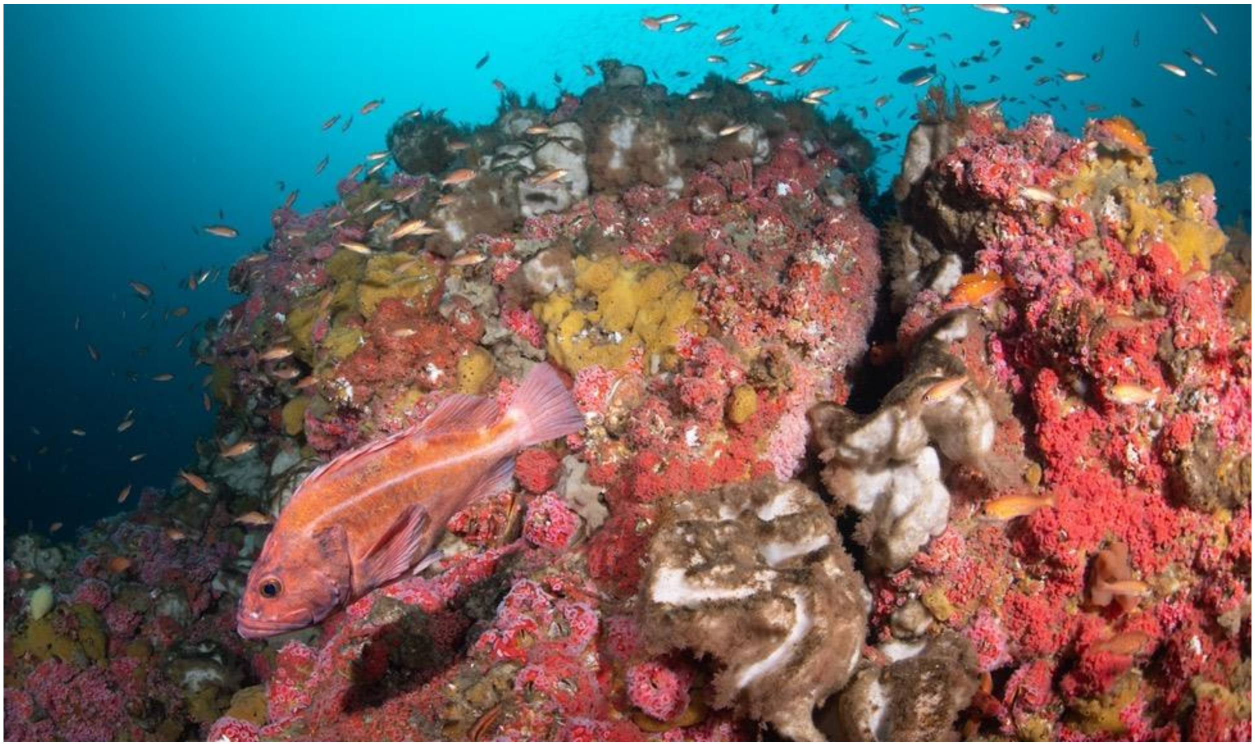
The offshore location of CBNMS protects it from most coastal anthropogenic influences. The sanctuary thus boasts good water quality and supports a diverse and abundant invertebrate and fish community. Photo: C. Bauder/Bay Area Underwater Explorers

Algal blooms affect the food web in the offshore environment and can result from warm ocean conditions. Photo: D. Devlin/Point Blue and NOAA

Habitat

Juvenile yelloweye rockfish rely on Cordell Bank as a key habitat. Photo: M. Vieta/Bay Area Underwater Explorers

Two major habitat types are present in CBNMS: the deep seafloor and the pelagic zone. The sanctuary's offshore location offers protection from coastal development and other direct anthropogenic disturbances to habitats. Therefore, CBNMS habitats were found to be relatively undisturbed and in good condition overall. However, climate change impacted the pelagic habitat through marine heatwaves, habitat compression, and ocean acidification. In addition, noise from ships has affected habitat quality, which can in turn affect animal behavior and health; however, more information is needed about the multi-year trend of this metric. There was also a lack of direct information on other indicators of habitat impacts. Although some inferences can be made about the effects of bottom contact fishing based on the levels and locations of fishing activity, direct information about the magnitude, extent, and duration of fishing impacts to habitat was lacking. Similarly, although contaminants in water and sediments are not expected to be a problem in CBNMS, direct information was lacking.



Cordell Bank is a valuable habitat for yelloweye rockfish, a federally designated overfished species that is slow growing, late maturing, and can reach an age of over 100 years. Photo: C. Bauder/Bay Area Underwater Explorers

Living Resources

Living resources in CBNMS are diverse and, as such, were characterized by a range of status and trends. Abundances of some foundation species (copepods, krill, corals, and sponges) were stable, while others were variable. Changes in abundance of foundation species can change community structure and ecosystem function. Krill and copepods fluctuated during the study period in response to variations in ocean conditions. Krill density and size decreased during the 2014–2016 marine heatwave, and boreal copepods declined during the study period. Variations in copepods and krill can affect predator species. During the 2014–2016 marine heatwave, copepod species composition shifted to less nutritious species. Whales, fish, and seabirds are predators of krill and copepods, and changes in these forage species affect their distribution, health, and breeding success.

Common murres breed on the nearby Farallon Islands and coastal rocks. Their breeding success is dependent on the availability of food in sanctuary waters. Photo: S. Webb/Point Blue and NOAA

Corals and sponges on Cordell Bank appeared to have stable densities in both the shallow and deeper depth strata of the bank, based on available data and observations. In addition, the majority of corals were healthy. Some sites on Cordell Bank are monitored, but the time series is not yet long enough to determine trends, and the number of monitored sites is small.

Bamboo corals are a long-lived deep-sea coral species, and are located in the deeper depths of CBNMS. They provide valuable habitat for other invertebrates and fishes. Photo: Ocean Exploration Trust/NOAA

Humpback whales feed seasonally in the sanctuary. Photo: Sophie Webb/NOAA and Point Blue

Blue and humpback whales, rockfish, seabirds, benthic invertebrates and fish, and turtles were selected as indicator focal species in the sanctuary. Whale populations on the West Coast are recovering from historic harvest, but these populations remain vulnerable. The status of blue, fin, and humpback whales is a concern because they face several threats in and around CBNMS, including ship strikes, entanglements, and climate-related changes in forage species and habitat compression. Habitat compression resulting from climate change and marine heatwaves affects forage species distribution and abundance, which subsequently increases the overlap of whales and human activities, such as shipping and fishing, making whales more vulnerable to ship strikes and entanglement.

Rockfish populations have improved since the last condition report, at least in part as a result of changes in management implemented by the Pacific Fishery Management Council. However, although rockfish are at management targets, they remain far below pristine levels.

Benthic rockfish species (pygmy, rosy, squarespot, and yelloweye rockfish) on Cordell Bank appeared to be abundant and stable throughout the assessment period. Similarly, on the soft sediment on the shelf, flat fish and sea pens were abundant and stable compared to past surveys, although a longer time series is needed to assess trends in both habitats.

Cordell Bank supports over 40 rockfish species in various developmental stages from young-of-year to adult. Photo: NOAA

One notable population decrease occurred in leatherback sea turtles, which have experienced a dramatic decline on the West Coast since 1990. Leatherback sea turtles forage in and migrate through CBNMS and other California national marine sanctuaries. They are vulnerable to a variety of threats throughout their lives including entanglement, bycatch, poaching, and habitat degradation.

There have been some records of non-indigenous species, but no indication that these were detrimental or outcompeting other species. Non-indigenous species are tracked during surveys in benthic and pelagic ecosystems.

Biodiversity in CBNMS appeared to be good and relatively stable based on groundfish, benthic invertebrates, and seabird communities in the sanctuary. This was an improvement from the previous condition report based largely on the recovery of rockfish populations along the West Coast, including in CBNMS. Deep-sea expeditions in 2017–2019 expanded the list of known species within the sanctuary, and further study is likely to increase knowledge of deep-sea biodiversity. In addition, range expansions and shifts in species distribution as a result of changing ocean conditions may contribute to changes in biodiversity.

Unidentified stalked sponge from some of the deepest depths explored in the sanctuary. Photo: Ocean Exploration Trust/NOAA

Status and Trends of Ecosystem Services

Ecosystem services evaluated in the report included heritage, commercial harvest, consumptive and non-consumptive recreation, education, sense of place and science. The heritage of CBNMS includes commercial and recreational fishing, science and exploration, and the presence of maritime heritage resources (archaeological, cultural, historical properties). There is one suspected shipwreck within the sanctuary, and there is limited information on other cultural resources. The Navy destroyer, USS *Stewart,* has not been specifically located or assessed since it was intentionally sunk in 1946 within what is now the sanctuary. It is assumed that the ship will have deteriorated to some degree due to being submerged in the Pacific Ocean. Regardless of the current condition of the shipwreck, it likely continues to retain cultural and historical significance and educational value. At this time, the sanctuary is unaware of other maritime heritage resources or information that suggests historical connections of Indigenous peoples to CBNMS specifically.

Consumptive harvest and consumptive recreation are ecosystem services to which CBNMS contributes, and are part of the sanctuary's heritage. Dungeness crab, salmon, and groundfish are commonly targeted. Recent changes in ocean temperature and extensive harmful algal blooms, which impacted fisheries, as well as fishery delays and closures, such as the ones to mitigate harmful algal bloom exposure and entanglement risk, have somewhat compromised the capacity of the sanctuary to provide these ecosystem services.

CBNMS is a challenging place to visit. A limited number of businesses provide trips to the sanctuary; therefore, very few people are able to access it. Demand to visit the sanctuary is supported by the abundance and variety of wildlife that the sanctuary supports, such as baleen whales and pelagic seabirds. Many of those who have experienced the sanctuary have developed strong, lasting connections. For those who cannot travel to the sanctuary, CBNMS staff and partners have worked to bring the sanctuary to people through media such as telepresence and photo exhibits. Improved imagery, exhibits, and technology such as telepresence opportunities have increased the quality of connections to the public. Staff have also worked with students and teachers through professional development training on specific ocean topics. However, CBNMS was unable to fully expand opportunities to the full potential with just one federal employee dedicated to education.

CBNMS is featured in the Natural Sciences Gallery at the Oakland Museum of California, where visitors and students are able to learn about the sanctuary, which is difficult to experience and see firsthand. Photo: S. Roberts/Oakland Museum of California

CBNMS has a strong science program, but the ecosystem service of science has been limited by the difficulty of accessing the sanctuary. Compared to other sanctuaries with a shoreline, accessing the sanctuary to conduct research presents challenges such as remoteness, rough weather, limited number of research vessels, a limited number of research institutions nearby, and a small science staff. The trend of this service was determined to be improving based on the sanctuary expansion, which spurred new research interest and expanded the area for research.

Data collected through the Applied California Current Ecosystem Studies program have been instrumental in assessing changing ocean conditions and supporting management decisions. Photo: NOAA

Response to Pressures

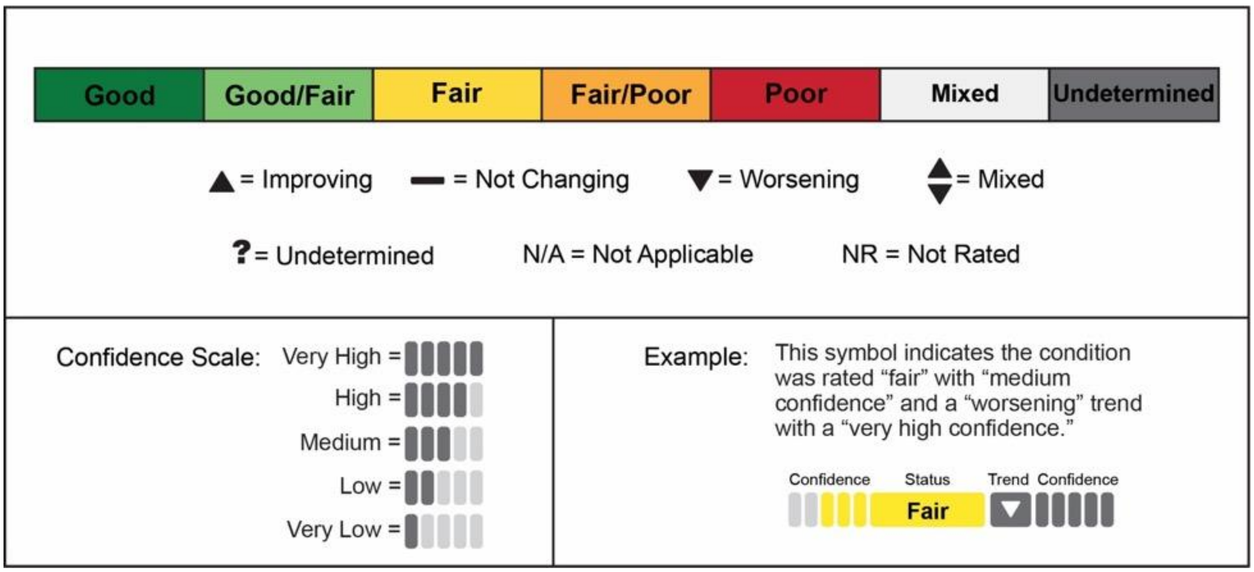
Significant responses to the pressures since the last condition report included investigations of changing ocean conditions, such as a climate change vulnerability assessment and a report on climate change impacts on sanctuary species and habitats. Targeted research and monitoring projects documented conditions and impacts, and the data informed management, including Pacific Fishery Management Council fishery management plans and CBNMS efforts to reduce ship strikes to whales. CBNMS' soundscape research identified the presence of whales year round within the sanctuary and established an acoustic baseline. Through targeted education, CBNMS staff has expanded awareness about the sanctuary among students and teachers, as well as within the larger Sonoma and Marin community. This report identifies gaps in current monitoring efforts, as well as pressures that may require monitoring and remediation through management actions in the coming years. The information in this report will inform the next CBNMS management plan to ensure the sanctuary continues to thrive.

Black-footed albatross are the most common albatross species that fly to CBNMS waters to feed. Photo: J. Hall/NOAA

Cordell Bank National Marine Sanctuary
Summary of Resource Conditions

The various resource status and trend evaluations presented in this report are summarized below. Each question used to rate the condition of and trends in sanctuary resources is listed, followed by:

1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status. The next symbol indicates trend. A shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
2) The status description, which is a statement that best characterizes resource status and corresponds to the assigned color rating and definition as described in Appendix A. The status description statements are customized for all possible ratings for each question.
3) The rationale, which is a short statement or list of criteria used to justify the rating.



Drivers and Pressures

Question 1: What are the states of influential human drivers and how are they changing?

Not Rated

Rationale: ONMS and CBNMS staff decided not to rate the status and trend of influential human drivers at CBNMS. The primary purposes for rating the status and trends of resources are to use condition reports to assess program effectiveness and to influence management of human activities and certain natural resource actions. For the most part, drivers are not manageable, at least not under the authority of the National Marine Sanctuaries Act, nor do most of them originate at scales relevant to national marine sanctuary management. While understanding them is important, rating them is not necessary to achieve the goals of the condition report.

Question 2: What are the levels of human activities that may adversely influence water quality and how are they changing?

Status Description: Some potentially harmful activities exist, but they have not been shown to degrade water quality.

Rationale: There are fairly high levels of human activity, mainly vessel traffic, that pose risks to water quality. Varying patterns make it difficult to discern a trend, but fuel carried per vessel is increasing, though spill volumes have decreased. In addition, although there has been increased vessel traffic over several decades, recent air quality regulations have resulted in a change to low-sulfur fuel and improved emissions. Overall, the levels of large commercial vessel traffic have remained the same during the study period. There were no reported oil spill incidents inside CBNMS, but incidents that occurred nearby had the potential to affect the sanctuary. Vessel discharges were recorded in the sanctuary, yet are likely underreported. New regulations on sulfur oxide emissions resulted in an increase in exhaust gas cleaning systems and a downward trend in emissions over the study period.

Question 3: What are the levels of human activities that may adversely influence habitats and how are they changing?

Status Description: Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.

Rationale: Vessels in and around CBNMS generate noise that can degrade habitat quality for marine species. The soundscape of CBNMS is dominated by ships and baleen whales and is at the threshold of good environmental health, according to European Union standards. Trend data on the CBNMS soundscape are not yet available, but ocean noise has increased globally since the 1950s due to larger vessels and more vessel traffic. Bottom trawling occurs in CBNMS, mainly on soft sediment, and marine debris is present in all sanctuary habitats. It is possible that conditions are improving because bottom trawling has decreased during the study period, but it is also likely that debris and noise in the sanctuary are increasing.

Question 4: What are the levels of human activities that may adversely influence living resources and how are they changing?

Status Description: Selected activities have caused measurable living resource impacts, but effects are localized and not widespread or persistent.

Rationale: Impacts of concern for living resources in CBNMS include vessel traffic, fishing, and entanglement. Vessel traffic poses a risk of ship strikes to whales in the sanctuary, especially in high-use habitat that includes a heavily trafficked shipping lane. In addition, whales are at risk of entanglements in the region, but the occurrence of entanglements in CBNMS is thought to be low. The trend for entanglement and strandings could not be determined due a lack of temporal data from the sanctuary. Generally, however, vessel speed decreased over the study period. A recent, slight increase in vessels and records from VMS suggest that fishing activity has increased from a low in 2018, but there was not a strong long-term trend.[2]

[2] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, "mixed," was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question based on the combination of trends from available data.

Question 5: What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?[3]

Good ?

Status Description: Few or no activities occur at maritime heritage resource sites that are likely to adversely affect their condition.

Rationale: The rating is good because the levels of human activities that may adversely affect the one maritime heritage resource documented to be in the sanctuary, the ex-USS *Stewart* (DD-224), are thought to be minimal. This is due to its isolated location at a depth of 6,000 feet. For example, commercial fishing bottom trawls do not reach to that depth. There may be deposition of marine debris on the shipwreck and the corrosion rate may be changed by increasingly acidic ocean waters. Natural processes of degradation are likely to pose a larger threat. The trend is undetermined due to a lack of information about changes in human activities that may impact the shipwreck. Note that a confidence score was not assigned to the status or trend rating for this question, because subject matter external experts were not consulted on these ratings.

Water Quality

Question 6: What is the eutrophic condition of sanctuary waters and how is it changing?

Good –

Status Description: Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

Rationale: Although data are limited and only provide proxy information, there is no clear evidence of eutrophication resulting from anthropogenic sources occurring in the sanctuary. Some data suggest that climate change may influence nutrients; this issue is discussed further in Question 8.

[3] A workshop was not convened for question 5. Archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject matter experts have been monitoring existing archaeological sites along the West Coast since the 1980s. Note that confidence scores were not assigned to the status or trend ratings for these questions, because subject matter external experts were not consulted on these ratings.

Question 7: Do sanctuary waters pose risks to human health and how are they changing?

Status Description: One or more water quality indicators suggest the potential for human health impacts but human health impacts have not been reported.

Rationale: Phytoplankton species that produce harmful algal blooms and biotoxins were present in CBNMS between 2010 and 2019. A harmful algal bloom event occurred in 2015 that was unprecedented in scope and impact. California sea lions and coastal bivalves, which were used as proxies for environmental biotoxins, indicated toxins were present throughout the region and appeared to worsen over time. Biotoxins were monitored in Dungeness and rock crabs by the California Department of Public Health, and levels often triggered fishery closures, which likely prevented human health impacts. The low confidence in the trend was due to the limited data availability for harmful algal bloom levels throughout the time period.

Question 8: Have recent, accelerated changes in climate altered water conditions and how are they changing?

Status Description: Climate-related changes have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Climate-related changes in some water quality indicators have been observed. Notably, a marine heatwave in 2014–2016 resulted in the highest sea surface temperature on record for the area. This marine heatwave was present for an extended duration, with modeling showing the heat extended into the water column to at least 100 meters. In addition, the record warmest and coolest conditions were observed during the assessment period, indicating high variability in the system. Periods of anomalous conditions, both warm and cool, appear to be more extreme and longer in duration than in the past. Increased variability is one potential outcome of climate change and can indicate worsening conditions. At times, localized upwelling appears to buffer CBNMS from anomalous heating events observed in the surrounding region. Low-pH water and low dissolved oxygen levels extend onto the bank and shelf periodically during the year, but trend data were not available. These climate-related changes are notable because they have been linked to changes in some ecosystem components, including abundance and distribution of pelagic prey and predator species, condition of krill, and the presence and intensity of harmful algal blooms and domoic acid. The low confidence in the trend was due to low agreement among the experts in how to interpret the high variability in the data and the lack of evidence of a clear trend during the time period that was evaluated.

Question 9: Are other stressors, individually or in combination, affecting water quality, and how are they changing?

Status Description: Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

Rationale: Microplastics are present in the sanctuary, but at levels within the range of other open ocean marine settings and much lower than San Francisco Bay. There were no reported oil spill incidents inside CBNMS, but incidents that occurred nearby had the potential to affect the sanctuary. Vessel discharges were recorded in the sanctuary and are likely underreported. Changes to ocean temperature and chemistry caused by global greenhouse gases have also affected CBNMS. The undetermined trend was based on the limited time-series data available for most indicators.

Habitat Resources

Question 10: What is the integrity of major habitat types and how are they changing?

Status Description: Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Direct measures of impacts to CBNMS benthic habitats are limited, but data show that trawling activities, Dungeness crab fishing, and marine debris are present in the sanctuary, albeit at lower levels than some other areas along the U.S. West Coast. Monitoring is required to establish trend data in recently opened and closed Essential Fish Habitat Conservation Areas. Chronic noise from shipping is approaching a threshold level that could cause stress to marine mammals, particularly whales. [4]

[4] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, "mixed," was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data.

Question 11: What are contaminant concentrations in sanctuary habitats and how are they changing?

Status Description: N/A

Rationale: This rating is based on the lack of data on contaminants in the water column, sediments, and animal tissues within the CBNMS region. Based on other ocean areas, stressors of concern for CBNMS include persistent contaminants and microplastics in the water column, sediments, and resident species; these are data gaps that should be considered as targets for future research efforts. Very little information was available on trends for any of the indicators.

Living Resources

Question 12: What is the status of keystone and foundation species and how is it changing?

Status Description: The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.

Rationale: Foundation species at CBNMS include benthic macroinvertebrates (deep-sea corals and sponges), krill, and calanoid copepods. The abundance and health of corals and sponges appears to be good; however, long-term trends are not known due to a lack of historic baseline data. Krill and copepod abundance and composition fluctuated during the assessment period, particularly in association with marine heatwaves.

Question 13: What is the status of other focal species and how is it changing?

Status Description: Selected focal species are at reduced levels, but recovery is possible.

Rationale: Some indicator species are variable, while others are stable and some are declining. Blue and humpback whales are still recovering from past impacts, remain endangered or threatened, and are vulnerable to impacts such as ship strikes and entanglements. Commercially harvested rockfish have improved since the last assessment and are at management targets, but are far below near-pristine levels in the absence of fishing pressure. Seabirds are variable, but there is no evidence of long-term declining trends. Fish and invertebrates on Cordell Bank and the shelf appear stable. However, leatherback sea turtles are at very low abundance throughout their range, and their population has been declining. Because some species appear to be stable, some are variable, and some are declining, the trend was determined to be mixed.[5]

Question 14: What is the status of non-indigenous species and how is it changing?

Status Description: Non-indigenous species are not suspected to be present or do not appear to affect ecological integrity (full community development and function).

Rationale: Limited data from CBNMS have documented no mature or reproductive populations of non-indigenous taxa, and there is no evidence of detrimental impact. Some species of concern exist in the region, but none have become invasive or exhibited significant growth or expansion in the sanctuary. Adequate data do not exist to assess a trend for non-indigenous species, and there was low confidence due to data limitations.

---

[5] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, “mixed,” was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question based on the combination of trends from available data.

Question 15: What is the status of biodiversity and how is it changing?

Status Description: Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

Rationale: Pelagic indicators such as zooplankton appear to have recovered; krill and copepod biodiversity returned to average following marine heatwave-induced changes. Groundfish diversity varied, but was stable and consistent across the region. Biodiversity of macroinvertebrates and fish communities on the bank appeared to be stable, yet the ability to detect trends was limited by the lack of long-term data. Knowledge of new species and range extensions in deep-water benthic communities has greatly improved with advancements in survey technologies and the increasing number of exploration missions. Seabird diversity appeared to be stable and changes in species composition reflected natural seasonal variation.

Maritime Heritage Resources

Question 16: What is the condition of known maritime heritage resources and how is it changing?[6]

Status Description: The status is undetermined.

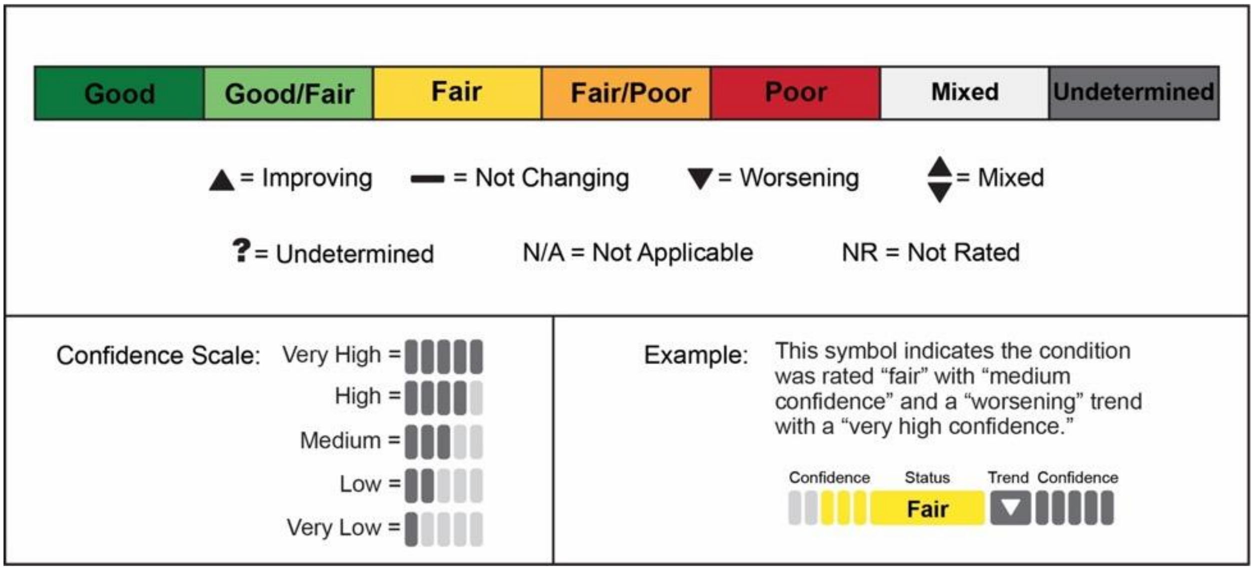
Rationale: The status rating is undetermined. The one maritime heritage resource documented to be sunk within the sanctuary, the ex-USS *Stewart* (DD-224), has not been specifically located or assessed since it sank in 1946 within what is now the sanctuary (see Sanctuary Setting for more information). It is assumed that the ship has deteriorated to some degree as a result of being submerged in the Pacific Ocean; accordingly, the trend for the condition of the shipwreck is thought to be worsening, most likely due to natural processes, though it is possible the condition may be somewhat influenced by human activities (see question 5 in this report). Note that a confidence score was not assigned to status and trend rating for this question because an actual assessment has not yet been conducted; also, subject matter external experts were not consulted on these ratings.

[6] A workshop was not convened for question 16. Archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject matter experts have been monitoring existing archaeological sites along the West Coast since the 1980s. Note that confidence scores were not assigned to the status or trend ratings for these questions, because subject matter external experts were not consulted on these ratings.

Cordell Bank National Marine Sanctuary
Summary of Ecosystem Services

The various ecosystem service evaluations presented in this report are summarized below. Each ecosystem service is listed, followed by:

1) A set of rating symbols that display key information. The first symbol includes a color and term to indicate status, the next symbol indicates trend, and a shaded scale adjacent to both symbols indicates confidence (see key for example and definitions).
2) The status description, which is a statement that best characterizes status and corresponds to the assigned color rating and definition as described in Appendix B.
3) The rationale, which is a short statement or list of criteria used to justify the rating.



Provisioning Services

Commercial Harvest — The capacity to support commercial market demands for seafood products

Fair

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Some fisheries in CBNMS have been impacted by changing environmental conditions, including ocean temperature shifts and algal blooms, as well as management interventions, such as fishery closures to mitigate whale entanglement risk.[7]

Cultural Services (Non-Material Benefits)

Consumptive Recreation — Recreational activities that result in the removal of or harm to natural or cultural resources

Fair

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: For species such as Chinook salmon, Dungeness crab, and the rockfish complex, enhancing existing management would help to improve resource conditions and satisfy demand. [8]

Non-Consumptive Recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources

Good/Fair

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: Public access to CBNMS can be challenging due to extreme and unpredictable weather conditions, offshore location, lack of infrastructure, and limited number of tour operators. However, despite these challenges, businesses and individuals in the area are performing acceptably, and there is still demand to travel to the sanctuary. Populations of certain species that are of interest to wildlife viewers, like humpback and blue whales and some seabirds, are compromised. The worsening trend was driven by extreme weather conditions, which have impacted the number of wildlife viewing businesses operating in the sanctuary.

[7] Because of a limited number of experts available to provide input, staff rated this service after the workshop. Therefore, a confidence rating was not assigned.
[8] Because a limited number of experts provided input, staff rated this service after the workshop. Therefore, confidence ratings were not assigned.

Science — The capacity to acquire and contribute information and knowledge

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Compared to some other national marine sanctuaries, the ability of CBNMS to support science is constrained by challenges associated with accessing the sanctuary, particularly for students and external researchers. These challenges include the sanctuary's remote offshore location, frequently rough sea conditions, and inconsistent access to a research vessel. In addition, the small number of science staff and limited funding hinder the ability of CBNMS to expand its science program and develop new partnerships. Though these limitations led to a rating of fair, the trend was rated as improving, primarily because the expansion of the sanctuary has spurred additional research activity.

Education — The capacity to acquire and provide intellectual enrichment

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: There was high confidence and support among workshop participants for CBNMS education efforts, programs, and outcomes to date; however, but the lack of labor and sustained funding for education and outreach has prevented this service from meeting some community needs.

Heritage — Recognition of historical and heritage legacy and cultural practices

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: The heritage of CBNMS includes commercial and recreational fishing, science and exploration, and the presence of maritime heritage (archaeological, cultural, historical properties) resources. The quality of information related to recent fishing and science activities within CBNMS is high, but other heritage activities lack information. There is currently no information that suggests a connection of Indigenous peoples specifically to the sanctuary prior to contemporary usage of motorized fishing vessels in the region, though there are demonstrated connections to coastal and ocean resources in the general region. In addition, the expansion of the sanctuary in 2015 increased the area where sanctuary maritime heritage resources may be located and increased the coastal area where communities may have connections to the sanctuary. However, information about maritime heritage resources in the sanctuary and its historical and heritage legacy in the broader sanctuary community are areas for further investigation.

Sense of Place — Aesthetic attraction, spiritual significance, and location identity

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: Due to physical barriers to in-person access, CBNMS has focused on bringing the sanctuary to the people through various means. As unique and difficult to visit as it is, CBNMS has cultivated a sense of place through a small but dedicated group of ocean users and has extended that sense of place to others remotely through education and outreach programming. In addition, visual resources created over the years through photography and videography have greatly aided in building a sense of place for local, regional, national, and international audiences. However, a lack of labor and sustained funding for CBNMS education and outreach programs has limited the ability to serve the needs of the community.

Sanctuary Setting

Overview

CBNMS is part of the National Marine Sanctuary System—a network of underwater parks encompassing more than 620,000 square miles of marine and Great Lakes waters. As a result of its unique features and exceptional biodiversity (Figure SS.1), CBNMS was designated in 1989 and expanded to its current size of 1,286 square miles in 2015. It is administered by NOAA. The sanctuary is entirely offshore, with its southernmost boundary located 42 miles north of San Francisco, eastern boundary six miles from shore, and the western boundary 30 miles from shore (Figure SS.2). Seafloor features, such as rocky Cordell Bank, deep Bodega Canyon, steep slope, and continental shelf habitats, combined with significant upwelling ocean conditions, create an extremely productive marine environment in CBNMS, with a wide array of species that contribute to the sanctuary's unique biodiversity.

Figure SS.1. Cordell Bank is a colorful feature in the sanctuary, a rocky bank rising up from the seafloor with its shallowest depths hosting a wide array of invertebrates and providing habitat for rockfish. Photo: R. Lee/Bay Area Underwater Explorers

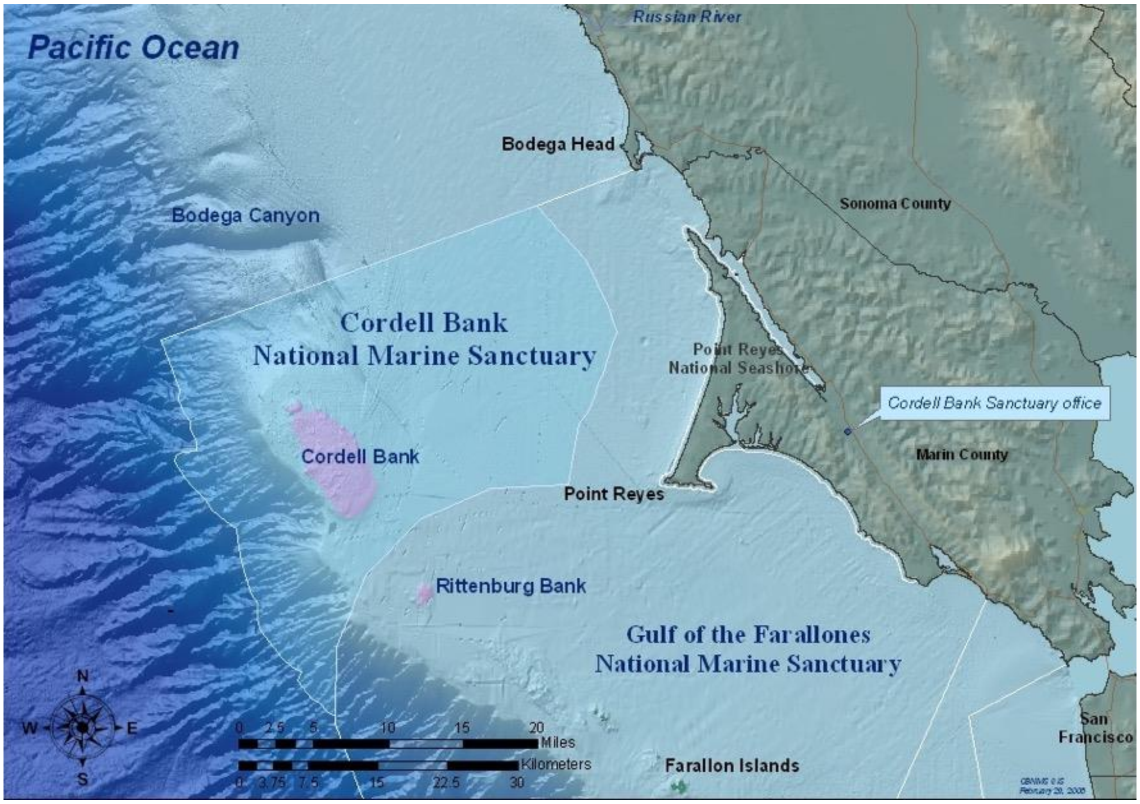


Figure SS.2a. Cordell Bank National Marine Sanctuary boundaries prior to its expansion in 2015. Image: NOAA

Figure SS.2b. The sanctuary is offshore of Marin and Sonoma counties and is surrounded on three sides by Greater Farallones National Marine Sanctuary (GFNMS). Image: NOAA

Discovery and Designation

Cordell Bank was first noted on charts in the 1800s (Figure SS.3) but was relatively unexplored and poorly known until the 1970s, when a group of scuba divers from Cordell Expeditions explored and photographed the bank. Through these efforts, images of the biological diversity of Cordell Bank were first made available to the public. These efforts were also instrumental in designating the site as a national marine sanctuary in 1989 (Figure SS.4). In 2015, NOAA completed a two-year public process that resulted in the expansion of the sanctuary (and neighboring GFNMS), more than doubling its size to include deep-water features such as Bodega Canyon and the western region of the continental slope. In addition to the Cordell Expeditions divers, who were instrumental in the original designation of the sanctuary, local coastal constituents supported the expansion of the sanctuary to encompass surrounding ecological features linked to the bank.

The Sanctuary Doubles in Size

In 2015, CBNMS expanded from its original 529 square miles to 1,286 square miles. The expansion ensured the protection of deeper slope and canyon habitats west and north of the original boundaries, including the highly productive region of Bodega Canyon. The neighboring GFNMS expanded during this process as well, effectively surrounding CBNMS on three sides. In 2021, CBNMS and GFNMS were combined administratively such that both national marine sanctuaries are managed together by one team.

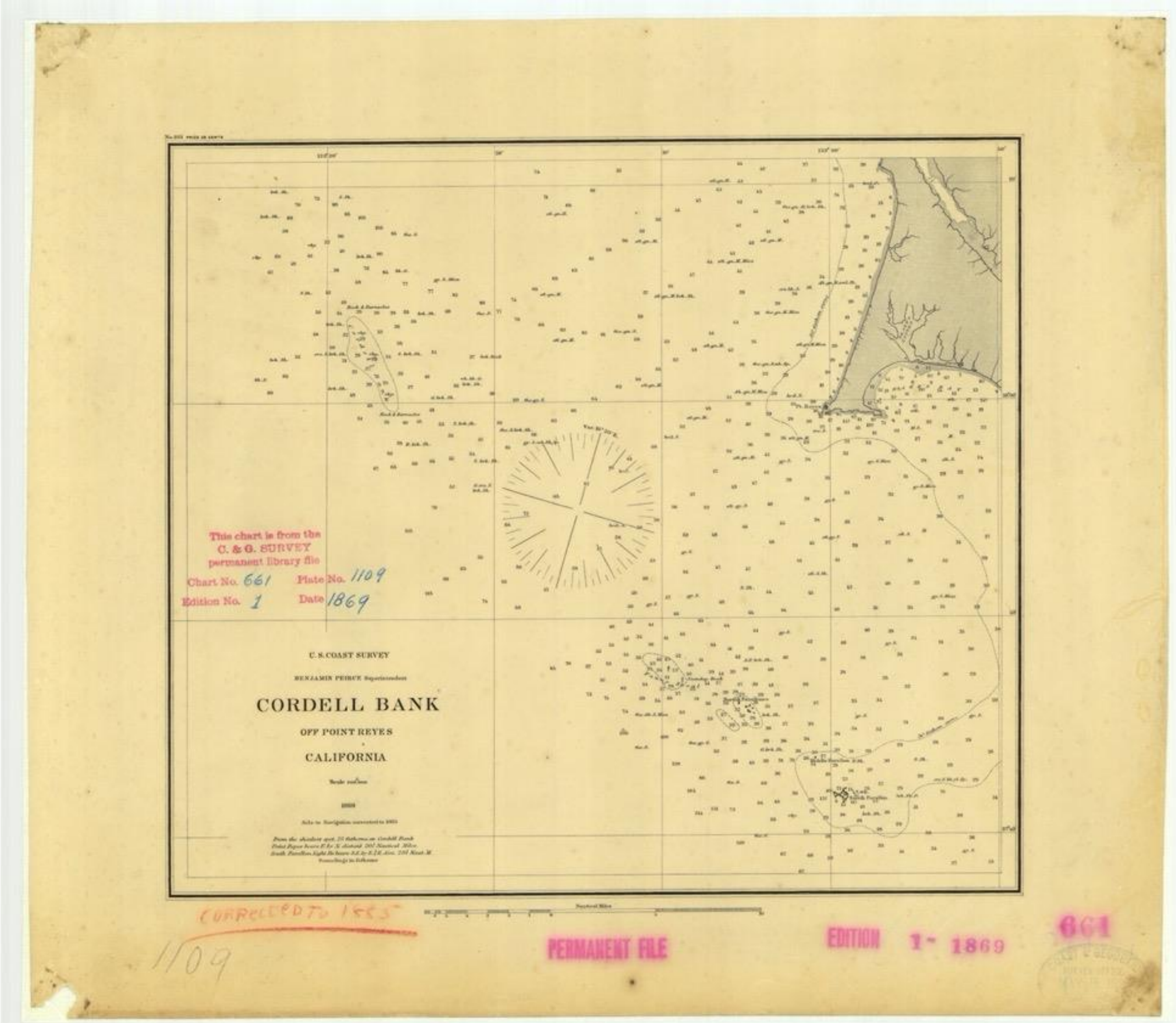


Figure SS.3. A nautical chart from 1869 showing the feature of Cordell Bank offshore of Point Reyes. Image: NOAA

Figure SS.4. Through the efforts of Cordell Expeditions, images of the biological diversity of Cordell Bank became available to the public for the first time. Image: Cordell Expeditions

Oceanographic Setting

Ocean Seasons

Three oceanographic seasons influence CBNMS. Although there is variability in when these seasons occur, they can generally be described as upwelling season in the spring and early summer (April–June), relaxation in the late summer and fall (July–September), and storm season in winter (December–February; Garcia-Reyes & Largier, 2012).

Upwelling Season

CBNMS is located in one of the world's four major coastal upwelling systems. During the upwelling season (April–June), strong northwest winds and the southward flowing California Current System combine with the earth's rotation to drive surface waters away from the shore (Figure SS.5). These surface waters are replaced by nutrient-rich deeper water from offshore via upwelling, which spurs phytoplankton growth, supporting zooplankton and fueling higher levels of the food web. While upwelled waters are rich in nutrients, they are also lower in oxygen and are more acidic than surface waters, which also influences the ecological community of the sanctuary. Upwelling is a major oceanographic and ecological process that is responsible for the incredible productivity of the ocean in the CBNMS region. The productivity driven by upwelling influences many aspects of the sanctuary's ecosystem, from the timing and success of seabird nesting (Piatt et al., 2020; Jahncke et al., 2008) to the presence of migratory species. Species such as blue whales (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) travel from Mexico and Central America to feed in the sanctuary, while seabirds arrive from as far as Papahānaumokuākea Marine National Monument in the Northwest Hawaiian Islands (Hyrenbach et al., 2005), New Zealand (Shaffer et al., 2006), and South America (Felis et al., 2019) to take advantage of upwelling-driven blooms of prey.

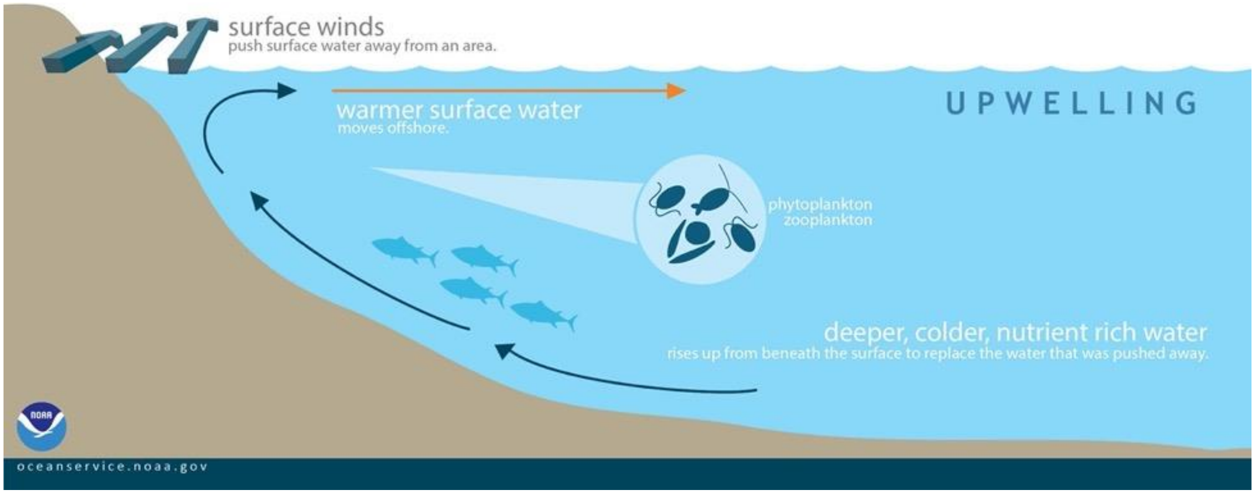


Figure SS.5. Spring/summer upwelling is the primary influence on productivity in CBNMS waters and beyond. Image: NOAA

Relaxation Season

During the late summer and fall (July–September), persistent coastal winds weaken, and the sea surface becomes calmer. Surface currents during this time period typically move northward, and water temperatures increase. During this time, many migratory animals are present in CBNMS, where they feed on an abundance of prey.

Winter Storm Season

The winter storm season (December–February) is dominated by rough seas and increased mixing of ocean water. Strong winter storms originating in the Gulf of Alaska cause turbulent conditions that break down stratified ocean layers in the upper water column, homogenizing temperature, salinity, and the distribution of nutrients. The northward-flowing Davidson Current has a stronger influence on circulation during this time period. Most migratory species are in their breeding grounds at this time, although some individuals may remain (e.g., humpback whales; Haver et al., 2020).

Geology

CBNMS is situated on the Pacific Plate, with its eastern boundary located 7.5 miles (12 km) west of the convergence zone of two of the Earth's major tectonic plates: the Pacific and North American plates. Cordell Bank is the most prominent geological feature in the sanctuary. Sediments surrounding the base of Cordell Bank on the continental shelf are composed predominantly of younger silt and sand deposits that originated from rivers and coastal erosion. These sediments continue to shift and break down due to energetic seafloor ocean currents.

Bodega Canyon, which extends from around 1,640 feet at its head to a maximum depth of nearly two miles at its western end, transports sediment from the continental shelf to the deep sea.

Habitat

The main habitats in the sanctuary include soft sediment on the continental shelf, continental slope, deep canyons, rocky bank, and water column and pelagic habitat. The continental shelf covers 356 square miles and is primarily soft sediment, including sand and mud, with isolated rock piles and outcroppings ranging from 230–656 feet deep (Figure SS.6). The deep slope and canyons (894 square miles) contain some steep walls and hard substrate, but also large areas of soft sediment. The continental slope is primarily mud bottom with some rock outcrops, steep rock walls, deep slope, and canyons down to depths of 11,614 feet. Cordell Bank, the main feature the sanctuary was designated to protect, and its namesake, is an offshore rocky bank roughly four miles wide by nine miles long, covering an area of approximately 36 square miles. The bank emerges from the soft sediments of the continental shelf, with the upper pinnacles reaching to within 115 feet of the ocean's surface (Figure SS.7, Figure SS.8). Shelf depths at the base of the bank are between 300–400 feet. The bank has a diversity of benthic habitats that include high-relief rock pinnacles, flat rock, boulders, cobble, sand, and mud. The pelagic zone, or open ocean water column, is the largest habitat type by volume in the sanctuary. The pelagic zone is subject to seasonal and annual variations in physical parameters like turbidity, temperature, and salinity, as well as stratification. Larger-scale oceanographic events, combined with local conditions, make the water column a dynamic habitat.

Figure SS.6. Slope and canyon are the dominant habitat types by area within CBNMS. The next most common habitat type is shelf, followed by the bank. Image: NOAA

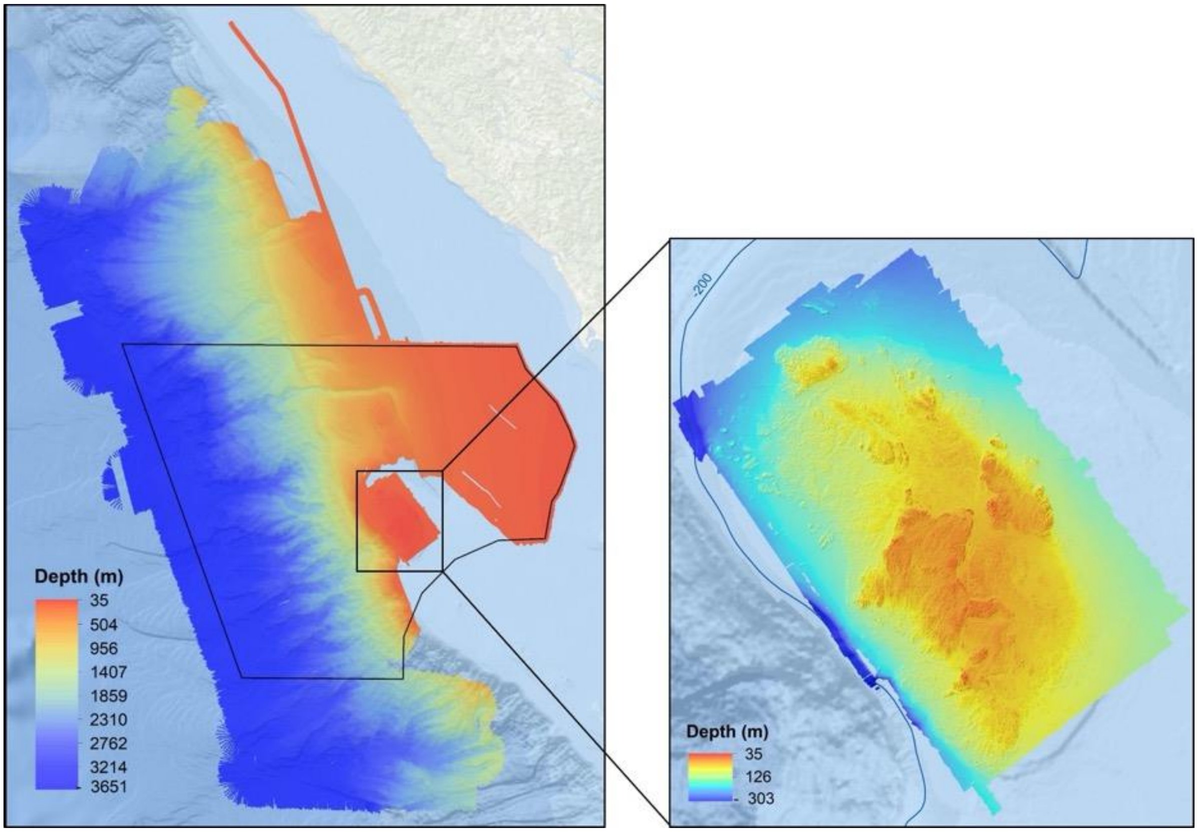


Figure SS.7. Bathymetry of Cordell Bank based on high-resolution multibeam echosounder data. Source: NOAA and California State University Monterey Bay.

Figure SS.8. The pinnacles of Cordell Bank harbor an abundance of life and provide structure for schooling rockfishes. Photo: C. Bauder/Bay Area Underwater Explorers

Living Resources

Benthic Invertebrates

Benthic organisms densely cover the shallower rock surfaces of Cordell Bank. The high light penetration in this offshore environment allows for algal photosynthesis in far deeper water than in similar nearshore habitats along the mainland coast. The abundant food supply drifting over the bank, combined with a hard substrate for larval settlement and attachment, provide ideal conditions that support a rich assemblage of benthic invertebrates (Figure SS.9). Ridges are thickly covered with sponges, anemones, hard hydrocorals, soft gorgonian corals, hydroids, tunicates, crabs, sea cucumbers, and snails.

Soft sediment habitats also support a thriving community of benthic invertebrates. Adapted to life in and on a shifting substrate, these animals are either buried in the sediment, like polychaete worms and clams, or are mobile on the surface, such as sea stars and Dungeness crabs (*Cancer magister*; Figure SS.10). The sea whip (*Balticina californica*) is one common soft bottom resident that extends into the water column, providing structure for fishes and other invertebrates on the flat, mostly featureless bottom of the continental shelf.

Figure SS.9. Dense cover of invertebrates such as hydrocorals, sponges, and anemones carpet the shallow areas on Cordell Bank. Photo: NOAA

Figure SS.10. Dungeness crabs occupy soft sediment habitats on the continental shelf and are an important commercial species in the region. Photo: NOAA

Zooplankton

Zooplankton are an important component of the open ocean ecosystem at Cordell Bank. Copepods and pteropods are tiny but significant food items for other species. Gelatinous zooplankton include moon jellies (*Aurelia aurita*) and sea nettles (*Chrysaora fuscescens*), which are important prey species for sea turtles. Less common gelatinous zooplankton include hydromedusae, ctenophores, siphonophores, pteropods, and heteropods. Fish and invertebrate larvae are also a large component of the plankton community.

Krill

Two species of krill (*Thysanoessa spinifera* and *Euphausia pacifica)* are important trophic links in the Cordell Bank ecosystem (Figure SS.11). These small, shrimp-like crustaceans are foundation species because they are critical prey for many other species on and around the bank. At Cordell Bank, the presence of krill is the primary reason the area is a destination feeding ground for many migratory animals such as Chinook salmon (*Oncorhynchus tshawytscha)*, humpback whales, and blue whales. In addition, krill are prey for resident species like yellowtail rockfish (*Sebastes flavidus*) and Cassin's auklets (*Ptychoramphus aleuticus*), which nest on the nearby Farallon Islands.

Figure SS.11. Krill are often found in large, concentrated groups, including dense swarms with as many as 100,000 krill per cubic meter of water. Photo: Sophie Webb and NOAA/Point Blue Conservation Science

Fishes

More than 250 species of fishes have been documented in CBNMS (CBNMS, 2022; Figure SS.12). Cordell Bank is known as a hotspot for adult rockfishes, and an abundance of juvenile rockfishes transitioning from a pelagic to benthic stage in their early life history can also be found there. Widow rockfish (*Sebastes entomelas*) and pygmy rockfish (*S. wilsoni*) are two of the most abundant rockfish species on the bank, along with young-of-year rockfishes, which are important prey for salmon, seabirds, and adult rockfishes. Deep boulder habitat provides a natural refuge for some species that recently recovered or are currently recovering from overfishing, such as bocaccio (*S. paucispinis)*, yelloweye rockfish (*S. ruberrimus)*, cowcod (*S. levis*), and canary rockfish (*S. pinniger)*. Lingcod (*Ophiodon elongatus*) are conspicuous in the wintertime, when they move up onto the bank to lay their eggs. The soft sediment of the shelf is habitat for flatfish such as sanddabs (*Citharichthys* spp.), rex sole (*Glytocephalus* zachirus), Dover sole (*Microstomus pacficus*), and skates (*Raja* spp.). In the deeper depths of the sanctuary, thornyheads (shortspine [*Sebastolobus alascanus*] and longspine thornyheads [*Sebastolobus altivelus*]) and sablefish (*Anoplopoma fimbria*) are common. In the pelagic habitat, species such as sharks (blue shark [*Prionace glauca*], white shark [*Carcharodon carcharias*], thresher shark [*Alopias vulpinus*], and salmon shark [*Lamna ditropis*]), jack mackerel (*Trachurus symmetuicus*), pacific mackerel (*Scomber japonicus*), and pacific hake (*Merluccius productus*) are present (Figure SS.13). The commercially important northern anchovy (*Engraulis mordax*) and pacific sardine (*Sardinops sagax*) also occupy this habitat. Fishes that inhabit this zone on a seasonal basis include albacore tuna (*Thunnus alalunga)* and salmon (Chinook and coho [*Oncorhynchus kisutch*]).

Figure SS.12. China rockfish (*Sebastes nebulosus*) make use of the living habitat on Cordell Bank for hiding and resting. Photo: NOAA

Figure SS.13. Hake and fragile pink urchins are found on soft bottom habitats along the continental shelf and slope. Photo: NOAA/Marine Applied Research and Exploration

Sea Turtles

The waters off central and northern California are critical foraging areas for one of the largest remaining Pacific nesting populations of endangered leatherback sea turtles, which migrate from Indonesia to feeding grounds off the west coast of North America, including CBNMS (Benson et al., 2007a, 2007b). Leatherback turtles feed on seasonally abundant jellyfishes (e.g., *Chrysaora fuscescens*, *C. colorata*, and *Aurelia* spp.) in CBNMS. Spatial and temporal abundance patterns of turtles in CBNMS and the surrounding region are believed to be driven by upwelling and relaxation events that favor phytoplankton growth and, in turn, increased production of gelatinous zooplankton (Benson et al., 2007a).

Seabirds

The waters around Cordell Bank provide critical foraging habitat for many species of seabirds. During the upwelling season, the highest levels of seabird biomass in the central portion of the California Current are found at Cordell Bank, Monterey Bay, and the Farallon Ridge (Ford et al., 2004). Over 70 seabird species have been identified in the sanctuary, including locally breeding birds and highly migratory open-ocean species. A large percentage of the world's population of ashy storm-petrels (*Oceanodroma homochroa*) nest on the nearby Farallon Islands and feed in the waters around Cordell Bank (Stallcup, 2010). Cassin's auklets are also common local breeders (Stallcup, 2010). Black-footed albatross (*Diomedea nigripes)* nest in the Northwestern Hawaiian Islands and travel to Cordell Bank waters to gather food for their chicks before returning to their nests (Hyrenbach et al., 2005; Figure SS.14). Other migratory species use the productive waters around the bank as a stopover on their annual migration route. For example, tens of thousands of sooty shearwaters (*Puffinus griseus*) pass through the sanctuary annually as part of their migration between the west coast of North America and New Zealand.

Figure SS.14. Black-footed albatrosses travel thousands of miles from the Northwestern Hawaiian Islands to feed in the waters of CBNMS. Photo: Mojoscoast

Marine Mammals

Nineteen species of resident and migratory marine mammals have been observed within CBNMS (National Centers for Coastal Ocean Science [NCCOS], 2007). Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) are frequently sighted in the sanctuary. Other common cetaceans include Dall's porpoise (*Phocoenoides dalli*) and northern right-whale dolphins (*Lissodelphis borealis)*. Humpback whales are present in the sanctuary year-round, but are most abundant in the summer and fall (Figure SS.15). Blue whales are present in the sanctuary in the summer, fall, and winter. Fin whales (*Balaenoptera physalus*) are present from at least late summer to spring (Haver et al., 2020). In addition, gray whales pass through the sanctuary on their annual migrations between feeding grounds in the Arctic and breeding areas off of Mexico. Other mammals seen in the sanctuary include Risso's dolphins (*Grampus griseus*), killer whales (*Orcinus orca*), California sea lions (*Zalophus californianus*), northern fur seals (*Callorhinus ursinus*), northern elephant seals (*Mirounga angustirostris*), and Steller sea lions (*Eumetopias jubatus*).

Figure SS.15. CBNMS is entirely offshore and contains an abundance of marine life, including humpback whales. Photo: S. Webb and NOAA/Point Blue Conservation Science

Commercial and Recreational Activities

Maritime activities are prominent in the history and development of California's North Coast. From the first Indigenous communities to the present, coastal waterways remain an important route of travel and supply. Hunting of marine mammals for meat and fur took place throughout northern California waters in the 1800s and early 1900s, contributing to declines of many species. Ocean-based industries (e.g., fisheries, export and import, and coastal shipping) continue to be important to the modern economy and the social character of this region.

The Cordell Bank region has historically supported important commercial and recreational fisheries. Commercial fisheries in CBNMS generally target rockfish and other groundfish species, Chinook salmon, Dungeness crab, and albacore tuna (Scholz et al., 2005). Private boats and recreational fishing charters originating from Bodega Bay also visit CBNMS waters, targeting salmon, lingcod, and rockfish.

Wildlife watching trips are infrequent, due to the absence of commercial wildlife watching tours available to the public from the sanctuary's closest port, but they can be good opportunities to see blue and humpback whales in their seasonal feeding grounds, as well as uncommon pelagic seabirds.

Maritime Heritage Resources

Ex-USS *Stewart* (DD-224; Figure SS.16) lies within the 2015 expanded boundaries of CBNMS. Records indicate ex-USS *Stewart* is about 39 miles west of Bodega Head. The vessel has a significant history as a U.S. Navy destroyer that served in World War II, for which it received two battle stars for its service (Rickard, 2019). It was captured during World War II and commissioned into the Japanese Imperial Navy in 1943, then went into service as a *Shokaitei (Patrol Boat) No. 102* (Edwards, 2010). Recaptured at the end of the war, *Stewart* was recommissioned into the U.S. Navy in 1945 (Edwards, 2010) and later scuttled in Bodega Canyon. There are records and good historical knowledge of this vessel, but no observations or indications of its presence in data collected on the seafloor. While other historic maritime heritage resources, including prehistoric and cultural resources, may be present within or associated with the sanctuary, at the time of this report, none are known. CBNMS staff have not been able to verify with certainty that additional resources beyond ex-USS *Stewart* (DD-224) lie within the sanctuary. Accordingly, assessment of non-substantiated and/or undocumented maritime heritage resources is not included in this condition report.

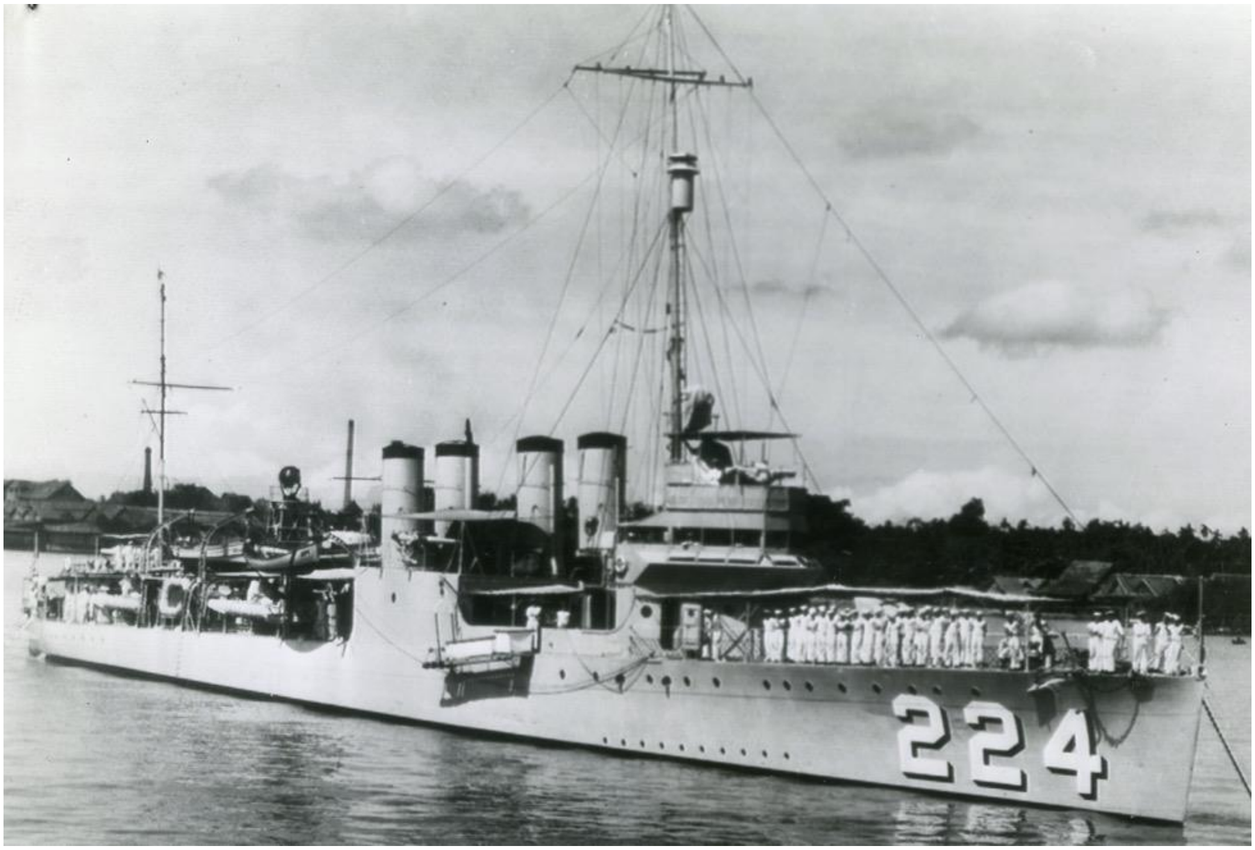


Figure SS.16. USS *Stewart* (DD-224) circa World War II. Photo: Robert Schwemmer Maritime Library

Drivers and Pressures on the Sanctuary

Drivers on the Sanctuary

For the purpose of condition reports, drivers (or driving forces) are defined as societal values, policies, and socioeconomic factors that influence human pressures on the ecosystem. By shaping the ways that humans interact with the marine environment, driving forces can result in either positive or negative impacts (pressures) to the condition of resources like water, habitat, living resources, and maritime heritage resources. In turn, the condition, or state, of resources determines the flow of benefits that humans are able to derive from that ecosystem. Accordingly, understanding driving forces can be useful in anticipating, evaluating, and reacting to changes in the condition of resources and ecosystem services.

Pressures on sanctuary resources occur locally; however, drivers emerge at many different scales, from local to global. A pressure may be affected by one or more drivers, and a driver may also affect multiple pressures. For example, human population growth at all scales can increase demand for seafood and, as a result, fishing pressure. Fishing pressure is also influenced by drivers like fuel prices and ocean policy, and population drivers simultaneously influence other pressures like marine debris, vessel traffic, and discharges. Drivers and pressures may vary from sanctuary to sanctuary. Relevant drivers and associated pressures for CBNMS were identified in consultation with sanctuary staff and based on past experience identifying drivers and pressures at other sanctuary sites. Table D.1 summarizes the drivers that influence pressures at CBNMS and the scale at which they occur.

Table D.1. Drivers and their relationship to pressures that affect CBNMS resources. Bullets indicate the influence of drivers on various pressures. The geographic scales at which different drivers originate to affect pressures are also shown (G = global, N = national, R = regional, L = local). See the text below for explanations of specific drivers and pressures.

		Pressures					
		Food Related	Development and Infrastructure	Transportation			Other
Drivers	**Scale**	**Fishing**	**Marine Debris**	**Vessel Use: Large Vessel Traffic**	**Vessel Use: Vessel Discharges**	**Vessel Use: Noise**	**Climate Change: Changing Ocean Conditions**
Population	G, N, R, L	•	•	•	•	•	•
Per capita income	G, N, R, L	•	•	•	•	•	•
GDP	G, N, R, L	•	•	•	•	•	•
Fuel prices	G, N, R, L	•	•		•	•	•
Demand for seafood	G, N, R, L	•	•	•	•	•	•
Regulatory exemptions	N, L			•	•	•	
Societal values and conservation ethic	N, R, L	•	•				•
Ocean policy	N, R, L	•	•	•	•	•	•
Tribal treaty rights and government relationships	N, R, L		•	•	•	•	•
Environmental activism	R, L	•	•	•	•	•	•
Technological advancement	G, N, R, L	•	•	•		•	

		Pressures					
		Food Related	Development and Infrastructure	Transportation			Other
Drivers	**Scale**	**Fishing**	**Marine Debris**	**Vessel Use: Large Vessel Traffic**	**Vessel Use: Vessel Discharges**	**Vessel Use: Noise**	**Climate Change: Changing Ocean Conditions**
Demand for energy	G, N, R, L			•		•	
U.S. national security	N			•	•	•	
Trade policy	G	•		•			

Drivers frequently affect pressures by influencing demand for marine-based goods and services like food, energy, recreation, and transportation. Drivers that influence demand include population, per capita income, trade policy, and societal values and conservation ethic. Other factors that can influence demand may include consumer tastes and preferences. As demand for marine resources increases, higher prices and/or demand create incentives for higher levels of extraction or use, which can impact the state of resources.

Other drivers influence the supply of or access to marine resources. Examples of these drivers include fuel prices, technological advancement, ocean policy, tribal government relationships, and regulatory exemptions. As production inputs, fuel prices and technology determine the cost and feasibility of exploiting marine resources and, subsequently, levels of activity and use. The other three drivers relevant to CBNMS relate to the governance of marine resources. Ocean policy (e.g., permitting for offshore energy, vessel speed reduction zones, fishing regulations), along with exemptions, may increase or decrease pressures on resources. Tribal government relationships can create cooperative management approaches that can preempt or mitigate pressures (e.g., cooperative fisheries management, preparation of oil spill response plans). Additionally, environmental activism, shaped by preferences, societal values and conservation ethic, can influence levels of ocean use by applying political pressure to ocean policymakers and stakeholders.

Population and Per Capita Income

International and domestic demand for goods and services, at all scales, ranging from local to global, is directly tied to changes in population and real per capita income. It is and will remain a ubiquitous, primary driver of pressures on sanctuary resources. The data provided in this section are from the U.S. Census Bureau and U.S. Bureau of Economic Analysis (2020; Table D.2).

Table D.2. Population and mean per capita income in an 11-county study area for CBNMS. The counties included in the study area are Alameda, Contra Costa, Marin, Mendocino, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma. Monetary values are inflation-adjusted to 2020 dollars. Source: U.S. Bureau of Economic Analysis, 2020; Federal Reserve Bank of Minneapolis, 2022

Year	Mean Per Capita Income	Population	Per Capita Income (% Change)	Population (% Change)
2010	$68,059	4,697,828	--	--
2011	$70,342	4,750,016	3.35%	1.11%
2012	$74,239	4,807,885	5.54%	1.22%
2013	$73,959	4,867,808	-0.38%	1.25%
2014	$77,836	4,925,586	5.24%	1.19%
2015	$84,086	4,979,820	8.03%	1.10%
2016	$87,860	5,011,267	4.49%	0.63%
2017	$91,748	5,026,510	4.43%	0.30%
2018	$96,111	5,023,105	4.76%	-0.07%
2019	$99,245	5,003,279	3.26%	-0.39%
2020	$106,445	4,960,724	7.26%	-0.85%

From 2010–2020, the population in the CBNMS study area (11 counties: Alameda, Contra Costa, Marin, Mendocino, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma) grew by 5.6%, which is less than the rate of population increase for the United States (6.5%) and slightly greater than that of California (5.5%). As of 2020, roughly 12.6% of California residents lived in the study area. In addition to being a determinant of demand for marine resources, population can influence land-based pressures on the marine environment, like changes in land use and waste management requirements. Given the decline in study area population in 2018, 2019, and 2020, population-driven pressures do not seem to be of immediate concern to the sanctuary on a regional level, although localized population pressures may persist.

From 2010–2020, real per capita income in the CBNMS study area increased by around 56%, outpacing income growth in the state of California and the United States, which saw increases of roughly 37% and 23%, respectively. With higher real incomes, consumers have greater purchasing power, enabling them to buy more of the products they already purchase and/or substitute preferred, more expensive products for cheaper ones. The expected result of increases in both per capita income and population over the past decade is an increase in pressures on resources in CBNMS, created by higher demand for products and services. Activities required to meet the demand could include fishing, transportation, construction and land development, and visitation, among others.

Fuel Prices

Fuel prices are an important and often immediate driver of many ocean activities. Ocean users consider fuel prices in their decisions about whether and how to conduct activities like commercial fishing, recreational boating, and shipping (e.g., Sumaila et al., 2008; Maloni et al., 2013). Importantly, changes in fuel prices do not impact all fisheries equally. Globally, fisheries targeting crustaceans or flatfish and those employing pots/traps or trawl gear have the highest intensity of fuel use in terms of volume of fuel per live weight landed (Parker & Tyedmers, 2015). The price of retail gasoline in California varied with no apparent trend from 2010–2020 (Figure D.1; U.S. Energy Information Administration, 2022).

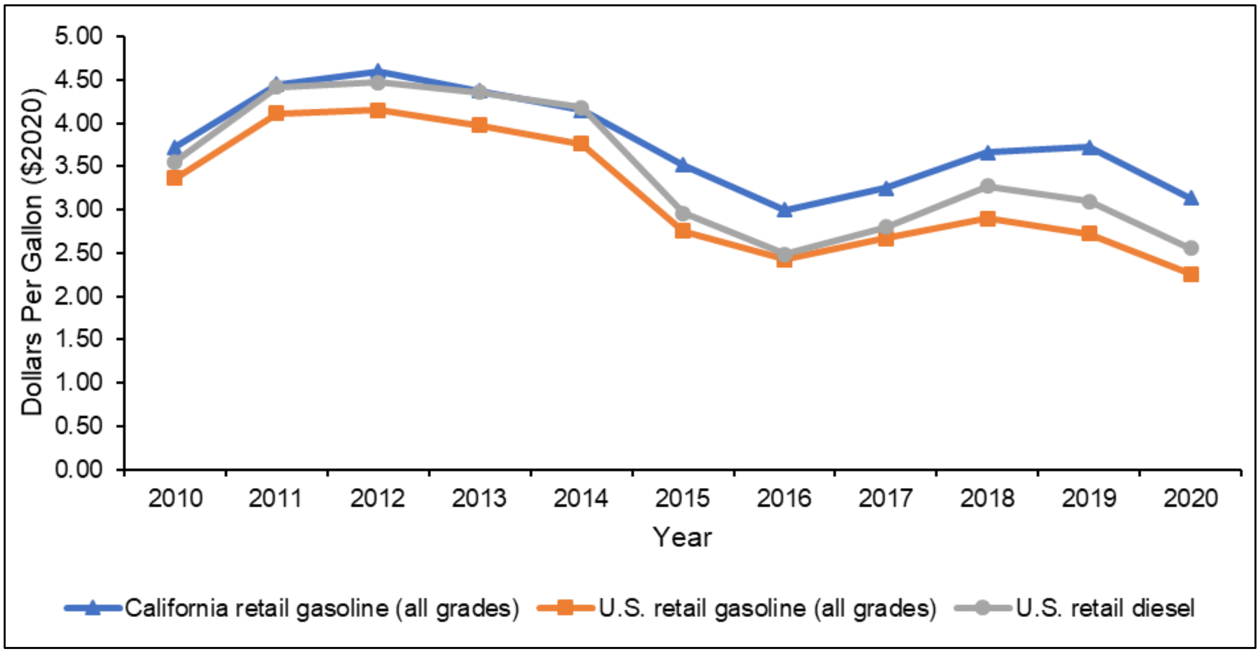


Figure D.1. Prices for California retail gasoline (all grades), U.S. retail gasoline (all grades), and U.S. retail diesel from 2010–2020. Source: U.S. Energy Information Administration, 2022

Trade Policy

As with many industries, U.S. seafood harvesters and producers are impacted by foreign trade policies, like import bans and tariffs, that reduce demand for exports. Since import competition can alter the incentives for resource use, harvesters are also affected by domestic trade policies that affect the competitiveness of U.S. seafood (Asche et al., 2022). In 2019, the seafood industry faced a major disruption due to a trade war with China, which is by far the largest importer and consumer of seafood (Froelich et al., 2021; Food and Agriculture Organization of the United Nations [FAO], 2020). As of spring 2022, the industry continues to be impacted by a Russian ban on all food imports from the U.S. that began in 2014.

Trade policy might also affect pressure on sanctuary resources by influencing the volume of trade flows and shipping activity between ports. Resource impacts related to vessel use are described below.

Ocean Policy

The United States is party to numerous agreements that establish international entities composed of member governments focused on various topics, ranging from managing shipping (International Maritime Organization [IMO]), global whale stocks (International Whaling Commission), fisheries (International Pacific Halibut Commission, Pacific Salmon Commission, etc.), and oil spill response (Canada-United States Pacific Geographic Annex [CANUSPAC]). These international agreements affect local activities, such as the designation of Areas to be Avoided by the IMO.

The West Coast states have collaborated on ocean policy initiatives since the Tri-State Agreement on Ocean Health was signed in 2006. Since that time, this regional ocean partnership has evolved to better include tribal governments, broaden federal agency representation, and identify a variety of regional priorities. Today, the West Coast Ocean Alliance is focused on: (1) compatible and sustainable ocean uses; (2) effective and transparent decision making; (3) comprehensive ocean and coastal data; and (4) increased understanding of and respect for tribal rights, traditional knowledge, resources, and practices.

The Pacific Fishery Management Council is another partnership of West Coast states that manages federal fisheries for around 119 species in the U.S. Exclusive Economic Zone (EEZ). The council collaborates with states, tribes, and international forums to develop management recommendations to NOAA Fisheries (Pacific Fishery Management Council, 2020). The California Department of Fish and Wildlife manages fisheries in state waters (1–3 miles offshore) and certain species like Dungeness crab and pink shrimp (California Department of Fish and Wildlife [CDFW], 2021a).

Demand for Seafood

Seafood is one of the top traded food commodities globally, and the United States is both a top importer and top five exporter of seafood (Froehlich et al., 2020). Global seafood consumption has increased by an estimated average annual rate of 3.1% from 1961 to 2017 (FAO, 2020). Further, consumption in 2030 is predicted to be 18% higher than it was in 2018, with the largest growth rates projected for Latin America (33%), Africa (27%), Oceania (22%), and Asia (19%; FAO, 2020). Aquaculture already accounts for over half of seafood produced for human consumption globally; however, farmed seafood in the U.S. makes up only 8% of domestic production (FAO, 2020; Froehlich et al., 2020). Offshore farming has been identified as a strategy (e.g., Executive Order 13921 [85 Fed. Reg. 28471]) to increase U.S. seafood production and reduce reliance on imports, which currently account for roughly two-thirds of domestic seafood consumption (Gephart et al., 2019).

From 2015 to 2019, the average volume of seafood products exported from the San Francisco U.S. Customs District, which covers all counties adjacent to CBNMS, totaled roughly 55.5

million pounds[9] (Office of Science and Technology, 2022). Over the same period, an average of over 132 million pounds of seafood products were imported[10] through the district (NMFS OST, 2022). Of the top species harvested in CBNMS, market squid had the highest volume of exports from San Francisco, with an average of 26.7 million pounds exported from 2015–2019 (NMFS OST, 2022). For other commercially important species, the average annual exports from San Francisco for 2015–2019 were approximately 601,000 pounds for sablefish, 364,000 pounds for Dungeness crab, 193,000 pounds for unspecified groundfish, and 170,000 pounds for salmon.[11]

The U.S. seafood industry has been heavily impacted by the COVID-19 pandemic and response. Restaurants and other "away from home" venues account for roughly 65% of consumer seafood expenditures in the U.S., and restaurant orders declined by upwards of 70% beginning in March of 2020 (Love et al., 2020; Froelich et al., 2021). These events resulted in processor closures, shortened fishing seasons, decreased catch, and revenue losses (White et al., 2021). Disruptions in the restaurant market were not felt equally across fisheries, as consumers are more likely to purchase some species in retail stores (e.g., canned tuna, salmon) and others in restaurants (e.g., crab, shrimp, cod; Love et al., 2020). Frozen and canned seafood products (e.g., sablefish, tuna) were less impacted than fresh seafood products (e.g., halibut; White et al., 2021).

Consumer tastes and preferences are an important determinant of demand for seafood and, consequently, resource impacts. As a potent example of this, the growing popularity of sushi and sashimi in the late twentieth century led to the industrialization of bluefin tuna fisheries and overfishing of stocks (Longo, 2011). Increasingly, demand for seafood is being driven by perceptions of health risks and benefits, as well as a desire for sustainable products (Lem et al., 2014).

Demand for Energy

The demand for energy, whether from non-renewable or renewable resources, is also a driver. Pressure to increase supplies of energy or energy products (e.g., raw or refined) may place pressures on sanctuary resources through increased development and/or shipping near or through the sanctuary. Development of renewable ocean and wind energy is currently prohibited in CBNMS. Substantial commercial vessel traffic passes through the sanctuary via the northern shipping lane of the San Francisco Bay Traffic Separation Scheme. Large volumes of energy products, including crude oil, refined petroleum products, and coal, are shipped in and out of the Bay Area, which includes the ports of Oakland and San Francisco and several refineries (San Francisco Bay Conservation and Development Commission, 2020). Expected to be finished in late 2023, the Transmountain Pipeline expansion in Canada would increase the volume of tar sands shipped to refineries in the Bay Area (Center for Biological Diversity, 2020). Along with infrastructure changes affecting supply, changes in the U.S. and global demand for

[9] This may include seafood of foreign origin that has been altered or enhanced in value from the time it was imported.
[10] Imports may include seafood of domestic origin that were processed abroad and returned to the U.S.
[11] Unless referring to a particular species, seafood trade data are generally available only by species group or product type. For example, salmon exports referenced here include several different species of salmon, many of which are harvested outside CBNMS or the Central California region.

energy products can impact levels of vessel traffic and associated impacts on sanctuary resources.

Regulatory Exemptions

Federal agencies implement regulatory requirements under their respective statutes and mandates. However, in some cases, individuals, entities, or certain activities are exempt from statutory or regulatory requirements. For example, the Clean Water Act provides a permit exemption for some point source pollution sources. These regulatory exemptions could affect the sanctuary through water quality degradation, injury to sanctuary resources or habitats, or other impacts. As outlined in CBNMS regulations, all activities carried out by the Department of Defense at the time of designation that are necessary for national defense are exempt from prohibition (74 Fed. Reg. 12088 [Mar 23, 2009]). This exemption does not extend to Department of Defense activities like routine exercises and vessel operations. Other activities exempt from prohibitions include the discharge of materials, like fish or chumming materials, as part of lawful fishing activity and activities necessary for emergency response (74 Fed. Reg. 12088 [Mar 23, 2009]).

U.S. National Security

The ocean plays a critical role in the mobility and readiness of U.S. armed forces and the preservation of national security. Uncertainty regarding the dynamics of future conflicts requires the U.S. military to train and prepare for a variety of scenarios, especially given emergent technologies. The State Department, Department of Defense, Department of Homeland Security, National Security Administration, Department of Transportation, and others all play key roles in national security. Climate change is also viewed as a national security issue, not only because of its direct effects on military infrastructure via sea level rise, but also because of its potential to exacerbate geopolitical tensions. The increasing intensity and frequency of natural disasters also increases demand for disaster relief, further threatening national security.

The Eleventh Coast Guard District, headquartered in San Francisco Bay, conducts training, search and rescue, and emergency response activities in the sanctuary. The U.S. Coast Guard (USCG) is responsible for enforcing federal laws in U.S. waters, including national marine sanctuary regulations. It is also responsible for vessel traffic management and managing the control and removal of oil and hazardous substances resulting from offshore spills (Office of National Marine Sanctuaries [ONMS], 2014b). Although the U.S. Navy no longer has active bases in the San Francisco Bay Area, it does conduct operations within or near CBNMS (ONMS, 2014). The Navy maintains two special-use airspaces in and around the boundaries of CBNMS and GFNMS, and naval submarines and surface ships routinely transit the area (ONMS, 2014).

Societal Values and Conservation Ethic

Information on societal values related to conservation can be obtained from various national or local opinion polls. A statewide study conducted in 2021 provides point estimates of Californians' attitudes and perceptions toward the environment (Baldassare et al., 2021). On the topic of offshore energy, around 72% of Californians indicated that they oppose more oil drilling off the coast of the state, while 81% were in favor of offshore wind power and wave energy projects (Baldassare et al., 2021). Almost half of adults reported that ocean and beach pollution along the coast is an issue, with 61% saying that plastics and marine debris are a big problem in the section of coast closest to them (Baldassare et al., 2021). An overwhelming majority of Californians (95%) stated that the conditions of oceans and beaches are either very important or somewhat important to the economy and quality of life in the state (Baldassare et al., 2021). Finally, about three in four respondents were either very or somewhat concerned about the impact of sea level rise on flooding and beach erosion (Baldassare et al., 2021).

A separate 2009 survey of Monterey Bay Area residents provides some indication of Californians' attitudes toward marine protected areas (Responsive Management, 2009). In 2009, an overwhelming percentage (93%) of respondents expressed support for "the designation of certain areas of U.S. ocean waters as sanctuaries for special management to conserve the marine habitats and cultural features" (Responsive Management, 2009). A majority (64%) also agreed that "sanctuary managers should have the power to make rules to prohibit human use of the designated sanctuaries," with 30% disagreeing (Responsive Management, 2009). Over half of residents (58%) supported funding the creation and management of marine protected areas through the general revenue fund from state taxes, but less than half supported a tax increase to fund that same goal (Responsive Management, 2009).

Environmental Activism

As conservation ethics change, levels of environmental activism are likely to change as well. This can affect the implementation of many types of activities and management actions, which can dramatically alter and redistribute pressures.

One focal area for environmental activism near the sanctuary is the issue of ship strikes on large whales and sea turtles. In 2021, two environmental non-governmental organizations, the Center for Biological Diversity and Friends of the Earth, sued USCG and NOAA Fisheries for failure to meet Endangered Species Act consultation requirements with respect to the impact of ship strikes on Endangered Species Act–listed species (*Center for Biological Diversity v. NOAA Fisheries*, 2021). The plaintiffs are seeking additional protections for whales and sea turtles through ship strike avoidance measures like temporary vessel speed reductions and/or routing measures (*Center for Biological Diversity v. NOAA Fisheries*, 2021). If successful, the lawsuit would likely affect vessel traffic patterns and associated pressures in CBNMS. In 2019, the same two NGOs, along with San Francisco Baykeeper, the Sierra Club, and Communities for a Better Environment, opposed a U.S. Army Corps of Engineers dredging project proposal for San Francisco Bay that would have increased oil tanker traffic through the sanctuary (Communities for a Better Environment et al., 2019; Karras, 2019). The project was terminated in 2020 due to lack of sponsor interest (85 Fed. Reg. 76544 [Nov. 30, 2020]).

Technological Advancement

Technology can influence pressures on marine resources in several ways. As mentioned previously, technological advancements can lower costs for existing marine-based industries. For example, technologies like electronic navigational aids, acoustic fish-finding equipment, and stronger polymers for line and netting increase fishing efficiency (Marchal et al., 2006). For a given level of human activity or ocean use, technological advancements can also result in lower levels of impact or pressure. Examples of these types of technologies include low-emissions propulsion systems and carbon capture in shipping, waste management technologies (e.g., marine sanitation devices, bioremediation of wastewater, new materials to replace plastics), and bycatch reduction devices (e.g., turtle excluder devices), among many others. In response to large whale and turtle entanglements in Dungeness crab gear on the West Coast and subsequent fishery closures, there has been considerable interest in developing ropeless crab gear to mitigate entanglement risk. The development of new technologies can also contribute to the growth or emergence of new sectors in the blue economy (e.g., offshore aquaculture, offshore wind), which may even substitute for traditional industries (e.g., wild capture fisheries, offshore oil). Finally, some technologies may contribute directly to improved resource management outcomes or ecosystem restoration (e.g., "green gravel" for kelp reforestation, drones for monitoring, wave attenuation devices).

Tribal Government Relationships

Federal agencies are required to consult with federally recognized tribes on policies with tribal implications under Executive Order 13175 (65 Fed. Reg. 67249 [Nov. 9, 2000]), and those requirements have been reaffirmed by subsequent presidential memoranda supporting the executive order.

Indigenous peoples on the west coast of North America had many connections to coastal and ocean resources in ancient times. However, at this time, CBNMS is unaware of any information that suggests historical connections of Indigenous peoples to the sanctuary prior to contemporary usage of motorized fishing vessels. There may be contemporary connections of Indigenous tribes and nations to CBNMS.

Pressures on the Sanctuary

Human activities and natural processes affect the condition of natural, cultural, and maritime heritage resources in national marine sanctuaries. The following section discusses the nature and extent of the most prominent human influences upon CBNMS, including climate change and ocean acidification, fishing, vessel use, and marine debris. Other pressures that were considered but omitted include non-indigenous species, tourism and visitation, coastal uses, human impacts to archaeological resources, and offshore industry.

Climate Change and Ocean Acidification

Located within the California Current System, CBNMS is exposed to strong seasonal variation in atmospheric and oceanographic conditions defined by upwelling, relaxation, and winter storm conditions. Longer-term climatic phenomena influencing the region include global climate change, the El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the North Pacific Gyre Oscillation—processes that operate on larger spatial and longer decadal scales (Cordell Bank National Marine Sanctuary [CBNMS], 2014; Largier et al., 2011). Climate change has profoundly impacted coastal and marine ecosystems on a global scale, with projected worsening effects on sea level, temperature, ocean chemistry, storm intensity, and ocean current patterns. At a regional scale, climate change is projected to result in significant shifts in the composition of ecological communities, seasonal flows in freshwater systems, rates of primary productivity, occurrence/persistence of hypoxia, sea level rise, coastal flooding and erosion, and wind-driven circulation patterns by the end of the century (Miller et al., 2013). Climate change is already affecting all aspects of the sanctuary, including, but not limited to, water quality, species abundance and distribution, human activities, and ecosystem services (ONMS, 2020a; Intergovernmental Panel on Climate Change [IPCC], 2022). The climate-related pressures of greatest concern are: ocean temperatures, upwelling patterns, ocean acidification, and deoxygenation and hypoxia. These stressors may be co-occurring with each other (Breitburg et al., 2015) and with the other pressures on the sanctuary.

Greenhouse Gases

Anthropogenic climate change is primarily caused by greenhouse gas emissions. Greenhouse gases (e.g., carbon dioxide, methane) trap heat in the atmosphere; as greenhouse gases increase, so does the amount of heat trapped, which leads to higher air and water temperatures. Since pre-industrial times, global air temperature has increased, on average, by 1.8 °F (1 °C), and in the last 50 years, this increase has been driven nearly entirely by anthropogenic greenhouse gas emissions (IPCC, 2019). As global temperatures have risen, the ocean has absorbed over 90% of the excess heat, causing the average ocean temperature to increase worldwide (IPCC, 2019). Excess greenhouse gases have also been absorbed by the ocean, resulting in changes in ocean chemistry (Haugan & Drange, 1996; Doney et al., 2009).

CBNMS is affected by global greenhouse gases due to the Earth's closed system (Figure P.1), with the main, direct sources of human-based air emissions into the air above the sanctuary stemming from vessel and aircraft engines, shipboard incinerators (ONMS, 2014b), and other motorized equipment that produces exhaust.

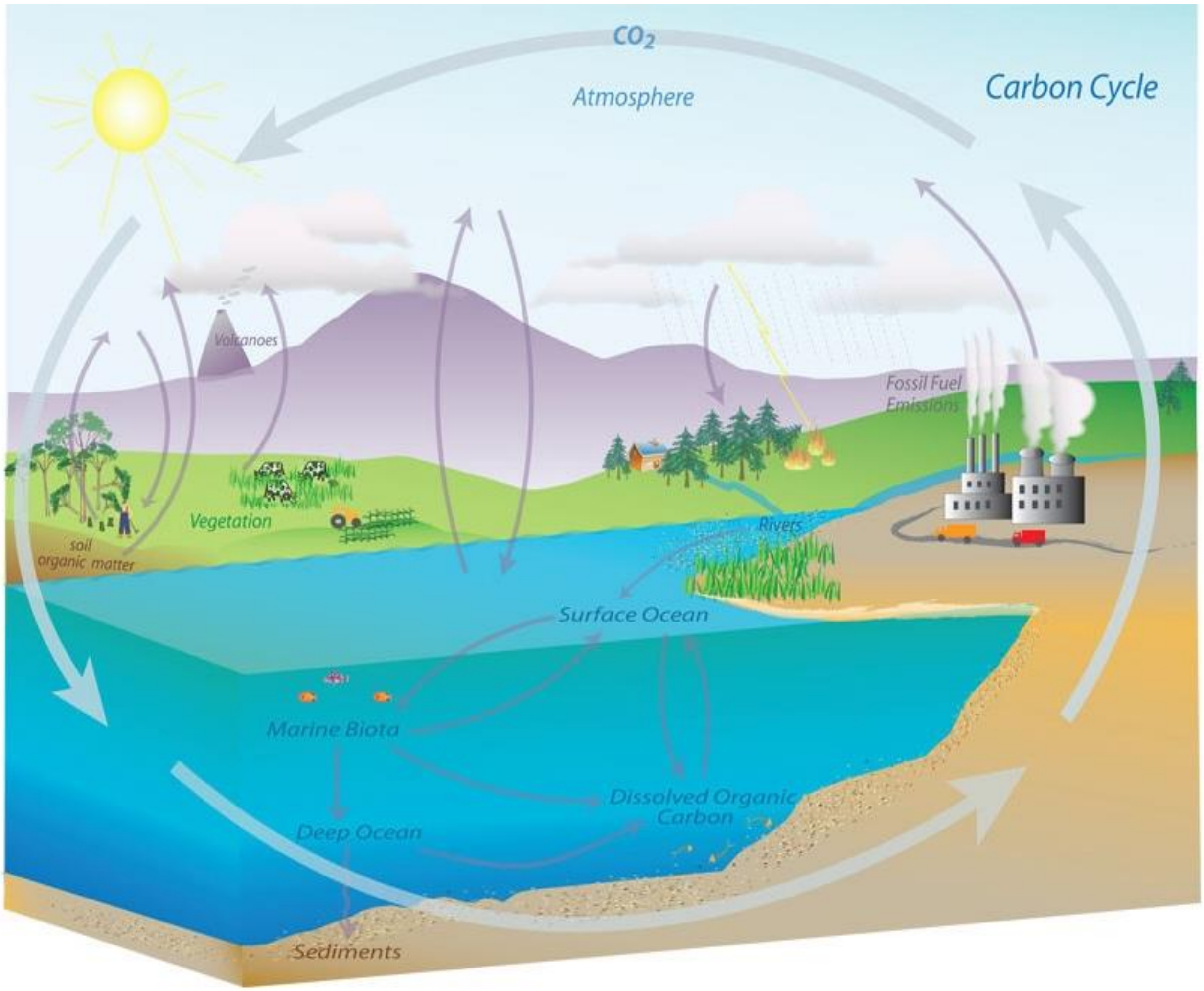


Figure P.1. Carbon dioxide and other greenhouse gases are released into the atmosphere, where they are absorbed into the ocean and other ecosystems via the carbon cycle. Image: NOAA, 2020b

Ocean Temperature, Marine Heatwaves, and Upwelling

Data from NOAA's National Centers for Environmental Information show that globally, sea surface temperatures were first observed to be above average starting in 1940; for the 40-year period following that, annual temperature varied, and was observed to be both above and below average (Figure P.2). From 1980–2019, globally, annual sea surface temperatures were consistently observed to be above average, and have been increasingly warmer (National Centers for Environmental Information [NCEI], 2020a). Water temperatures in the CBNMS region have risen slightly over the past century (Johnstone & Mantua, 2014; ONMS, 2020a).

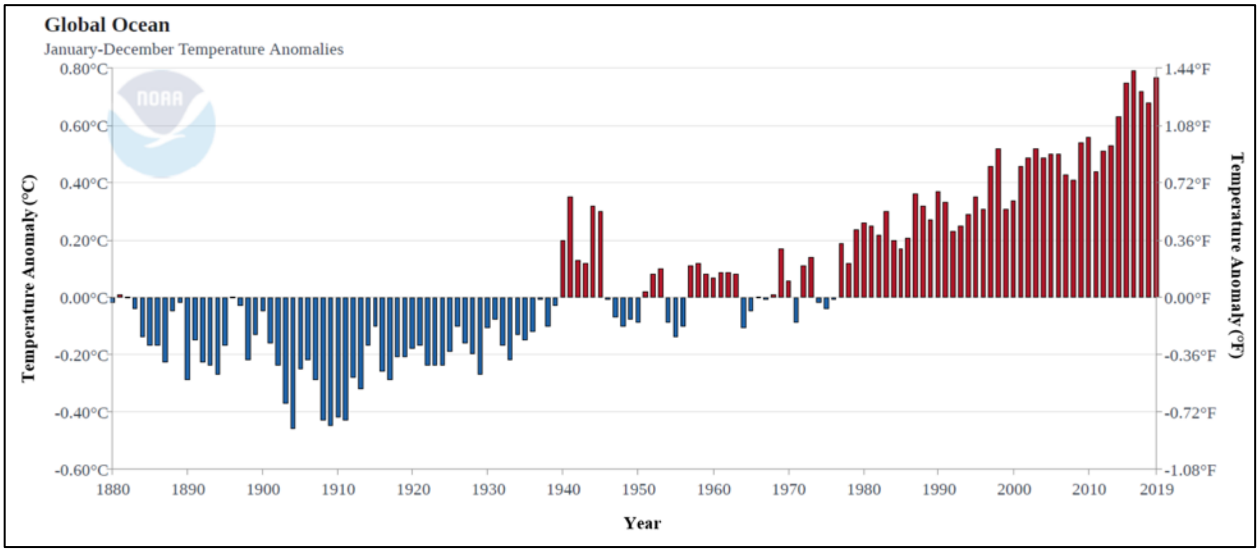


Figure P.2. Annual global ocean surface temperature anomalies, 1880–2019. Image: NCEI, 2020a

As described in the Sanctuary Setting chapter, upwelling is a major oceanographic process that results in high productivity, both in the sanctuary and regionally. Warmer sea surface temperatures could alter circulation patterns, which may result in changes to timing and intensity of upwelling seasons and lower productivity (ONMS, 2020a). Warm water events like El Niño events and marine heatwaves can reduce upwelling by creating stratification or forcing nutrient-rich water closer to shore, away from the majority of the sanctuary (Santora et al., 2020; Jacox et al., 2016). When this occurs, sanctuary waters receive less nutrients, leading to lower biological productivity (Cavole et al., 2016; McGowan et al., 1998). Such changes can lead to cascading effects throughout the food web, potentially affecting zooplankton, krill, fish, seabirds, and marine mammals (Piatt et al., 2020; Cavole et al., 2016; McGowan et al., 1998; Sanford et al., 2019; Di Lorenzo & Mantua, 2016). For example, during past El Niño events and recent marine heatwaves in the California Current Ecosystem, there were shifts in the zooplankton community in which smaller, less nutritious species from the south became more dominant, and overall biomass declined by as much as 90% (Roemmich & McGowan, 1995; Cavole et al., 2016; McGowan et al., 1998; Fisher et al., 2015; Elliot & Jahncke, 2019; ONMS 2020a).

2014–2016 Marine Heatwave

Marine heatwaves are declared when sea surface temperatures exceed the 90th percentile of the baseline climatology (previous three decades) for at least five consecutive days (Hobday et al., 2016). First detected in 2014, peaking in 2015, and finally dissipating in mid-2016, a marine heatwave in the Pacific Ocean led to water temperatures 1.8–7.2°F (1.0–4.0°C) above normal (Bond et al., 2015; Gentemenn et al., 2017; Kintisch, 2015). Large numbers of southern species moved north (Sanford et al., 2019; Lonhart et al., 2019), and a large harmful algal bloom killed fish, birds, and marine mammals (Cavole et al., 2016); delayed the opening of the Dungeness crab fishery (Cavole et al., 2016; Sanford et al., 2019); and had impacts on prey species that altered the food web (Santora et al., 2020). For example, reductions in krill in offshore areas, such as CBNMS, forced humpback whales to feed on fish that were closer to shore, resulting in record numbers of whale entanglements in fishing gear across the West Coast in 2015 and 2016 (Santora et al., 2020; ONMS 2020a).

Ocean Acidification

Increased levels of carbon dioxide in the atmosphere have further increased the dissolved carbon dioxide concentration in seawater, reducing pH and making the ocean more acidic (ONMS, 2020b); this process is called ocean acidification. The global ocean, on average, has become 30% more acidic since the beginning of the industrial revolution (Haugan & Drange, 1996; Doney et al., 2009). Due in part to upwelling, the acidity of U.S. West Coast waters has risen faster than other regions, up to 60% since 1895 (Gruber et al., 2012; Osborne et al., 2020; ONMS, 2020a).

These conditions could be detrimental to many marine organisms, including mollusks, corals, and certain shell-producing plankton, which rely on carbonate from seawater to build their shells and other hard parts. CBNMS is located in an area of persistent high acidity as a result of the productive upwelling in the region (Chan et al., 2017; ONMS, 2020a). Increasingly acidic waters make it difficult for shell-forming animals like Dungeness crab and deep-water coral to make and maintain shells and stony skeletons (Keeling et al., 2010). Deep-water corals are particularly susceptible, as deep waters are naturally more acidic than surface waters and some areas are already acidic enough to slow their growth (Gómez et al., 2018). Further, acidification could reduce larval survival in Dungeness crab (Bednaršek et al., 2020) and krill (McLaskey et al., 2016), while also increasing stress and decreasing larval survival in rockfish and other species without shells (Keller et al., 2010; McClatchie et al., 2010; Munday et al., 2010; Rossi et al., 2016). Krill have reduced reproductive success under acidic conditions (McLaskey et al., 2016) and the shells of pteropods, small sea snails that are important prey for fish such as salmon, become thinner under acidic conditions (Bednaršek et al., 2017; Bednaršek et al., 2014; ONMS, 2020a).

Fish, birds, mammals, and coral can also be indirectly affected by acidification through adverse impacts on their prey (McLaskey et al., 2016; Bednaršek et al., 2017; Hodgson et al., 2018). Warmer and more acidic waters could adversely affect zooplankton, a critical link in the food web, potentially reducing their numbers. Susceptible pteropods are important prey for salmon and other fish (Bednaršek et al., 2017). Similarly, acidification-sensitive krill are prey for salmon, seabirds and whales (McLaskey et al., 2016). Dungeness crab in particular may be more negatively affected by acidification-driven reductions in prey than by direct impacts of acidification (Hodgson et al., 2018). The effects of ocean acidification on prey species could thus have consequences for the entire food web from corals to blue whales (Gentemann et al., 2017; Lonhart et al., 2019; McLaskey et al., 2016; ONMS, 2020a).

Ocean acidification, in combination with other local conditions, may also affect historic resources. Ex-USS *Stewart* (DD-224), the historic former U.S. Navy destroyer submerged within the sanctuary since 1946, could be threatened, as increasingly acidic waters have the potential to change the corrosion rate of metal (Rockman et al., 2016), which may include the ship itself as well as artifacts.

Deoxygenation and Hypoxia

As ocean waters warm, their ability to hold oxygen decreases and stratification occurs, which reduces mixing and limits the exchange of oxygen and nutrients (Chan et al., 2017). Ocean deoxygenation, the reduction of oxygen in the ocean, has already led to a 2% decline in global ocean oxygen since 1960 (Stramma & Schmidtko, 2019). Low-oxygen conditions, called hypoxia, have become increasingly common in the ocean off California in recent years (Chan et al., 2017; Keller et al., 2015). Ocean oxygen concentrations off California have fallen 20% since 1980 (Bograd et al., 2015; Ito et al., 2017). Dissolved oxygen concentrations are affected by many factors, including: water temperature and salinity, light availability, stratification of water layers, tidal and wind mixing, upwelling of deep waters, abundance and decay of organic material, and runoff of high-nutrient waters from land—all phenomena that can fluctuate interannually with the Pacific Decadal Oscillation and El Niño Southern Oscillation, as well as seasonally. Organisms have high variability in their sensitivity to hypoxia and those in environments that do not typically experience low dissolved oxygen may not be well-adapted to survive and may experience stress or mortality under hypoxic conditions (Vaquer-Sunyer & Duarte, 2008).

Changes in dissolved oxygen can have cascading impacts on the entire ecosystem. Typically, surface waters contain higher levels of dissolved oxygen than subsurface waters due to photosynthesis and diffusion from the oxygen-rich atmosphere. Ocean currents and vertical mixing transport these oxygen-enriched waters throughout the water column. Climate change can cause regional changes in dissolved oxygen by altering water circulation and currents, vertical mixing, air-sea oxygen exchange, and biological production and respiration; these can co-occur with ocean acidification (Largier et al., 2011) and changing temperatures (Breitburg et al., 2015).

Fishing

Commercial[12] and recreational fishing in CBNMS contributes to the coastal economy, supports livelihoods in industries such as seafood and tourism, and provides valuable, nutritious food sources to nearby communities and beyond. Recreational fishing provides health and well-being benefits and sometimes food for anglers. Fishing also occurs within the sanctuary for research purposes; for example, collecting fisheries-independent data for stock assessments or testing new fishing methods. Information collected through efforts like trawl surveys improve understanding of ecosystem function and ultimately management outcomes. All fishing within the sanctuary occurs by boat due its offshore, open ocean location.

Despite the benefits offered by fishing, historical and current fishing practices can negatively impact sanctuary resources such as habitat, water quality, maritime archaeological resources, and/or ecosystem function. For example, the removal of targeted fish species, along with mortality through bycatch, can result in changes in biodiversity and ecosystem health. Catch-and-release fishing (and the release of incidentally caught species) can result in mortality through barotrauma, increased depredation, hook wounds, and other pathways, as well as sublethal effects like behavioral impairment and decreased feeding success (Campbell et al., 2010). Derelict (lost or discarded) fishing gear can continue to trap and kill marine life for many years. Additionally, certain fishing methods and gears can result in damage to bottom habitats (ONMS, 2020a). Use of mobile fishing gear, such as bottom trawls, has been of particular concern. Bottom trawling disturbs the structure of the seafloor, affects the three-dimensional character and availability of fish habitat, changes the composition of biologic communities in the area, disrupts the food web, and results in additional adverse effects (National Research Council, 2002). Habitats may take a long time to recover following these disturbances.

In addition to the drivers previously listed, other influences that could affect fishing include environmental and resource conditions such as the availability of the target species, habitat health, physical ocean conditions, and harmful algal blooms.

It is important to note that CBNMS does not have the authority to manage fisheries. Instead, federal fisheries in CBNMS are managed by NOAA's National Marine Fisheries Service (NMFS) and the Pacific Fishery Management Council. State fisheries in CBNMS (e.g., Dungeness crab) are managed by the California Department of Fish and Wildlife.

Commercial Harvest

There are a number of wild-caught fish and invertebrate species in CBNMS and the surrounding region. On average from 2015–2019, the top five species-gear groups caught in the sanctuary (by pounds landed) were Dungeness crab; Dover sole, thornyheads, and sablefish (trawl); sablefish (non-trawl); market squid; and salmon (see Commercial Harvest section for rankings by species; CDFW, 2020a). Together, these species-gear groups account for over 80% of the pounds landed commercially in CBNMS from 2015–2019.

---

[12] Defined in National Marine Sanctuary Program regulations (15 C.F.R. §§ 922.3) as "commercial fishing means any activity that results in the sale or trade for intended profit of fish, shellfish, algae, or corals." Recreational fishing is not defined in National Marine Sanctuary Program regulations.

From 2015–2019, the top five gear types used for commercial fishing by average pounds landed were trawl gear, pots/traps, set longlines, trolling gear, and purse seines (CDFW, 2020a). Other seines/dip nets and hook and line were commonly employed as well. Commercial fishing vessels come from various parts of the state to fish within the sanctuary. Landings from fish and shellfish caught within the sanctuary mainly occurred at Bodega Bay, Fort Bragg, San Francisco Bay, and Princeton-Half Moon Bay (CDFW, 2020a). On average, about 151 vessels reported catch from the sanctuary from 2010–2020, but that number varies from year to year. In 2010, only 72 vessels reported catch from CBNMS, but in 2013 there were at least 237 vessels using the sanctuary (CDFW, 2020a).

Recreational Fishing

Boats used for recreational fishing within the sanctuary are relatively limited in number; rough ocean conditions can prevent small boats from easily accessing the sanctuary. On average from 2015–2019, the top five species groups caught by commercial passenger fishing vessels within the sanctuary were rockfish, whitefish, yellowtail, sanddab, and Dungeness crab. Common gear types used for recreational fishing within the sanctuary include hook and line, trolling gear, and pots and traps.

Vessel Use

The pressures from vessel traffic vary with the size, number, and type of vessels transiting the sanctuary. Vessel impacts include the introduction of contaminants and non-indigenous species; spills; discharge of oil, sewage, and/or non-biodegradable materials; increased ocean noise; anchor damage; vessel collisions; sinking; wildlife disturbance, including ship strikes on whales and other species; and air and water pollution via exhaust gas emissions.

The San Francisco Traffic Separation Scheme (TSS) is one of the busiest port systems on the West Coast, and includes the ports of San Francisco and Oakland (Figure P.3). The TSS supports the economy of the entire region through national and international commerce and trade. The northern traffic lane of the TSS goes through CBNMS. The TSS is used by numerous types of domestic and foreign-flagged vessels, including container ships (some with hazardous materials), tankers, car carriers, as well as an increasing number of cruise liners.

The largest and most numerous vessels that use CBNMS are commercial ships. Nearly 2,000 vessels annually transit through the northern shipping lane (U.S. Coast Guard [USCG], 2021). Commercial ships make about 8,000 annual transits through the San Francisco TSS (which includes lanes within and adjacent to CBNMS). Regulatory and economic changes over time have affected the amount and pattern of shipping traffic passing through the sanctuary (e.g., recent California state regulations required the use of cleaner fuels by ships traversing within 24 nautical miles of the California coast). The size of commercial ships has steadily increased over the last several decades since the sanctuary was designated. Since 1968, container carrying capacity has increased by 1,200% (Jaradat, 2018).

Other vessel types in the sanctuary include smaller and more regional commercial, recreational, military, research, and fishing vessels.

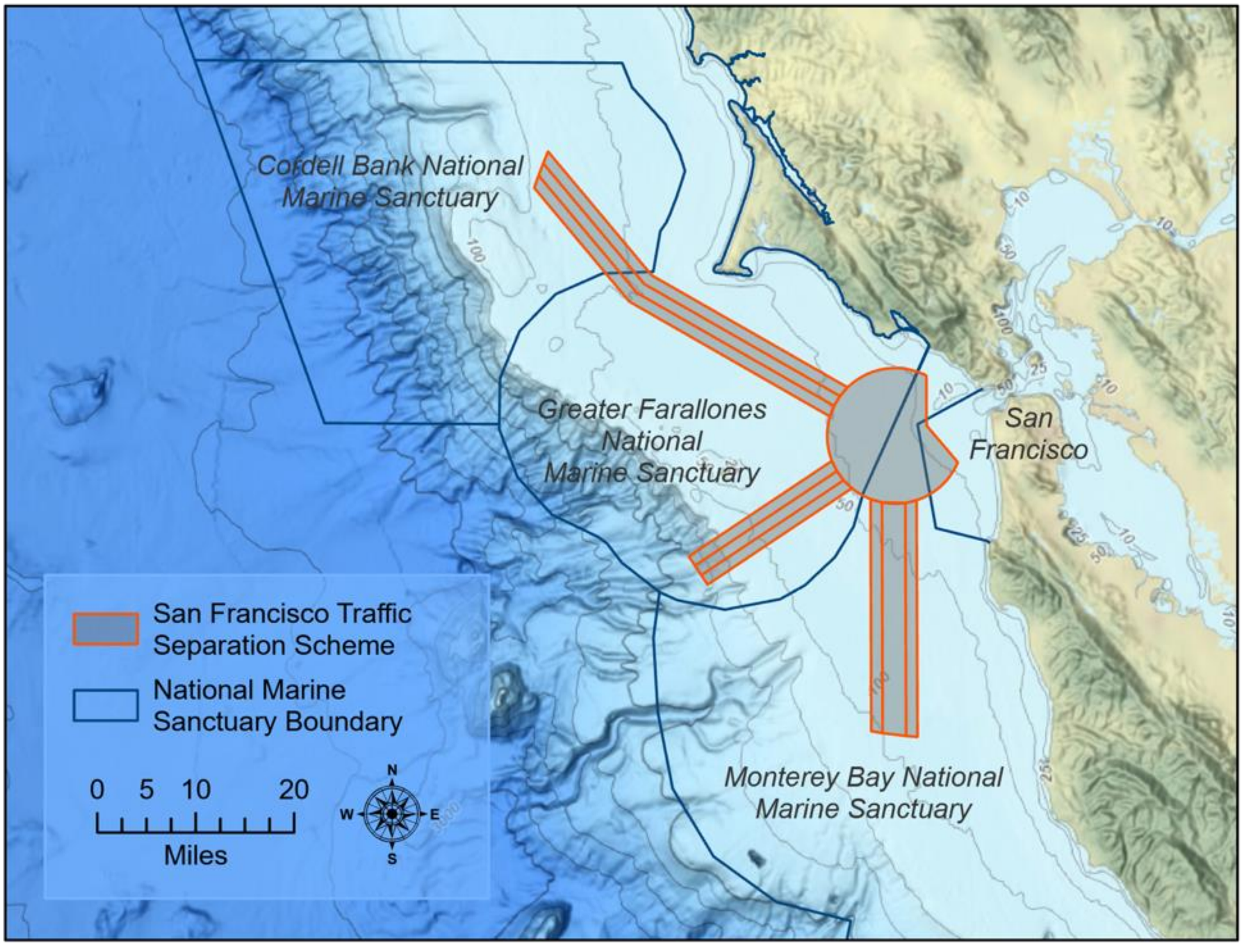


Figure P.3. Map of CBNMS and the San Francisco TSS. Image: NOAA

Noise

The level of noise pollution in the ocean has increased dramatically during the last 50 years, largely as a result of commercial shipping in coastal environments (National Research Council, 2003; Frisk, 2012). Large, ocean-going commercial traffic produces low-frequency noise through cavitation (the bursting of bubbles from propellers), the flow of water over the hull, as well as other onboard sources such as machinery (McKenna et al., 2013; Richardson et al., 1995). Smaller vessel types usually produce reduced sound levels, measured as energy or pressure, and higher-frequency noise (Richardson et al., 1995). Despite these differences, McKenna et al. (2017) found that concentrations of smaller vessels can result in significant potential for disturbance of resident marine mammal and seabird species, including disruption of feeding, communication, mating, and predator avoidance. Many marine mammals respond to noise by altering their breathing rates, increasing or reducing their time underwater, changing the depths or speeds of their dives, shielding their young, changing their song durations, and swimming away from the affected area.

The northern shipping lane of the San Francisco TSS goes through CBNMS, with large ships transiting through the sanctuary daily. Large vessels were determined to be a primary low-frequency anthropogenic noise contributor to the sanctuary soundscape (Haver et al., 2020). In addition, smaller vessels, such as those used for commercial and recreational fishing, transit through the sanctuary.

Spills

Vessel spills could significantly impact sanctuary resources. Historically, the total number of oil spills from transiting vessels in the CBNMS region has been small, and there were no known spills in the sanctuary from 2009–2021 (see Other Stressors section for data). However, potential impacts could be enormous, given the number and volume of vessels that transit the region and the sensitivity of resources in the area. Given this risk, the sanctuary devotes significant resources to emergency preparedness, enforcement partnerships, and ecosystem monitoring that can help identify events and contribute to damage assessment. Understanding the potential risk is important for CBNMS to be able to manage effectively.

Cargo, fishing, and passenger vessels can hold substantial quantities of petroleum products in their fuel tanks and are at risk for spills through groundings, collisions, sinkings, and other vessel incidents (Figure P.4). Because of the sanctuary's close proximity to the San Francisco TSS, various types of spills, particularly petroleum and other chemicals, are a substantial threat to sanctuary resources. Oil spills directly and adversely impact water quality, plants, animals, and habitats. Oil contamination of marine mammals and seabirds can cause eye irritation, impairment of thermal regulation, loss of buoyancy, toxicity, reproductive abnormalities, and ultimately death. Oil spills can deplete food sources and destroy habitat characteristics essential for survival of vertebrate species. A spill could significantly impact populations and, in a worst-case scenario, extinguish multiple species on a local or regional scale. Oil spills can have lethal as well as long-term, sublethal effects on fish (e.g., behavioral changes, reproductive abnormalities) and can also contaminate fish targeted for human consumption. Some sectors of the fishing and shellfishing industries could be shut down for years by an oil spill.

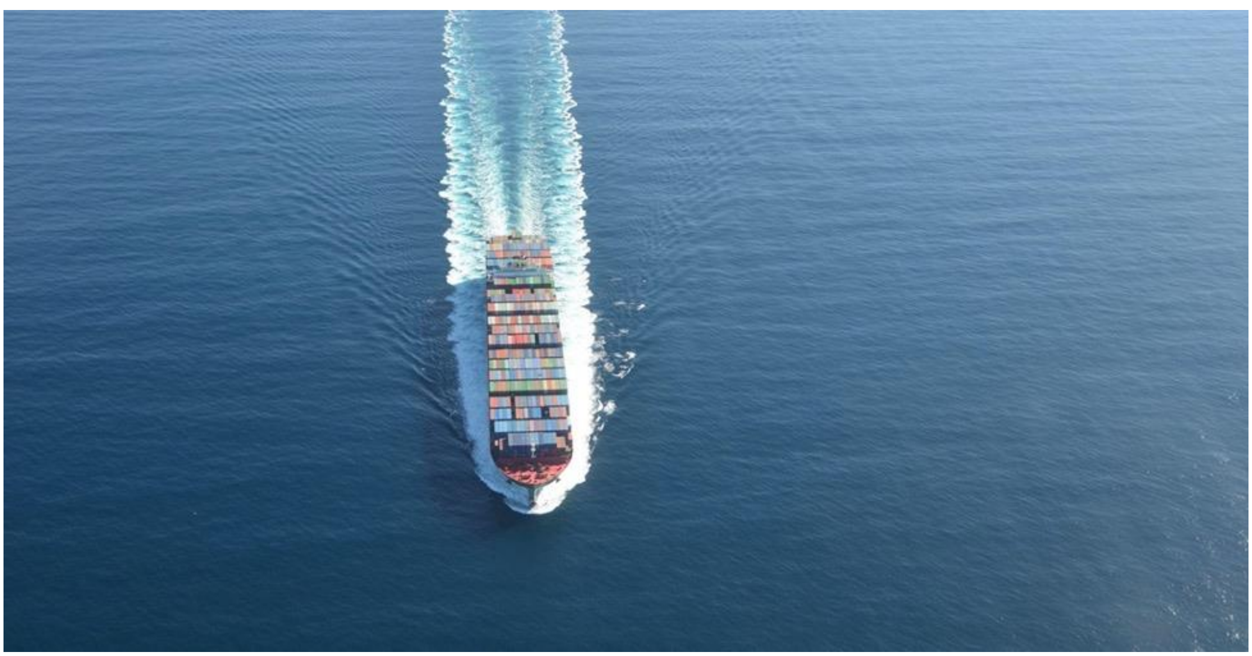


Figure P.4. Container ships frequently transit through CBNMS. Photo: J. Morten/NOAA

In addition to oil tankers, large cargo vessels are a concern because, in addition to their cargo, they can carry up to one million gallons of bunker fuel, a heavy, viscous fuel similar to crude oil.

Disposal of bilge water with any concentration of oil and disposal or discharge of any harmful substance is prohibited within CBNMS waters. However, the release of water and other biodegradable effluents incidental to vessel use, including treated effluent from Type 1 or Type 2 marine sanitation devices, deck wash down, and engine exhaust, is currently allowed. Cruise ships can carry over 3,000 people on board and generate large volumes of waste. The primary pollutants generated by cruise ships are sewage (also referred to as black water), gray water, oily bilge water, hazardous wastes, and solid wastes; cruise ships have the potential to severely impact water quality in localized areas if they are not responsibly operated. They also generally incinerate the majority of waste produced.

Sunken vessels on the seafloor have the potential to leak oil or other contaminants into the sanctuary. Other than one intentionally scuttled vessel that is suspected to be in the sanctuary, it is unknown if other sunken vessels could be worsening the water quality within CBNMS. Natural seeps exist in the area but are not thought to be a significant contributor to oil secretions into the sanctuary.

Ship Strikes

Whales rely on the highly productive waters of the California Current as part of their migratory routes. Vessels can alter the behavior of marine mammals and seabirds, changing the distribution of animals or the amount of time that they spend feeding and resting. In some instances, vessel strikes can injure or kill animals in the sanctuary. Slow-moving animals, like ocean sunfish (*Mola mola*) and whales, are particularly vulnerable to ship strikes as they swim or rest. Ship strikes have increased in recent decades due to increasing shipping traffic, vessel speeds, and whale abundance (Laist et al., 2006; Neilson et al., 2012). Most strikes occur in coastal waters on the continental shelf, where large marine mammals aggregate to feed and vessel traffic is concentrated.

Ship strikes, along with entanglements, are the primary sources of anthropogenic mortality (Carretta et al., 2021). Scientists estimate that the rate of detection and reporting of ship strikes is a small percentage of the actual number of animals struck; about 2% for blue whales and 10% for humpback whales (Carretta et al., 2021). The impact of ship strikes on blue whales is of concern, given their small population (1,496 in California, Oregon, and Washington; Carretta et al., 2021), but humpback and fin whales are also at considerable risk. Blue whales remain listed as endangered under the Endangered Species Act. Humpback whales that travel to CBNMS are part of the Mexico and Central America distinct population segments, which are listed as threatened and endangered, respectively (Carretta et al., 2021).

Marine Debris

Marine debris in the ocean is a known and growing threat to marine life and biological diversity, even in remote offshore locations like CBNMS.

According to NOAA's Marine Debris Program, marine debris is any persistent, manufactured or processed solid material that is directly or indirectly, intentionally or unintentionally, disposed of or abandoned in the marine environment. The prevalence of debris within the sanctuary is affected by both natural forces (e.g., currents) and human drivers, including population growth, consumer culture, economics, policy, and increased coastal development. Marine debris enters the sanctuary from both water- and land-based activities, and it is likely accumulating in the water column and benthic habitats. Land-based sources include stormwater runoff, landfills, loss during garbage transport, recreational and commercial activities, and military activities. Ocean-based sources include commercial and recreational fishing, research operations, and loss of cargo containers from ships in high seas (Keller et al., 2010).

Marine debris can include a wide variety of objects, such as lost fishing gear, overboard disposal of passenger and commercial shipboard waste, lost vessel cargo, metal military debris, and essential household goods. Plastic is the most prevalent type of marine debris found in the ocean. Plastic debris comes in all shapes and sizes, but those that are less than five millimeters in length are called microplastics. Plastics in the marine environment never fully degrade, and recent studies show organisms consume plastic at all levels of the marine food web. Given the quantities of plastic debris floating in the ocean, the potential for ingestion is enormous. The ability for plastics to attract and transport contaminants into the marine food web has been documented (Arthur et al., 2009), and recent research suggests these microplastics can accumulate in seafood (Avio et al., 2017).

Marine mammals and seabirds are known to be affected by marine debris (Gall & Thompson, 2015; NOAA Marine Debris Program, 2014a). Entanglement in marine debris is a significant problem, and it has been linked to measurable population declines for a variety of marine mammals. Marine debris can be ingested, which may result in drowning, starvation, physical trauma, systemic infections, or increased susceptibility to other threats, such as ship strikes (NOAA Marine Debris Program, 2014a, 2014b). Surface-feeding seabirds common in CBNMS include albatross, shearwaters, fulmars, and storm-petrels, which are highly susceptible to plastic ingestion. The frequency of individuals with plastic in the stomach ranges from 50 to 80% (Nevins et al., 2005). Tagging studies have documented black-footed albatross crossing the eastern Pacific to feed in and around CBNMS (Hyrenbach et al., 2005). Albatross often mistake floating plastic debris for food and ingest large quantities of plastic bottle caps, plastic fragments, discarded cigarette lighters, and plastic toys. When these adults return to their nests to feed their chicks, a high percentage of the meal is composed of plastic.

Evidence from at-sea and benthic surveys suggests that marine debris is widespread in CBNMS (Elliott et al., 2020; Graiff & Lipski, 2020a). In addition to altering the structure of habitats within CBNMS, lost or discarded fishing gear can continue to catch and kill fish for years.

Status and Trends of Drivers and Pressures

This section answers questions related specifically to the drivers and pressures discussed above. The status and trends of sanctuary resources are addressed in the next section.

A virtual expert workshop was convened by CBNMS staff on June 29, 2021 (see Appendix A and Appendix C) to discuss the following series of questions.[13] It is important to note that, in general, the assessments of the status and trends of key indicators in CBNMS are for the period from 2009–2021. During the virtual workshop, indicators for each topic were presented, accompanied by datasets ONMS had collected prior to the meeting. Attendees were then asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest any additional datasets that may be relevant. Once all datasets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the sources of information they used to make judgments; and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence ratings. Appendix C provides a detailed description of the methods used to develop this report.

The following responses for each question summarize the key indicators, supporting data sets, and rationale for each status and trend rating. Where published or additional information exists, the reader is provided with appropriate references. Workshop discussions and ratings were based on data available at the time (e.g., through spring 2021). However, in some instances, sanctuary staff later reevaluated and/or incorporated newly available data in order to more accurately describe the current status and trends of resources. Situations where post-workshop rating decisions were made and/or data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

[13] Note that a workshop was not convened for the question that asks "What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?" Due to a limited number of experts in the maritime heritage field, archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject matter experts have been monitoring existing archaeological sites along the West Coast, including CBNMS, since the 1980s.

Status and Trends of Drivers (Question 1)

Question 1: What are the states of influential human drivers and how are they changing?

Not Rated

Rationale: ONMS and CBNMS staff decided not to rate the status and trend of influential human drivers at CBNMS. The primary purposes for rating the status and trends of resources are to use condition reports to assess program effectiveness and to influence management of human activities and certain natural resource actions. For the most part, drivers are not manageable, at least not under the authority of the National Marine Sanctuaries Act, nor do most of them originate at scales relevant to national marine sanctuary management. While understanding them is important, rating them is not necessary to achieve the goals of the condition report.

The primary drivers influencing pressures on CBNMS resources were previously described in the Drivers section of this report. Drivers are the societal values, policies, and socioeconomic factors that influence human pressures on marine ecosystems. Understanding drivers helps to explain the origins of pressures on resources and potentially anticipate future trends for those pressures. Drivers include economic factors, such as income and spending; policies and legal frameworks; demographics, like population levels and urbanization; and societal values, such as levels of conservation awareness, political leanings, or changing opinions about the acceptability of specific behaviors (e.g., littering). All influence pressures on resources by changing the ways that humans interact with the marine environment.

After thoughtful consideration, ONMS and CBNMS staff decided not to rate the status and trend of influential human drivers at CBNMS. Condition reports are designed to assess program effectiveness, management of human activities, and certain natural resource actions, such as restoration. While it is important to understand drivers, they are generally large in scale and not manageable under the authority of the National Marine Sanctuaries Act. Conversely, the pressures that result from drivers can be managed, either directly by ONMS or through engagement with those who have appropriate authority. Thus, status and trend ratings for pressures (i.e., human activities) and their potential effects on sanctuary resources have been determined and are described in Questions 2–5.

Status and Trends of Pressures (Questions 2–5)

Human activities that adversely impact water quality are the focus of Question 2. These include vessel traffic (as a proxy for oil spill risk), known spills, discharges, and emissions.

Question 3 covers human activities that may adversely influence habitats. Some human activities may have structural and non-structural impacts to habitats. For example, fishing activities that physically disrupt the seafloor (e.g., trawling, lost gear) may result in structural impacts to seafloor habitats. Non-structural impacts could include oil spills, anthropogenic sounds, and climate change. For this question, we focus on structural impacts to habitats.

Human activities that have the potential to negatively impact living resources are the focus of Question 4. These include activities that remove plants or animals, as well as activities that have the potential to injure or degrade the condition of living resources.

Activities that influence maritime heritage resource quality are the subject of Question 5. These include activities that diminish resource quality through intentional or inadvertent destruction of maritime heritage resources. Importantly, and unlike most natural resources, maritime archaeological resources are non-renewable. Once degraded or destroyed, their archaeological value is lost forever.

Human activities that influence climate change at a global scale (i.e., those that produce greenhouse gases) are not evaluated in this report. National marine sanctuary managers are not charged with controlling these or other large-scale activities (e.g., global plastic pollution) and therefore do not regulate or otherwise control the activities that cause them, at least not for the purpose of reducing their global impact. ONMS does recognize, however, that some activities in national marine sanctuaries that contribute to climate change (e.g., ship and boat traffic, facility construction, and the transport of harvested food and products) also have local and direct impacts on sanctuary resources. ONMS has a responsibility to minimize impacts of those activities, and they are thus considered in this report.

Table S.HA.2.1. 2009 (left) and 2009–2021 (right) status, trend, and confidence ratings for the human activities questions.

2009 Condition Report Questions	2009 Rating	2009–2021 Condition Report Questions	2009–2021 Condition Report Rating
N/A	N/A	1. Influential Drivers	Not rated
4. Human activities and water quality	?	2. Human activities and water quality	Good/Fair
8. Human activities and habitat	▲	3. Human activities and habitat	Fair
14. Human activities and living resources	▲	4. Human activities and living resources	Fair
17. Human activities and maritime archaeological resources	?	5. Human activities and maritime heritage resources	Good

Question 2: What are the levels of human activities that may adversely influence water quality and how are they changing?

Status Description: Some potentially harmful activities exist, but they have not been shown to degrade water quality.

Rationale: There are fairly high levels of human activity, mainly vessel traffic, that pose risks to water quality. Varying patterns make it difficult to discern a trend, but fuel carried per vessel is increasing, though spill volumes have decreased. In addition, although there has been increased vessel traffic over several decades, recent air quality regulations have resulted in a change to low-sulfur fuel and improved emissions. Overall, the levels of large commercial vessel traffic have remained the same during the study period. There were no reported oil spill incidents inside CBNMS, but incidents that occurred nearby had the potential to affect the sanctuary. Vessel discharges were recorded in the sanctuary, yet are likely underreported. New regulations on sulfur oxide emissions resulted in an increase in exhaust gas cleaning systems and a downward trend in emissions over the study period.

Findings From the 2009 Condition Report

In 2009, the status was good/fair and the trend was undetermined (Table S.HA.1). The rating was based on the presence of some potentially harmful activities, but the level of human activities in CBNMS was considered low. The 2009 condition report also noted uncertainty about the levels of vessel discharges. Over the last decade, our understanding of vessel traffic has grown substantially, largely due to Automatic Identification Systems (AIS), and our awareness of discharges has risen significantly. Our understanding of small traffic still lags, along with our understanding of the scope and scale of illegal vessel discharges.

New Information in the 2009–2021 Condition Report

Information considered for this question included vessel traffic (as a proxy for spill and discharge risks), as well as known spills, discharges, and emissions (Table S.HA.2.2).

Table S.HA.2.2. Summaries for the key indicators related to human activities that may adversely influence water quality that were discussed during the June 29, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Vessel traffic (as proxy for oil spill risk)	Jensen et al., 2015; USCG, 2021; Bureau of Ocean Energy Management & NOAA, 2021	Pelagic	**Status:** Overall level of large commercial vessel traffic has remained the same. **Trend:** Conditions do not appear to be changing.	S.HA.2.1
Spills	Office of Response and Restoration, 2016; Washington State Department of Ecology, 1996	Pelagic	**Status:** No reported incidents in CBNMS, some nearby. **Trend:** Conditions do not appear to be changing.	None
Discharges	USCG, 2020	Pelagic	**Status:** Small and large discharges likely underreported. **Trend:** Undetermined trend.	None

Indicator	Data Source	Habitat	Data Summary	Figures
Exhaust gas cleaning system discharges	Moore et al., 2018	Pelagic	**Status:** New regulations on sulfur oxide emissions resulted in increased industry use of exhaust gas cleaning systems, and new fuels resulted in decreased use of exhaust gas cleaning systems. **Trend:** Conditions appear to be improving.	Table S.HA.2.3
Greenhouse gas emissions	Smith et al., 2015	Pelagic	**Status:** Greenhouse gases are high and are affecting water chemistry and temperature. **Trend:** Some recent improvements, not enough to counteract high levels.	None
Data gaps	Volume and impacts of vessel discharges and emissions, including black water and gray water discharges, and exhaust gas cleaning system effluent; continuous archived AIS data; analysis of AIS for summary statistics			

CBNMS has regulations that prohibit discharge of material within sanctuary boundaries, except by lawful fishing. Other agencies also have regulations that apply in CBNMS, including USCG regulations on trash disposal and the IMO Ballast Water Management Convention requirements to limit invasive species in ballast water. Because there are limited data on how human activities influence water quality, vessel traffic data were used as a proxy for oil spill and discharge risk. Given the large volume of commercial traffic that transits through the sanctuary, there is a heightened risk for spills and discharges. Large commercial ships use the San Francisco TSS, the northern lane of which bisects the sanctuary. Large vessel traffic poses threats that include oil spills and other water pollution, air pollution (which can affect water quality, e.g., through ocean acidification), container loss, and biological invasions (Jagerbrand et al., 2019; Hassellöv et al., 2013; Ruiz et al., 2000). During the study period, the size of commercial ships increased but the number of ships using all three lanes of the TSS stayed relatively constant at about 8,000 transits per year, including inbound and outbound transits (Jensen et al., 2015; USCG, 2021; Bureau of Ocean Energy Management & NOAA, 2021). Over one million miles (898,369 nm) of vessel transits through CBNMS occurred from 2009 to 2020 (Bureau of Ocean Energy Management & NOAA, 2021), and this does not include vessels that are not required to carry AIS (Figure S.HA.2.1). Vessel Management System (VMS) records from NOAA Fisheries show an increasing trend in the number of fishing vessels in CBNMS carrying VMS over the last decade. Spatial data on vessels not equipped with VMS or AIS beacons are not available.

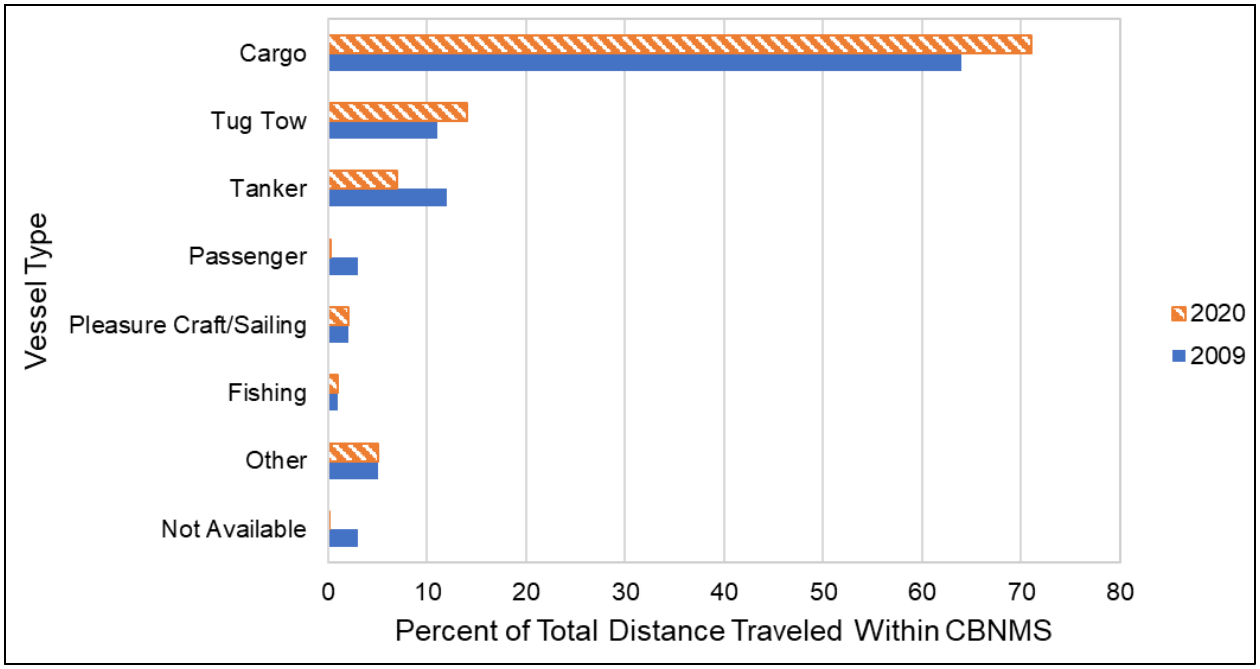


Figure S.HA.2.1. Percent of total distance traveled within CBNMS by various vessel types in 2009 and 2020. All vessel types traveled a total of 88,578 nm in 2009 and 59,379 nm in 2020. “Not available” indicates that the vessel type was not provided in the data. Source: Bureau of Ocean Energy Management & NOAA, 2021; Image: Heidi Burkart/NCCOS

Vessel Monitoring Systems and Automatic Identification System

Vessel Monitoring Systems (VMS) and the Automatic Identification System (AIS) are tools for tracking vessels. VMS consists of a NOAA Fisheries type-approved transmitter that automatically determines a vessel's position and transmits it to a communications service provider. The communications service provider receives the transmission and relays it to NOAA Fisheries. In the Pacific Coast groundfish fishery, position data are primarily used to monitor fishing activity relative to closed areas. VMS is required on (1) commercial fishing vessels registered for use with a Pacific Coast groundfish limited entry permit in California, (2) any vessel that uses non-groundfish trawl gear to fish within the U.S. EEZ, and (3) any vessel that uses open access gear to take, retain, or possess groundfish in the EEZ or land groundfish taken in the EEZ. VMS is also required on drift gillnet vessels participating in highly migratory species fisheries (NCCOS, 2020a; USCG, 2021). More simply, VMS is required for any vessel that commercially sells groundfish caught in federal waters.

Vessels with federal groundfish limited entry permits are required to have VMS regardless of whether they operate in state or federal waters. CBNMS includes only federal waters. Therefore, fisheries active in CBNMS that are required to use VMS include black cod, groundfish trawl, and groundfish caught using pot and trap. Vessels targeting squid or tuna are only required to have VMS if they land groundfish from federal waters at other times of year. For salmon trollers, VMS is only required if they retain incidentally caught groundfish.

AIS is an on-board navigation safety device that transmits and monitors the location and characteristics of large vessels in U.S. and international waters in real time. In the U.S., USCG collects AIS data, which can be used for a variety of coastal management purposes. Since 2015, vessels over 65 feet are required to carry AIS.

Cruise ships transiting through the sanctuary are one vessel type of particular concern. Cruise ship arrivals in San Francisco increased from 65 in 2013 to 81 in 2015. Many carry over 3,000 people, generate and incinerate large amounts of waste, and have the potential to severely impact water quality in localized areas if they are not responsibly operated. The main pollutants generated by cruise ships are sewage (also referred to as black water), gray water, oily bilge water, hazardous wastes, and solid wastes. NOAA prosecuted two related cases involving 190 separate, prohibited discharges from cruise ships during the study period (2015–2017), totaling approximately eight million gallons of untreated black and gray water, membrane bioreactor sludge, exhaust gas cleaning system effluent, and food waste released in CBNMS and GFNMS (Office of General Counsel, 2021). In 2010, there was also a bilge water discharge nearby in GFNMS. Cases of vessel discharges within and near the sanctuary are likely underreported despite the legal requirement for reporting vessel discharges.

Cargo ships and oil tankers transiting through the sanctuary are of concern for spills and discharges. Large cargo ships can carry up to four million gallons of fuel oil (Office of Response and Restoration, 2016). Oil tanker sizes vary, and these ships can carry between 9–150 million gallons of oil (Washington State Department of Ecology, 1996).

High-sulfur fuel used in commercial shipping for much of the 20th century emitted significant amounts of pollution. Pollutants from fuels are redirected from entering the atmosphere and the water column through the use of properly functioning exhaust gas cleaning systems. While exhaust gas cleaning systems are used to meet air emission standards, discharge from these systems has potential effects on atmospheric chemistry and marine ecosystems. Exhaust gas from smokestacks leads to atmospheric pollution by releasing hydrocarbons, carbon dioxide, and aerosols. The scrubber wash water discharges into marine environments and increases the risk for eutrophication, acidification, and heavy metal pollution (Endres et al., 2018). In 2009, the California Air Resources Board (CARB) instituted emission control areas (ECA) for ocean-going vessels that mandate the use of low-sulfur fuels and restricted the use of exhaust gas cleaning systems to comply with these standards. In 2015, California ECA areas were expanded to all U.S. waters out to the EEZ. While the net effect of these regulations was a reduction in emissions from ships over the study period, some ships used exhaust gas cleaning systems illegally, and there is uncertainty as to the scale of exhaust gas cleaning system effluent that entered CBNMS. Fuel changes also resulted in reductions in greenhouse gas emissions, although emissions remain high and are affecting water chemistry (Smith et al., 2015; Table S.HA.2.3).

Table S.HA.2.3. Summary of fuel regulation changes that impacted vessel traffic in CBNMS. Source: Adapted from Moore et al., 2018

Fuel Regulation Changes	**Date**
California ECAs in effect by CARB (sulfur: 1.5% marine gas oil/0.5% marine diesel oil)	July 1, 2009
California ECA boundary modification by CARB	December 1, 2011
Global fuel standard made more stringent by IMO (3.5% sulfur)	January 1, 2012
North American ECA in effect by IMO (1.0% sulfur)	August 1, 2012
California ECA standard made more stringent by CARB (sulfur: 1.0% marine gas oil /0.5% marine diesel oil)	August 1, 2012
TSS modified by IMO/USCG	June 1, 2013
California ECA standard made more stringent by CARB (sulfur: 0.1% marine gas oil/0.1% marine diesel oil)	January 1, 2014
North American ECA fuel standard made more stringent by IMO (0.1% sulfur)	January 1, 2015

Conclusion

Several human activities have the potential to adversely influence water quality. The primary consideration for the good/fair rating and the not changing trend continues to be the level of shipping in the sanctuary, as this activity poses a risk for oil spills. Data gaps that were identified include, but are not limited to, volume and impacts of vessel discharges, including black water and gray water discharges, and exhaust gas cleaning system effluent.

Question 3: What are the levels of human activities that may adversely influence habitats and how are they changing?

Fair

Status Description: Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.

Rationale: Vessels in and around CBNMS generate noise that can degrade habitat quality for marine species. The soundscape of CBNMS is dominated by ships and baleen whales and is at the threshold of good environmental health, according to European Union standards. Trend data on the CBNMS soundscape are not yet available, but ocean noise has increased globally since the 1950s due to larger vessels and more vessel traffic. Bottom trawling occurs in CBNMS, mainly on soft sediment, and marine debris is present in all sanctuary habitats. It is possible that conditions are improving because bottom trawling has decreased during the study period, but it is also likely that debris and noise in the sanctuary are increasing.

Human activities that degrade habitat quality do so by affecting structural (physical), biological, oceanographic, acoustic, or chemical characteristics of the habitat. Structural impacts, such as removal or mechanical alteration of habitat, including critical biological habitat components, can result from various fishing methods, particularly trawling. Marine debris, particularly in large quantities (e.g., lost nets and other types of fishing gear), can degrade both biological and structural habitat components. Management actions such as no-anchoring prohibitions on Cordell Bank are in place to help protect fragile habitat. Chemical alterations most commonly occur following spills and can have both acute and chronic impacts. Many of these activities are regulated to limit their impact on protected resources.

Findings From the 2009 Condition Report

In 2009, this question was rated fair and improving (see Table S.HA.2.1). The report noted that there had been impacts to habitat from bottom contact fishing gear, which supported the fair status. At the time, spatial management zones had recently been implemented by the Pacific Fisheries Management Council to restrict bottom contact fishing in some areas of the sanctuary designated as Essential Fish Habitat or Rockfish Conservation Areas, which contributed to the improving trend.

New Information in the 2009–2021 Condition Report

The indicators evaluated for this question included noise, marine debris, and trawling for commercial fishing and research purposes (Table S.HA.3.1).

Table S.HA.3.1. Summaries for the key indicators related to human activities that may adversely influence habitats that were discussed during the June 29, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Noise	Pacific Marine Environmental Laboratory et al., 2014; Haver et al., 2020, 2021; Tasker et al., 2010	Pelagic	**Status:** Whales and shipping dominate the soundscape; CBNMS is at the threshold of "good ecosystem status." **Trend:** No long-term trend data from NOAA Noise Reference Station yet; overall ocean noise has been increasing since the 1950s.	S.H.10.2
Marine debris	CBNMS, 2020, 2021a	Pelagic and benthic	**Status:** Marine debris found in the surface waters and benthos of the sanctuary. **Trend:** Undetermined.	App.E.10.7; App.E.10.7; App.E.10.8
Research trawling	West Coast Groundfish Bottom Trawl Survey [WCGBTS], 2019	Benthic	**Status:** Research trawling on the shelf and slope has occurred at low levels. **Trend:** Conditions do not appear to be changing.	S.HA.3.1
Fishing	CDFW, 2020a; NOAA Northwest Fisheries Observation Science Program, 2021; WCGBTS, 2019	Benthic	**Status:** Fish trawling has occurred on the shelf and slope, but less than other areas. Crab effort over time appears to be consistent. **Trend:** Improving (trawling has decreased); however, recent Rockfish Conservation Area changes in 2020 increased the area open to trawling (trend not yet known).	S.HA.3.2; S.HA.3.3; S.HA.3.4
Data gaps	Analysis of acoustic data, particularly trends over time; more information on bottom contact fishing trends, including information about habitat impacts from fishing on the seafloor, such as the amount of fixed gear deployed and lost, and the severity and duration of impacts from fixed gear and trawling			

Many marine organisms, including baleen whales, rely on sound for their life functions, and anthropogenic noise can impact their habitat (Hatch et al., 2008; Redfern et al., 2017; Richardson et al., 1995). CBNMS provides habitat for many species of marine mammals, including large baleen whales. Substantial vessel traffic occurs in and out of the San Francisco Bay Area, which includes the Port of Oakland, a major port for container vessels. The levels of large commercial vessel traffic, as recorded with USCG AIS data, have remained similar throughout the study period (Jensen et al., 2015; Moore, 2018; USCG, 2021).

A baseline assessment of the CBNMS soundscape has been completed (Haver et al., 2020), but no trend data are available. NOAA does not have a standardized threshold for chronic noise in marine environments, but the European Union developed a standard that states noise at certain frequencies should not exceed 100 decibels over a seasonal time period to be considered in "good ecosystem status." According to these guidelines, the CBNMS soundscape is at the threshold of "good ecosystem status," and falls in the middle of the range compared to other listening station sites around the U.S. (Haver et al., 2021; Tasker et al., 2010; see Question 10). Large vessel traffic is the primary source of anthropogenic noise in the sanctuary (Haver et al., 2020). Although we do not yet have a trend analysis for CBNMS, research suggests that from

1950–2007 low-frequency, ambient noise levels in the open ocean have increased approximately 3.3 decibels each decade, a doubling of noise intensity every decade since 1950 (Hatch et al., 2008; Frisk, 2012).

Increases in noise in the Pacific basin over the past several decades have been correlated with increases in shipping volume and size of ships (Vos & Reeves, 2005; McKenna et al., 2012a; 2012b). Therefore, it is likely that noise from commercial shipping has increased in CBNMS in the past half century, with market-driven dynamics over the past ten years, such as recessions and the COVID-19 pandemic, linked to interannual variability.

Marine debris is found in all CBNMS habitats. A variety of human activities contribute to marine debris, including fishing, plastic manufacturing, littering, improper trash disposal, and waste water disposal. Data on contributions to sanctuary debris from these activities are not available, but increases in human population and production of goods, without a tangible solution for removing significant amounts of marine debris from the ocean, suggests that the problem is not improving. And, while records within CBNMS are sparse, marine debris accounts for 106 confirmed injuries and deaths to marine mammals along the West Coast from 2011–2015 (Carretta et al., 2017) and 123 deaths from 2014–2018. These numbers are considered a minimum value, as the recovery rates of cetacean carcasses are consistently quite low (<1% to 33%) across different species (Carretta et al., 2021)

Bottom contact fishing gear can alter and damage seafloor habitat. The types of fishing that occur in CBNMS and could impact the seafloor include research trawling, commercial trawling, and fixed gear, such as that used for Dungeness crab (see question 10). Research trawling is conducted by the NMFS Fisheries Resource and Monitoring Division and uses short-duration tows to assess the stock of groundfish. Because of its standardized design, research trawling effort has not changed significantly over time (Figure S.HA.3.1). Commercial trawling in CBNMS occurs on the shelf and the slope (Figure S.HA.3.2) at low levels compared to the entire West Coast. NMFS groundfish observer data, analyzed using approaches from NOAA's California Current Ecosystem Status Report (Harvey et al., 2021), showed commercial trawling declined during the study period and shifted to areas on the shelf and away from the slope (Figure S.HA.3.2, Figure S.HA.3.3). Fixed gear for Dungeness crab occurs mainly in the eastern portion of the sanctuary. Because of its offshore location, less crab fishing occurs in CBNMS than at other sanctuaries in California. During the study period, Dungeness crab landings in CBNMS remained fairly constant, except for a peak in 2010–2011 (see Figure App.E.3.4).

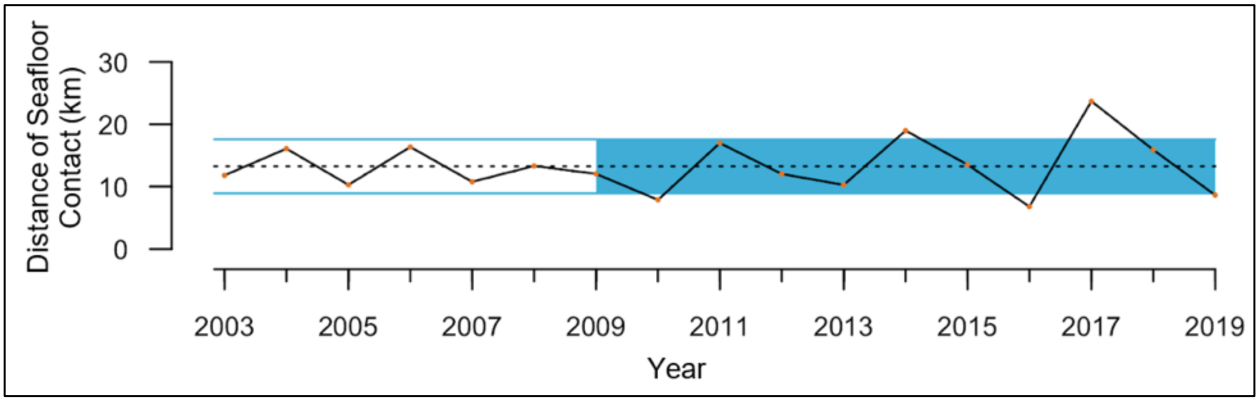


Figure S.HA.3.1. Distance of seafloor contact (in km) by bottom trawl gear from the NMFS groundfish survey within CBNMS. The dashed line is the mean and the solid horizontal lines are ±1 standard deviation of the full time series. The blue shaded area is the time period evaluated for this report. Source: West Coast Groundfish Bottom Trawl Survey [WCGBTS], 2019; Image: CCIEA

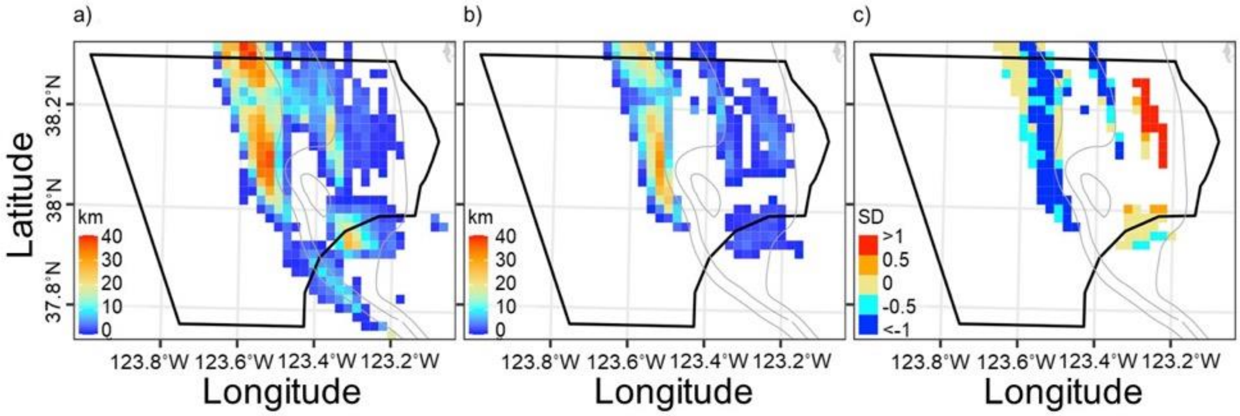


Figure S.HA.3.2. Spatial representation of seafloor contact by bottom trawl gear from federal groundfish fisheries operating within CBNMS and nearby areas, calculated from annual distances trawled within each 2x2-km grid cell from 2002–2019. (a) Mean distance trawled annually from 2002–2008. (b) Mean distance trawled annually from 2009 to 2019. (c) Normalized trend values from 2009–2019; standard deviation (SD) values are for the long-term mean (2002–2019) of that cell. Gray lines represent 100-, 200-, and 500-m depth contours. Grid cells with <3 vessels operating within the time period represented have been removed for confidentiality. Source: NOAA Northwest Fisheries Observation Science Program, 2021; Image: CCIEA

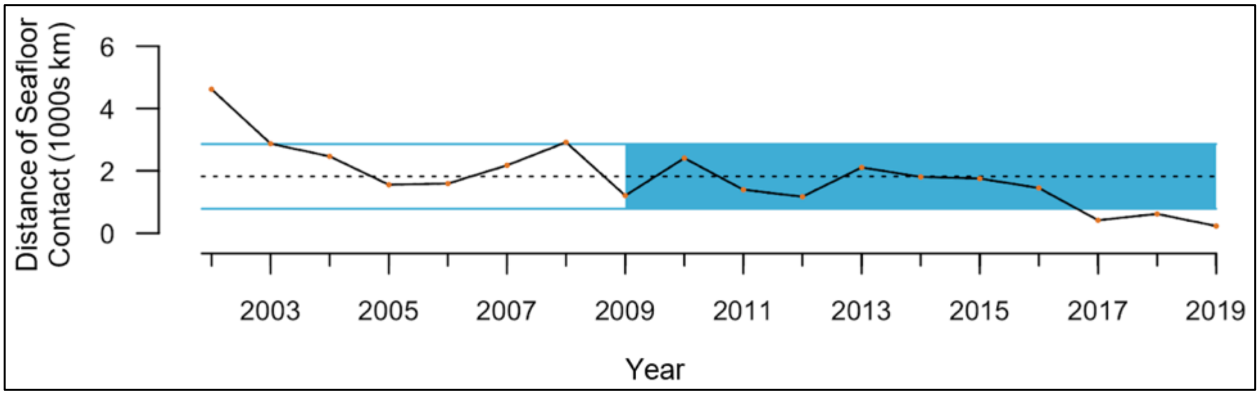


Figure S.HA.3.3. Distance of bottom trawl gear contact with seafloor by limited-entry and catch share permitted groundfish bottom trawl vessels in 1000's of kilometers. The dashed line is the mean and the solid horizontal lines are ±1 standard deviation of the full time series. The blue shaded area is the time period evaluated for this report. Source: WCGBTS, 2019

Conclusion

The rating is fair because CBNMS habitat is impacted by noise, marine debris continues to be documented in the sanctuary and is likely increasing, and areas of the sanctuary were recently opened to trawling. The improving trend is based on a decrease in bottom trawling during the time frame. The level of noise is a concern, but long-term monitoring data are not yet available to evaluate the trend for ocean noise in CBNMS; continued monitoring and analysis in the coming years is needed. More information on bottom contact fishing trends is needed to better assess human activities that may adversely influence habitats. This includes information about the habitat impacts from fishing on the seafloor, such as the amount of fixed gear deployed and lost and the severity and duration of impacts from fixed gear and trawling.

Question 4: What are the levels of human activities that may adversely influence living resources and how are they changing?

Status Description: Selected activities have caused measurable living resource impacts, but effects are localized and not widespread or persistent.

Rationale: Impacts of concern for living resources in CBNMS include vessel traffic, fishing, and entanglement. Vessel traffic poses a risk of ship strikes to whales in the sanctuary, especially in high-use habitat that includes a heavily trafficked shipping lane. In addition, whales are at risk of entanglements in the region, but the occurrence of entanglements in CBNMS is thought to be low. The trend for entanglement and strandings could not be determined due a lack of temporal data from the sanctuary. Generally, however, vessel speed decreased over the study period. A recent, slight increase in vessels and records from VMS suggest that fishing activity has increased from a low in 2018, but there was not a strong long-term trend. [14]

Findings From the 2009 Condition Report

The 2009 rating was fair and improving and was based on selected activities that had resulted in measurable living resource impacts, including fishing and associated habitat disturbance, vessel traffic (discharge, noise, collision), and marine debris (lost gear and plastics; see Table S.HA.2.1).

New Information in the 2009–2021 Condition Report

Human activities currently considered to pose the greatest threat to living resources in CBNMS are vessel traffic (mostly because of ship strikes), removal by fishing, and commercial fishing with gear that can entangle whales (Table S.HA.4.1). Vessel strikes to baleen whales are thought to be a significant source of mortality, and the northern shipping lane of the San Francisco Bay TSS goes through CBNMS, funneling large vessel traffic into those lanes and through the sanctuary to vessel routes seaward of the shipping lane. Fishing activity, such as trawling and fixed gear, can reduce target and non-target species. Fishing gear, as well as marine debris and research gear, poses an entanglement risk to whales.

---

[14] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, “mixed,” was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data.

Table S.HA.4.1. Summaries for the key indicators related to human activities that may adversely influence living resources that were discussed during the June 29, 2021 virtual workshop.

Indicator	Data Source	Data Summary	Figures
Vessel traffic	Gatehouse Maritime, 2021; Moore et al., 2018; NOAA Fisheries, 2022a; Rockwood et al., 2020b	**Status:** Mean speed in CBNMS dropped 3.1 knots from 2009–2020. The size of ships increased, but the number of ships stayed relatively constant. **Trend:** Conditions appear to be improving.	S.HA.4.2; S.HA.4.3; S.HA.4.5
Ship strikes	Carretta et al., 2021	**Status:** Ship strikes continue to be a significant cause of human-induced mortality. **Trend:** Conditions appear to be worsening.	S.HA.4.1
Whale entanglement	NOAA Fisheries, 2021a	**Status:** Whale entanglements continue to be a significant cause of human-induced mortality. **Trend:** Conditions initially worsened but appear to have improved in the last two years.	S.HA.4.7
Fishing activities	BOEM et al., 2021; NOAA Fisheries, 2021b	**Status:** Trolling, trawlers, and fixed gear make up the majority of fishing activity in CBNMS. **Trend:** VMS records indicated an increase in time spent fishing in CBNMS.	S.HA.4.4; S.HA.4.6
Data gaps	Information about fishing activity (including vessel types and locations), whale entanglements, ship strikes, and acoustic impacts to improve the ability to assess human activities that may adversely influence living resources		

Vessel Traffic

Vessel traffic has a direct and indirect impact on some living resources in CBNMS through ship strikes and noise (note that noise is discussed in questions 3 and 10). Ship strikes continue to be a significant cause of human-induced mortality and injury to baleen whales in the sanctuary (Carretta et al., 2021). Blue and humpback whales are still recovering from past impacts (see question 13). These species are listed as endangered (blue whales, humpback whale Central American Distinct Population Segment) and threatened (humpback whale Mexico Distinct Population Segment), and are vulnerable to impacts (Carretta et al., 2021). Experts believe that not all whales that are killed by ship strikes are detected; therefore, documented ship strike deaths are considered minimum values. Documented stranded animals appear to be about 2% (blue whales) to 10% (humpback whales) of actual whale vessel strikes, because most dead whales will drift offshore or sink (Carretta et al., 2021). The total number of fatal strikes on endangered whales may be much higher than recorded totals, based on modeling estimates (Rockwood et al., 2020a). Cetacean carcass detection is consistently low across regions; therefore, observed species and numbers underrepresent true impacts. However, the trend in documented stranded animals appears to be increasing (NOAA Fisheries, 2021; Figure S.HA.4.1). Due to the wide range of whale populations, uncertainty in where vessel impacts to whales occur versus where struck whales are observed, and limited data availability, a broader look at the issue, including regional observations, is required.

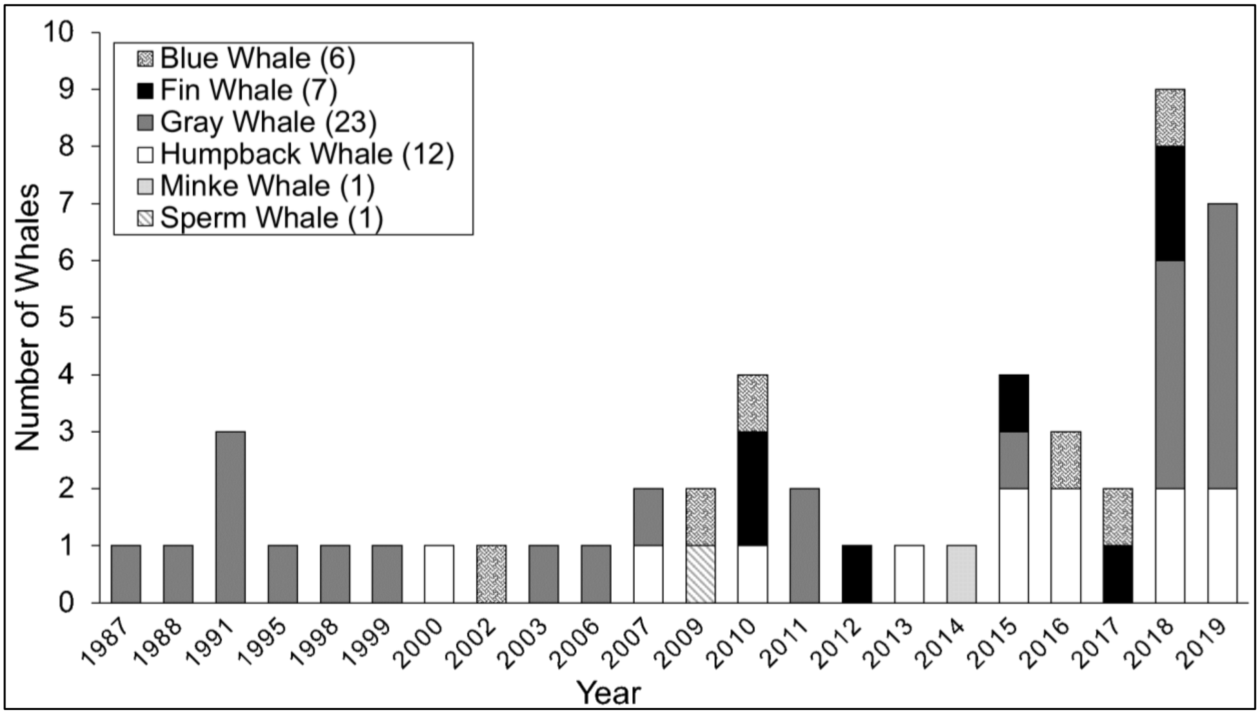


Figure S.HA.4.1. Recorded fatal ship strikes on large whales in San Francisco Bay Area counties from 1986–2020 by species. Data include Sonoma, Marin, Contra Costa, Alameda, San Francisco, San Mateo, and Monterey counties. Only years with recorded data are shown. Due to the COVID-19 pandemic, 2020 necropsies were limited, and cause of death was not reported for six large whale strandings in San Francisco Bay Area counties after February 2020. Source: NOAA Fisheries, 2022a; Image: J. Morten/NOAA

The risk of fatal ship strikes to whales is influenced by the number, size, and speed of vessels, and how much vessel traffic overlaps with preferred whale habitat. While the number of ships that transit the sanctuary did not change significantly during the study period, globally the size of ships increased (Boulougouris, 2021), increasing the probability of mortality in marine mammals that are struck (Silber et al., 2010). The number of large commercial vessels (>100 gross tons) have increased from 11,108 to over 94,000 over the last 100 years (Schoeman et al., 2020), indicating there are more large ships, which are more likely to cause fatal injuries. However, large freight vessel speeds in CBNMS decreased by approximately 3 knots between 2009 and 2020 (Moore et al., 2018), from 15.2 knots in 2009 to 12.1 knots in 2020. In 2013, the TSS for the entrance to San Francisco was modified to increase navigational safety by lengthening and narrowing the lanes, which also allowed for a decrease in the overlap of ship traffic and preferred whale habitat (Figure S.HA.4.2). However, later modeling work showed that the shift increased the risk of ship strikes in the northern traffic lane by concentrating vessel traffic over key blue whale habitat (Rockwood et al., 2020b). Ship strike risk is also influenced by the distribution of whales and the recovery of whale populations (Redfern et al., 2020).

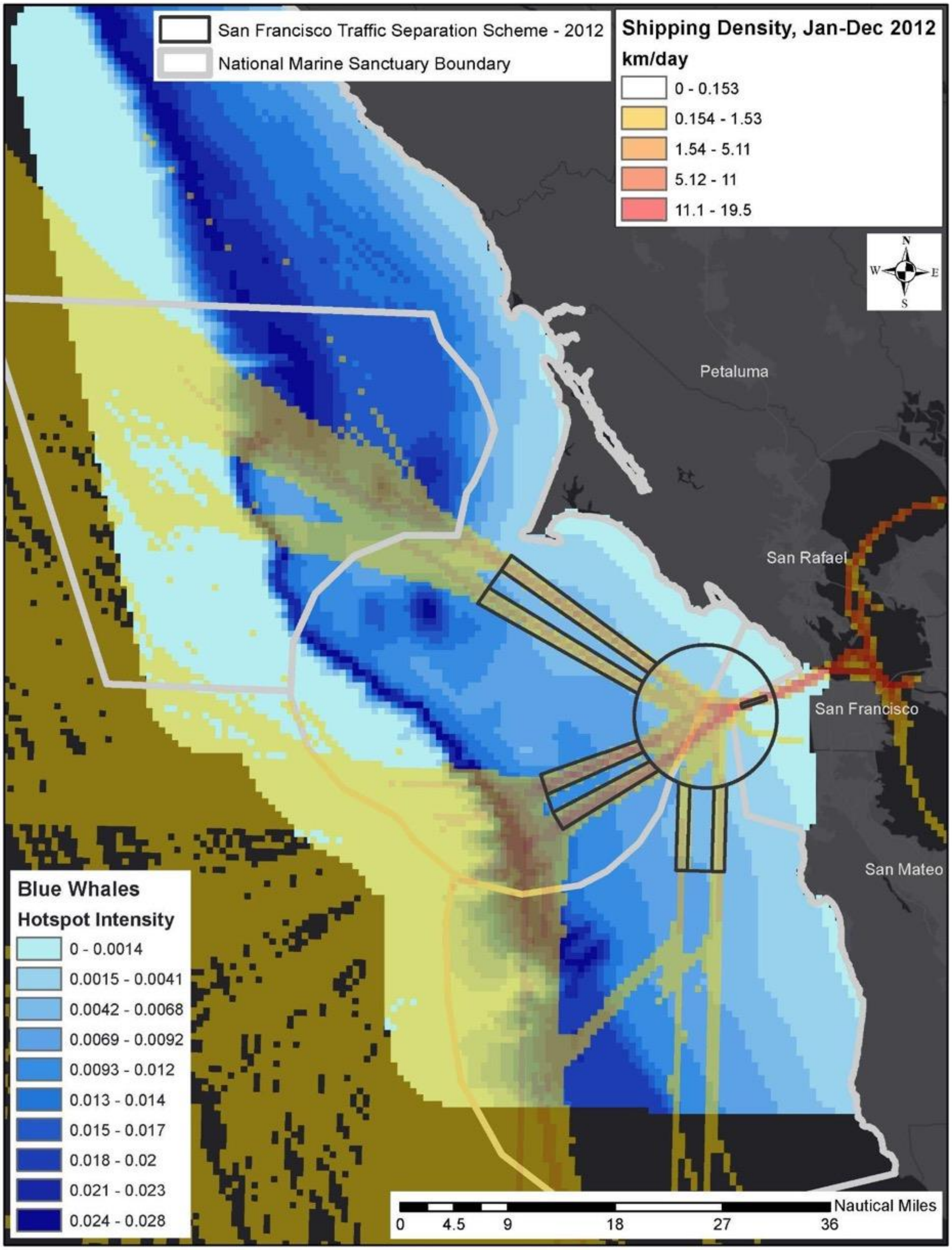


Figure S.HA.4.2. Traffic patterns for vessels equal to or greater than 80 m in 2012, prior to shipping lane changes, overlaid on predicted whale density. Sources: Moore et al., 2008; Rockwood et al., 2020b; Image: J. Morten/NOAA and California Marine Sanctuary Foundation

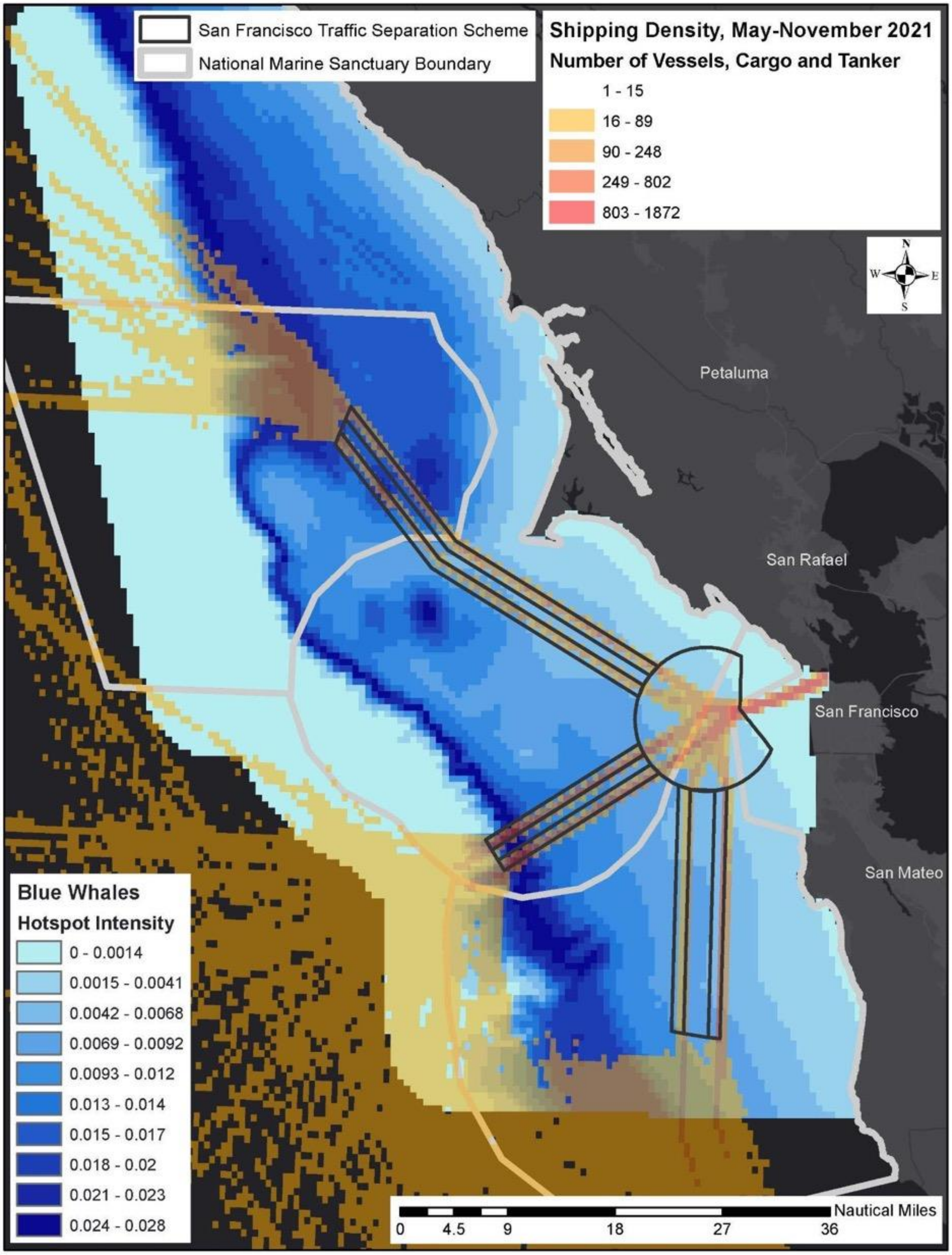


Figure S.HA.4.3. Traffic patterns for cargo and tanker vessel types in 2021, after shipping lane changes were implemented in 2013, overlaid on predicted whale density. Sources: Rockwood et al., 2020b; Gatehouse Maritime, 2022; Image: J. Morten/NOAA and California Marine Sanctuary Foundation

Fishing Activity

Recreational and commercial harvest have direct effects on animal and plant populations, either through the removal of or injury to organisms. Some fishing techniques are size-selective, resulting in impacts to particular life stages. In addition, lost fishing gear can cause extended periods of loss for some species through entanglement and "ghost fishing" (the continuous capture and serial mortality of animals by lost gear).

The majority of targeted species caught in CBNMS consists of various species of groundfish, salmon, and crab. Trolling, trawlers, and fixed gear make up the majority of fishing activity in CBNMS. NOAA VMS (see text box in question 2) records indicate no strong trends, but a slight increase from 2018–2020 in the number of vessels and duration of fishing was apparent, following a low in 2018 (Figure S.HA.4.4). VMS beacons are only carried by certain vessels and do not reflect all fishing effort in CBNMS (50 C.F.R. § 660.14; NOAA Fisheries, 2020a). Therefore, VMS records only represent a subset of the fishing vessels in the sanctuary and do not provide a complete picture of fishing effort or fishing type. Total landings of all species, excluding market squid, have remained fairly constant since 2009. Including market squid, total landings declined significantly from 2009–2020, but this was driven by a very large squid harvest in 2010. Based on VMS records, fishing activity was concentrated in the eastern portion of the sanctuary and along the shelf break north of Cordell Bank during the study period (Figure S.HA.4.5).

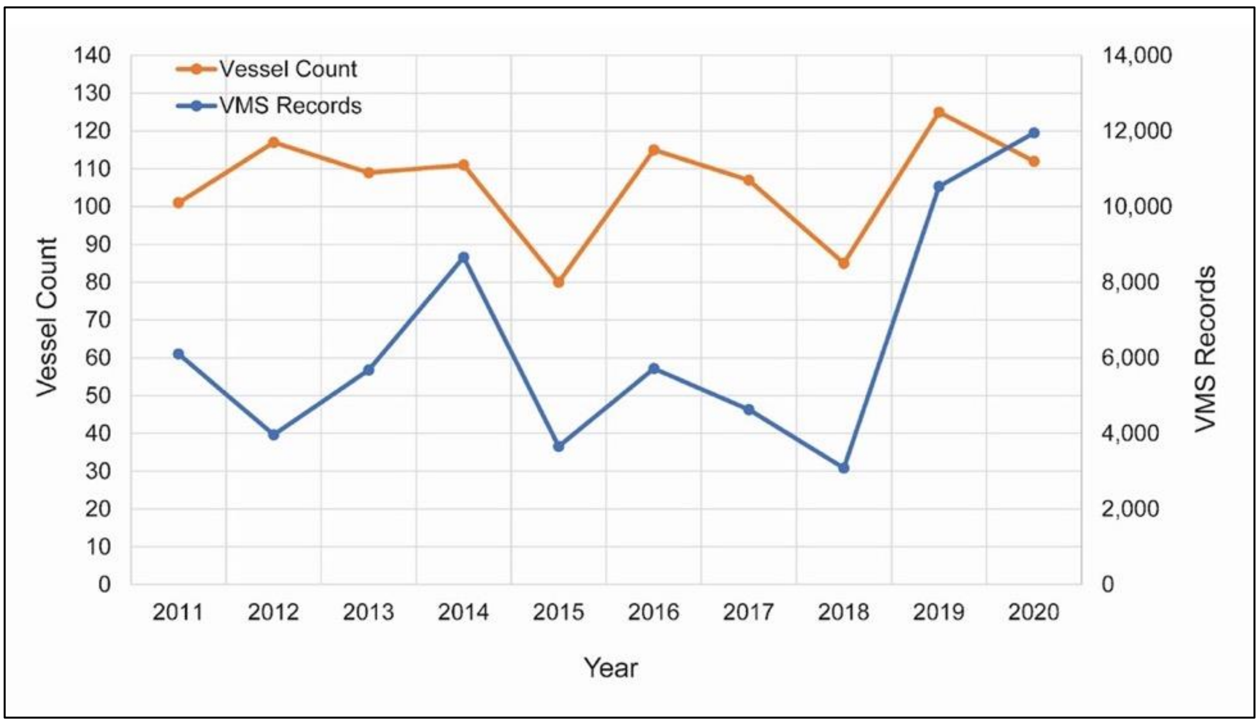


Figure S.HA.4.4. Fishing vessels in CBNMS from 2011 to 2020, based on VMS records. Source: NOAA Fisheries, 2021b; Image: NCCOS

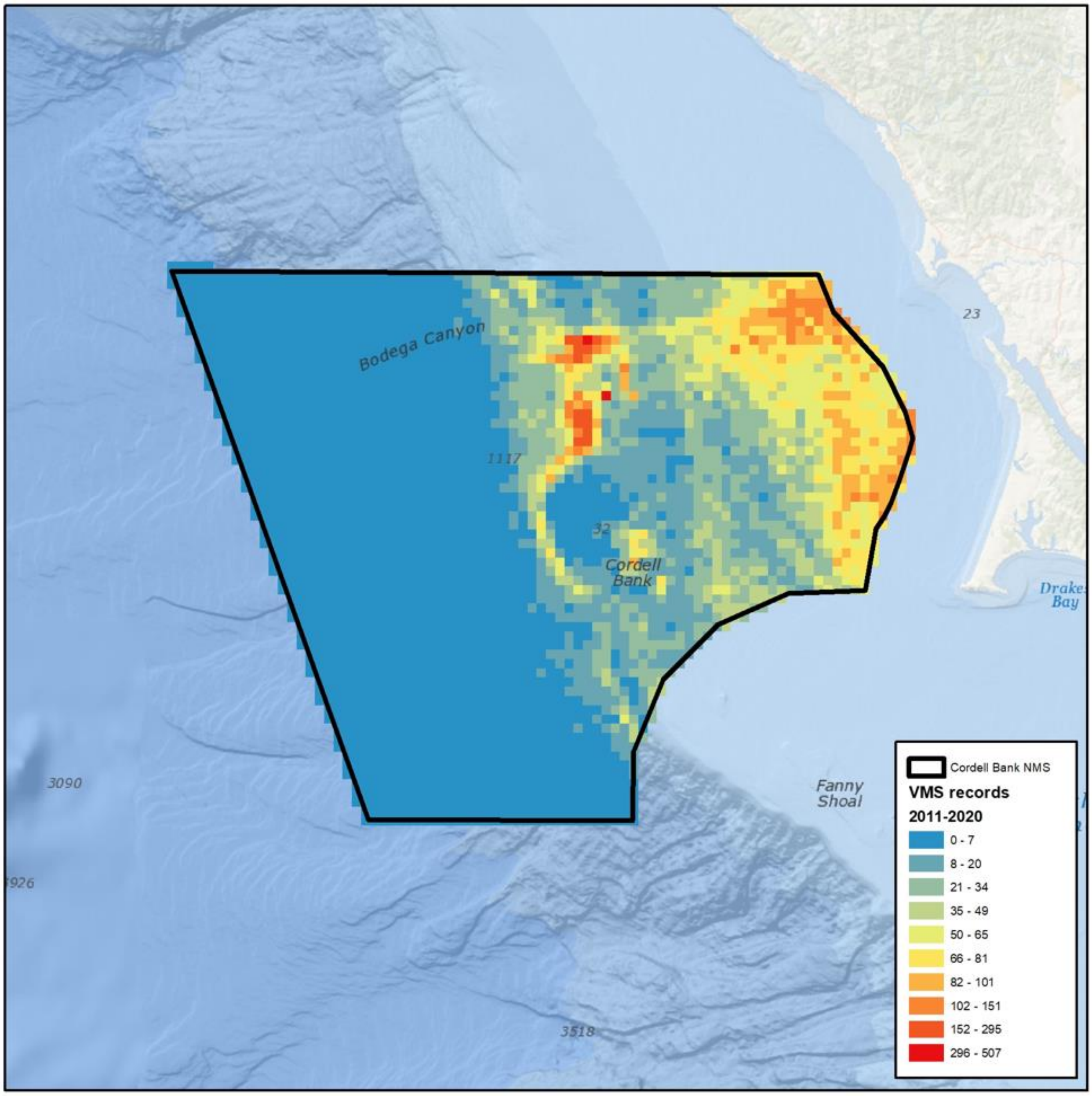


Figure S.HA.4.5. NMFS VMS records for CBNMS during the study period, including all vessels with VMS. VMS records are pings, and a single vessel may generate more than one ping in the sanctuary during the same trip. Source: NOAA Fisheries, 2021b; Image: NCCOS

AIS (see text box in question 2) data indicate an increasing number of fishing vessels and distance traveled within the sanctuary during the study period, but trend likely reflects an increase in the number of vessels using AIS (Figure S.HA.4.6). AIS carriage requirements for commercial vessels expanded in 2015, with a 2016 deadline for installation of working transponders in all commercial vessels and passenger and fishing vessels 65 ft or greater in length. Previously, only vessels 300 gross tonnage and larger were required to carry and transmit AIS (33 C.F.R. § 164). The increase in carriage requirements biases the data significantly, as many vessels were not required to carry a transponder before 2016. With this in mind, the data show the number of unique fishing vessels from 2009–2020 was 269, with the most in any one year approximately 85 vessels. The total distance traveled by fishing vessels, a measure of fishing vessel usage of an area, was 26,682 miles within the sanctuary.

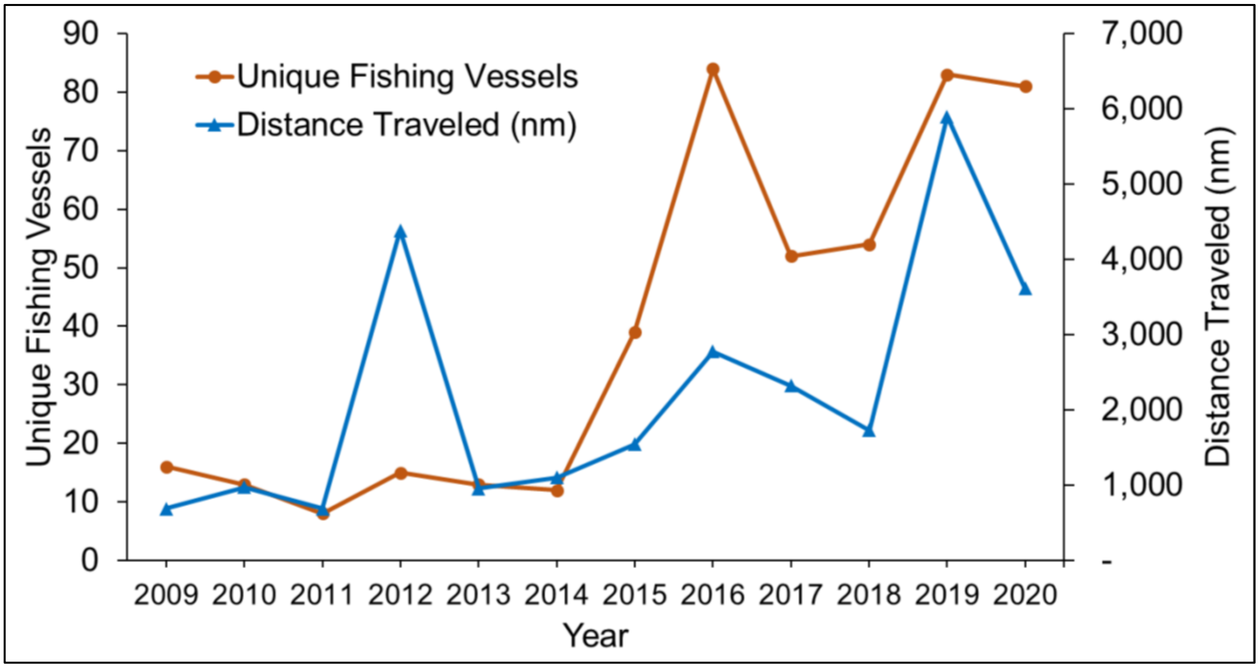


Figure S.HA.4.6. AIS data from fishing vessels from 2009 to 2020. Data include the number of unique fishing vessels and distance traveled. Source: BOEM et al., 2021

The vessels represented by VMS and AIS data are part of fisheries that remove target species, including groundfish, black cod, salmon, and crab, from the sanctuary. Although there are limited data available to evaluate seafloor impacts, fishing gear may also be impacting benthic invertebrate species. On the soft sediment in the eastern portion of the sanctuary, these could include sea pens, infauna (worms and bivalves), crustaceans, sea urchins, sea cucumbers, and sea stars. At the shelf break, the sediment is likely to be a mixture of soft and hard sediment. Species possibly affected by fishing in this area could include corals and sponges, crustaceans, sea stars, urchins, and sea cucumbers, among others. Additionally, non-target species can be caught as bycatch, and foragers in the water column, including whales, dolphins, pinnipeds, and seabirds, can be impacted by fishing gear and activity. Data were not available to evaluate the level of these impacts.

Whale Entanglement

Entanglement in fishing gear, marine debris, and research gear is a significant threat to marine wildlife. Baleen whales are particularly vulnerable to entanglement because of their habitat use and behavior. Humpback whales continue to be the most common species entangled. While during the study period there was only one confirmed entanglement within CBNMS, there were over 118 confirmed entanglements in neighboring GFNMS and Monterey Bay National Marine Sanctuary (MBNMS) from 2000–2019, indicating that it is a concern in the region. And in 2020, despite significant efforts to reduce entanglements, there were 17 confirmed whale entanglements off the coasts of Washington, Oregon, and California, or off the coast of other countries but entangled in U.S. commercial fishing gear (NOAA Fisheries, 2021a; Figure S.HA.4.7). In addition, unidentified whales represent approximately 15% of entanglement cases along the U.S. West Coast (Carretta et al., 2016). Entanglements are likely underreported, as they rely on opportunistic sightings. During the study period, the 2014–2016 marine heatwave caused a habitat compression that concentrated humpback whales in areas of high use by the Dungeness crab fishery (exacerbated by prey switching and changes to the timing of the fishery, also a result of the marine heatwave), resulting in an increase in entanglements (Santora et al., 2020). Additionally, in response to the change in the northern shipping lane in 2013, the commercial fishery for Dungeness crab began placing pots along the eastern edge of the northbound lane in a configuration that may increase the risk for whale entanglement (R. Ogg, personal communication, May 7, 2022). In recent years, there have been increasing efforts to disentangle humpback whales along the west coast through the Large Whale Entanglement Response Network coordinated by NOAA (NOAA Fisheries, 2022b). In addition, the Risk Assessment and Mitigation Program California Dungeness Crab Fishing Gear Working Group is working to reduce overlap of the Dungeness crab fishery with whales and modify fishing gear to reduce the risk of entanglement (Ocean Protection Council, 2018).

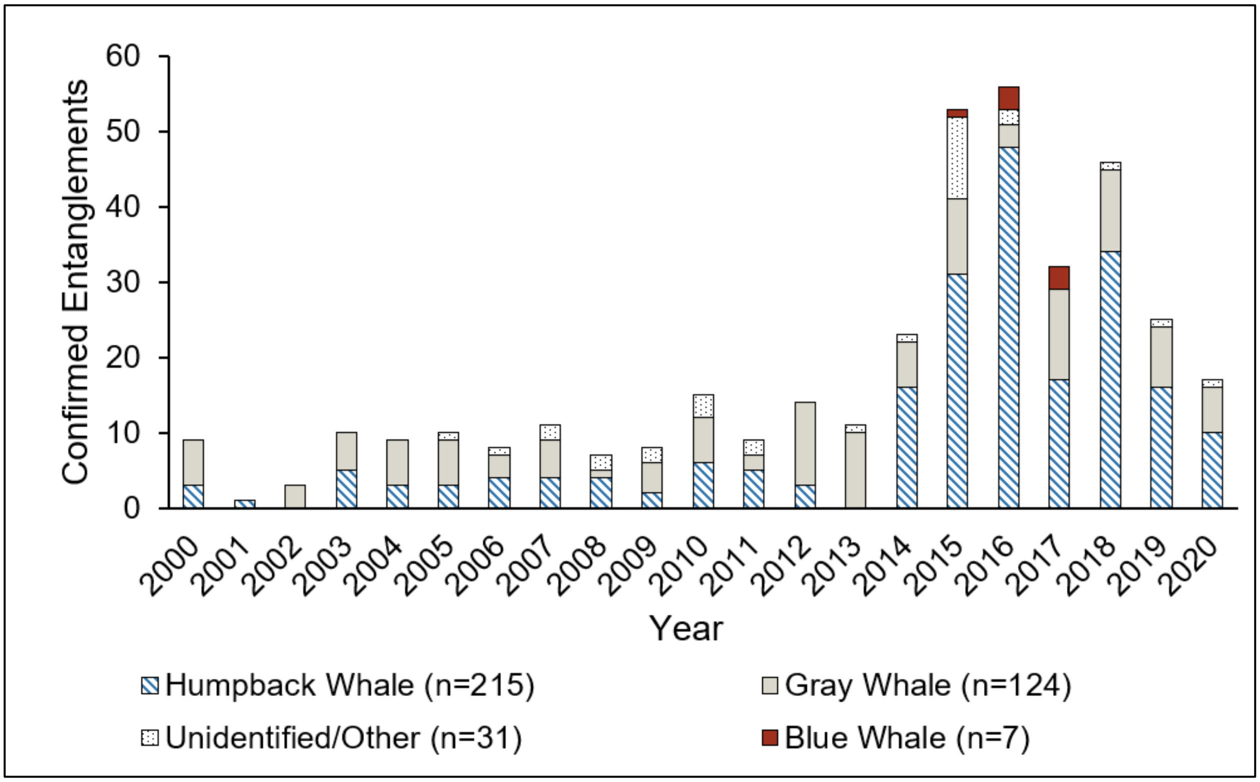


Figure S.HA.4.7. Number of confirmed entanglements by species reported to the NMFS West Coast Region each year from 2000–2020. Source: NOAA Fisheries, 2021a; Image: J. Morten/NOAA

Conclusion

The rating of fair considers whale entanglements in the region (though most of those observed are outside of CBNMS) and the fairly high risk of ship strikes within the sanctuary due to high traffic volume, increasing ship size, and the intersection of a shipping lane with key whale habitat in the sanctuary. The trend was mixed, based on two considerations. First, the spatial coverage of stranding and entanglement data does not allow for an assessment of sanctuary-scale temporal change. Second, the decreased risk of ship strikes as a result of reductions in vessel speed could be offset by a slight but recent increase in the number of fishing vessels and duration of fishing based on VMS records. This could increase entanglements and impacts to other living resources such as benthic species, but the result of this dynamic is not yet known. The adjustment of shipping lanes narrowed their footprint in some whale habitat, but directed traffic toward a whale hotspot. The shipping lane adjustment also changed the distribution of fishing activity, possibly creating more overlap between Dungeness crab gear and whale habitat. Addressing data gaps in fishing activity (including vessel types and locations), whale entanglements, ship strikes, and acoustic impacts will improve the ability to assess human activities, as well as co-occurring environmental stressors (e.g., marine heatwaves) that may adversely influence living resources.

Question 5: What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?[15]

Good ?

Status Description: Few or no activities occur at maritime heritage resource sites that are likely to adversely affect their condition.

Rationale: The rating is good because the levels of human activities that may adversely affect the one maritime heritage resource documented to be in the sanctuary, the ex-USS *Stewart* (DD-224), are thought to be minimal. This is due to its isolated location at a depth of 6,000 feet. For example, commercial fishing bottom trawls do not reach to that depth. There may be deposition of marine debris on the shipwreck and the corrosion rate may be changed by increasingly acidic ocean waters. Natural processes of degradation are likely to pose a larger threat. The trend is undetermined due to a lack of information about changes in human activities that may impact the shipwreck. Note that a confidence score was not assigned to the status or trend rating for this question, because subject matter external experts were not consulted on these ratings.

Findings From the 2009 Condition Report

In the 2009 condition report, both the status and trend ratings for this question were undetermined, because at that time, there were no documented underwater maritime archaeological sites within CBNMS boundaries (see Table S.P.2.1).

New Information in the 2009–2021 Condition Report

As a result of sanctuary expansion in 2015, one maritime heritage resource is now known by historical records and news accounts to be located within the sanctuary, the ex-USS *Stewart* (DD-224) (ONMS, 2014a, 2014b). The estimated depth of this shipwreck, around 6,000 feet below the surface, precludes direct disturbance from human activities such as commercial and recreational fishing (bottom trawls do not reach this deep), inadvertent damage by recreational divers, looting, or vessel anchoring. It is possible that marine debris has been deposited on the remains of the ship, as different types of marine debris have been observed throughout the sanctuary. However, the amount of debris, if any, on the shipwreck and any damage such debris may have caused to the ship have not been assessed. Also, there are no existing or planned offshore developments, and no military activities are known to exist near the location of this shipwreck. Due to these factors, the rating for this question is good. The trend rating is undetermined due to a lack of information about changes in human activities that may impact the shipwreck.

[15] A workshop was not convened for the question that asks, What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing? Archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject matter experts have been monitoring existing archaeological sites along the West Coast since the 1980s. Note that a confidence score was not assigned to the status or trend rating for this question, because subject matter external experts were not consulted on these ratings.

As described in the pressures section of this report, human activities are contributing to a changing climate and ocean that may also affect submerged maritime heritage resources. The wreck of *Stewart* could be threatened by an increasingly acidic ocean, as this has the potential to change the corrosion rate of metal parts and artifacts on the ship (Rockman et al., 2016). Corrosion on shipwrecks is affected by a number of variables (Wright, 2016), including metal composition, pH, dissolved oxygen, temperature, salinity, and water movement, among others (North & Macleod, 1987). In addition, *in situ* corrosion analyses on shipwrecks must consider the effects of microbiologically influenced corrosion on both the position of an iron or steel archaeological shipwreck site, the locations they colonize, and the prevalent chemical and physical environmental conditions, as these directly influence the species of microorganisms that settle on the shipwreck and microbial metabolic rates (Moore, 2015). Thus, corrosion rates vary for different parts of a shipwreck, based on the variables present. But while ocean acidification will have a detrimental effect on shipwrecks and other underwater cultural heritage sites, the corrosion potential of metal-hulled shipwreck sites needs to be explored, as the impacts of ocean acidification on metals and organic materials and implications for artifact stability are not yet well understood (Dunkley, 2015). The depth of the shipwreck suggests that overall microbial activity may be limited and that concretion products formed by calcifying marine organisms around ferrous artifacts and on vessel structures may not be as prevalent as at a shallower site. Cold water temperature would likely preserve organic materials and slow the rate of deterioration (J. Hoyt/NOAA, personal communication, May 27, 2020).

Conclusion

The estimated depth of *Stewart* has precluded direct human activities that would disturb it, though there is a possibility marine debris impacts on the wreck. While ocean acidification will have a detrimental effect on shipwrecks and other underwater cultural heritage sites, the corrosion potential of metal-hulled shipwreck sites such as this one need to be explored, as the impacts on materials and implications to artifact stability are not yet well understood. The wreck of *Stewart* and the effects of disturbance from human activities on it have not been assessed. However, depth of and cold temperature at the wreck site suggest overall microbial activity may be limited, concretion products formed by calcifying marine organisms may not be as prevalent, and cold water temperature may preserve organic materials and slow deterioration. Due to these factors, the rating for this question is good and the trend rating is undetermined due to a lack of baseline information about human activities that may have adversely affected the wreck and changes to those activities.

Status and Trends of Sanctuary Resources

This section summarizes resource status and trends within four areas: water quality, habitat, living resources, and maritime heritage resources. Virtual expert workshops were convened by CBNMS staff on various dates from March–April, 2021 (see Appendices A and C) to discuss the series of questions about each resource area. It is important to note that, in general, the assessments of the status and trends of key indicators in CBNMS are for the period from 2009–2021. For this reason, in many instances, trendlines were added to figures to aid in interpretation of status and trends during expert workshops. In each said figure caption, the fit of each trendline is described. Trendlines do not represent statistical significance. During the virtual workshops, indicators for each topic were presented, accompanied by datasets ONMS compiled prior to the meeting. Attendees were then asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest any additional datasets that may be relevant. Once all datasets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the sources of information they used to make judgments; and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence rating. Appendix C provides a detailed description of the report development methods.

The following responses for each question summarize the key indicators, supporting data sets, and rationale for each status and trend rating. Where published or additional information exists, the reader is provided with appropriate references and web links. Workshop discussions and ratings were based on data available at the time (e.g., through spring 2021). However, in some instances, sanctuary staff later reevaluated and/or incorporated newly available data in order to more accurately describe the current status and trends of resources. Situations where post-workshop rating decisions were made and/or data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

Status and Trends of Water Quality (Questions 6–9)

The following is an assessment of the status and trends of key water quality indicators in CBNMS for the period from 2009–2021.

Question 6 focuses on eutrophic conditions and their influence on primary production in sanctuary waters. Eutrophication is the accelerated production of organic matter, particularly algae, usually caused by an increase in the amount of nutrients (primarily nitrogen and phosphorus) from human sources in surface waters. Eutrophication can impact the condition of sanctuary resources, for example, by promoting nuisance and toxic algal blooms or impacting dissolved oxygen levels.

Question 7 focuses on parameters affecting public health. Human health concerns can arise from water or seafood contamination (bacteria, chemicals, and biotoxins). Indications of health impacts may include fishery closures and shellfish consumption advisories. Such impacts can be devastating, both ecologically and economically, in affected coastal communities.

Question 8 focuses on shifts in water quality due to climate drivers. Climate indicators include indices of large-scale climate patterns, upwelling intensity, water and air temperature, dissolved oxygen, and pH. Shifts in water temperature can affect species growth rates, phenology, distribution, and susceptibility to disease. Acidification can affect organism survival, growth, and reproduction. Upwelling influences oxygen content and nutrient cycling.

Question 9 assesses biotic and abiotic stressors not addressed in other questions that, individually or in combination, may influence sanctuary water quality. Examples include nonpoint source contaminants and hard-to-quantify stressors that influence the condition of habitats and living resources. Such inputs may include industrial discharges and emissions.

Table S.WQ.6.1. 2009 (left) and 2009–2021 (right) condition report ratings for the water quality questions.

2009 Condition Report Questions	2009 Rating	2009–2021 Condition Report Questions	2009–2021 Condition Report Rating
2. Eutrophic condition	—	6. Eutrophic condition	Good —
3. Human health risks	—	7. Human health risks	Good/Fair ▼
1. Multiple stressors (including climate)	?	8. Climate drivers	Fair ▼
		9. Other stressors	Good/Fair ?

Question 6: What is the eutrophic condition of sanctuary waters and how is it changing?

Status Description: Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.

Rationale: Although data are limited and only provide proxy information, there is no clear evidence of eutrophication resulting from anthropogenic sources occurring in the sanctuary. Some data suggest that climate change may influence nutrients; this issue is discussed further in Question 8.

Findings From the 2009 Condition Report

Eutrophication is characterized by an increase in organic productivity and is often caused by an increase in nutrients, which can occur due to natural processes, such as upwelling, or anthropogenic causes, like runoff. Nutrients can trigger algal blooms, which can result in the production of toxins and low oxygen levels. In 2009, this question was rated as good with a trend of not changing because there was no evidence of eutrophication in the sanctuary or surrounding region; chlorophyll concentrations did not reach levels of concern for eutrophication and there was an absence of harmful algal blooms (HABs; Table S.WQ.6.1).

New Information in the 2009–2021 Condition Report

The current condition report also rated this question as good with a trend of not changing, based on nutrient data (nitrates), chlorophyll concentrations, net primary productivity, and dinoflagellate/diatom ratios (Table S.WQ.6.2).

Table S.WQ.6.2. Summaries for the key indicators related to eutrophication that were discussed during the March 24, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Nitrates	ACCESS, 2021	Pelagic	**Status:** Variable; concentrations not of concern for eutrophication **Trend:** Possible declining trend	S.WQ.6.1
Nitrates vs. temperature	ACCESS, 2021; García-Reyes et al., 2014	Pelagic	**Status:** Higher nitrates in cooler water temperatures **Trend:** No trend	App.E.6.1–App.E.6.4
Chlorophyll *a* (satellite)	NASA, 2020	Pelagic	**Status:** Seasonal patterns, higher when upwelling was weaker **Trend:** No strong trends	S.WQ.6.2
Net primary productivity (seasonal)	Huang et al., 2020; MODISA, MODIST, VIIRS-SNNP, and VIIRS-JPSS1 satellites	Pelagic	**Status:** Seasonal patterns, higher in cold years, patterns consistent across larger area **Trend:** No long-term trends	S.WQ.6.3

Indicator	Data Source	Habitat	Data Summary	Figures
Net primary productivity (monthly and annual)	Huang et al., 2020; MODISA, MODIST, VIIRS-SNNP, and VIIRS-JPSS1 satellites	Pelagic	**Status:** Seasonal patterns, higher in cold years, patterns consistent across larger area **Trend:** No long-term trends	App.E.6.5
Phytoplankton species (diatom/ dinoflagellates)	ACCESS, 2021	Pelagic	**Status:** Higher ratios of diatoms than dinoflagellates **Trend:** No strong trends	S.WQ.6.4; App.E.6.6
Data gaps	Data with increased temporal and spatial resolution to capture episodic eutrophication events; data on ammonium and dissolved oxygen			

Nutrients can play a limiting role in primary production, and increases in nutrient loads can be a cause of eutrophication. Average nitrate (NO_3 + NO_2) concentrations in CBNMS varied over time, with a slightly declining trend (Figure S.WQ.6.1). Nitrate concentrations ranged between 0 and 21.9 µM from 2009 to 2019 (ACCESS, 2021). These values correspond to typical upwelled waters that range from low to high in nutrients but not enough to cause eutrophication (Frances Wilkerson, pers.comm., February 23, 2023). There was a relationship between nitrate levels and temperature; nitrates were higher in years when Applied California Current Ecosystem Studies (ACCESS) cruises measured cooler water temperatures compared to cruises that measured warmer ones (Figure App.E.6.1–Figure App.E.6.3). This relationship was also observed at a regional scale (García-Reyes et al., 2014; Figure App.E.6.4). Higher nitrate levels occurred in 2010 and 2012 (when ACCESS cruises measured average water temperatures) and lower levels of nitrates occurred in 2014 and 2015 (when ACCESS cruises measured warmer water temperatures[16]). Contributions of nutrients from anthropogenic sources were presumed to be minimal, given the sanctuary's distance from land. Furthermore, outflow from the bay was unlikely to enter the sanctuary, as water tends to flow southward (Largier, 2020).

[16] For consistency throughout the report, we used ±0.5 °C as a threshold to delineate temperature anomalies and define warm vs. cold years. Methodology is described in the caption of each figure.

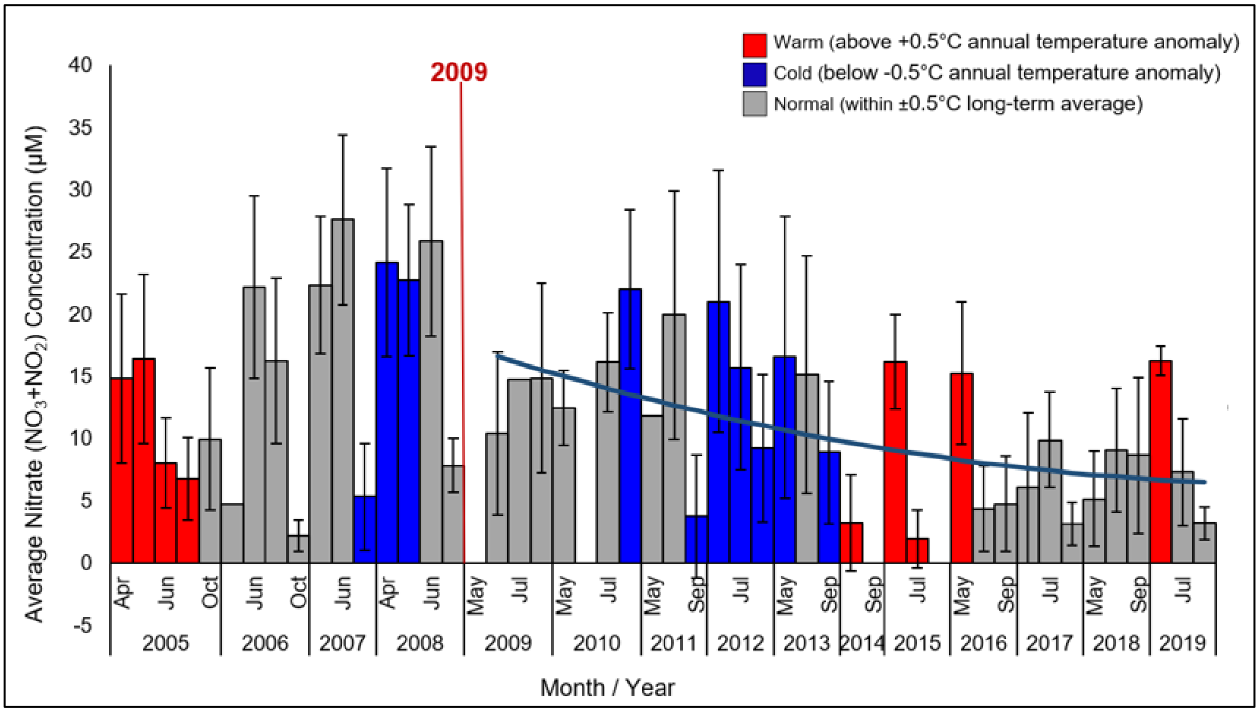


Figure S.WQ.6.1. Mean surface water nutrient levels (mean ± standard deviation) from ACCESS cruise samples. Cruises occur three to four times per year (except in 2005, when five occurred). Each bar is the average from samples collected along a transect within CBNMS (line 2). There were no data for blank bars in 2009 and 2010; blanks in 2014 and 2015 indicate nitrates were not detected. Red bars represent warm years (above +0.5 °C annual temperature anomaly), blue bars represent cold years (below -0.5 °C annual temperature anomaly), and gray bars represent normal years (within ±0.5 °C of the long-term average) calculated from conductivity, temperature, and depth (CTD) sensor data collected on ACCESS cruises. The trendline is a second-degree polynomial line and calculated using data for 2009 to 2019 only (time period of interest for this condition report). The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

Chlorophyll *a* concentrations in the CBNMS region showed strong seasonal patterns (Figure S.WQ.6.2). There was also a correlation between annual water temperature and chlorophyll *a*, as some cold water years (e.g., 2007 and 2012) had lower chlorophyll *a* levels than warmer or average water years. Although upwelling can bring nutrients, cold water, and high productivity, blooms were more common during weak upwelling years (e.g., 2004–2006, 2013–2016) in CBNMS, perhaps as a result of relaxation and stratification. The highest chlorophyll *a* concentrations for the study period occurred in 2011 and 2019, with the lowest concentrations in 2015 and 2016. Occasionally, high chlorophyll *a* concentrations resulted in toxic conditions, such as during the 2015 HAB event (see Question 7 for further discussion of this event).

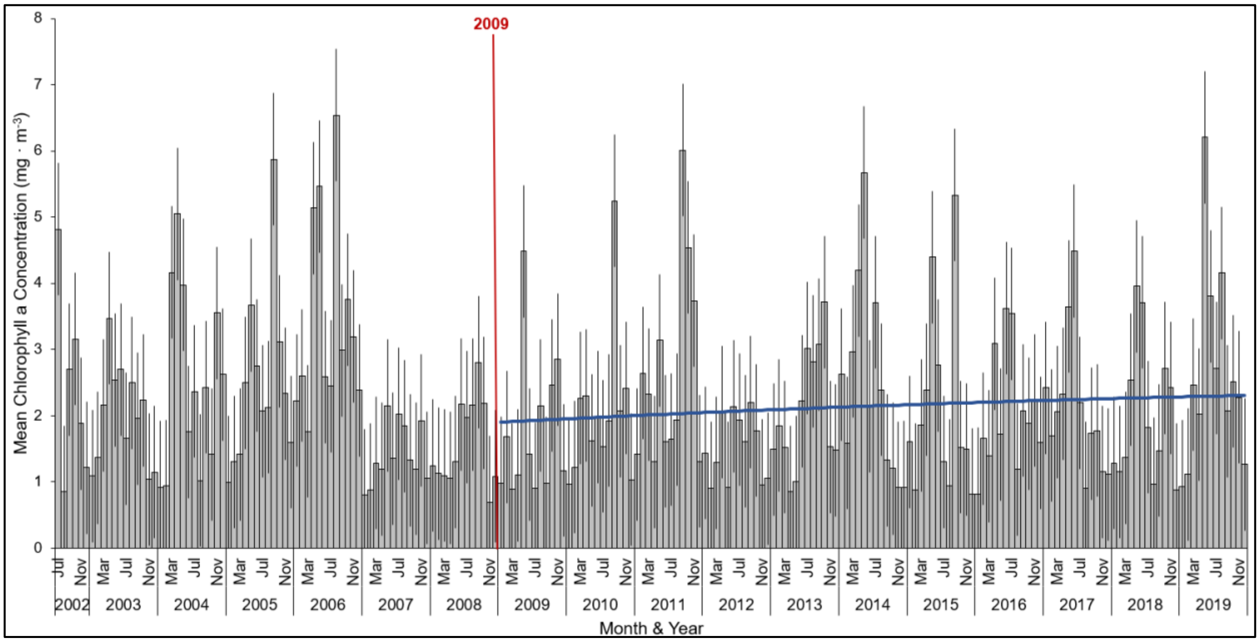


Figure S.WQ.6.2. Mean chlorophyll a concentrations, derived from satellite data (Aqua MODIS) at 4 km resolution, for the CBNMS region from 2002–2019. Error bars show standard deviation. The trendline is a second-degree polynomial line and was calculated using 2009 to 2019 data (time period of interest for this condition report). The vertical red line indicates the year of the last condition report (2009). Source: NASA, 2020; Image: Point Blue Conservation Science

Net primary productivity (NPP), carbon assimilation by phytoplankton, showed consistent seasonal patterns in CBNMS. NPP was lowest during winter seasons, and increased during relaxation and upwelling seasons (Figure S.WQ.6.3). The highest NPP occurred during the 2014 and 2019 upwelling seasons and during the 2011 and 2019 relaxation periods. There were no strong trends, and patterns in CBNMS were consistent with nearby sanctuaries (GFNMS and MBNMS; Figure App.E.6.5).

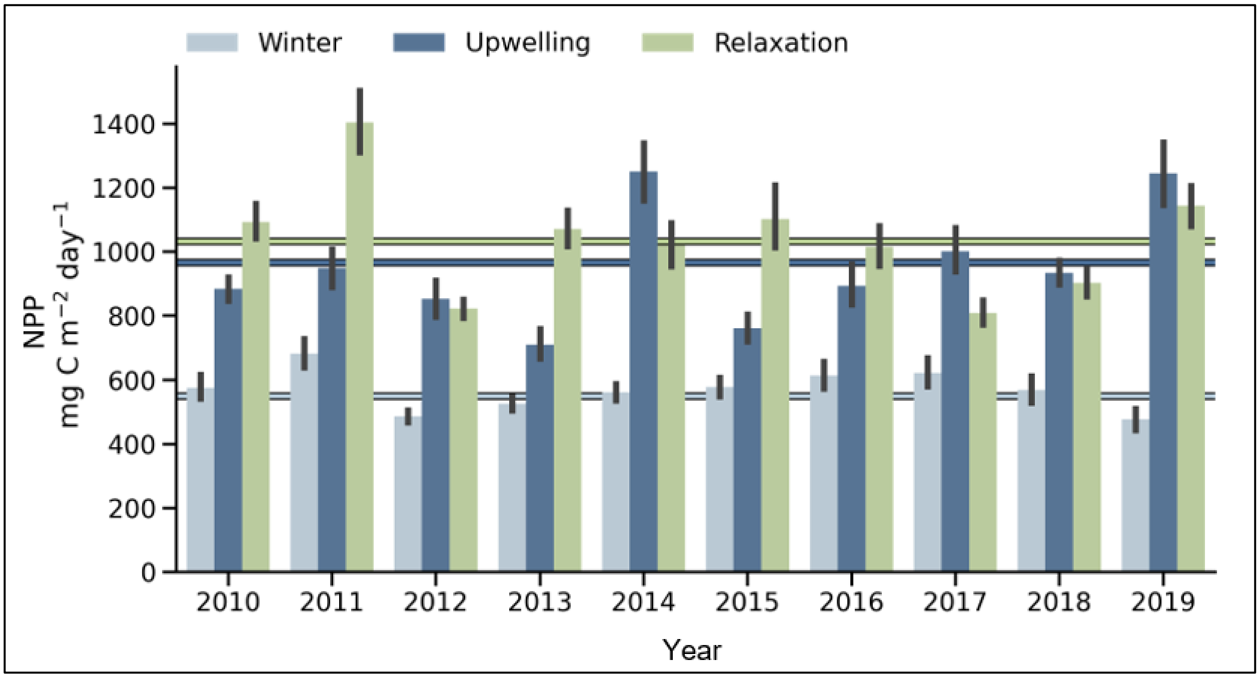
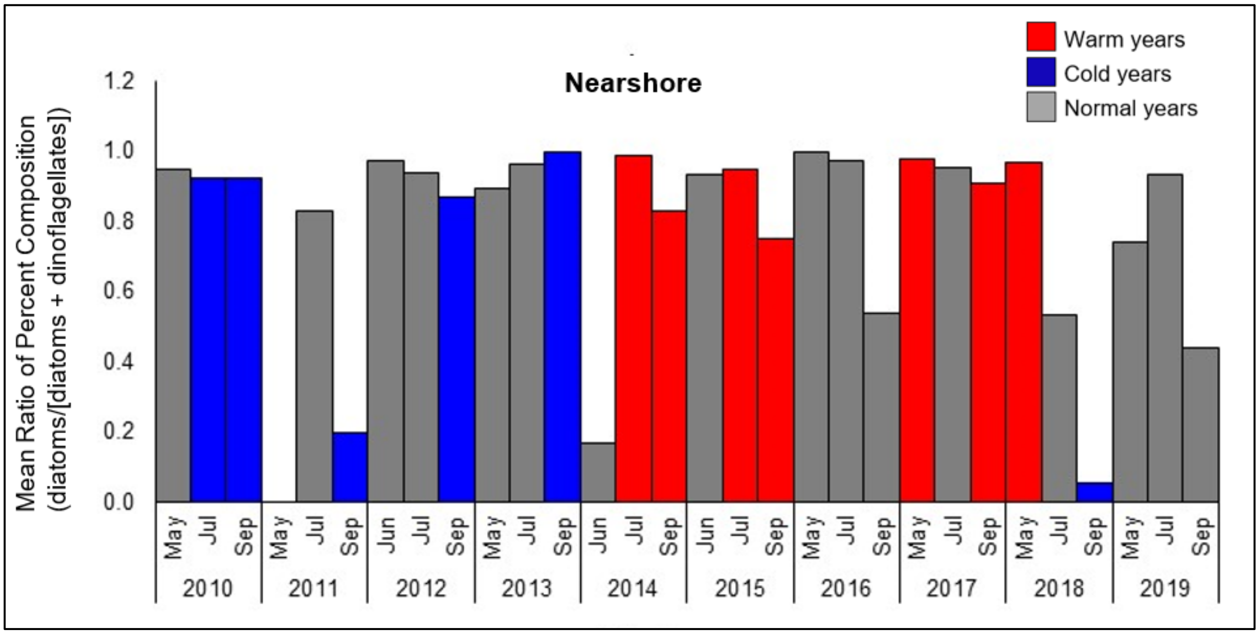
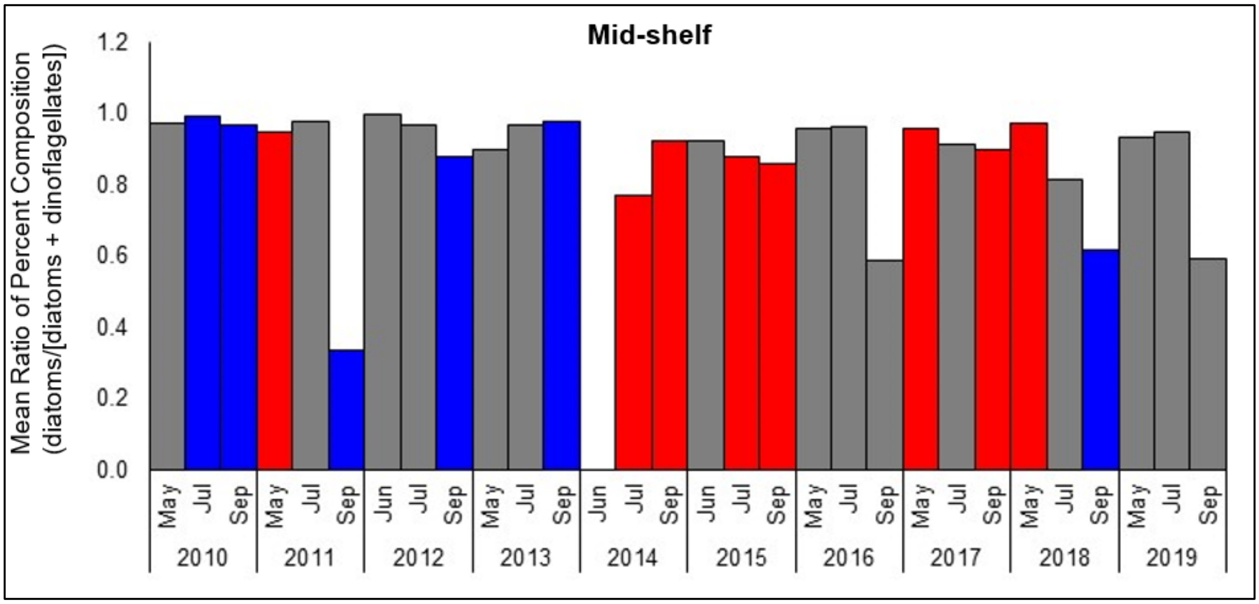


Figure S.WQ.6.3. Average seasonal NPP in CBNMS, estimated by calculating the monthly mean from daily NPP averages for the winter (Nov–Feb), upwelling (March–June), and relaxation (July–Oct) seasons. Seasonal averages for the entire time series (2000–2019) are shown as horizontal lines. NPP estimates were calculated from 5-day merged chlorophyll *a*, merged daily photosynthetically available radiation (from MODISA, MODIST, VIIRS-SNNP, and VIIRS-JPSS1 satellites), and daily sea surface temperature-optimum interpolation datasets. The error bars are a boot-strapped 95% confidence interval around the mean. Source: Huang et al., 2020; Image: CenCOOS

Diatoms can become dominant in a system following the addition of nutrients (Malone, 1980; Bode et al., 1997), and therefore an increase in diatoms could be an indicator for eutrophication, but in CBNMS could also indicate upwelling and cold, productive conditions. Changes in the relative abundance of phytoplankton groups can affect the food web, beginning with the grazers that consume them (Wasmund et al., 2017). Under the right conditions, both diatoms and dinoflagellates produce toxins (e.g., *Alexandrium* spp. dinoflagellates and *Pseudo-nitzschia* spp. diatoms; Question 7 provides additional information). Additionally, diatoms tend to sink more rapidly, which could reduce the secondary effects of eutrophication while enhancing rates and magnitudes of carbon delivery to deep ecosystems (Wasmund et al., 2017). The ratio of diatoms to dinoflagellates (based on the percent composition of the number of individuals found in phytoplankton samples) in CBNMS was calculated for offshore, mid-shelf, and nearshore sampling locations (Figure S.WQ.6.4). Overall ratios tended to be relatively high (i.e., more diatoms than dinoflagellates) across years and sampling locations. Lower ratios tended to occur in the sanctuary in years that ACCESS cruises measured cooler and average water temperatures compared to warmer water temperatures. Ratios also tended to be slightly lower in CBNMS nearshore sampling locations than mid-shelf and offshore locations. Percent composition of diatoms was highest from March to July 2014 for all CBNMS locations combined (Figure App.E.6.6).


Nearshore
Warm years
Cold years
Normal years
Mean Ratio of Percent Composition (diatoms/[diatoms + dinoflagellates])
1.2
1.0
0.8
0.6
0.4
0.2
0.0
May Jul Sep
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019


Mid-shelf
Mean Ratio of Percent Composition (diatoms/[diatoms + dinoflagellates])
1.2
1.0
0.8
0.6
0.4
0.2
0.0
May Jul Sep
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

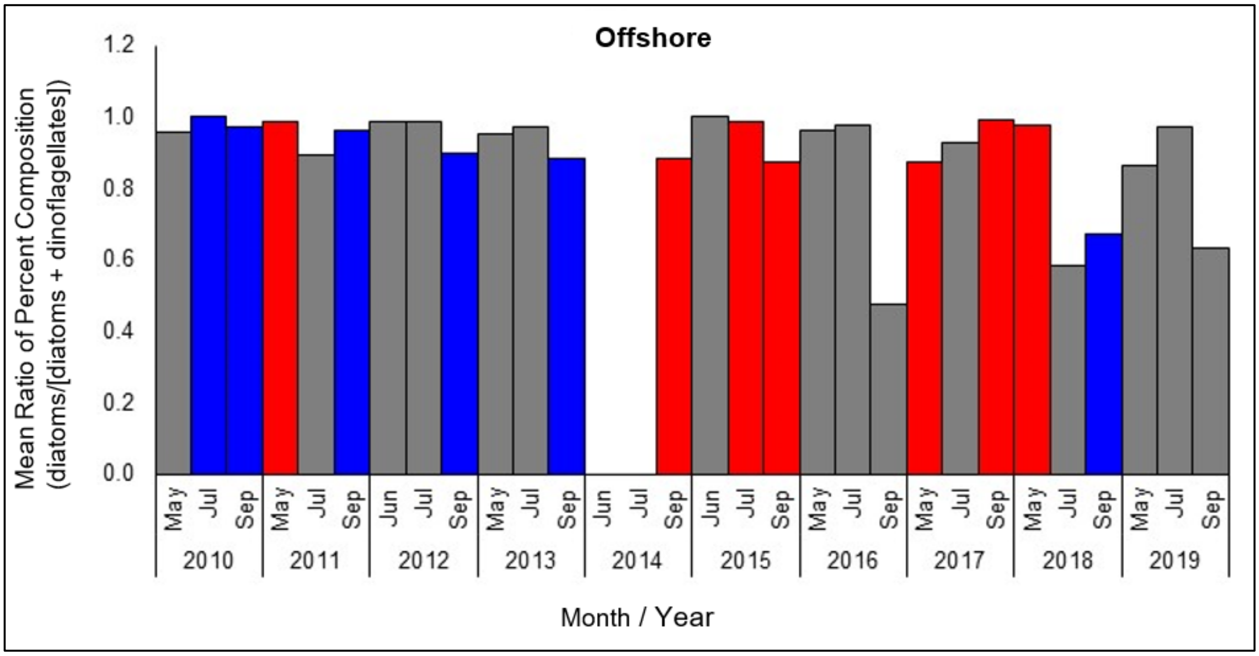


Figure S.WQ.6.4.[17] Mean ratio of percent composition of diatoms to dinoflagellates in nearshore, mid-shelf, and offshore areas in CBNMS. Phytoplankton samples were collected during ACCESS cruises and analyzed by the California Department of Public Health Biotoxin Monitoring Program. The percent composition of each species was estimated qualitatively and averaged, and the ratio of diatoms to dinoflagellates was calculated and averaged for each sample in the three regions. Data from stations N4-WN and N2-WN (nearshore), 4-E and 2-E (mid-shelf), and 4-W and 2-W (offshore) were used in these figures. No samples were collected nearshore in May 2011 or mid-shelf and offshore in June 2014. The July 2014 offshore sample contained dinoflagellates but no diatoms. Red bars represent warm years (above +0.5 °C annual temperature anomaly), blue bars represent cold years (below -0.5 °C annual temperature anomaly), and gray bars represent normal years (within ±0.5 °C of the long-term average), calculated from CTD data collected on ACCESS cruises. Source: ACCESS, 2021; Image: Point Blue Conservation Science

Conclusion

In this condition report, the status of eutrophic conditions in CBNMS was rated good with a trend of not changing, both with a medium confidence. Although data are limited and only provide proxy information, there is no clear evidence of eutrophication resulting from anthropogenic sources. To better understand eutrophication and conditions that could lead to eutrophication, CBNMS requires data with an increased temporal and spatial resolution, particularly because eutrophication events can be episodic. Additionally, data on ammonium and dissolved oxygen would further inform this topic.

---

[17] These data sets and figures were not presented to experts during the status and trends workshop.

Question 7: Do sanctuary waters pose risks to human health and how are they changing?

Good/Fair ▼

Status Description: One or more water quality indicators suggest the potential for human health impacts but human health impacts have not been reported.

Rationale: Phytoplankton species that produce harmful algal blooms and biotoxins were present in CBNMS between 2010 and 2019. A harmful algal bloom event occurred in 2015 that was unprecedented in scope and impact. California sea lions and coastal bivalves, which were used as proxies for environmental biotoxins, indicated toxins were present throughout the region and appeared to worsen over time. Biotoxins were monitored in Dungeness and rock crabs by the California Department of Public Health, and levels often triggered fishery closures, which likely prevented human health impacts. The low confidence in the trend was due to the limited data availability for harmful algal bloom levels throughout the time period.

Findings From the 2009 Condition Report

In 2009, this question was rated good and not changing (see Table S.WQ.6.1). Phytoplankton species that were known to produce biotoxins were monitored in the sanctuary, and their levels were not elevated. Additionally, there were no known cases of shellfish poisoning reported to the California Department of Public Health (CDPH). Consequently, the good rating was based on the lack of any indications that CBNMS waters posed a risk to human health.

New Information in the 2009–2021 Condition Report

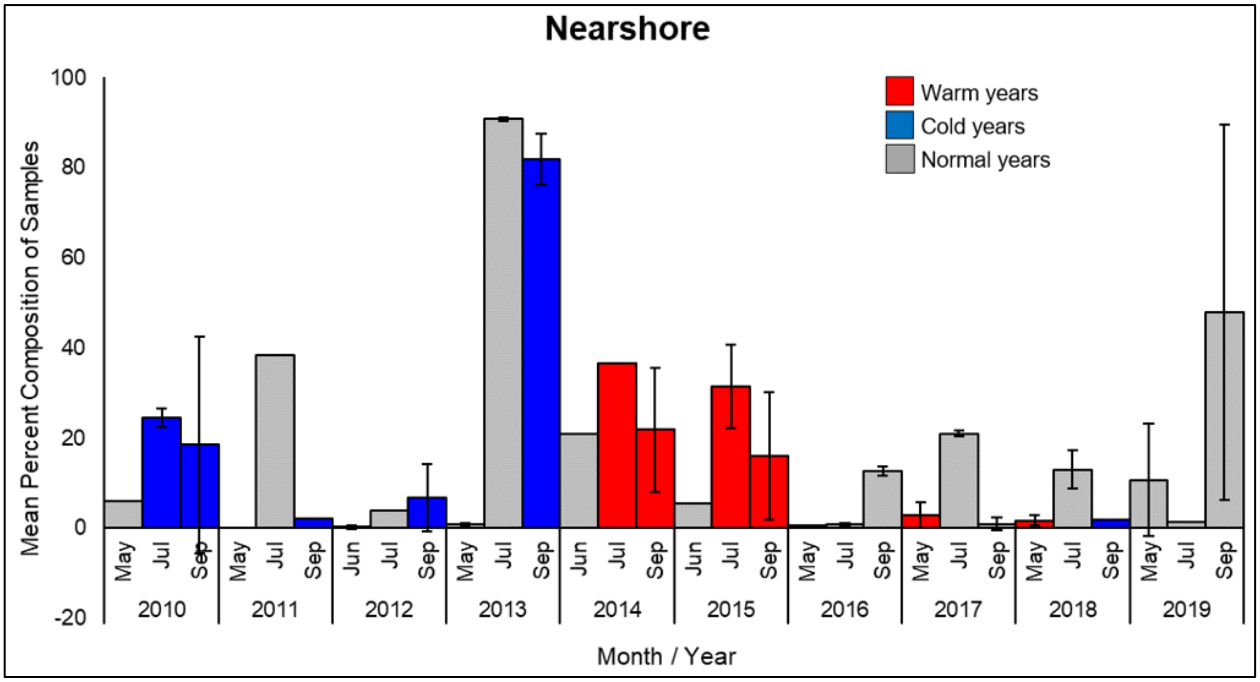
The new rating for this question is good/fair with a worsening trend. The basis for this rating was that phytoplankton species that produce biotoxins, as well as the biotoxins themselves, were documented in CBNMS during the study period (Table S.WQ.7.1). Additionally, HABs occurred during the study period, including an event in 2015 that was unprecedented in scope and impact. Domoic acid (DA) in crabs and bivalves also indicated biotoxins were present in the environment, and DA toxicosis in California sea lions appeared to worsen over time. These data indicate that there is the potential for human health to be negatively affected by water quality in the sanctuary. However, CDPH and Central and Northern California Ocean Observing System closely monitor these biotoxins and blooms, and fisheries closures likely prevented people from ingesting toxic seafood. As a result, there were no known cases of shellfish poisoning in humans during this time.

Table S.WQ.7.1. Summaries for the key indicators related to sanctuary waters posing a risk to human health that were discussed during the March 24, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures and Tables
HAB-producing phytoplankton	ACCESS, 2021	Pelagic	**Status:** HAB-producing species were present, and were higher in warmer years **Trend:** No strong trend	Figure S.WQ.7.1, Table App.E.7.1
DA and *Pseudo-nitzschia*	McCabe et al., 2016	Pelagic	**Status:** Elevated levels of DA and *Pseudo-nitzschia* during marine heatwave **Trend:** No trend	Figure S.WQ.7.2
DA in crabs	CDPH, 2020a	Benthic	**Status:** At least one positive DA sample in crabs each year of sampling **Trend:** Higher levels in 2015–2016	Figure S.WQ.7.3
Crab fishery closures	Free et al., 2022; McCabe et al., 2016	Benthic	**Status:** DA caused fishery delays and closures during the reporting period **Trend:** Delays in 2016–2017, 2019	Figure S.WQ.7.4; Figure S.WQ.7.5; Table S.WQ.7.2
DA in sea lions	The Marine Mammal Center; McCabe et al., 2016	Pelagic	**Status:** Sea lions with DA recorded in region since 1998; high levels during the marine heatwave **Trend:** Higher levels now than previous reporting period	Table App.E.7.2; Figure S.WQ.7.4
DA in bivalves	CDPH, 2020b	Coastal	**Status:** Variable, peak during heatwave **Trend:** No trend	Figure App.E.7.1
Bivalve paralytic shellfish poisoning	CDPH, 2020b	Coastal	**Status:** Variable **Trend:** No trend	Figure App.E.7.2
Data gaps	Continued monitoring data from within the sanctuary; research on how biotoxins are transferred through marine food web			

HAB Phytoplankton Species and Biotoxins

Phytoplankton species that can cause HABs (see Table App.E.7.1 for a full list of species) were measured in the CBNMS water column during ACCESS cruises from 2010 to 2019 (Figure S.WQ.7.1). Note that not all of the HAB species identified produce biotoxins, but some species could be harmful in other ways (e.g., mechanical clogging of gills). While these are not direct measurements of biotoxins in the water column, changes in the presence, abundances and/or distributions of certain species could indicate the potential presence of biotoxin in the sanctuary (e.g., two of the main HAB species and biotoxins found locally: *Pseudo-nitzschia* spp. and domoic acid, *Alexandrium* spp. and paralytic shellfish poisoning toxins). Some of these species were prevalent in CBNMS and the surrounding region throughout the 2010 to 2019 time period, although there was no clear long-term trend. The average percent composition of HAB species in samples ranged from 0 to 65%, with peaks in 2013 and 2019. Note that some HAB species (e.g., *Pseudo-nitzschia* spp.) produce high biotoxin levels only when found in high abundances, while others (e.g., *Alexandrium* spp.) can still produce high biotoxin levels when found in relatively low abundances. Concentrations of *Pseudo-nitzschia australis* and water column particulate domoic acid (pDA) were also measured along the West Coast, including CBNMS, during a NOAA cruise from June to September 2015 (Figure S.WQ.7.2). Both *P. australis* and pDA were elevated (Figure S.WQ.7.2), although measurements at stations located in the sanctuary were relatively low compared to other areas (in CBNMS, *P. australis* abundances ranged between 0 and 107000 cells/L and pDA ranged from 73 to 76.3 ng/L). The 2015 HAB event was the largest DA event off the west coast of North America (McCabe et al., 2016), and a marked change from the previous condition report time period. This event was likely caused by warm and nutrient-poor waters associated with the marine heat wave (Bond et al., 2015).



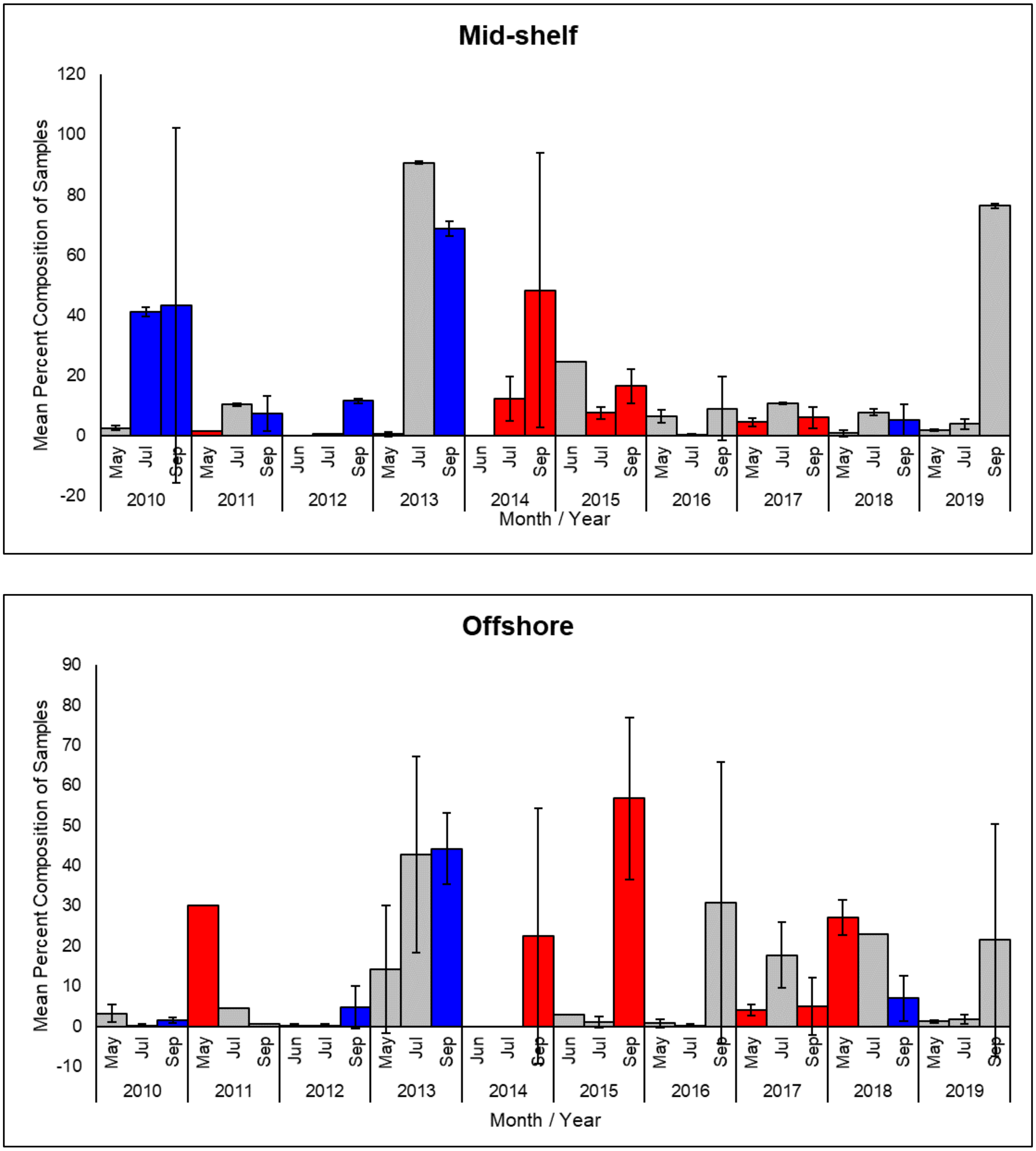


Figure S.WQ.7.1. Average percent composition of phytoplankton species (mean ± standard deviation) that can produce HABs (see Table App.E.7.1 for a species list) in samples taken during ACCESS cruises from 2010 to 2019 at stations in CBNMS. Red bars represent warm years (above +0.5 °C annual temperature anomaly), blue bars represent cold years (below -0.5 °C annual temperature anomaly), and gray bars represent normal years (within ±0.5 °C of the long-term average), calculated from CTD data collected on ACCESS cruises. Image: Point Blue Conservation Science

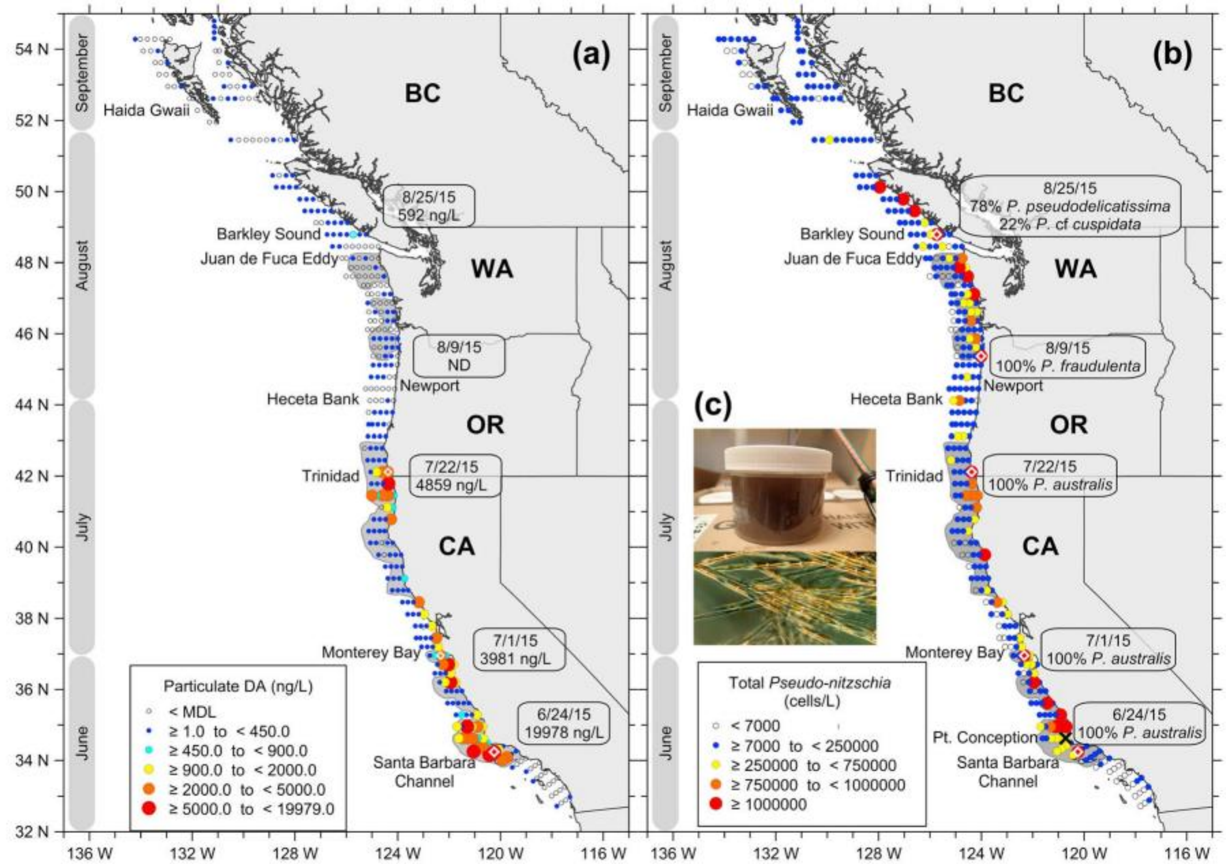


Figure S.WQ.7.2. (a) pDA and (b) *Pseudo-nitzschia* abundance in surface (3 m) seawater samples collected aboard the NOAA Ship *Bell M. Shimada* from June through September (months shown in shaded boxes, left side of both panels). Red "targets" in (b) are locations where representative pDA and *Pseudo-nitzschia* abundances are shown on select dates in adjacent boxes. Gray shading along the coast indicates regions where *Pseudo-nitzschia* was the dominant phytoplankton. (c) A Bongo net tow sample off Point Conception on 24 June (concentrated sample, top panel; microscopic image of ~100X diluted sample at 200X magnification, bottom panel). ND = not detected. Image: McCabe et al., 2016

Biotoxins and Fisheries

For CBNMS, human health would most likely be affected through the consumption of contaminated crabs. Dungeness and rock crabs are recreationally and commercially fished from the sanctuary and the surrounding region, and the CDPH Food and Drug Branch closely monitors DA levels (Figure S.WQ.7.3). Since 2015, crabs have been collected offshore between San Francisco and Point Arena, California (exact locations are unknown, but at least some samples were likely from CBNMS) and tested annually prior to the opening of the fisheries. DA levels in crabs have exceeded the action limit of 30 ppm at least once every year, with the highest levels occurring in 2015 and 2016. Consequently, human consumption of contaminated seafood could have posed a serious risk to human health, however management action prevented such impacts. Based on data compiled from the California Department of Fish and Wildlife (CDFW), CDPH, and the Pacific States Marine Fisheries Council, public health advisories were issued in 2015, and fishery openings were delayed or closed in multiple locations along the West Coast (Figure S.WQ.7.4; Table S.WQ.7.2), including the CBNMS region (Figure S.WQ.7.5). These management actions greatly reduced the risk of shellfish poisoning in humans.

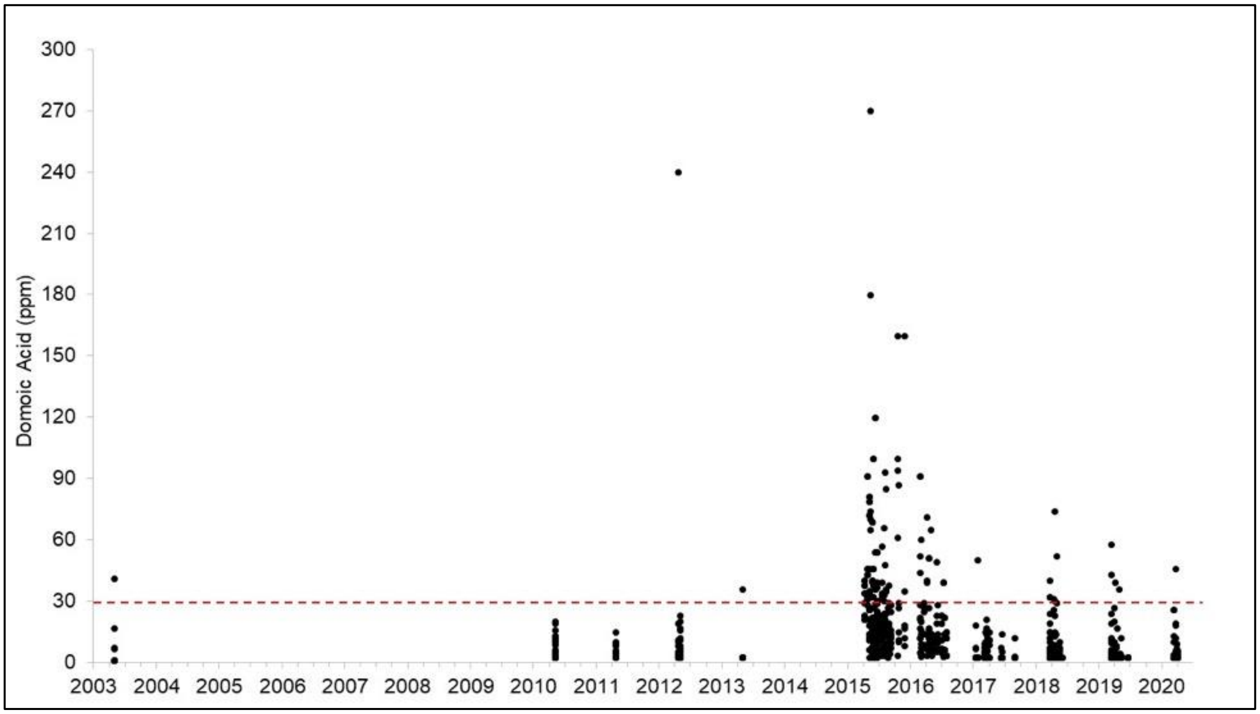


Figure S.WQ.7.3. DA in Dungeness and rock crabs from Point Arena to San Francisco, California. Regular sampling began in 2015, although some sampling occurred prior to that. The dashed line indicates the action limit for crab viscera (30 ppm). Source: CDPH, 2020a

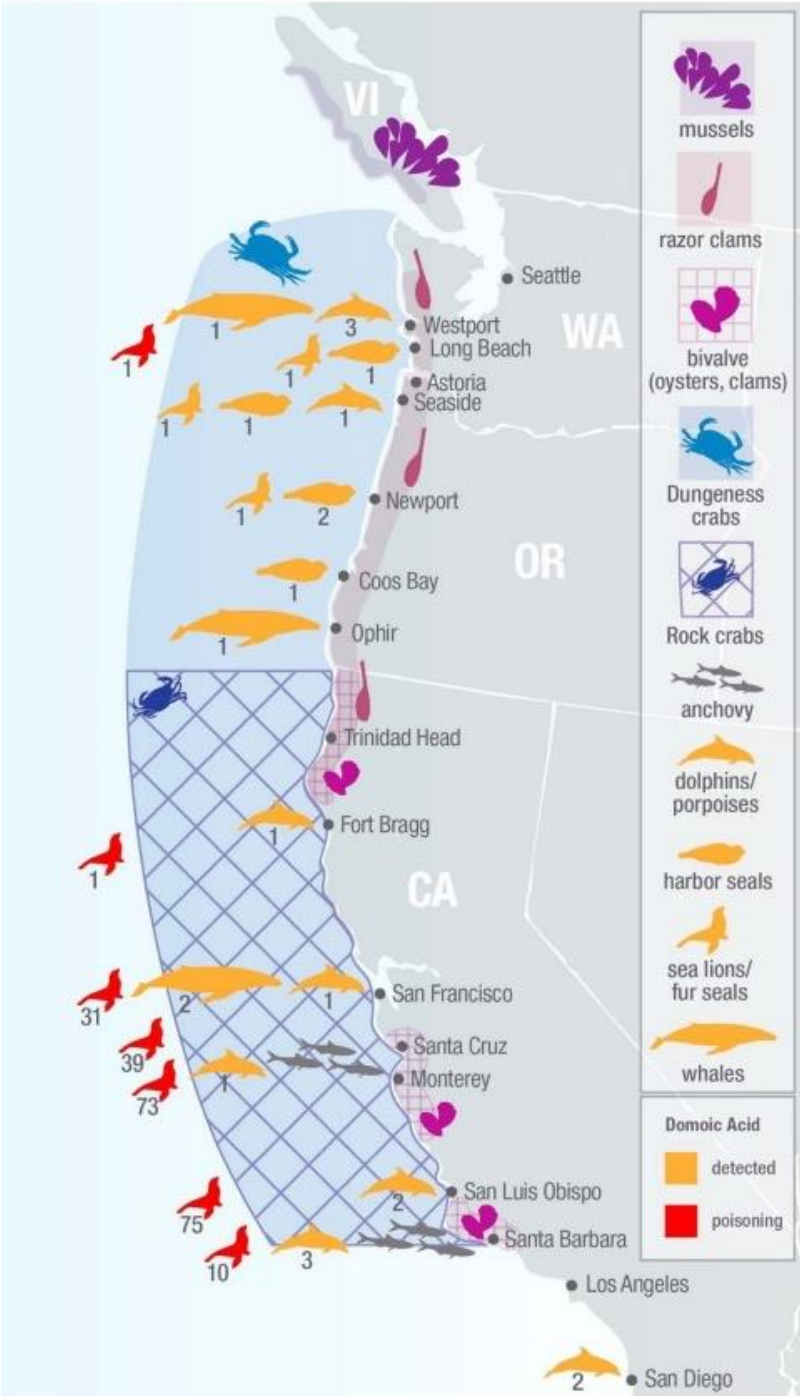


Figure S.WQ.7.4. Impacts of DA on fisheries and marine mammals in 2015. Shaded areas with shellfish symbols on land denote shellfish closures. Fish symbols indicate northern anchovy closures at designated landing sites. Shaded or hatched areas offshore (Dungeness crab and rock crab) correspond to the closures listed on the left. Stranded marine mammals with detectable DA and California sea lions diagnosed with DA poisoning are pictured with the number of individuals indicated. DA poisoning is defined as the presentation of at least two of the following: neurologic signs (seizures, head weaving, ataxia), detectable DA, histopathologic lesions, and/or blood chemistry changes. Image: McCabe et al., 2016

Table S.WQ.7.2 Dates of fishery and shellfish closures throughout the West Coast due to domoic acid levels. Source: McCabe et al., 2016

Date	Shellfish and Fishery Closures and Warnings (With Maximum Domoic Acid Values as Available)
7-May-15	Quinault tribe razor clam harvest closure (Washington)
8-May-15	Commercial, tribal, and recreational razor clam harvest closure (Washington)
9-May-15	Razor clam harvest closure (northern Oregon)
14-May-15	State wide razor clam harvest closure (Oregon)
15-May-15	Shellfish harvest closure (British Columbia, Canada)
29-May-15	Anchovy, viscera maximum 1671 ppm (California)
1-June-15	Anchovy, sardine fishery closure (California)
3-June-15	Dungeness crab, maximum 65 ppm (Washington)
5-June-15	Dungeness crab fishery closure (Washington)
3-July-15	Anchovy, sardine, mussel, and clam closures expanded to southern California
11-September-15	Dungeness crab, maximum 140 ppm (northern California)
27-October-15	Razor clam, maximum 170 ppm (southern Oregon)
3-November-15	Dungeness crab and rock crab warning for recreational harvest (California)
6-November-15	Commercial rock crab fishery closed (California)
8-November-15	Dungeness crab, maximum 70 ppm (southern Oregon)
11-November-15	Dungeness crab and rock crab recreational and commercial fishery closure (California)
22-November-15	Dungeness crab, maximum 270 ppm (northern California)
23-November-15	Rock crab, maximum 1000 ppm (southern California)
23-November-15	Delayed opening of commercial Dungeness crab fishery (Washington, Oregon, California)
9-February-16	California seeks federal disaster declaration for commercial crab fishery

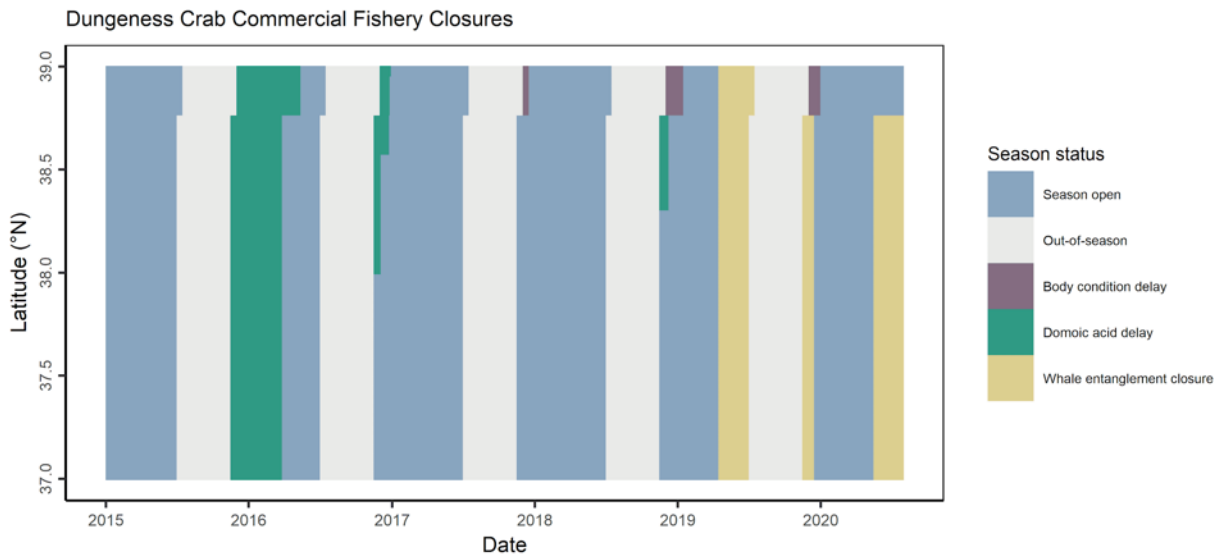


Figure S.WQ.7.5. Dungeness crab commercial fishery delays and closures by reason. Source: Free et al., 2022; Image: Chris Free/University of California, Santa Barbara

Regional Biotoxins Measured by Environmental Proxies

Some marine organisms, such as California sea lions and bivalves, can serve as proxies for measurements of environmental biotoxins, as these animals can be impacted by directly or indirectly consuming biotoxins. California sea lions become poisoned with DA after ingesting contaminated prey items, such as anchovies, and are good indicators of the severity of blooms (McCabe et al., 2016; Bejarano et al., 2008). Since 1998, California sea lions have shown signs of DA intoxication and/or tested positive for DA at nearshore sites adjacent to the sanctuary (between San Mateo to Mendocino counties, including San Francisco Bay; see Table App.E.7.2). While no tested animals can be directly linked to CBNMS, their health may reflect DA toxicity in the greater sanctuary region. The highest number of stranded animals occurred in 2009 (41 sea lions) and the lowest number occurred in 1998 (2 sea lions). The 2015 DA event resulted in high numbers of California sea lions, as well as other marine mammal species, with detectable DA levels and/or DA poisoning throughout the West Coast (McCabe et al., 2016; Figure S.WQ.7.5). Overall, there were higher numbers of stranded sea lions from 2009–2020 (mean of 15.5 ± 12.0 SD) than 1998–2008 (mean of 9.7 ± 6.1 SD), suggesting that this trend could be worsening.

Consuming contaminated bivalves can cause shellfish poisoning in humans. However, because bivalves from CBNMS are not sampled, those from other locations serve as proxies for environmental biotoxins in the general sanctuary region. The CDPH Environmental Management Branch closely monitors coastal bivalves for DA and a suite of neurotoxins responsible for paralytic shellfish poisoning. Biotoxin levels exceeding the action limit (set by the Food and Drug Administration) can result in the issuance of health advisories, or fishery delays or closures (see Figure App.E.7.1, Figure App.E.7.2). All DA measurements taken since the program began in 1991 were below the action limit (20 ppm), and the maximum measured DA levels coincided with the marine heat wave of 2015. DA was therefore unlikely to have posed a risk to human health in the CBNMS region. By comparison, paralytic shellfish poison levels in bivalves have often exceeded the action limit (80 µg/100 g), with levels varying between 25 and

10,000 µg/100 g. The presence and pervasiveness of paralytic shellfish poisoning biotoxins in the region surrounding CBNMS throughout the time period may suggest a risk to human health via consumption.

Conclusion

HAB-producing phytoplankton species and biotoxins were detected in sanctuary and regional waters, crabs, and proxy species from 2010–2019. Biotoxin levels in crabs frequently exceeded the action level, which may have resulted in human health impacts if not for protective mitigating measures. As a result, this question is rated good/fair and worsening, and it is critical this issue continues to be monitored in the sanctuary, particularly as HABs are predicted to worsen under future climate change scenarios (Gobler, 2020). Additionally, further research is needed to document how biotoxins are transferred throughout the marine food web and to higher trophic levels.

Question 8: Have recent, accelerated changes in climate altered water conditions and how are they changing?

Status Description: Climate-related changes have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Climate-related changes in some water quality indicators have been observed. Notably, a marine heatwave in 2014–2016 resulted in the highest sea surface temperature on record for the area. This marine heatwave was present for an extended duration, with modeling showing the heat extended into the water column to at least 100 meters. In addition, the record warmest and coolest conditions were observed during the assessment period, indicating high variability in the system. Periods of anomalous conditions, both warm and cool, appear to be more extreme and longer in duration than in the past. Increased variability is one potential outcome of climate change and can indicate worsening conditions. At times, localized upwelling appears to buffer CBNMS from anomalous heating events observed in the surrounding region. Low-pH water and low dissolved oxygen levels extend onto the bank and shelf periodically during the year, but trend data were not available. These climate-related changes are notable because they have been linked to changes in some ecosystem components, including abundance and distribution of pelagic prey and predator species, condition of krill, and the presence and intensity of harmful algal blooms and domoic acid. The low confidence in the trend was due to low agreement among the experts in how to interpret the high variability in the data and the lack of evidence of a clear trend during the time period that was evaluated.

Findings From the 2009 Condition Report

A direct comparison between this assessment and the 2009 condition report was not possible, because this specific question was not included in the 2009 report. In 2009, a question was included for water quality that asked, “are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality and how are they changing?” The narrative to this question stated, “stressors on water quality from changing oceanographic and atmospheric conditions are currently not producing long-term negative effects.” Other factors that were considered for this question in 2009 included El Niño events, flooding, and debris flow. The rating for this question was good and the trend was undetermined due to a paucity of data (see Table S.WQ.6.1).

New Information in the 2009–2021 Condition Report

CBNMS is within the California Current Ecosystem, a dynamic system driven by upwelling. Upwelling brings cold, nutrient-rich waters to the surface, resulting in high productivity, and high variability in the system occurs as conditions transition between upwelling and relaxation states. The prominent coastline feature of Point Reyes and the influence of strong upwelling from the Point Arena region, together with the features of Cordell Bank and Bodega Canyon, cause the sanctuary to experience a range of currents and oceanographic conditions. Changes in the magnitude, periodicity, and synchronicity of these processes could make resident and transient sanctuary resources, which are highly adapted to this dynamic system, particularly vulnerable to climate-altered conditions. For this question, ocean indices, timing of upwelling, ocean temperature, dissolved oxygen, ocean acidification, and marine heatwaves were considered (Table S.WQ.8.1).

Table S.WQ.8.1. Summaries for the key indicators related to climate change that were discussed during the March 26, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Oceanic Niño Index	National Centers for Environmental Information, 2020a	Pelagic	**Status:** Cold and warm phases during reporting period **Trend:** Recent trend toward warmer conditions	App.E.8.1
Pacific Decadal Oscillation	National Centers for Environmental Information, 2020b	Pelagic	**Status:** Warm and cold phases during reporting period **Trend:** Recent trend toward warmer conditions	App.E.8.2
North Pacific Gyre Oscillation	Di Lorenzo et al., 2016	Pelagic	**Status:** High- and low-productivity phases during reporting period **Trend:** Recent trend toward warmer conditions	App.E.8.3
Upwelling index (CUTI)	Jacox et al., 2018; NOAA, 2021a	Pelagic	**Status:** Upwelling-dominated area **Trend:** No trend	App.E.8.4; App.E.8.5
Upwelling index (BEUTI)	Jacox et al., 2018	Pelagic	**Status:** Strong nutrient upwelling **Trend:** Slight decline, no long-term trend	App.E.8.6; App.E.8.7
Timing of upwelling	National Data Buoy Center, 1971	Pelagic	**Status:** Variability in timing of upwelling **Trend:** No trend	App.E.8.8; App.E.8.9
SST (satellite-regional)	NOAA Polar-orbiting Operational Environmental Spacecraft	Pelagic	**Status:** Patterns similar across CBNMS, GFNMS, MBNMS **Trend:** Recent warm years	S.WQ.8.2
SST (satellite - CBNMS)	NASA, 2020	Pelagic	**Status:** Typical seasonal variability with peaks in 2014–2015 **Trend:** Increasingly warm years	App.E.8.10
SST (buoy)	National Data Buoy Center, 1971; Jacox et al., 2018	Pelagic	**Status:** Warm and cold anomalies since 2009 **Trend:** Recent warm years	S.WQ.8.1
Temperature at depth	University of California Davis Bodega Marine Laboratory and Cordell Bank National Marine Sanctuary, 2021	Pelagic	**Status:** Seasonal pattern, warmer in winter **Trend:** No long-term trend	App.E.8.11
Heat content	University of California Santa Cruz, 2016	Pelagic	**Status:** Water column warming is evident **Trend:** Unknown	S.WQ.8.3

Indicator	Data Source	Habitat	Data Summary	Figures
Marine heatwaves	NOAA, 2021b	Pelagic	**Status:** Strong recent heatwaves **Trend:** Unknown	S.WQ.8.4
OA (regional)	Feely et al., 2016	Pelagic	**Status:** Low-aragonite conditions are more severe in CBNMS than in some other places along the coast **Trend:** Undetermined	App.E.8.13
OA (local)	ACCESS, 2021	Pelagic	**Status:** Low-aragonite conditions are present at times **Trend:** No trend	S.WQ.8.5
OA impacts	ACCESS, 2021	Pelagic	**Status:** Fewer juvenile krill and pteropods in low-aragonite conditions **Trend:** No data	App.E.8.14; App.E.8.15
Dissolved oxygen (mooring)	University of California Davis Bodega Marine Laboratory and CBNMS, 2021	Benthic	**Status:** Low DO conditions at times **Trend:** No trend	App.E.8.16
Dissolved oxygen (CTD casts)	ACCESS, 2021	Pelagic	**Status:** Low DO conditions at times **Trend:** No trend	App.E.8.17
Dissolved oxygen (deep habitat)	Ocean Exploration Trust, CBNMS, 2017	Benthic	**Status:** DO is low in this habitat **Trend:** No data	App.E.8.18
Data gaps	Time series data for all metrics to assess trends			

CBNMS waters are influenced by both large-scale and local conditions. The basin-level indicators considered for this assessment included the Oceanic Niño Index (Figure App.E.8.1), Pacific Decadal Oscillation (Figure App.E.8.2), and North Pacific Gyre Oscillation (Figure App.E.8.3).The Oceanic Niño Index and the Pacific Decadal Oscillation indices, although different, are associated with warm and cold water conditions off California, which result in low and high productivity respectively. Over the study period, there were both warm and cold phases and high- and low-productivity phases in all indices, indicating variability in the system. Examining the time period several decades prior to the study period, a long-term increase in frequency or number of extreme phases was not evident. The oceanographic system off the U.S. West Coast is highly driven by upwelling. In recent decades, increases in alongshore winds have resulted in a rise in upwelling duration and intensity (García-Reyes & Largier, 2010). During the study period, the West Coast-wide or regional indices for upwelling show that there was clear seasonality and high variability in the strength and timing of upwelling, but a long-term trend in index values or timing of upwelling was not evident (Figure App.E.8.4–Figure App.E.8.9).

Sea surface temperature (SST) data from multiple sources and scales, including NOAA satellite (advanced very-high-resolution radiometer) and NOAA buoy data, indicate that there have been both cold and warm conditions since 2009, with a trend toward warmer temperatures in the second half of the assessment period. The satellite data allowed for a regional assessment, while the buoy data (NOAA buoy 46013, located within CBNMS) provided local measurements. Both data sets showed peaks during the coastwide marine heatwave from 2014–2016 (NOAA, 2021a; Elliott et al., 2020; Figure S.WQ.8.1, Figure S.WQ.8.2, Figure App.E.8.10). The buoy data showed predominantly cold water anomalies during the first half of the assessment period, but there was a clear change in 2014–2015 when the marine heatwave occurred, and warm water anomalies have dominated since 2016 (Elliott et al., 2020). Satellite data were used to compare CBNMS to the surrounding region; GFNMS and MBNMS had similar SST patterns, indicating SST drivers are large in scale (NOAA, 2021a).

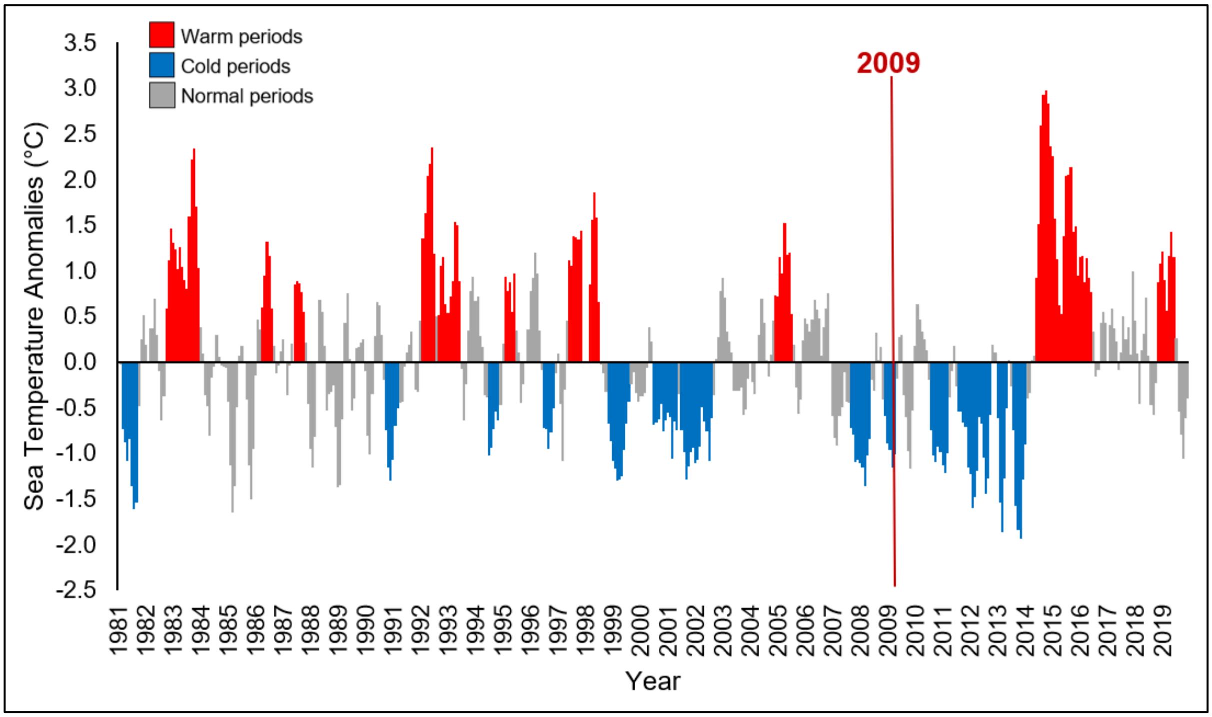


Figure S.WQ.8.1. Persistent sea surface temperature anomalies from NOAA buoy 46013 in Bodega Bay, 1981–2019. Bars represent the three-month means subtracted by the monthly long-term mean. Positive values represent warm periods (i.e., +0.5 ºC for 5 months in a row), and negative values represent cold periods (i.e., -0.5 ºC for 5 months in a row). Source: National Data Buoy Center, 1971; Image: Point Blue Conservation Science

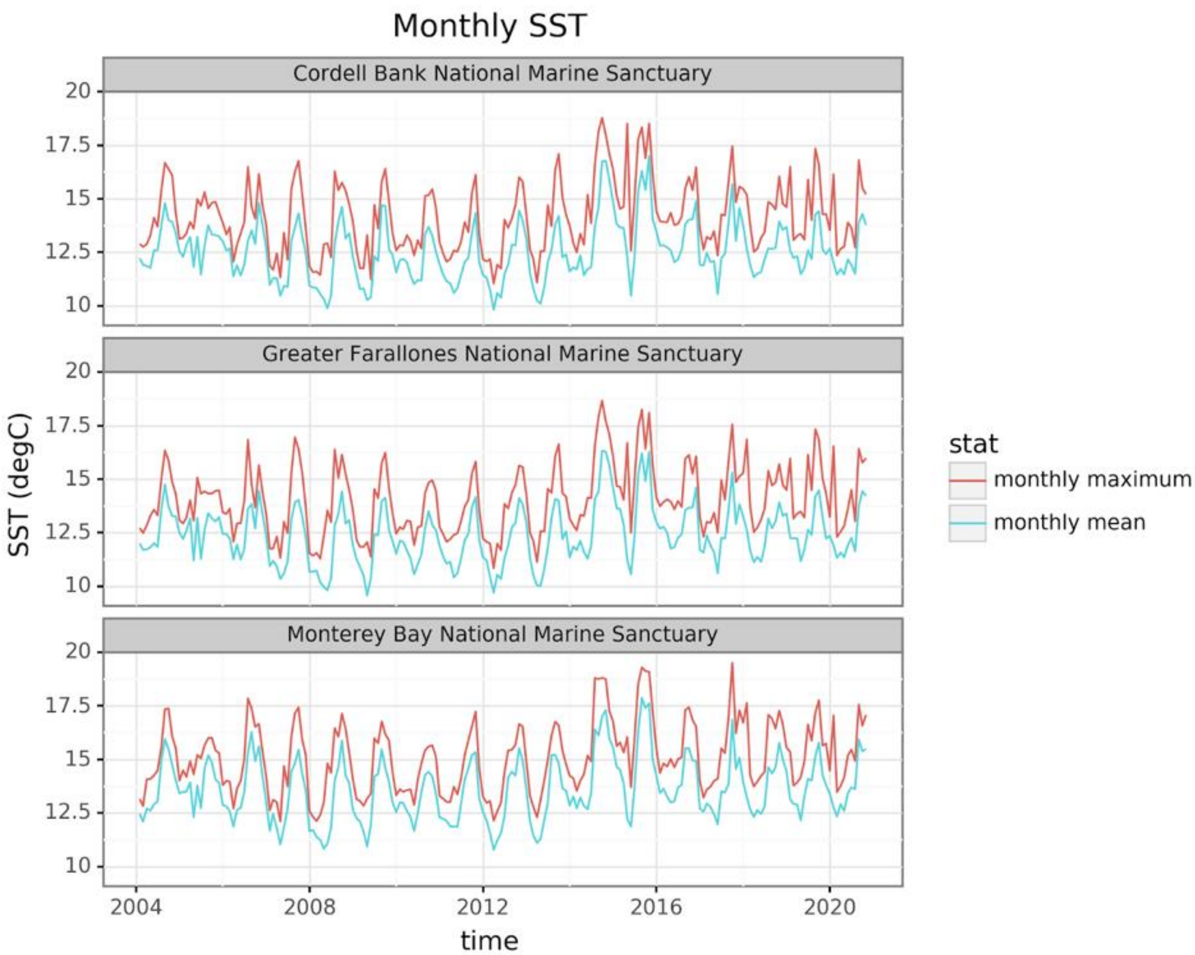


Figure S.WQ.8.2. Monthly SST from satellite data for CBNMS, GFNMS, and MBNMS. Source: NOAA Polar-orbiting Operational Environmental Spacecraft; Image: Central and Northern California Ocean Observing System

In addition to assessing SST, temperature was measured on a mooring at a depth of 80 meters on Cordell Bank. Temperature at depth showed a seasonal pattern, with warmest temperatures occurring in the winter (University of California Davis Bodega Marine Laboratory & CBNMS, 2021; Figure App.E.8.11). At the time of this report, a summary was available for only two years of data, so a trend analysis was not informative. Modeled data for heat content of the top 100 meters of the sanctuary from the University of California Santa Cruz Regional Ocean Modeling System, analyzed by Central and Northern California Ocean Observing System, indicated seasonal fluctuations and warming through the water column, but no long-term trend (Moore et al., 2013; Figure S.WQ.8.3). There were peaks in 2015–2016 from the marine heatwave, and a smaller peak in 2019.

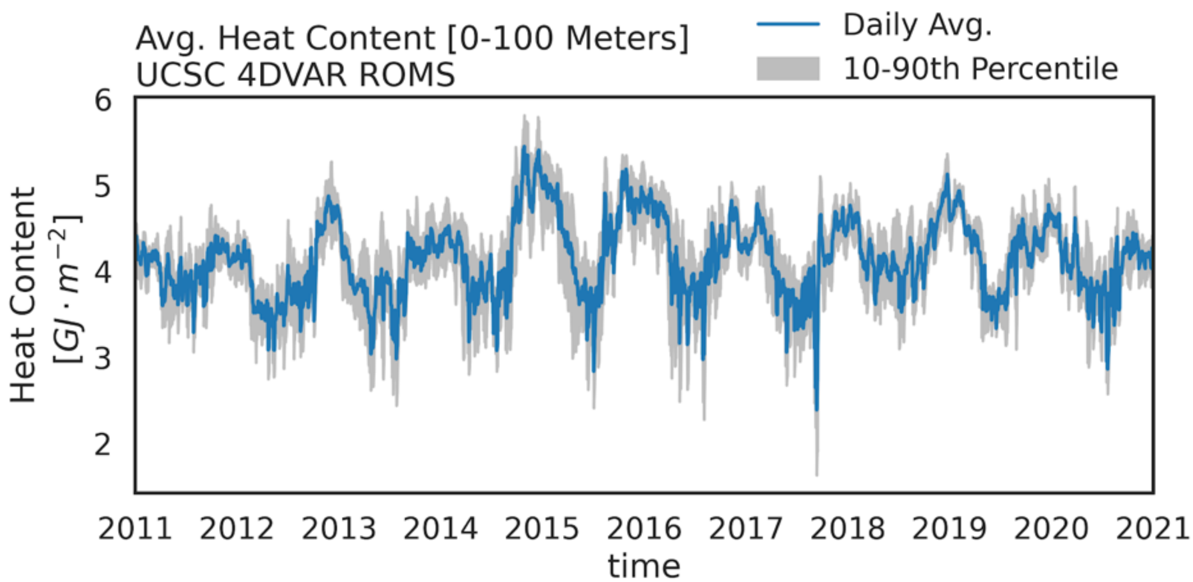


Figure S.WQ.8.3. Daily average (spatial mean) heat content to 100 meters depth in CBNMS. Source: University of California Santa Cruz, 2016; Image: Central and Northern California Ocean Observing System

In 2014, a marine heatwave that formed in the Gulf of Alaska extended to the entire West Coast and was present into 2016 (Bond, et al., 2015; Di Lorenzo & Mantua, 2016; Gentemann et al., 2017). The heatwave had numerous impacts to species and their distributions (Cavole et al., 2016; Lonhart et al., 2019; Sanford et al., 2019; Santora et al., 2020). Analysis of coast-wide conditions showed that temperatures were above normal for extended periods (NOAA, 2021a). These conditions were detected in the sanctuary on moored instruments and in at-sea monitoring data (Elliott et al., 2020; University of California Davis Bodega Marine Laboratory & CBNMS, 2021). Analysis of satellite imagery showed that, at times during the 2014–2015 period, the entire sanctuary was in a marine heatwave status, the heatwave was intense, and the heatwave was a large feature and not a localized event (NOAA, 2021b; Figure S.WQ.8.4). Looking back several decades to 1982, other warming events occurred, but these were El Niño-driven, and the mechanism and timing of these events differed from the 2014–2015 marine heatwave (NOAA, 2021a). During some periods when there was a large and intense heatwave feature in the region, CBNMS experienced some cooler temperatures (NOAA, 2021b; Figure App.E.8.12). This may be a result of the strong upwelling in the region in combination with the coastal geography of Point Reyes, which can funnel water offshore.

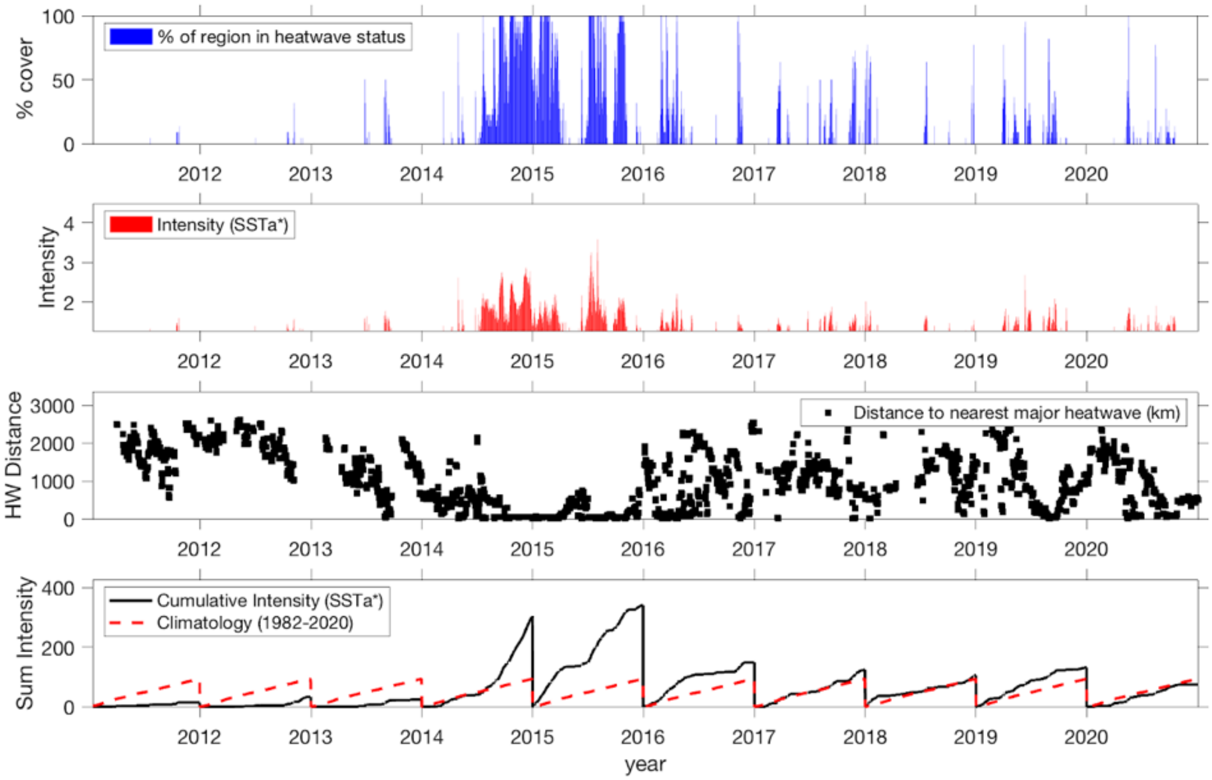


Figure S.WQ.8.4. From top to bottom: (1) percent of the area in heatwave status, (2) average SST anomaly standardized for all pixels in the area, (3) distance from the center of the area to the nearest major heatwave feature, and (4) the cumulative intensity summed over time at each pixel for a year. Source: NOAA, 2021b

The West Coast is highly vulnerable to ocean acidification because the variability created by seasonal upwelling conditions in combination with anthropogenic CO_2 accumulation exacerbates ocean acidification (Feely et al., 2008, 2016; Gruber et al., 2012; Osborne et al., 2020). Aragonite saturation was calculated from pH and total alkalinity data collected regularly since 2010 during ACCESS at-sea surveys that occur three to four times a year at repeated sampling stations throughout CBNMS. ACCESS data indicate that there are low-aragonite conditions in the sanctuary, particularly at stations beyond the shelf break in deeper water. In the spring, mixing prevents shoaling of the aragonite saturation horizon to shallower waters, but later in the year, stratification is more prevalent (Elliott et al., 2020; Figure S.WQ.8.5). Ocean acidification can affect the calcification, growth, behavior, and survival of marine organisms (Cooper et al., 2017; Fabry et al., 2008; Miller et al., 2016). Analysis of plankton samples co-located with ACCESS oceanographic data show that there are lower counts of juvenile krill and *Limacina* spp. pteropods when aragonite saturation is lower, although the causality cannot be determined (Figure App.E.8.14, Figure App.E.8.15).

There are less frequent, but broader-scale surveys conducted by NOAA for ocean acidification that include sampling in CBNMS at depths similar to those sampled in local surveys, allowing for comparison to the larger region. These surveys show that, along with the Pacific Northwest, the area around Point Reyes, including CBNMS, can be an area of low aragonite saturation compared to other areas along the coast (Feely et al., 2016). As such, calcifying organisms in the sanctuary have experienced stressful conditions, which may worsen in the future.

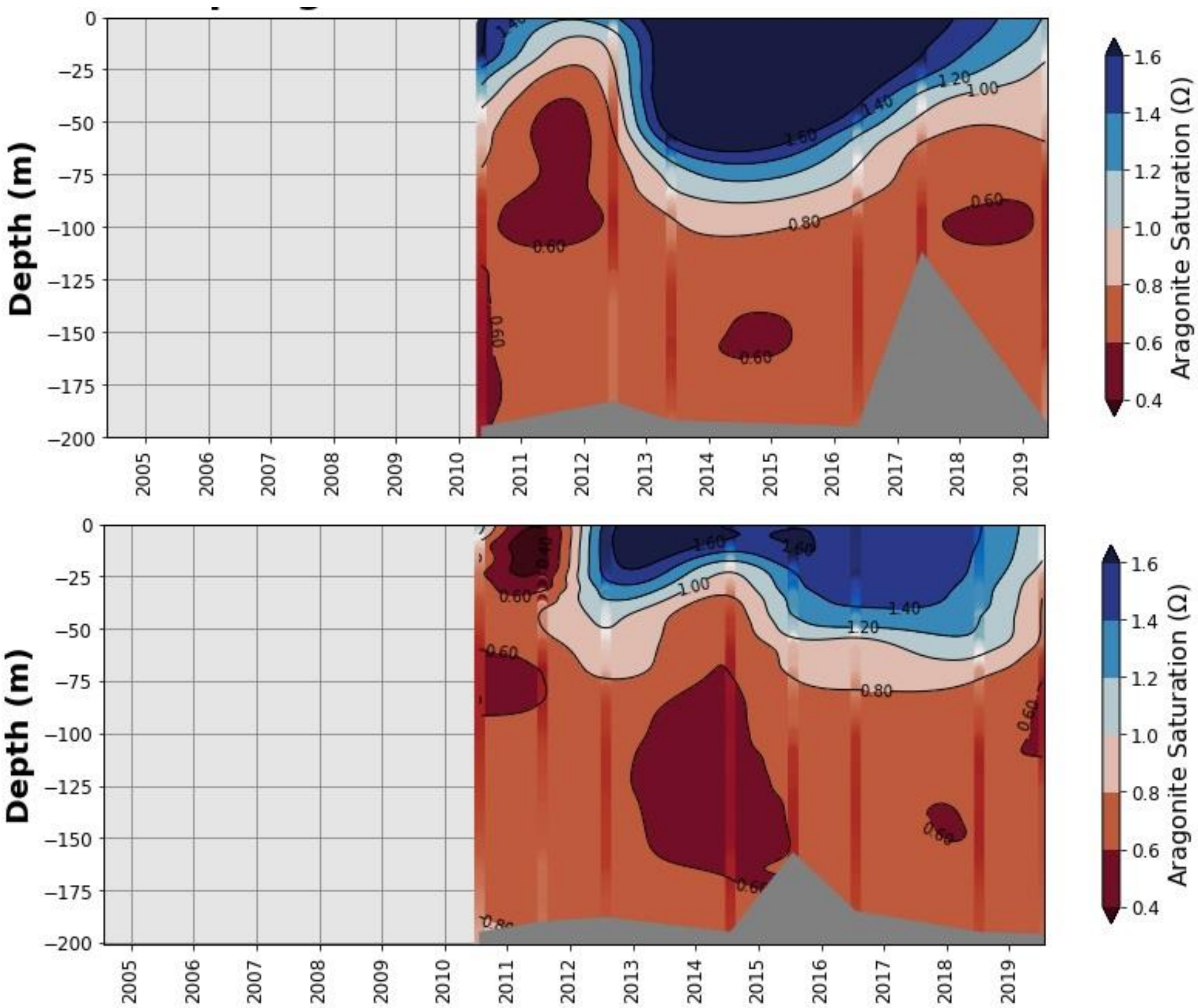


Figure S.WQ.8.5. Aragonite saturation values with depth at ACCESS station 2-W (west of Cordell Bank) in spring (top) and summer (bottom), 2010–2019. Source: ACCESS, 2021; Image: Point Blue Conservation Science

Along the California coast, low oxygen levels have been observed and the low oxygen zone has increased (Chan et al., 2017; Keller et al, 2015). Locally, dissolved oxygen is measured at a buoy on Cordell Bank and during ACCESS at-sea sampling. The mooring measures dissolved oxygen, salinity, and temperature, and has been deployed since 2014. Data from the mooring indicate that Cordell Bank occasionally experiences low dissolved oxygen levels (≤5 mg/L) for short periods. There is no evidence to date of severe hypoxia (University of California Davis Bodega Marine Laboratory & CBNMS, 2021). ACCESS at-sea monitoring indicated that low oxygen levels were present in CBNMS, particularly in the deep offshore waters beyond the shelf break.

Low oxygen has been observed in surface waters at times, but these conditions typically occur below 75 meters at the westernmost station sampled, past the shelf break (Elliott et al., 2020). This has the potential to impact large areas of sanctuary habitat. Deep habitats in the sanctuary are naturally lower in oxygen (Table App.E.8.1, Figure App.E.8.17)

Conclusion

In 2021, the status of climate-altered water conditions was fair with a worsening trend. Climate-altered water conditions were much more evident in 2021 than in 2009, when the first CBNMS condition report was published. Large-scale data, both modeled and observed, as well as local monitoring data provided a fairly robust assessment of these conditions, resulting in high confidence for the status rating. However, the confidence in the worsening trend was low, largely due to the high variability in the system as well as the absence of long-term data and the inability to detect trends for most indicators. Increased variability is one potential outcome of climate change and can be indicative of a worsening condition. The 2014–2016 marine heatwave was an unprecedented event, but heatwaves are occurring with greater frequency (Tanaka & Van Houtan, 2022). Continued monitoring of these oceanographic conditions in the coming years will be key for assessing status and trends within the sanctuary.

Question 9: Are other stressors, individually or in combination, affecting water quality, and how are they changing?

Status Description: Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.

Rationale: Microplastics are present in the sanctuary, but at levels within the range of other open ocean marine settings and much lower than San Francisco Bay. There were no reported oil spill incidents inside CBNMS, but incidents that occurred nearby had the potential to affect the sanctuary. Vessel discharges were recorded in the sanctuary and are likely underreported. Changes to ocean temperature and chemistry caused by global greenhouse gases have also affected CBNMS. The undetermined trend was based on the limited time-series data available for most indicators.

Findings From the 2009 Condition Report

In the 2009 condition report, "other stressors" were part of a question that combined climate and non-climate stressors: "Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality and how are they changing?" In 2009, that question received a good rating and an undetermined trend; impacts to CBNMS were not suspected, but data were lacking (see Table S.WQ.6.1). In addition, there was no indication of reduced productivity or degraded water quality resulting from inputs from San Francisco Bay or the Russian River. The current report considers climatic drivers of water quality and other stressors separately, in questions 8 and 9, respectively; hypoxia and ocean acidification are addressed in Question 8.

New Information in the 2009–2021 Condition Report

Microplastics, oil spills, and vessel discharge are the non-climate stressors most likely to affect CBNMS (Table S.WQ.9.1). Unfortunately, there are no long-term monitoring studies in the sanctuary for these indicators, and, thus, there are limited data available. Nevertheless, experts considered data that were available, and recognized the limited potential for land-based pollution and runoff due to the sanctuary's offshore location and the low numbers of reports related to these problems.

Table S.WQ.9.1. Summaries for the key indicators related to other stressors that were discussed during the March 26, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Microplastics	San Francisco Estuary Institute; Sutton et al., 2019	Pelagic	**Status:** Fewer microplastics in the sanctuary than San Francisco Bay, similar to levels found in the open ocean **Trend:** No trend data	S.WQ.9.1; Figure App.E.9.1
Oil spills	Office of Response and Restoration, 2021; USCG, 2020	Pelagic	**Status:** No incidents in the sanctuary, some nearby **Trend:** Unknown/no trend	S.WQ.9.2

Indicator	Data Source	Habitat	Data Summary	Figures
Vessel discharges	USCG, 2020	Pelagic	**Status:** Generally few incidents in CBNMS, recent cruise ship incidents **Trend:** No trend data	
Greenhouse gas emissions (California)	U.S. Environmental Protection Agency (EPA), 2021; California Air Resources Board, 2020	Pelagic	**Status:** High levels in California throughout the study period **Trend:** Some recent improvements, not enough to counteract high levels	S.WQ.9.3; App.E.9.4
Greenhouse gas emissions (states and sectors)	EPA, 2021; California Air Resources Board, 2020	Pelagic	**Status:** High levels in some California sectors **Trend:** No trend	App.E.9.4
Greenhouse gas emissions (gas type)	EPA, 2021	Pelagic	**Status:** Overall high levels of greenhouse gases in California and the U.S. **Trend:** Consistent over time	S.WQ.9.3; App.E.9.5
Heat content anomalies	National Centers for Environmental Information, 2020b	Pelagic	**Status:** Heat content consistently above average since mid-1990s **Trend:** Increasing over time	App.E.9.2
Carbon dioxide and pH	Tans & Keeling, 2021; Adapted from Dore et al., 2009	Pelagic	**Status:** Higher carbon dioxide and lower pH **Trend:** Carbon dioxide has increased and pH has decreased over time	App.E.9.3
Data gaps	Continued sampling for microplastics; monitoring of vessel discharges; impacts of greenhouse gas emissions on water quality; relevance of and data on of ship exhaust deposition, ship scrubber wash, and wildfires			

Microplastics degrade water quality and threaten ecosystem and human health when present in seafood. They are found in nearly every environment on Earth (Thompson et al., 2004). Plastic debris, including microplastics, in the marine environment contains organic contaminants, some added during manufacturing and some absorbed from the surrounding seawater (Teuten et al., 2009). The San Francisco Estuary Institute studied microplastics from 2017–2018 in three California national marine sanctuaries (CBNMS, GFNMS, and MBNMS), as well as in San Francisco Bay (Sutton et al., 2019; Figure App.E.9.1). Surface water samples were collected using manta trawls during the dry and wet seasons. The results showed that microparticles, including plastics, were present in CBNMS; however, the abundance of these was much lower than in San Francisco Bay, and was within the range of other open ocean marine settings (Figure S.WQ.9.1). There were no long-term data available to determine a trend. Other types of marine debris were considered in Question 10 regarding habitat integrity and Question 3 regarding human activities and impacts to water quality.

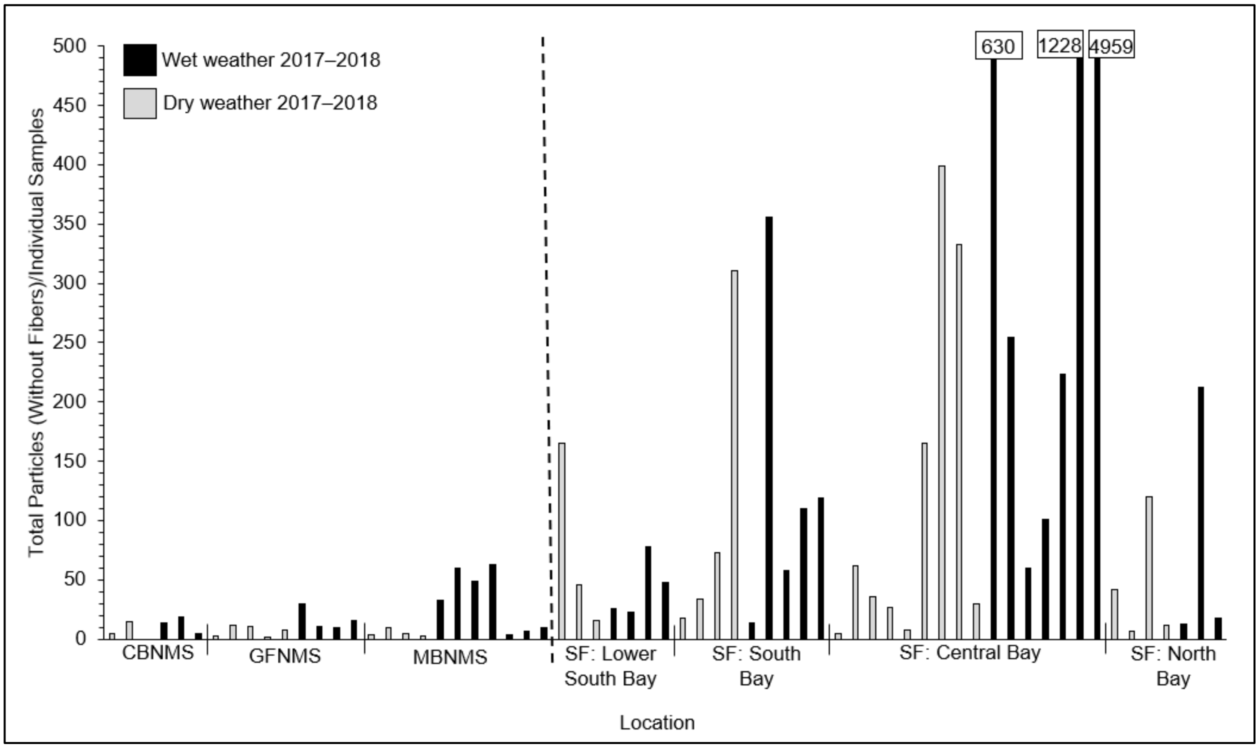


Figure S.WQ.9.1. Total particles (excluding fibers) per individual samples collected by the San Francisco Estuary Institute in CBNMS, GFNMS, MBNMS, and San Francisco (SF) Bay in the dry and wet seasons, 2017–2018. Numbers in boxes indicate values that exceed the axis maximum. Source: Sutton et al., 2019

NOAA's Office of Restoration and Response and the U.S. Coast Guard collect data on reported oil spills. Since 2009, there have been no reported oil spill incidents in CBNMS; however, oil spills have been recorded near the CBNMS boundary. In 2013, a fishing boat spilled 70 gallons of diesel, and another fishing boat sank in 2019 with 17,000 gallons of diesel on board. These incidents could affect the water quality of the sanctuary (Figure S.WQ.9.2).

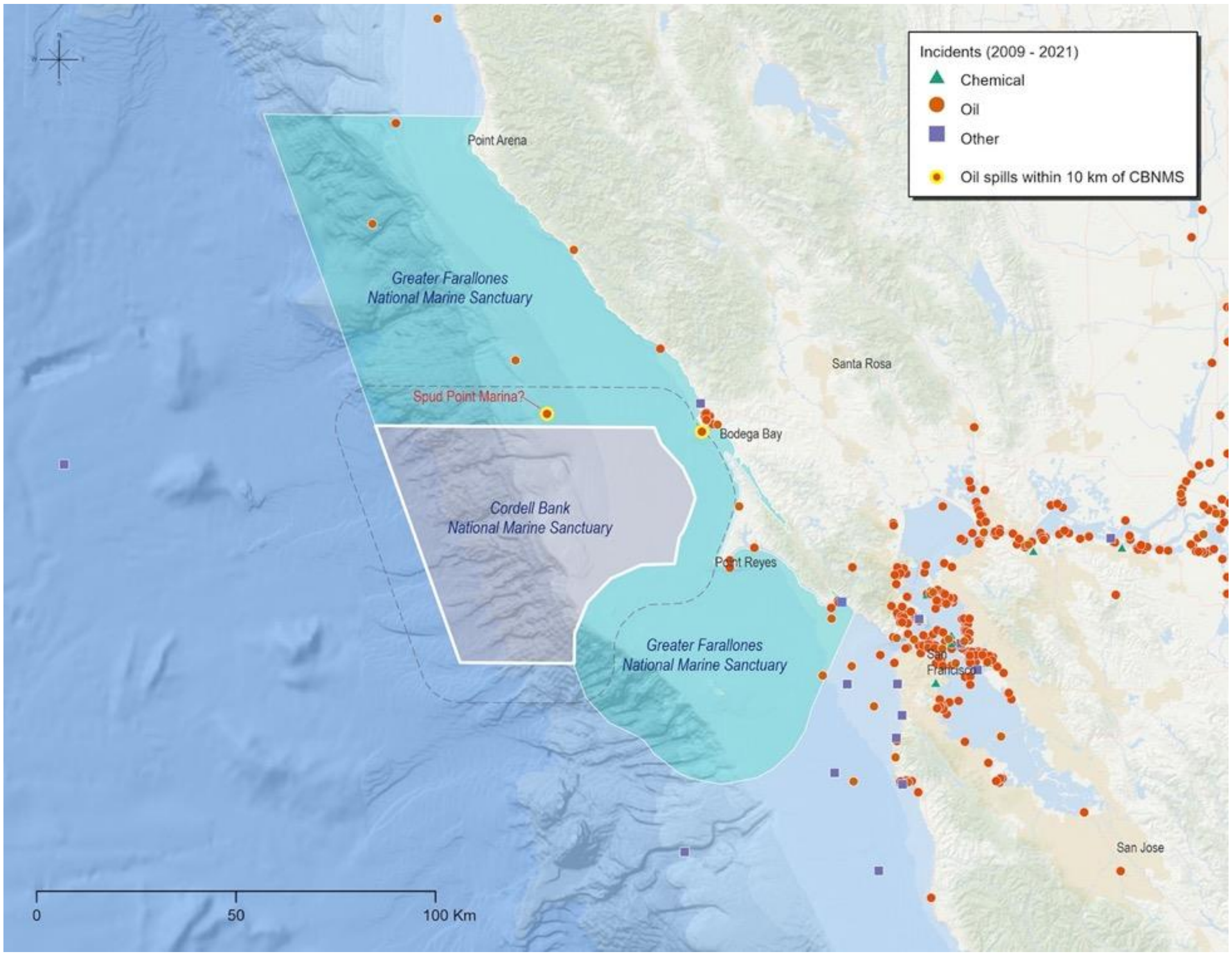


Figure S.WQ.9.2. Locations of oil spill incidents near CBNMS. Note that the point labeled “Spud Point Marina?” is likely a latitudinal data entry error for an incident directly east in Bodega Bay. Source: Office of Response and Restoration, 2021; U.S. Coast Guard, 2020

Most vessel discharges are prohibited in CBNMS, except for those from lawful fishing and certain types of treated sewage. Although it is a legal requirement to report vessel discharges, small and large vessel discharge data are limited and likely underreported. However, enforcement authorities documented extensive cruise ship discharges (190 prohibited discharges) in CBNMS and GFNMS from June 2015–April 2017. These discharges included 8.4 million gallons of untreated and treated black and gray water, as well as water treatment sludge, exhaust gas cleaning system discharge, and food waste. Additionally, in 2019, a large ship that drifted into CBNMS self-reported that it had discharged black water for 18 minutes.

Greenhouse gas emissions affect ocean temperatures and ocean chemistry globally, including in CBNMS. Global ocean heat content anomalies (Figure App.E.9.2) have increased over time as a result of greenhouse gas emission-caused warming and increasing greenhouse gas levels (Figure App.E.9.3). Although there have been some recent reductions, the levels of greenhouse gases generated by many sectors in the state of California (U.S. Environmental Protection Agency [EPA], 2021; Figure S.WQ.9.3, Figure App.E.9.4) and the United States (Figure App.E.9.5) remain high. These emissions and their impacts are discussed further in Question 8.

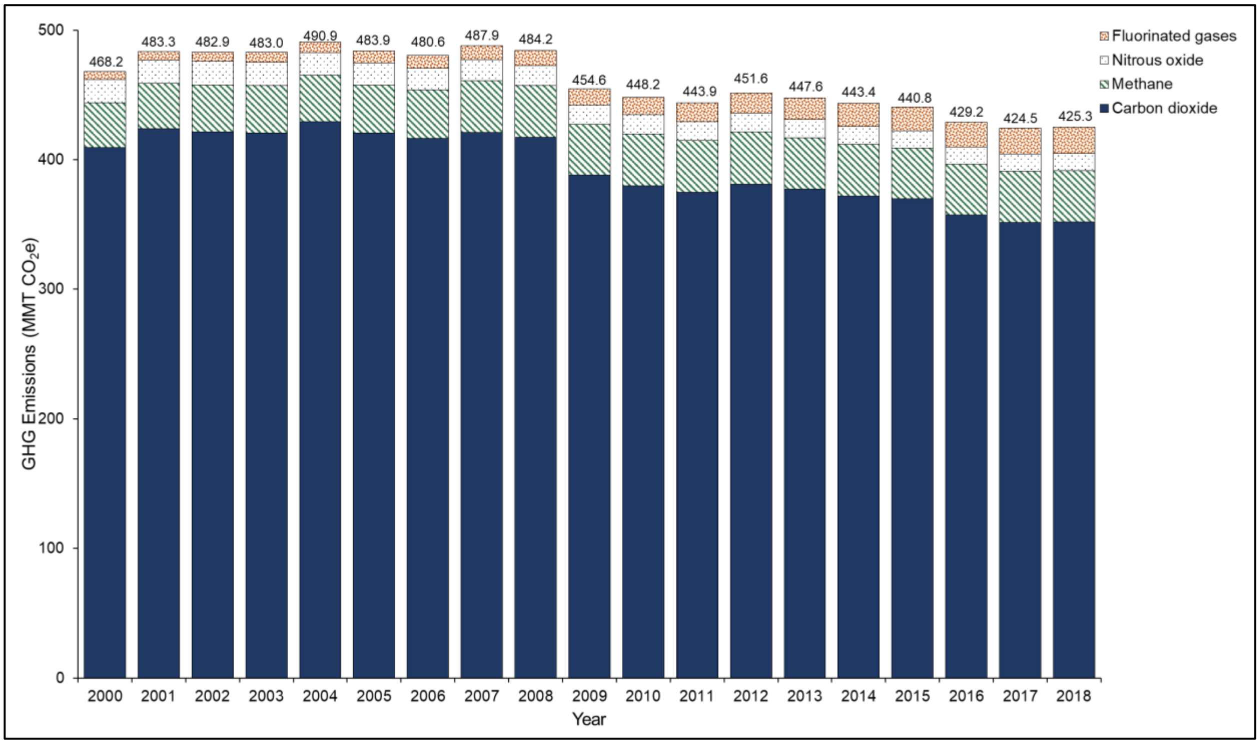


Figure S.WQ.9.3. Greenhouse gas (GHG) emissions in million metric tons for California from 2000–2018. Source: EPA, 2021; Image: NCCOS

Conclusion

The distance of CBNMS from land-based sources of pollution provides some protection against common water quality stressors. Experts agreed that although some extreme storms can result in debris and runoff reaching the sanctuary, these occur rarely enough to limit the level of concern. Still, it was evident that some stressors have affected water quality in the sanctuary, namely plastics, vessel discharges, and oil spills. Data on these stressors are increasingly available, leading to increased awareness of their potential to threaten marine resources.

The lack of long-term monitoring for these indicators led experts to recommend an undetermined trend and identify data gaps. Continued sampling for microplastics, monitoring of vessel discharges, and increased outreach about regulations and reporting requirements could improve future knowledge about these stressors. Increased understanding of greenhouse gas emissions, their trends, and their effects on CBNMS water quality will also be helpful. Other indicators like ship exhaust deposition, ship scrubber wash, and wildfires were considered by experts but were not included due to a lack of data. Should data become available, it should be evaluated for relevance to CBNMS water quality.

Status and Trends of Habitat (Questions 10–11)

Pelagic and benthic habitats are present within CBNMS. The following sections assess the status and trends of key habitat indicators in CBNMS for the period from 2009–2021.

Question 10 focuses on the integrity of major habitats within the sanctuary, including biologically (biogenic) and abiotically (physical) structured habitats. Physical habitats are abiotic structures, while biogenic habitats are composed of species that form structures used by other living marine resources. Biogenic habitats are layered on top of, and are often associated with, specific physical habitat types. Changes to both biotic and abiotic habitat can significantly alter the diversity of living marine resources and ecosystem services.

Question 11 examines the types and amounts of contaminants in major sanctuary habitats. Like the other condition report questions, the status and trend ratings represent assessments by subject matter experts given readily available data.

Table S.H.10.1. 2009 (left) and 2009–2021 condition report ratings (right) for the habitat questions.

2009 Condition Report Questions	**2009 Rating**	**2009–2021 Condition Report Questions**	**2009–2021 Condition Report Rating**
5. Habitat abundance/distribution	–	10. Integrity of major habitats	Fair ▲▼
6. Condition of biologically structured habitat	?		
7. Contaminants	–	11. Contaminants	Undetermined ?

Question 10: What is the integrity of major habitat types and how are they changing?

Status Description: Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Direct measures of impacts to CBNMS benthic habitats are limited, but data show that trawling activities, Dungeness crab fishing, and marine debris are present in the sanctuary, albeit at lower levels than some other areas along the U.S. West Coast. Monitoring is required to establish trend data in recently opened and closed Essential Fish Habitat Conservation Areas. Chronic noise from shipping is approaching a threshold level that could cause stress to marine mammals, particularly whales. [18]

Findings From the 2009 Condition Report

In the 2009 condition report, the topic of habitat integrity was addressed in two separate questions. The first examined the abundance and distribution of major habitats, and the second assessed the condition of biologically structured habitats. These questions both received status ratings of fair with an undetermined trend. The ratings were based heavily on expert opinion that there were impacts to physical and biological habitats from historic longline and bottom trawling activities, as well as lost fishing gear. Although trawling closures were implemented from 2005–2006, there were no data to determine differences in habitat quality between open and closed areas and recovery rates of benthic habitats that were relieved of fishing pressure. Additionally, the impacts of climate change were unknown for the slow-growing invertebrate communities on the bank and shelf, particularly deep-sea corals (Table S.H.10.1).

New Information in 2009–2021 Condition Report

In this report, all major habitat types were assessed collectively (Table S.H.10.2). The area of the sanctuary more than doubled in size in 2015 from a total area of 529 square miles to 1,286 square miles, and now includes deep-water habitats off the continental slope, Bodega Canyon, and the surrounding pelagic habitat. Habitat types include mud bottom on the shelf (70–200 m), mud bottom with some rock outcrops, steep rock walls, and deep slope and canyons out to depths greater than 3500 meters. The bank is made up of high-relief consolidated rock at the shallowest depths (35 m) and mixed boulder, cobble, and sand habitats at the base (91–122 m; Figure SS.6).

[18] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, "mixed," was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data.

Table S.H.10.2. Summaries for the key indicators related to habitat integrity that were discussed during the March 29, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Habitat protections	Pacific Fishery Management Council	Benthic	**Status:** Protections are in place for key habitat features **Trend:** No change; Essential Fish Habitat Conservation Area maintained	App.E.10.1
Commercial trawling activity	NOAA Northwest Fisheries Observation Science Program, 2021; WCGBTS, 2019	Benthic	**Status:** Trawling on the shelf and slope, less than other areas **Trend:** Improving (lower amounts of trawling)	S.HA.3.3; App.E.3.3; App.E.10.2
Research trawling activity	WCGBTS, 2019	Benthic	**Status:** Trawling on the shelf and slope at low levels **Trend:** No change	S.HA.3.1; App.E.3.1; App.E.10.3; App.E.10.4
Crab fishing (recreational)	CDFW, 2020a	Benthic	**Status:** Low levels in CBNMS **Trend:** Variable	
Crab fishing (commercial)	CDFW, 2020a	Benthic	**Status:** Low levels in CBNMS **Trend:** Decreased following peaks in 2010 and 2011	ES.CH.3
Marine debris (surface)	ACCESS, 2021	Pelagic	**Status:** Marine debris found in surface waters of the sanctuary **Trend:** Undetermined	App.E.10.5
Marine debris (bank)	CBNMS, 2020, 2021a	Benthic	**Status:** Marine debris found on the bank **Trend:** Undetermined	App.E.10.6
Marine debris (deep)	CBNMS, 2020, 2021a	Benthic	**Status:** Marine debris found in deep habitat, mostly trash **Trend:** No trend data	App.E.10.7
Soundscape	CBNMS, 2020; Haver et al., 2020, 2021	Pelagic	**Status:** Whales and shipping dominate the soundscape; CBNMS is at the threshold of “good ecosystem status” **Trend:** No long-term trend data yet	S.H.10.1; App.E.10.8–App.E.10.11
Data gaps	Analysis of additional years of Noise Reference Station data; direct measures of habitat impacts from bottom contact fishing			

Fisheries Management Protections

Multiple habitat and seafloor protections exist in the sanctuary, including Essential Fish Habitat Conservation Areas (EFHCAs) and Rockfish Conservation Areas (RCAs), which are managed by NOAA and the Pacific Fishery Management Council. RCAs are depth-based closed areas where fishing for groundfish is prohibited depending on the type of fishing gear used. EFHCAs are closures for habitats that are necessary for fish spawning, breeding, feeding, and growth to maturity.

The Cordell Bank RCA was originally established in 2005, and the EFHCAs within CBNMS were put in place in 2006. Cordell Bank is protected by an EFHCA at 50 fathoms in which fishing for groundfish, use of bottom contact gear, and removal or modification of any benthic animals or substrate is prohibited (Figure App.E.10.1a).

In 2014, the Pacific Fishery Management Council determined that new information from a multi-year public review justified developing modifications to groundfish essential fish habitat. The Pacific Fishery Management Council began developing essential fish habitat alternatives and, separately, considered changes to RCA trawling regulations. These efforts were merged into a single action under Amendment 28 to the groundfish fisheries management plan. The final rule went into effect on January 1, 2020 (50 C.F.R. § 660) and changed bottom trawl fishing closures to minimize adverse effects of fishing, reopened historically important fishing grounds to groundfish bottom trawling, and prohibited fishing with bottom-contact gear in deep waters (>3,500 m) off California to protect deep-water ecosystems, including deep-sea corals. In CBNMS, Amendment 28 opened 20 square miles of EFHCA in the sanctuary's sand-mud habitat on the continental shelf, while closing 19 square miles of EFHCA on the sanctuary's shelf and slope habitats, composed of hard and mixed substrate. A total area of 60 square miles of trawl RCA in the sanctuary was removed (Figure App.E.10.1b).

Benthic surveys were conducted in 2018 in the reopened EFHCA and RCA areas in CBNMS using a remotely operated vehicle (ROV; Graiff & Lipski, 2020a). These surveys provided a baseline assessment and characterization of habitat types and densities of fish and invertebrates for a portion of these areas before the final ruling on Amendment 28 went into effect, opening these areas to commercial bottom trawling. Monitoring will continue in these areas to assess how habitats are impacted by changes in fishing activities. Continued EFHCA protections on Cordell Bank and surrounding shelf and slope habitats contribute to the integrity of the associated biological communities.

Fishing Impacts

Bottom-contact fishing gear, such as trawls, traps, and pots, can significantly impact benthic habitats, and the level of impact is largely based on the magnitude, spatial extent, and frequency of gear use (National Research Council, 2002; Morgan & Chuenpagdee, 2003). Commercial trawling data from federal groundfish fisheries operating within the boundaries of CBNMS, analyzed by NOAA's California Current Integrated Ecosystem Assessment (CCIEA) team based on analytical approaches used in Harvey et al. (2021), show that seafloor contact by bottom trawl gear decreased from the period of the last condition report (2002–2008) to the current assessment period of this report (2009–2019; Figure S.HA.3.1a, b). Trawling mainly occurs on the soft shelf and soft upper slope habitats (Figure App.E.3.3). There was a shift in effort, based on distance trawled, from the shelf to the slope between 2009 and 2019 compared to the long-term mean (2002–2019). Bottom trawl contact has decreased from 2009–2019 in most areas of CBNMS, with the exception of a band of grid cells stretching north-south along the eastern boundary (Figure.S.HA.3.1c). When scaled to distances trawled across the entire U.S. West Coast, total distance and frequency of trawling within CBNMS were lower compared to other West Coast areas (Figure App.E.10.2).

Trawling is permitted by the sanctuary for research purposes, except for in sensitive habitat like Cordell Bank. Research trawls occur from the sanctuary's eastern boundary to a depth of about 1,312 feet (Figure App.E.10.3, Figure App.E.10.4). Groundfish time series were provided by CCIEA and derived from the U.S. West Coast Groundfish Bottom Trawl Survey (WCGBTS, 2019) based on the analytical approaches used in NOAA's California Current Ecosystem Status Report (Harvey et al., 2021). The data show that groundfish survey trawling within CBNMS occurs at low levels on the shelf and slope, and seafloor contact distance by bottom trawl gear shows no trend from 2009–2019 (Figure S.H.A.3.1, Figure App.E.3.1).

Limited information is available on the fine-scale spatial footprint of recreational Dungeness crab (*Metacarcinus magister*) fishing in CBNMS, but it is mainly concentrated in the eastern portion of the sanctuary (NOAA Fisheries, 2021b). Crab pots are a type of bottom-contact gear with the potential to cause disturbance to the seafloor when they are set or hauled for retrieval. Information is not available about crab pot impacts to the seafloor, so reported landings of Dungeness crab were used as a proxy for the frequency of gear use and thus potential impact to the seafloor. Commercial Dungeness crab landings were relatively high in 2013 and 2016. In 2015, landings decreased to a time series low, as elevated levels of DA, a neurotoxin produced by a HAB, triggered health advisories and fishery closures for Dungeness crab (California Ocean Science Trust, 2016). Following another peak in 2016, landings decreased to low levels in 2019 and 2020 (see Figure ES.CH.3). There are years when Dungeness crab have aggregated offshore in deeper water, and populations can differ substantially from year to year (R. Ogg, personal communication, March 29, 2021). The fishery was subject to delays and closures in 2019, 2020, and 2021 due to elevated risk of whale and sea turtle entanglement in gears used by the fleet (CDFW, 2019, 2020a, 2021b).

Marine Debris

Marine debris has been found in the sanctuary's surface waters and in all benthic habitats on the bank, shelf, and deep canyons. Surface debris, particularly plastic, is a threat to sea turtles, marine mammals, and seabirds that ingest the debris if they confuse it for prey. The most significant type of marine debris found on seafloor habitats is derelict fishing gear, including longlines, gill nets, and crab gear. Derelict fishing gear has been observed entangled on the sanctuary's benthic structures and can damage the associated biological communities. Such gear can also be an entanglement hazard to other pelagic marine life if it extends into the water column.

ACCESS surveys documented marine debris on the surface, including plastic bags, bottles, balloons, polystyrene, wood debris, and out-of-season crab pots. Marine debris was observed on all cruises in CBNMS and GFNMS from 2008 to 2019, with a peak in marine debris density in

2010, but relatively consistent density from 2009 to 2019 (Elliott et al., 2020; Figure App.E.10.5).

Marine debris is recorded by type and either count or density when observed on the sanctuary's seafloor during ROV surveys, which vary in frequency and survey effort. Observations of marine debris are not collected in a standardized way, which limits comparison of marine debris across spatial and temporal scales. On Cordell Bank, marine debris primarily consists of different types of derelict fishing gear, such as gillnets, longlines, monofilament lines, and cables (Figure App.E.10.6). However, because of EFHCA and RCA management zones established over the bank from 2005–2006, there should not be any recent fishing gear lost on the bank. Similarly, derelict fishing gear has been observed in the deeper slope and canyon habitats during ROV surveys (Figure App.E.10.7). Anthropogenic trash such as plastic bags, bottles, and cans are observed in greater numbers than derelict fishing gear on the deepest surveys (740–3,318 m; Graiff & Lipski, 2020b). It is possible that this trash was discarded from ships transiting through the area or originated from areas outside of the sanctuary and was transported by ocean currents.

Soundscape

Anthropogenic noise can affect the sanctuary's pelagic habitat. The main source of anthropogenic noise in the sanctuary is ship traffic. Previously, the noise dynamics in the sanctuary were not well understood, but in October 2015, a stationary, bottom-mounted noise reference station hydrophone was deployed in CBNMS to record the underwater ambient soundscape. The noise reference station is located near the southern border of the sanctuary, approximately 30 km offshore of the northern approach San Francisco Bay Area TSS shipping lane (Figure App.E.10.8). Data on sound types, frequency, and levels collected from October 2015–October 2017 show that vessels transit close to this recording station in the sanctuary year-round with minimal seasonal variation (Haver et al., 2020; Figure App.E.10.9, Figure App.E.10.11).

The European Marine Strategy Framework Directive requires European Union (EU) Member States to develop marine strategies to achieve or maintain good environmental status, and dedicates a qualitative descriptor of this condition to human-induced underwater noise (Dekeling et al., 2014). The Technical Group on Underwater Noise is the EU advisory body that supports the EU's implementation of descriptors for both impulsive and continuous noise. Their early work identified the 63 Hz and 125 Hz one-third octave frequency bands as benchmarks for regional EU monitoring of the influence of continuous vessel noise (European Commission, 2017). While there is currently no U.S. equivalent standard, these one-third octave bands have been increasingly applied in U.S. studies to support international comparisons of the impact of vessel noise (e.g., Haver et al., 2021; Ryan et al., 2021; McKenna et al., 2023). Figure S.H.10.1 plots 63 Hz and 125 Hz one-third octave frequency band sound levels near a hydrophone for multiple U.S. regions, including CBNMS. At the CBNMS location, 2016–2017 median sound levels were 99.5 and 98 dB at 63 Hz and 125 Hz, with higher levels at 63 Hz in fall months due to seasonal peaks in whale calling activity. This study showed that sound levels at some other U.S. locations (e.g., the Gulf of Mexico and Northeast Canyons and Seamounts Marine National Monument in the North Atlantic) are considerably higher than levels measured in CBNMS, while levels in other U.S. locations are considerably lower (e.g., Hawaiʻi). Additional monitoring efforts through the Sanctuary Soundscape Monitoring Project (SanctSound) evaluated 63 Hz and 125 Hz one-third octave levels over three years at vessel-influenced locations north and south of CBNMS, including Olympic Coast, Monterey Bay, and Channel Islands national marine sanctuaries (Wall et al., 2021). Median sound levels at Monterey Bay and Olympic Coast national marine sanctuaries were broadly comparable to recordings in CBNMS, with median levels at 63 Hz and 125 Hz ranging from 98–100 dB. Median levels at traffic-influenced sites in Channel Islands National Marine Sanctuary were 88–91 dB in the same bandwidths. For comparison, sound levels across the National Marine Sanctuary System generally ranged between 70 and 80 dB median values in these frequency bands at sites with marginal exposure to vessel traffic, while those with moderate exposure had median values between 80 and 90 dB over multiple years.

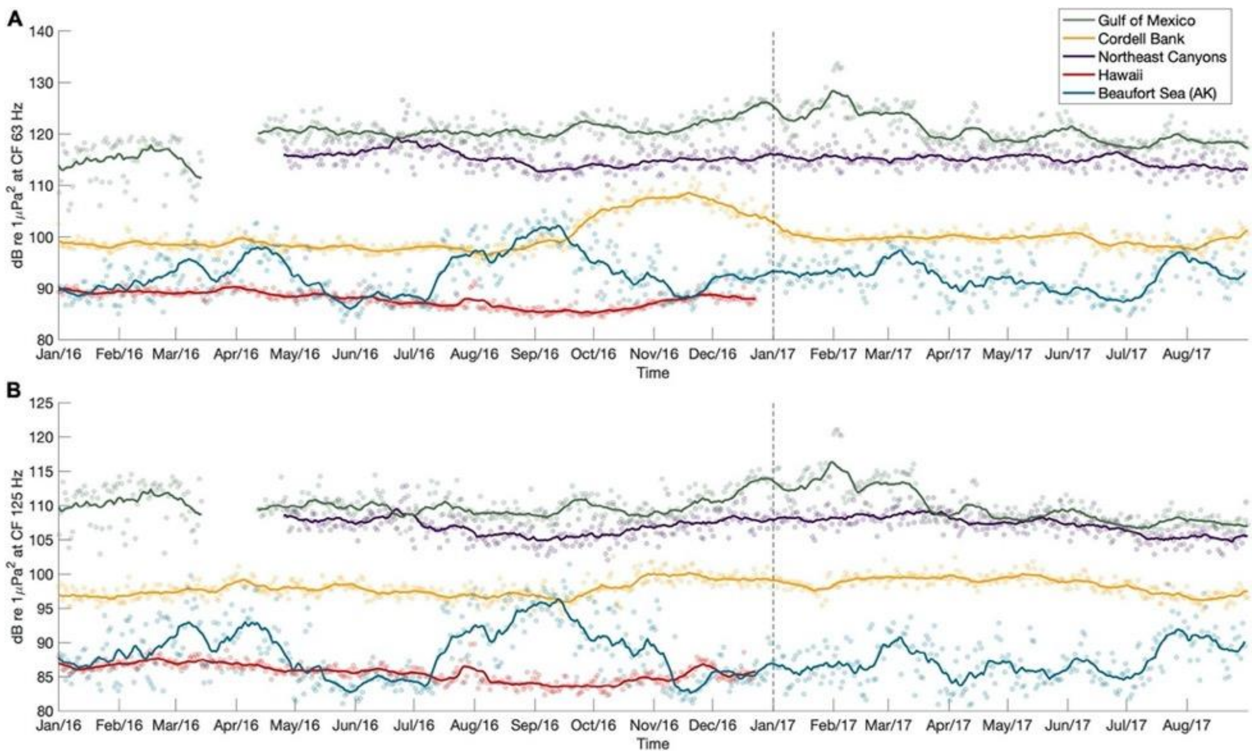


Figure S.H.10.1. Daily one-third octave band sound pressure level measurements for (A) 63 Hz and (B) 125 Hz center frequencies (scatter plot) and overlaid 14-day moving average for five deep-water autonomous underwater hydrophone moorings from January 2016 through August 2017. Source: Pacific Marine Environmental Laboratory et al., 2014; Image: Haver et al., 2021

In addition to providing benchmarks for the influence of vessel noise on a given habitat, EU thresholds also highlight the importance of assessing both the area and amount of time over which listening and vocalizing animals are exposed to noise that exceeds levels of concern within key bandwidths. The Technical Group on Underwater Noise recently finalized a framework for setting threshold values beyond which noise has the potential to compromise the health of marine organisms (Sigray et al., 2021). This framework highlights the importance of long-term monitoring and spatial modeling to establish targets for reducing both the spatial and temporal extent over which noise levels exceed a “level of onset of significant effect.” This value is considered to vary regionally and even subregionally based on the vulnerability of acoustically sensitive taxa to acoustic disturbance, communication masking, and lost listening opportunity. Continued monitoring at CBNMS, as well as spatial modeling evaluation of priority sanctuary habitats, will be necessary to evaluate threshold conditions and trends. Noise reference station data collected in 2015–2017 serve as a baseline for future recordings and analysis (Figure App.E.10.10).

Conclusion

Habitat integrity data indicators demonstrated different levels of impacts. Information on the direct impacts to benthic habitats and living resources by these activities was limited, which limited assessment of the severity of impacts. Instead, the assessment relied on interpreting levels of human activities in these habitats. Fishing effort was relatively low compared to some other West Coast areas, while marine debris was present across all habitat types, and the acoustic environment was affected by noise from commercial shipping. Trawling may impact bottom habitat, but trawl contact has decreased and impacts may not be severe in certain types of habitat (e.g., soft sediment). CBNMS is an important habitat for marine mammals, and high levels of chronic, low-frequency sound from vessel traffic is a concern for animals that generate and use low-frequency sound. Marine debris is known to impact habitat integrity. Therefore, selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity. The trends for each indicator also varied. Benthic indicators related to fishing activity appear to have improved, while pelagic indicators appear to have not changed (remained stable) or worsened, resulting in an overall trend of mixed.

Question 11: What are contaminant concentrations in sanctuary habitats and how are they changing?

Status Description: N/A

Rationale: This rating is based on the lack of data on contaminants in the water column, sediments, and animal tissues within the CBNMS region. Based on other ocean areas, stressors of concern for CBNMS include persistent contaminants and microplastics in the water column, sediments, and resident species; these are data gaps that should be considered as targets for future research efforts. Very little information was available on trends for any of the indicators.

Findings From the 2009 Condition Report

In 2009, the status and trend of contaminant concentrations in CBNMS were both rated as undetermined due to a lack of data (see Table S.H.10.1). Sediment samples taken within CBNMS indicated that dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) were present in low levels (Hartwell, 2007, 2008).

New Information in the 2009–2021 Condition Report

In this assessment, the status and trend of contaminants were again rated undetermined, as there continues to be a lack of information regarding contaminant levels in the water column, sediments, and animal tissues in CBNMS. While we are not aware of any direct measurements of contaminants within CBNMS since 2009, indirect contaminant measurements have been made in the region. Although these data must be interpreted with caution, they provide an indication of contamination that could be present in the sanctuary (Table S.H.11.1).

Table S.H.11.1. Summaries for the key indicators related to contaminants that were discussed during the March 29, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures and Tables
Contaminants in harbor seals	Brookens et al., 2007, 2008; Van Hoomissen et al., 2015, and McHuron et al., 2019	Pelagic/ Coastal	**Status:** Levels of concern in seals **Trend:** Undetermined	Figures S.H.11.1
Contaminants in fish	California Environmental Data Exchange Network, 2021; San Francisco Estuary Institute, 2021; Surface Water Ambient Monitoring Program, 2021	Pelagic/ Coastal	**Status:** Mercury levels of concern in fish **Trend:** Undetermined	Table App.E.11.1
Fukushima radiation	Buesseler et al., 2012; 2017, Madigan et al., 2012; 2017,Neville et al., 2014	Pelagic	**Status:** No levels of concern **Trend:** Any radiation would diminish over time	
Data gaps	Contaminants in water, sediments, or animals within the sanctuary			

Contaminants in Animal Tissue

Due to a lack of direct measurements of contaminants in sanctuary habitats, contaminants in local harbor seals and fish, as well as organisms from the Fukushima earthquake and radiation event were considered as proxies. Harbor seals are known to swim through and feed in CBNMS (Carretta et al., 2021; Elliott et al., 2019). Mercury levels were measured in harbor seal pups from 2002 to 2017 (Brookens et al., 2007, 2008; Van Hoomissen et al., 2015; McHuron et al., 2019; Figure S.H.11.1). These measurements were taken from stranded animals admitted to the Marine Mammal Center for rehabilitation or animals that were captured and released in the wild along the outer coast of Marin, Sonoma, and Mendocino counties (three counties animals coming from sanctuary waters were hypothesized to use; San Francisco County was not included due to a lack of rookeries). Animals were collected on land, therefore no animals were collected from within the sanctuary. Mercury was present in all sampled harbor seals, and there were no discernable patterns in mercury levels during this study period (note: there were no published data in 2005, 2009, 2010, or 2011). Of concern, many of these pups had levels exceeding 30 µg/g dry weight, which is a threshold at which neurological effects have been observed in other fisheating wildlife (Basu et al., 2007). These data indicate that mercury exists in the environment in close proximity to the sanctuary. However, it is important to note that while these animals may have passed through and/or fed in CBNMS, the contaminants cannot be directly linked to sources within the sanctuary, as they bioaccumulate and may have been picked up throughout the region, such as in San Francisco and Tomales bays, which are known to have elevated levels of mercury (Davis et al., 2002; Hornberger et al., 1999; Martin et al., 1984; Ohlendorf et al., 1988) and where harbor seals are known to occur.

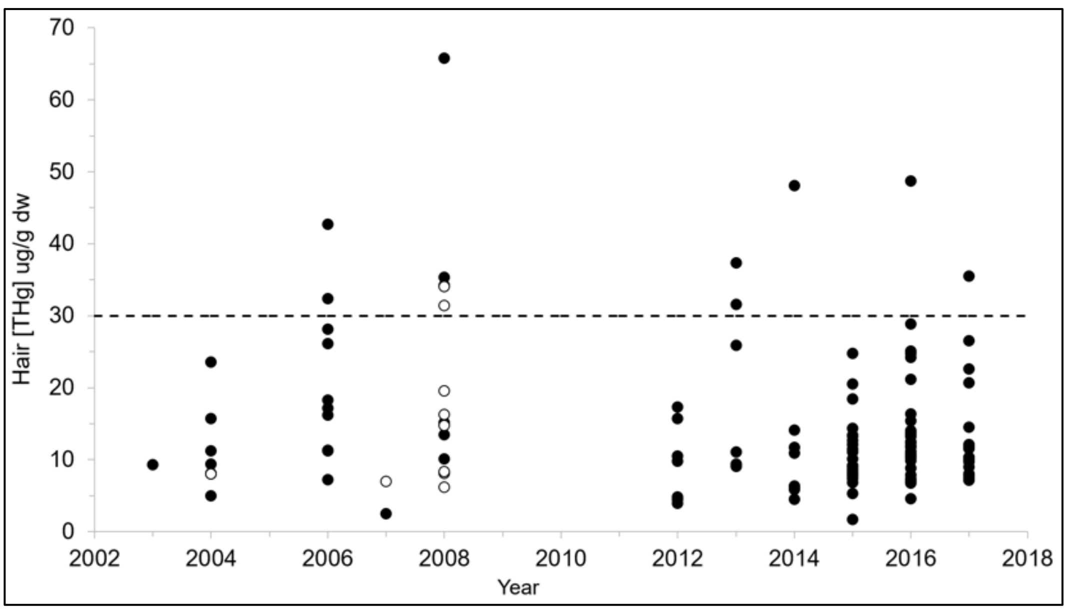


Figure S.H.11.1. Mercury concentrations in the hair of stranded harbor seal pups (*n* = 128) that were admitted for rehabilitation at the Marine Mammal Center (closed circles) or that were captured, sampled, and released in the wild (open circles) along outer coast of Marin, Sonoma, and Mendocino counties (counties located closest to CBNMS). The dashed line indicates the level at which neurological effects have been observed in fish-eating wildlife (Basu et al., 2007). No samples were taken in 2005, 2009, 2010, or 2011. Source: Brookens et al., 2007, 2008; Van Hoomissen et al., 2015; McHuron et al., 2019; Image: Denise Greig/NOAA

As part of a state-wide program that monitors fish for human consumption, contaminant levels were measured in fish from coastal sites between Año Nuevo and Jenner, California (including the Farallon Islands, the only offshore site) in 2009 and 2010 (Davis et al., 2010; Table App.E.11.1). No samples were collected in CBNMS. At each location, five species were sampled (species varied between sampling sites); most species selected had been used previously to detect contamination. At least one species from each sampling location contained levels of mercury that exceeded a threshold for concern and should either be limited or excluded from a person's diet (based on assessment of human health risk by the California Office of Environmental Health Hazard Assessment; Klasing & Brodberg, 2008). Only one species from one site exceeded an Office of Environmental Health Hazard Assessment threshold for concern in PCBs (barred surfperch, which has not been observed in CBNMS and is typically found nearshore). No fish from any sampling sites in the region exceeded the thresholds for DDT, selenium, chlordanes, and dieldrin. These data suggest that fish in the general region, including the sanctuary, could contain concerning levels of mercury, particularly species that are relatively long-lived and prone to bioaccumulation (Davis et al., 2010). However, studies that include samples from CBNMS are required to test this hypothesis, particularly as many of these fish species demonstrate site fidelity.

Fukushima Earthquake

The 2011 Fukushima earthquake and subsequent nuclear accident at the Fukushima Daiichi Nuclear Power Plant in Japan is a source of concern for contamination. The majority of radiation that leaked from the power plant was in the form of radiocesium, which dilutes rapidly and has a short half-life (Buesseler et al., 2017). While radiation impacts have been documented for biota in the nearshore environment in the Fukushima region, current levels are below thresholds considered harmful for human consumption (Buesseler et al., 2012) and are similar to general background fallout from nuclear weapons testing (Buesseler et al., 2017). On the west coast of North America, detectable Fukushima radionuclides were not above pre-incident levels in several predatory migratory species caught from 2012 to 2015 (Madigan et al., 2017) or in fish caught from 2008–2012 (Neville et al., 2014), and most migration-aged fish did not exhibit any radiocesium accumulation, suggesting they had not recently migrated near Japan (Neville et al., 2014). However, the presence of radiocesium in fish (tuna) caught in the Eastern Pacific Ocean indicates additional studies are warranted for migratory fish and marine mammals (Madigan et al., 2012).

Conclusion

Currently, information on contaminants in CBNMS and the surrounding region is sparse, preventing the assessment of status and trend. The regulation prohibiting the discharge of certain types of material into the sanctuary is intended to reduce pollution and contamination; however, many contaminants are widespread throughout the ocean. Additionally, the offshore location and relative inaccessibility of CBNMS may mitigate some of the harmful effects of coastal pollutants and direct human impacts. However, given the sanctuary's proximity to San Francisco Bay, increasing our understanding of contaminants in CBNMS is particularly important. While outflow from San Francisco Bay typically moves southward, strong freshwater runoff or weak winds can cause water to move northward, in the direction of the sanctuary (Largier, 2020). Storm events that are strong enough to bring land-based pollution from San

Francisco Bay or the Russian River are uncommon. What little evidence we have of regional contaminants indicates that legacy contaminants are present in the environment. More work is needed to understand contaminant concentrations, transport pathways, and changes in contaminant concentrations over time, particularly considering that stressors could be exacerbated when combined (e.g., climate change and contamination).

Status and Trends of Living Marine Resources (Questions 12–15)

The following describes the status and trends of living marine resources inside CBNMS from 2009–2021. The term “living marine resources” encompasses a range of organisms in CBNMS, including keystone, foundation, focal, and non-indigenous species. The status for a species describes changes to their abundance compared to their historical abundance. The historical time period used for comparison depends on data availability and differs across indicators. The trend for a species describes changes to their abundances from 2009–2021. Each of the living marine resource questions focus on specific groups of species in CBNMS.

Question 12 evaluates changes to foundation species (e.g., benthic macroinvertebrates, calanoid copepods, and krill), which are critical to maintaining CBNMS’s ecosystem structure, function, and stability over time.

Question 13 is centered around focal species (e.g., whales, seabirds, leatherback turtles, rockfish, benthic fish on Cordell Bank, and benthic fish and invertebrates on shelf habitat), which may not be abundant or be key to CBNMS’s ecosystem function, but their presence and health is important for the provision of economic, cultural, spiritual, recreational, ecological, or conservation-related values and services. Some focal species discussed here (e.g., whales and turtles) are also threatened or endangered and protected under state and/or federal laws.

Question 14 focuses on the impacts of non-indigenous species (e.g., green crabs and other invertebrates), which are not native to the region. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their endemic geographical range. Often having arrived in the sanctuary as a result of human activity, either deliberately or accidentally, their abundance in sanctuary habitats, along with any known ecological impacts, will be discussed. These species are of concern because they have the potential to impact CBNMS’s ecosystem structure and function, at which point they are considered invasive species.

Lastly, Question 15 addresses the status of biodiversity, which is defined as variation of life at all levels of biological organization and commonly encompasses diversity within species (genetic diversity), among species (species diversity), and comparative diversity among ecosystems (ecosystem diversity). Biodiversity can be measured in many ways. The simplest measure is to count the number of species found in a certain habitat or ecosystem, termed species richness. Other indices of biodiversity couple species richness with relative abundance to provide a measure of evenness and heterogeneity. When discussing “biodiversity” in response to Question 15, the report primarily refers to diversity indices and the abundance of species that influence the integrity of food webs and other aspects of ecosystem function.

Table S.LR.12.1. 2009 and 2009–2021 condition report ratings for the living marine resources questions.

2008 Condition Report Questions	2008 Rating	2008–2019 Condition Report Questions	2008–2019 Condition Report Rating
12. Status of key species	▲	12. Keystone & foundation species	Good/Fair ?
13. Condition/health of key species	–	13. Other focal species	Fair ▲▼
11. Non-indigenous species	?	14. Non-indigenous species	Good ?
9. Biodiversity	▲	15. Biodiversity	Good/Fair –

Question 12: What is the status of keystone and foundation species and how is it changing?

Good/Fair ?

Status Description: The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.

Rationale: Foundation species at CBNMS include benthic macroinvertebrates (deep-sea corals and sponges), krill, and calanoid copepods. The abundance and health of corals and sponges appears to be good; however, long-term trends are not known due to a lack of historic baseline data. Krill and copepod abundance and composition fluctuated during the assessment period, particularly in association with marine heatwaves.

Keystone species are organisms on which a large number of other species in the ecosystem depend (Paine, 1969), and their contribution to ecosystem function is disproportionate to their abundance or biomass. We did not identify keystone species as data indicators for CBNMS and focused on foundation species. Foundation species are single species that create locally stable conditions for other species (Dayton, 1972). These are typically the dominant biomass producers (e.g., mussels, hake, anchovy, krill) in an ecosystem, and they can strongly influence the abundance and biomass of many other species. Changes in either keystone or foundation species may transform ecosystem structure through disappearances of, or dramatic increases in, the abundance of dependent species.

Findings From the 2009 Condition Report

A direct comparison between the current rating and the 2009 condition report is not possible because this specific question was not previously addressed (Table S.LR.12.1). However, there were two questions in the 2009 condition report that assessed the status and condition and health of "key species." In 2009, the status of key species was rated fair with an improving trend and the condition or health of key species was rated good and not changing. In 2009, several indicator species appeared to have been negatively impacted by a combination of natural and human-induced forces. However, some (e.g., krill, blue whales, and Cassin's auklet) that feed within the sanctuary exhibited healthy populations that were increasing. Additionally, stock assessments of many overharvested rockfish species that had been declared to be overfished in the early 2000s were increasing. The rating in the current report integrates the status and trends for numerous foundation species, including benthic macroinvertebrates (particularly deep-sea corals and sponges), krill, and calanoid copepods.

New Information in the 2009–2021 Condition Report

We did not identify keystone species, so this section focuses on foundational functional groups, including benthic macroinvertebrates (deep-sea corals and sponges), calanoid copepods, and krill (Table S.LR.12.2). For the 2009–2021 study period, the status of these groups was good/fair (with high confidence) and the trend was undetermined (with high confidence).

Table S.LR.12.2. Summaries for the key indicators related to keystone and foundation species that were discussed during the March 31, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Macroinvertebrates	CBNMS, 2020	Benthic	**Status:** Densities appear to have been good during the reporting time period **Trend:** No trend data	App.E.12.1; App.E.12.2; App.E.12.3
Coral health	Graiff et al., 2019; Graiff and Lipski, 2020a	Benthic	**Status:** Few unhealthy gorgonian corals **Trend:** No trend data	S.LR.12.1; App.E.12.4
Krill abundance	ACCESS, 2021	Pelagic	**Status:** Densities are good but varied during the reporting time period **Trend:** Variable among water temperature regimes	S.LR.12.2
Krill size	ACCESS, 2021	Pelagic	**Status:** Larger krill in cold water years **Trend:** Variable in cold versus warm water years	S.LR.12.3
Krill biomass	Southwest Fisheries Science Center, 2021	Pelagic	**Status:** Good, decreases in 2015–2016 not as low as other areas **Trend:** Increase in 2013–2014, then decrease	App.E.12.5
Zooplankton (copepods)	ACCESS, 2021	Pelagic	**Status:** Generally high abundances of copepods, compositional changes with warm water **Trend:** Increasing	S.LR.12.4
Data gaps	Benthic monitoring data collected consistently using comparable methods			

Macroinvertebrate Abundance on Cordell Bank

CBNMS conducted benthic characterization surveys on Cordell Bank in 2002 through 2005 using the human-occupied submersible *Delta*. As technological advances in underwater survey equipment became available after the publication of the 2009 condition report, sanctuary staff started using ROVs with high-definition video and enhanced LED lights to survey the sanctuary's benthic habitats. Sanctuary research staff also held a workshop in 2016 with local experts to develop a long-term benthic monitoring plan for CBNMS (Lipski & Graiff, 2017). The plan identified stratified random locations on the bank from 70–120 m and fixed locations (hereafter referred to as "fixed sites") on the bank's shallowest reef tops. The fixed sites were established to be repeatedly surveyed in order to track long-term changes in benthic community assemblages.

Two of these shallow reef-top fixed sites are North Point (<70 m depth) and Northwest Ridge (<76 m depth). Densities (per square meter) of foundation species of coral, including California hydrocoral (*Stylaster californicus*), gorgonians (*Chromoplexaura* spp.), and sponges, classified by morphology (foliose and mound), were compared at each fixed site using 2003 submersible data and 2017 and 2018 ROV data. There were significantly more foundation species in the 2017 and 2018 surveys, often more than double the densities of foundation species observed in 2003 (CBNMS, 2021; Figure App.E.12.1, Figure App.E.12.2).This increase could be due to recruitment of new individuals, as a large majority of the foundation species quantified in 2017 and 2018 were small individuals (5–10 cm) that could have recently established on the bank. It is also possible that these smaller individuals were more easily detected and thus quantified due to the advancements in video and lighting technology on the ROV versus the technology used in 2003. Given this uncertainty, quantifying the abundances of benthic invertebrate foundation species will continue to be a part of CBNMS's long-term monitoring surveys at the fixed sites to establish trend data for benthic communities.

A similar analysis was completed for the mid-depth habitats on Cordell Bank (70–120 m), as these habitats have different benthic structure and community assemblages than shallower reefs. The foundation species selected were gorgonians (*Chromoplexaura* spp.) and foliose sponges. Densities (per square meter) were compared for all transects within 70–120 m depth from 2002 and 2003 submersible surveys and 2017 ROV surveys. As on shallow reefs, the mid-depth habitats had higher abundances of macroinvertebrates in 2017 compared to 2002 and 2003 (CBNMS, 2021). The average density of *Chromoplexaura* spp. in 2017 was four times greater than the average density in 2002 and 2003 (Figure App.E.12.3). Additionally, the greatest frequency of *Chromoplexaura* spp. documented in 2017 were single stalked and 5 cm tall (18% of total, n = 751; Graiff et al., 2019). It is possible these are newly established individuals on the bank, although these small individuals may also have been more easily detected and quantified due to advancements in technology. Future ROV surveys will be conducted to detect long-term changes.

Coral Condition

The condition of deep-sea corals and sponges is classified during video analysis to support long-term monitoring of foundation species in CBNMS. Corals and sponges are of interest because they are long-lived and provide structure and habitat for other invertebrates and fish. During characterization, the condition of each coral and sponge is rated as either healthy (<10% dead), unhealthy (10–50% dead), or dead (>50% dead). Other invertebrates (e.g., predators) on the corals and sponges are also documented.

To assess the condition of gorgonian corals on Cordell Bank, the percent of total *Chromoplexaura* spp. in each of the three condition categories was compared from ROV data collected in 2017 (48–119 m) and 2018 (84–55 m; Graiff et al., 2019; Graiff & Lipski, 2020a, CBNMS, 2021a). In 2017 and 2018, 86% and 90% of *Chromoplexaura* spp. were healthy, respectively. Fewer than 10% were classified as unhealthy and less than 5% were classified as dead (Figure S.LR.12.1). Unhealthy or dead gorgonians were usually covered in amphipod tubes, and others had associated zoanthids that colonize dead or dying parts of the coral's skeleton. An unknown ovulid snail (possibly *Simnia* sp.) was also observed on gorgonians, and was most abundant on healthy corals and less abundant on dead or dying corals (Graiff et al., 2019). Ovulid snails are known predators of gorgonian corals (G. Williams/California Academy of Sciences, personal communication, March 18, 2019; Gerhart, 1990; Goh et al., 1999), and zoantharians are known to be parasites on primnoid corals in the northeast U.S., progressively eliminating gorgonian tissue, then using coral sclerites for protection and the coral axis for structure and support (Carreiro-Silva et al., 2017).

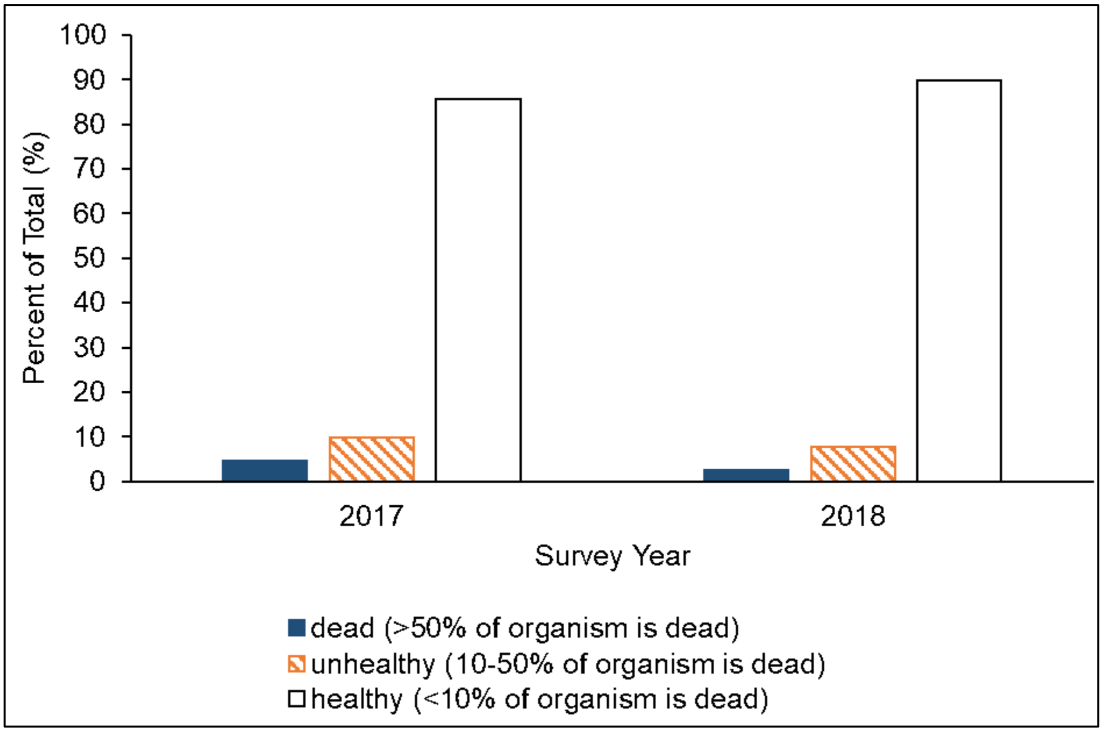


Figure S.LR.12.1. Percent of total *Chromoplexura* spp. gorgonians per condition category, healthy (< 10% of organism is dead), unhealthy (10–50% is dead), or dead (> 50% of organism dead), observed during ROV surveys in 2017 and 2018. Source: Graiff et al., 2019 and Graiff and Lipski, 2020a; Image: NOAA

Although most corals with ovulid snails on Cordell Bank were healthy, it is likely that the snails were grazing on coral tissue, exposing a small area on the axis that could allow other organisms, such as commensal barnacles in the genus *Conopea*, to settle (G. Williams/California Academy of Sciences, personal communication, March 18, 2019). After feeding, the snails typically move on to other healthy corals. This could explain why unhealthy and dying corals were often observed without snails. Conversely, zoanthids and amphipod tubes were always associated with dead or dying corals and likely colonized the structure once the corals' living tissue was eliminated and the axis was exposed. In addition, nudibranchs in the genus *Tritonia* have also been found on octocorals such as *Chromoplexaura* spp., and are presumed to graze on surface tissues (G. Williams/California Academy of Sciences, personal communication, March 9, 2022). To date, nudibranchs preying on *Chromoplexaura* spp. have not been observed on Cordell Bank.

To assess trends in gorgonian condition for this report, videos from submersible surveys at Cordell Bank from 2002–2005 were reviewed, because the condition of invertebrates was not classified during the initial analyses. Unfortunately, coral condition or associations could not be determined due to the low resolution and lighting of the submersible's video. This limited an assessment of trends, but CBNMS will continue to monitor coral condition on future benthic surveys.

Deep-water habitats on the CBNMS slope and canyons were unexplored at the time of the 2009 condition report. ROV surveys conducted in 2017, 2018, and 2019 focused on characterizing the seafloor in the sanctuary's deepest areas (415–3,318 m) and subsequently classifying the condition of all deep-sea corals (Graiff & Lipski, 2020a, 2020b; Graiff & Lipski, 2023). Although a long-term data set has not been established, in general, the majority (>60%) of *Swifita* spp. gorgonian corals observed in 2018 were healthy (Figure App.E.12.4). CBNMS will continue to track the condition and associated taxa for these slow-growing and long-lived species.

Krill

Krill serve as the primary food source for many marine mammals, seabirds, and fish in marine food webs (Murphy, 2001). Large changes in krill abundance and size are related to changing ocean conditions. Krill are monitored in CBNMS and GFNMS by ACCESS. Offshore transect lines in both sanctuaries have been repeatedly sampled via ACCESS since 2004. Krill data are collected along transects using acoustic technologies while the ship is underway and by using collection nets at set sampling stations.

From 2004–2019, densities of krill (*Euphausia pacifica* and *Thysanoessa spinifera*), as measured using acoustic methods, varied and were not correlated with cold, average, or warm temperature regimes (Figure App.E.6.1). Since 2009, overall krill density was highest in 2010, 2011, and 2018, and was lowest in 2012 through 2016 (Elliott et al., 2020; Figure S.LR.12.2).

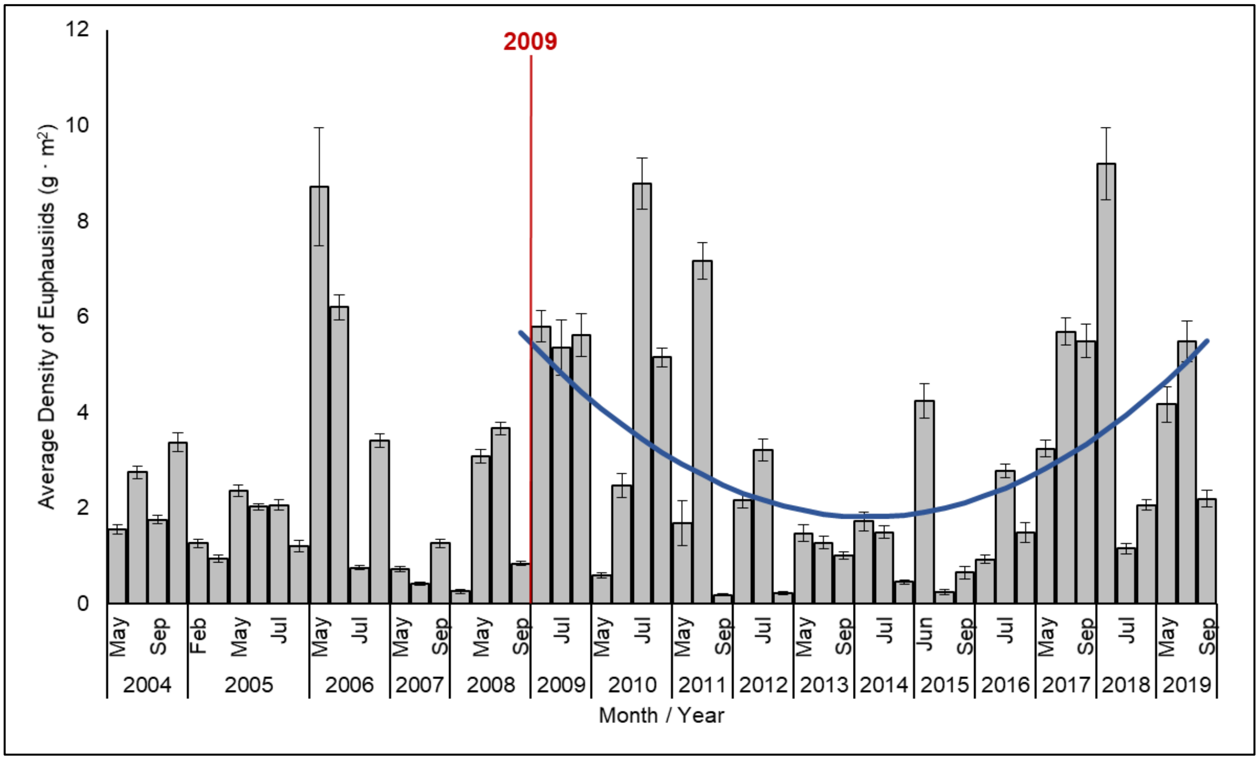


Figure S.LR.12.2. Average densities (grams standardized per square meter of ocean surface ± standard error) of krill (euphausiids) collected using acoustic methods to a depth of 200 m during ACCESS sampling on lines 1–7 in CBNMS and GFNMS. The trendline reflects a polynomial trend for the assessment period of this condition report, 2009–2019. The vertical line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Elliott et al., 2020

The lengths of adult krill (*Euphausia pacifica*) are measured from net samples during ACCESS cruises. Figure S.LR.12.3 shows the length of *E. pacifica* collected during spring and summer surveys from 2005–2019. Smaller adult krill were found during warm water periods (e.g., 2005, 2014, and 2015). In addition to smaller krill, there were fewer adult krill captured during and after the marine heatwave (2013–2017). Changes in krill abundance and size can have impacts on predator species. For example, Cassin's auklets are sensitive to climate-induced changes in prey availability, which can affect the timing and success of breeding (Wolf et al., 2009).

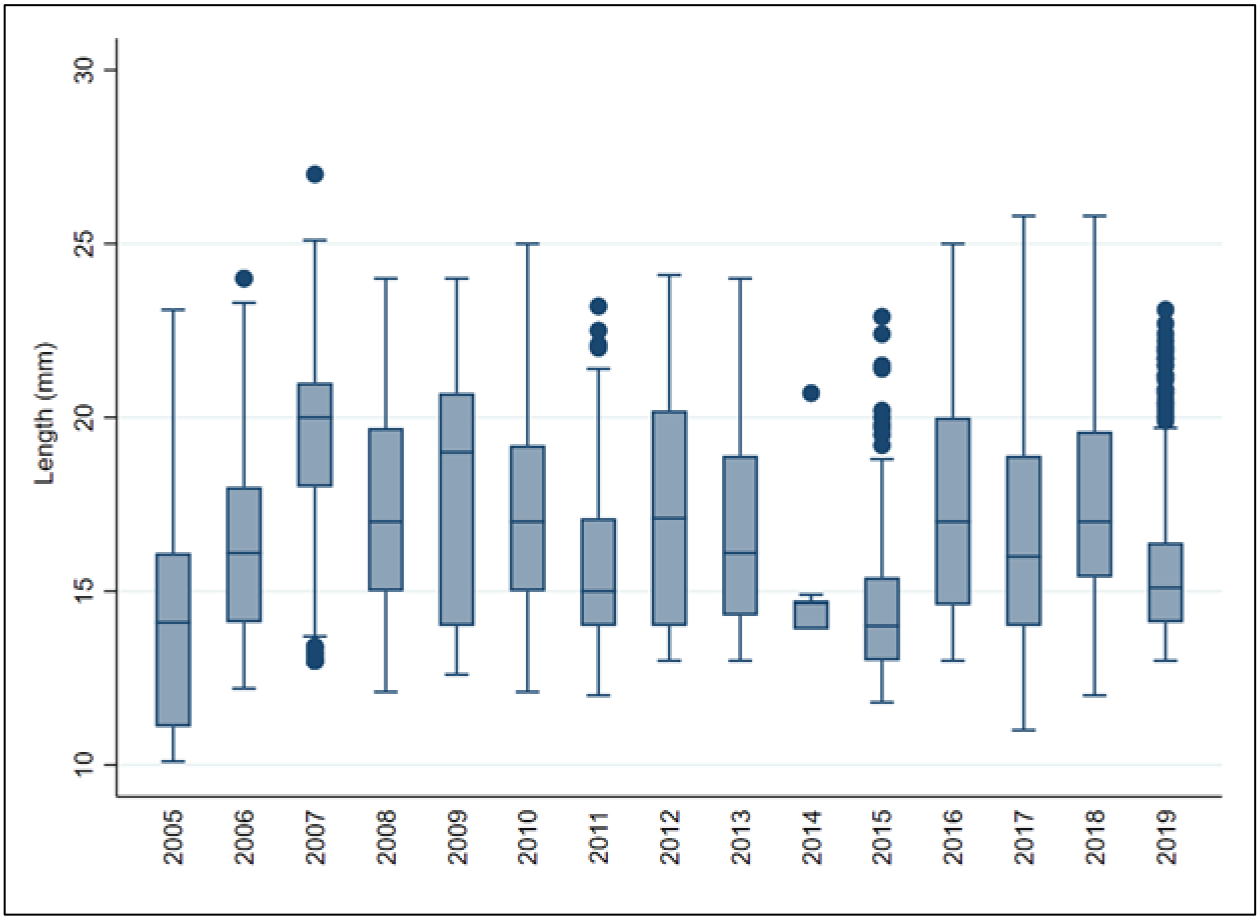


Figure S.LR.12.3. Mean and distribution of adult krill *Euphausia pacifica* length, collected from Tucker trawls during spring and summer ACCESS cruises (May–July) from 2005–2019. Smaller krill were found in warm water periods (2005, 2014, and 2015). Source: ACCESS, 2021; Image: Point Blue Conservation Science

Krill biomass from 2012–2018 acoustic data collected during NOAA Rockfish Recruitment and Ecosystem Assessment Surveys and analyzed by the Farallon Institute shows some variability in CBNMS, and some differences from the ACCESS data. There was a large increase in krill biomass in 2013 and 2014 and decreased biomass for subsequent years through 2018, which was not observed in the ACCESS data (Figure App.E.12.5; Table App.E.12). However, when a larger sampling region, including CBNMS and areas to the south, is considered, 2012–2014 were high to normal krill biomass years, followed by low biomass in 2015–2016 that increased in 2017 to reach high biomass again in 2018. This highlights the natural variability of krill within the sanctuary and spatial or temporal differences in scale and sampling accuracy of surveys. These changes in krill size and biomass as a result of ocean conditions can have impacts on krill predators, including their foraging behavior, condition, and distribution (Croll et al., 2005; Fleming et al., 2016; Jahncke et al., 2008; Santora et al., 2011, 2020), which could be exacerbated with climate change.

Copepods

Calanoid copepods are primary consumers, transferring carbon from primary producers to zooplankton and fish. Copepod species composition is an indicator of seasonal and intra-seasonal variability in oceanographic conditions. ACCESS surveys include hoop net sampling for zooplankton at predetermined stations in CBNMS in the upper 50 meters of the water column. From these samples, copepods are categorized into three main groups based on their common distribution along the west coast of North America. The three main copepod groupings are: cold water boreal species found at higher latitudes (roughly north of 40 °N); transition zone species commonly found in temperate latitudes (about 20–40 °N); and warm water equatorial species found at lower latitudes (about 10–20 °N). Average abundance (number per cubic meter) of copepods from 2004–2015 samples reflected an increasing abundance of multiple species (Figure S.LR.12.4). The highest abundance of copepods were found in samples from 2011, 2014, and 2015. Boreal species were not present in samples from September 2014 through September 2015 (Elliott et al., 2020). These years coincide with the North Pacific marine heatwave.

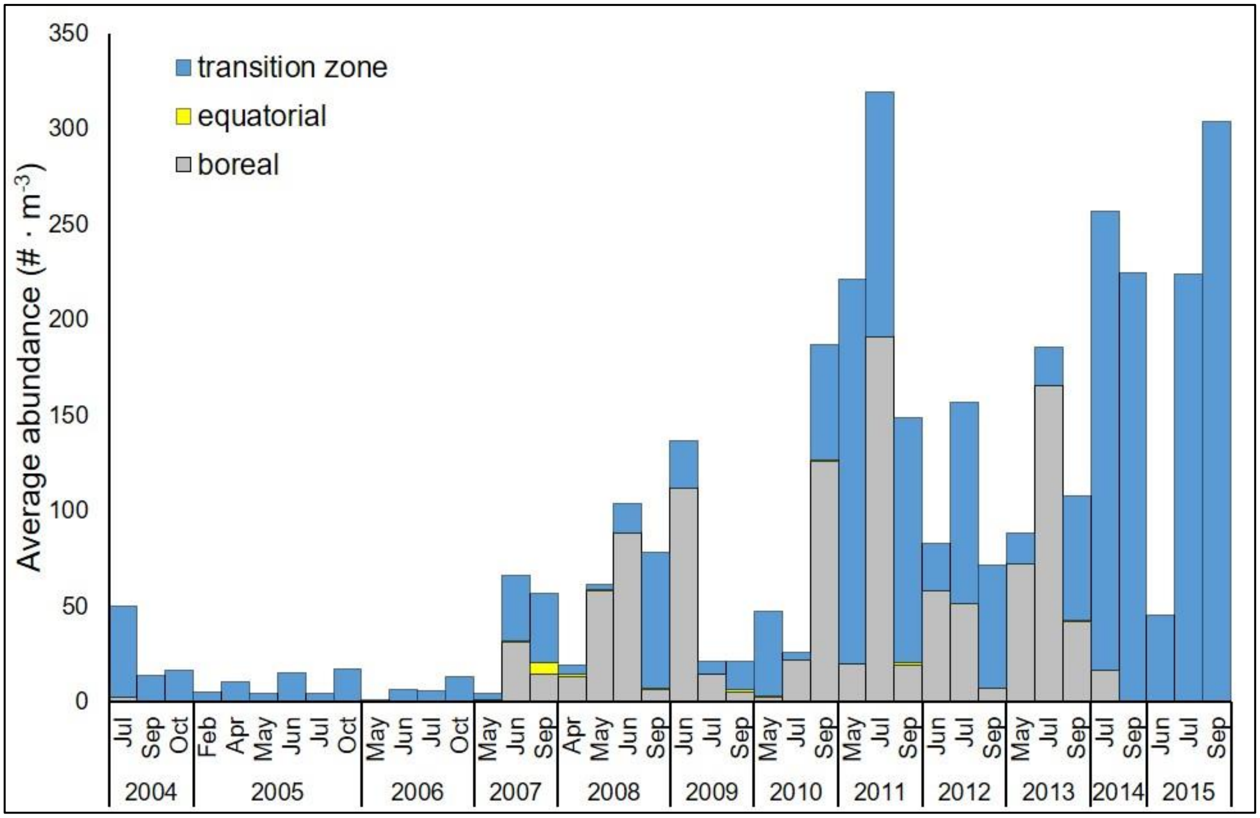


Figure S.LR.12.4. Average abundance (number per cubic meter) of copepods by distribution group (boreal, equatorial, and transition zone) in the upper 50 m of the water column at CBNMS ACCESS stations from 2004–2015. Source: ACCESS, 2021; Image: Elliott et al., 2020

Conclusion

In general, abundances of corals and sponges on Cordell Bank appear to be good. There may be some degradation in coral condition, but the lack of historical data limits confidence in assigning a status rating. Krill and copepod abundances were highly variable in the sanctuary region during the assessment period, which was also a time of high environmental variability (e.g., marine heatwave). There is some concern about the observed increase in variability in the system, including more frequent warm water years and associated decreases in krill size and copepod fat content. The limited availability of long-term data on krill and copepods in the sanctuary region resulted in an undetermined trend.

Question 13: What is the status of other focal species and how is it changing?

Status Description: Selected focal species are at reduced levels, but recovery is possible.

Rationale: Some indicator species are variable, while others are stable and some are declining. Blue and humpback whales are still recovering from past impacts, remain endangered or threatened, and are vulnerable to impacts such as ship strikes and entanglements. Commercially harvested rockfish have improved since the last assessment and are at management targets, but are far below near-pristine levels in the absence of fishing pressure. Seabirds are variable, but there is no evidence of long-term declining trends. Fish and invertebrates on Cordell Bank and the shelf appear stable. However, leatherback sea turtles are at very low abundance throughout their range, and their population has been declining. Because some species appear to be stable, some are variable, and some are declining, the trend was determined to be mixed. [19]

This question targets species of particular interest from the perspective of CBNMS sanctuary management, local partners, and experts. These "focal species" (e.g., whales, seabirds, leatherback sea turtles, rockfish, benthic fish on Cordell Bank, and benthic fish and invertebrates on shelf habitat) may not be abundant or control ecosystem function, but their presence and health is important for the provision of economic, cultural, recreational, ecological, and/or conservation-related values and services. Some species considered here are also threatened or endangered and are protected by state and/or federal laws.

Findings From the 2009 Condition Report

In 2009, this question was included as the status of key species (see Table S.LR.12.1). In this report, the question has been split into two separate questions to address the status of keystone and foundation species and the status of other focal species (see Appendix A for an explanation on changes to the resource questions since the previous report). In 2009, the status of key species was rated as fair and the trend was improving. The taxa considered were: reef top invertebrates, krill, rockfish, sea turtles, Cassin's auklets, black-footed albatross, sooty shearwaters, California sea lions, humpback whales, and blue whales. The report noted, "several of the indicator species appear to have been negatively impacted by the combination of natural and human-induced forces. Substantial or persistent declines, however, are not expected for most of these species and several of the indicator species that feed within the sanctuary exhibit healthy populations that are increasing." For these reasons, the status of key species in 2009 was rated as fair and improving.

---

[19] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, "mixed," was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question based on the combination of trends from available data.

New Information in the 2009–2021 Condition Report

Taxa considered for this new assessment include whales, seabirds, leatherback sea turtles, rockfish, benthic fish on Cordell Bank, and benthic fish and invertebrates on shelf habitat (Table S.LR.13.1).

Table S.LR.13.1. Summaries for the key indicators related to other focal species that were discussed during the March 31, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures and Tables
Whale populations	Carretta et al., 2020	Pelagic	**Status:** Species are endangered and threatened **Trend:** Minor population increases, threats remain	Table S.LR.13.2
Whale density models	Becker et al., 2020	Pelagic	**Status:** Density of blue and humpback whales is high in CBNMS **Trend:** No trend data	Figure App.E.13.1
Whale density (ACCESS)	ACCESS, 2021	Pelagic	**Status:** Blue and humpback whales are common in CBNMS and GFNMS **Trend:** Increasing	Figure S.LR.13.1; Figure S.LR.13.2
Seabirds	ACCESS, 2021	Pelagic	**Status:** Cassin's auklets, black-footed albatross, sooty shearwaters, and pink-footed shearwaters are common in CBNMS and GFNMS **Trend:** Variable, no trend	Figure App.E.13.2–Figure App.E.13.5
Rockfish populations	Pacific Fishery Management Council, 2020	Benthic	**Status:** Species have recovered or are recovering **Trend:** Increasing	Figure S.LR.13.3
Juvenile rockfish	WCGBTS, 2019	Pelagic	**Status:** Abundance is similar to historical levels **Trend:** Peak from 2014–2016	Figure App.E.13.6
Rockfish catch per unit effort	WCGBTS, 2019	Benthic	**Status:** Abundance is similar to historical levels **Trend:** Peak from 2014–2016	Figure S.LR.13.4
Benthic fish (bank)	CBNMS, 2020	Benthic	**Status:** Abundance is similar to historical levels **Trend:** No trend data	Figure App.E.13.7–Figure App.E.13.9
Benthic fish and inverts (shelf)	CBNMS, 2020	Benthic	**Status:** Abundance is similar to historical levels **Trend:** No quantitative trend data, appears stable	Figure App.E.13.10
Data gaps	Data that increases understanding of how CBNMS contributes to wide-ranging populations			

A number of whale species are common seasonally in CBNMS and include blue, fin, humpback, and gray whales (Table S.LR.13.2, Figure App.E.13.1). Other species that are known to be present but are less commonly observed include orca (killer) whales, sperm whales, and beaked whales. Blue and humpback whales are prevalent in the sanctuary seasonally as they migrate along the coast to forage. At a population level, blue whales are endangered and are experiencing low population levels and slow rates of recovery (Carretta et al., 2021; Figure S.LR.13.1). Humpback whales that migrate to CBNMS include the threatened Mexico Distinct Population Segment and endangered Central America Distinct Population Segment (Carretta et al., 2021). Humpback whale populations are slowly increasing (Carretta et al., 2021; Calambokidis & Barlow, 2020). Tagging studies of blue whales (Irvine et al., 2014) and observational surveys during ACCESS cruises indicate that CBNMS contains hotspot habitat along the shelf break for both whale species (Rockwood et al., 2020a) and they are seasonally abundant (Elliott et al., 2020). Both species of whales are vulnerable to ship strikes in and outside CBNMS (Rockwood et al., 2020b), as well as climate-induced changes in foraging and distribution (Gulland et al., 2022). Humpback whales are particularly vulnerable to entanglement in fishing gear, especially when oceanographic conditions compress suitable inshore habitat, resulting in foraging and fishing areas overlapping (Santora et al., 2020; Figure S.LR.13.2). Such habitat compression was observed in the region during the 2014–2016 marine heatwave (Santora et al., 2020).

Table S.LR.13.2. Stock assessment for four whale species that inhabit CBNMS seasonally. Source: Carretta et al., 2020

Species	Minimum Population Size	Stock Assessment Published	Potential Biological Removal*	Trend (Increase Per Year)	Notes
Blue	1,050	August 2020	2.1 total (1.23 U.S. waters)	4%	• Endangered • Rockwood et al. (2017) model suggests 18 deaths annually coast-wide from ship strikes
Humpback (California, Oregon, and Washington)	2,784	August 2020	33.4 total (16.7 U.S. waters)	~8%	• Endangered and threatened distinct population segments • Rockwood et al. (2017) model suggests 22 deaths annually coast-wide from ship strikes; entanglements are also an issue
Fin	8,127	February 4, 2019	81	7.5%	• Endangered
Gray (eastern North Pacific)	25,849	May 15, 2019	801	22%	• Not listed

*Potential Biological Removal is defined as “the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population. The potential biological removal level is the product of the following factors: (A) The minimum population estimate of the stock. (B) One-half the maximum theoretical or estimated net productivity rate of the stock at a small population size. (C) A recovery factor of between 0.1 and 1.0” (16 U.S.C. § 1362).

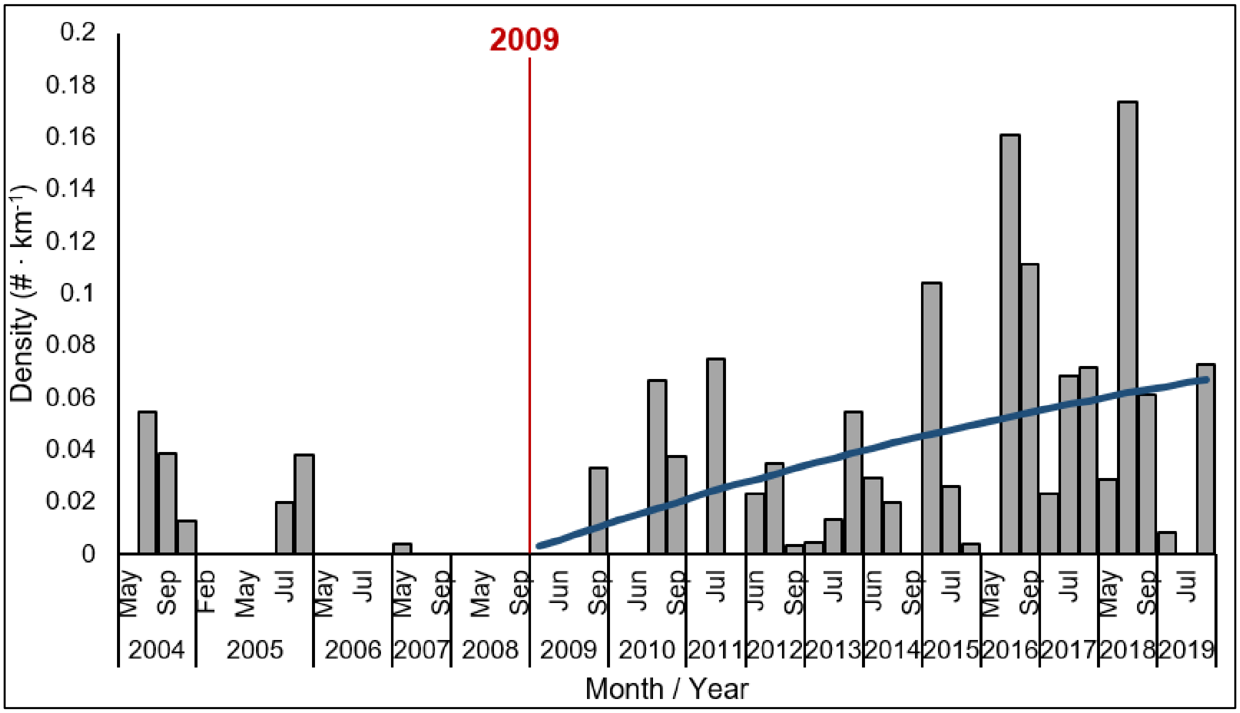


Figure S.LR.13.1. Density of blue whales from boat-based observations as part of the ACCESS project. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

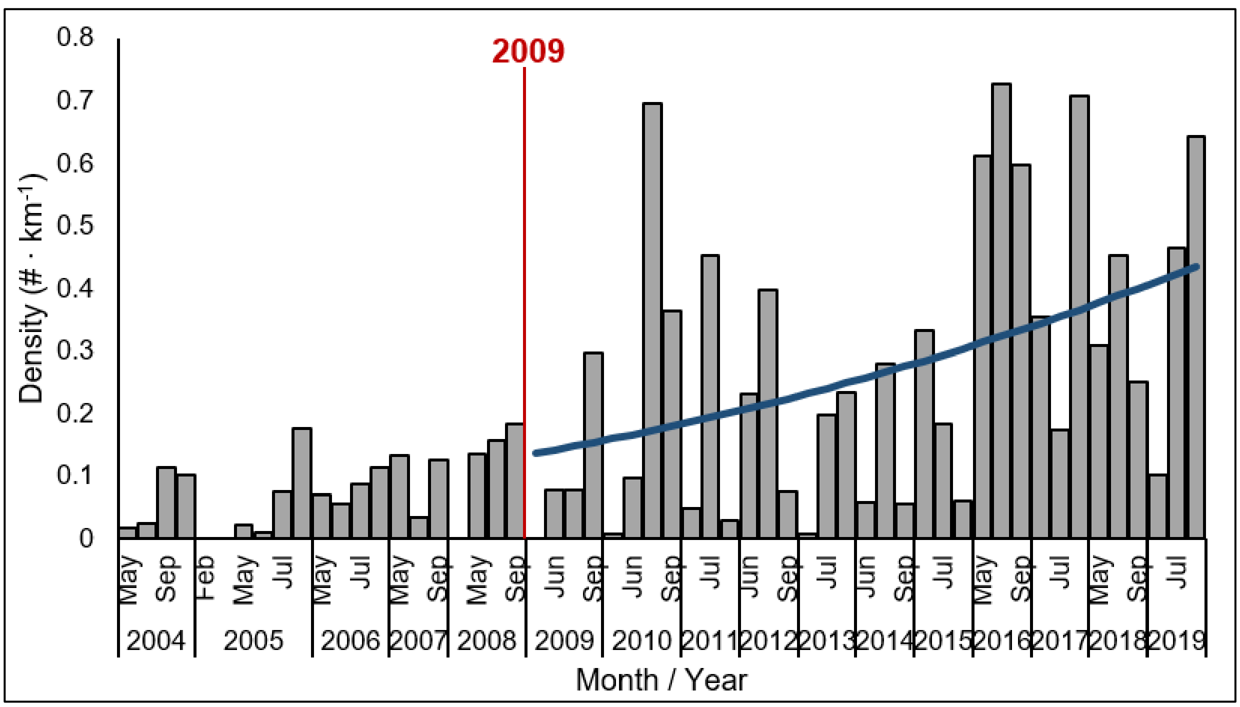


Figure S.LR.13.2. Density of humpback whales from boat-based observations as part of the ACCESS project. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

A number of resident and seasonal seabird species are common within CBNMS. Four species were included as indicator species for this report: Cassin's auklets, black-footed albatross, sooty shearwater, and pink-footed shearwater. Cassin's auklets breed locally, while the other three species migrate from Hawai'i (black-footed albatross), New Zealand (sooty shearwaters), and Chile (pink-footed shearwaters) to forage in CBNMS in the summer and fall. Seabirds are vulnerable to impacts such as to fisheries bycatch and ingesting marine debris (Croxall et al., 2012; Wilcox et al., 2015) and are considered indicators of ecosystem conditions (Piatt et al., 2007). Data from ACCESS show variability in the abundance of all four species, likely as a result of their travel and feeding patterns and coincidence with periodic observational surveys (Elliott et al., 2020; Figure App.E.13.2–Figure App.E.13.5). This variability is not thought to directly correspond to increases or decreases in populations, and was therefore considered cautiously in the rating for this question.

Leatherback sea turtles use CBNMS habitat, particularly the eastern portion of the sanctuary, for foraging and traveling (Benson et al., 2011). Leatherback sea turtles are listed as critically endangered at the federal level (National Marine Fisheries Service & U.S. Fish and Wildlife Service, 2020) and endangered by the state of California (California Natural Diversity Database, 2023) and are at low abundances throughout their range. There has been an estimated 5.6% annual rate of decline in leatherback sea turtle foraging off central California between 1990 and 2017 (Benson et al., 2020). Their complex life cycle and migration from nesting grounds in Indonesia makes them vulnerable to a variety of threats, including entanglement, bycatch, poaching, and habitat degradation at multiple points throughout their life (Tiwari et al., 2013). Bycatch continues to be a risk in California waters in the gill net and fixed gear fisheries (Benson et al., 2020).

CBNMS is home to many species of rockfish that occupy the pelagic habitat and benthic habitat on the bank, shelf, and slope. NMFS samples both juvenile and adult rockfish in CBNMS to inform stock assessments. At the time of the 2009 condition report, NMFS listed seven rockfish species as overfished: bocaccio, canary rockfish, cowcod, darkblotched rockfish, Pacific ocean perch, widow rockfish, and yelloweye rockfish. All of these species occur in CBNMS. At the time of writing this report, six of those species were considered recovered by NMFS (above 25% of virgin biomass) and yelloweye rockfish was classified as "rebuilding" (Pacific Fishery Management Council, 2020; Harvey et al., 2021; Figure S.LR.13.3). Although the threshold for a rebuilt population is far below near-pristine levels, the trajectory does indicate that populations have recovered somewhat since the 2009 report and stocks are improving.

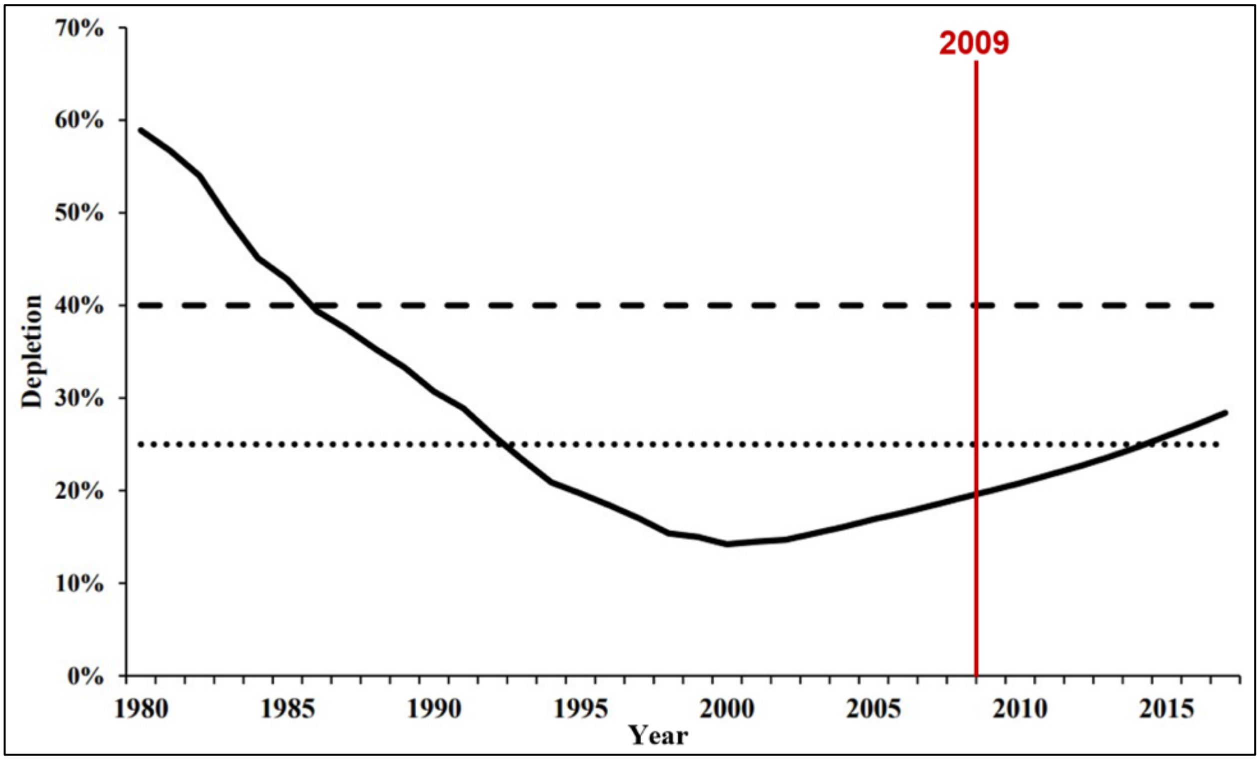


Figure S.LR.13.3. Relative depletion of yelloweye rockfish, the remaining groundfish species in the rebuilding phase. The dashed line indicates the “overfishing” threshold (catch exceeds or is expected to exceed the overfishing limit). The dotted line indicates the “overfished” threshold (the minimum stock size threshold, the default of which is 25% of the estimated unfished biomass level). The vertical red line indicates the year of the last condition report (2009). Source: Pacific Fishery Management Council, 2020

West Coast Groundfish Bottom Trawl Survey data (WCGBTS, 2019) were analyzed by CCIEA using the methods of Harvey et al. (2021) to assess rockfish catch per unit effort (CPUE) on the CBNMS shelf. Rockfish CPUE from 2014–2019 was within 1 standard deviation of the long-term mean and did not increase or decrease more than 1 standard deviation (Figure S.LR.13.4). Mean CPUE during the previous (2003–2008) and current (2009–2019) condition report periods were similar. CPUE on the upper slope had a declining trend, but this was driven by a small peak with high variability in 2016. Slight peaks in CPUE were observed for both the shelf and upper slope in 2016, with an additional increase on the shelf in 2018 and 2019. These data indicate that although there was variability, the status appeared stable and there was no indication of a long-term trend. These results are largely consistent with those observed across a broader region that includes both CBNMS and GFNMS.

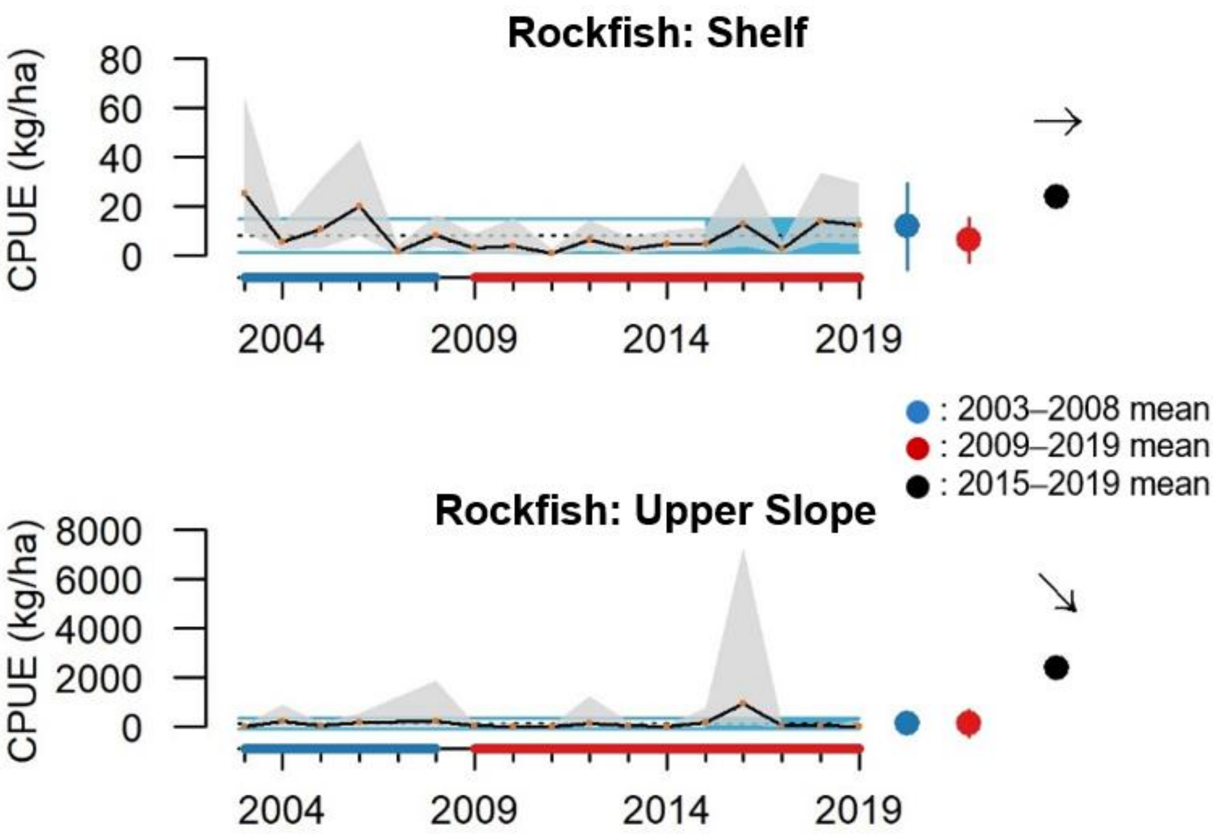


Figure S.LR.13.4. Rockfish CPUE from NMFS groundfish trawls in two CBNMS habitats: the shelf and the slope (NOAA Fisheries, 2019). The gray shading indicates ± 1.0 standard error. The blue and red dots indicate the mean and 95% confidence interval for 2003–2008 and 2009–2019, respectively. The black dots indicate the recent mean (2015–2019) is within 1.0 standard deviation of the long-term mean (2003–2019). The arrows indicate that the trend from 2015–2019 remained stable on the shelf and decreased more than 1.0 standard deviation on the upper slope compared to the full time series. Source: WCGBTS, 2019; Image: CCIEA

Rockfish recruitment is monitored by NMFS through the Rockfish Recruitment and Ecosystem Assessment Survey, which includes sampling in the CBNMS region (Field et al., 2021). Data from this survey were analyzed by CCIEA (Harvey et al., 2021). The long-term trend appeared to be stable, although there were anomalous peaks in 2013–2016 in the region that includes CBNMS and the regions to the north and south. Even with these peaks, the pre-recruit index for 2015–2019 was within 1 standard deviation of the long-term mean. There was a declining trend during this time period, which was driven by the peak in 2015–2016, but otherwise, there was not a concerning trend (Field et al., 2021).

CBNMS uses ROV surveys to characterize and monitor seafloor habitats and species. To evaluate benthic fish on Cordell Bank, species that are commonly observed and tracked in these surveys, like pygmy, rosy, squarespot, and yelloweye rockfish, were examined. A comparison of recent (2017 and 2018) and historical (2003) surveys proved inconclusive due to changes in camera and vehicle technology over the time period. However, the 2017 and 2018 surveys showed that fish on the bank appeared to be abundant and there were no obvious signs of declines, as judged by staff members familiar with the historical and current surveys (Graiff et al., 2019; Graiff & Lipski, 2020a; CBNMS, 2021). Monitoring will continue to better track changes over time.

Recent ROV surveys on the shelf were similarly incompatible with data from camera sled surveys in 2004, so a comparison was not possible. ROV surveys from 2017 and 2018 showed that flatfish and seapens appeared to be abundant and stable, as judged by staff members familiar with the current and historical surveys. The habitat was fairly homogeneous and seapen densities were consistent at about 1 per square meter (Graiff & Lipski, 2020a; CBNMS, 2021a). With only two years of data to compare, it was not possible to determine a trend, but monitoring will continue.

Conclusion

The status of other focal species is fair with a mixed trend. The status is supported by the fact that populations of focal species were reduced from near-pristine conditions (see Appendix A for definition), but most have remained stable or increased since 2009. However, leatherback sea turtles have declined severely. The fact that many protected species still face threats from climate change, ship strikes, entanglement, and/or fishing activity was also considered. The mixed trend was selected due to the improvement of some species and the worsening of others. In addition, there was variability in some taxa, such as seabirds, which can be a result of their transient and episodic occurrences as they follow food sources, as well as the nature of the programs that monitor them, which are typically periodic, boat-based surveys. Much of the information used in this assessment comes from ongoing research and monitoring programs, which are important to continue. Many of the species considered are wide-ranging and transient, and come to CBNMS to forage. Therefore, studies and management efforts that address the population throughout their range, as well as how these species fare locally, are important to understand the status of other focal species.

Question 14: What is the status of non-indigenous species and how is it changing?

Status Description: Non-indigenous species are not suspected to be present or do not appear to affect ecological integrity (full community development and function).

Rationale: Limited data from CBNMS have documented no mature or reproductive populations of non-indigenous taxa, and there is no evidence of detrimental impact. Some species of concern exist in the region, but none have become invasive or exhibited significant growth or expansion in the sanctuary. Adequate data do not exist to assess a trend for non-indigenous species, and there was low confidence due to data limitations.

Findings From the 2009 Condition Report

In the 2009 condition report, the status and trend of non-indigenous species (NIS) were both rated as undetermined, though no NIS were known to exist in the sanctuary at the time (see Table S.LR.12.1).

New Information in the 2009–2021 Condition Report

To assess the presence of NIS in CBNMS for this report, we compared species found in the CBNMS species database, an inventory of species observed within the sanctuary, with sources documenting NIS in the region or those that could be found in CBNMS (Table S.LR.14.1). Data sources for the inventory included reports, peer-reviewed literature, and consultation with experts (Table S.LR.14.2). Since 2009, four confirmed NIS have been observed in the sanctuary: green crab (*Carcinus maenas*), Australian tubeworm (*Ficopomatus enigmaticus*), breadcrumb sponge (*Halichondria panicea*), and crumb-of-bread sponge (*Hymeniacidon perlevis*). Additionally, one cryptogenic species (i.e., there is uncertainty about its native range), the slender ragworm (*Nereis pelagica*), was observed. *Carcinus maenas* has only been observed in larval forms, collected during net tows of pelagic habitats. *Ficopomatus enigmaticus* and *H. panicea* were collected by scuba divers and *H. perlevis* and *N. pelagica* were found on submerged gill nets recovered during a marine debris removal expedition, all of which were located on Cordell Bank. For these species, there has been no documentation of established benthic (mature and/or reproductive) populations, nor has there been any evidence of negative impacts to the environment or native communities. The status of NIS in CBNMS was therefore rated as good. The trend is undetermined due to the low resolution of video imagery and limited specimens collected during benthic ROV surveys. Additionally, the amount of habitat surveyed by ROVs is limited, reducing the power to detect small changes in NIS abundance.

Table S.LR.14.1. Summaries for the key indicators related to non-indigenous species that were discussed during the April 7, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Table
Species observed	See Table S.LR.14.2	Benthic/ pelagic	**Status:** NIS exist in the sanctuary but are not problematic **Trend:** Unknown	Table S.L.R.14.1
Species of concern	See Table S.LR.14.2	Benthic	**Status:** Small number of species of concern **Trend:** Unknown	None
Data gaps	Taxonomic expertise in identifying multiple non-indigenous taxa; continued sampling of biological samples in multiple habitats			

Table S.LR.14.2. Sources consulted on the topic of NIS in CBNMS.

Source	Title/Description
Bullard et al., 2007	The colonial ascidian *Didemnum* sp. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America
Fofonoff et al., 2018	California Non-native Estuarine and Marine Organisms (Cal-NEMO) database
Carlton et al., 2017	Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography
Cordell et al., 2008	Factors influencing densities of non-indigenous species in the ballast water of ships arriving at ports in Puget Sound, Washington, United States
deRivera et al., 2005	Broad-scale non-indigenous species monitoring along the West Coast in national marine sanctuaries and national estuarine research reserves
Frey et al., 2014	Fouling around: Vessel sea-chests as a vector for the introduction and spread of aquatic invasive species
Gulf of the Farallones National Marine Sanctuary, 2014	Non-indigenous species of GFNMS and CBNMS from the GFNMS final management plan
Hanyuda et al., 2018	Genetic identification of macroalgal species on Japanese tsunami marine debris and genetic comparisons with their wild populations
W. Kimmerer/San Francisco State University, personal communication, December 16, 2020	Copepod introductions to the San Francisco Estuary

Source	Title/Description
Lu et al., 2007	Preliminary investigation on aquatic invasive species of marine and estuarine macrobenthic invertebrates on floating structures in five British Columbia harbors
Multi-Agency Rocky Intertidal Network (MARINe), 2021	Multi-Agency Rocky Intertidal Network (MARINe), University of California Santa Cruz
Pederson et al., 2021	2019 rapid assessment survey of marine bioinvasions of southern New England and New York, USA, with an overview of new records and range expansions
Ray, 2005	Invasive marine and estuarine animals of California
B. Rubinoff, A. L. Chang, E. D. Grosholz, & C. Gross/University of California, Davis, personal communication, March 12, 2021	Potential non-native species in CBNMS
Sanctuary Integrated Monitoring Network (SIMoN), 2021	An integrated, long-term program that seeks to identify and understand changes within sanctuaries managed by the Office of National Marine Sanctuaries
Zabin et al., 2018	Non-native species colonization of highly diverse, wave swept outer coast habitats in Central California

It is possible that the sanctuary's offshore location and lack of shallow or emergent habitat may protect CBNMS from some of the problematic coastal species nearby. But vectors of transmission (e.g., shipping and other human uses) and other factors that could promote introductions (e.g., climate change) exist in the sanctuary. For that reason, staff and partners will continue to monitor the sanctuary for pelagic and benthic NIS. Of particular concern, based on observations elsewhere in the region, are the kelp *Undaria pinnatifida* (Silva et al., 2002; Zabin et al., 2009), didemnid tunicates (Bullard et al., 2007), and the bryozoan *Watersipora subtorquata* (Lonhart, 2012; Zabin et al., 2018), all of which can become significant competitors for benthic habitat. For example, the colonial tunicate *Didemnum vexillum*, has smothered areas of George's Bank in the Gulf of Maine (Bullard et al., 2007).

Conclusion

Currently, data on NIS in CBNMS are limited due to low-resolution video imagery and limited amount of habitat surveyed, preventing the assessment of conditions and trend. While four NIS and one cryptogenic species have been observed in the sanctuary, there do not appear to be any detrimental effects on sanctuary habitat. Sanctuary staff will continue to monitor the sanctuary for NIS, particularly for species of concern.

Question 15: What is the status of biodiversity and how is it changing?

Status Description: Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.

Rationale: Pelagic indicators such as zooplankton appear to have recovered; krill and copepod biodiversity returned to average following marine heatwave-induced changes. Groundfish diversity varied, but was stable and consistent across the region. Biodiversity of macroinvertebrates and fish communities on the bank appeared to be stable, yet the ability to detect trends was limited by the lack of long-term data. Knowledge of new species and range extensions in deep-water benthic communities has greatly improved with advancements in survey technologies and the increasing number of exploration missions. Seabird diversity appeared to be stable and changes in species composition reflected natural seasonal variation.

Findings From the 2009 Condition Report

In the 2009 condition report, the status of biodiversity in the sanctuary was rated as fair with an improving trend (see Table S.LR.12.1). The rating reflected changes in oceanic conditions that altered productivity in the sanctuary, with consequent changes in the abundance and distribution of krill, blue whales, and Cassin's auklets. Also considered was the historic depletion of rockfish stocks from overfishing and poor recruitment. While negative impacts were measured for some species, declines were not substantial or persistent. Communities of benthic invertebrates on the bank and shelf and many populations of marine mammals (such as North Pacific humpback whales and California sea lions) were determined to be healthy and increasing.

New Information in the 2009–2021 Condition Report

Zooplankton, groundfish, benthic communities, and seabirds were assessed in order to determine the overall status and trend of biodiversity (Table S.LR.15.1).

Table S.LR.15.1. Summaries for the key indicators related to biodiversity that were discussed during the April 7, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures
Zooplankton	ACCESS, 2021	Pelagic	**Status:** Changes with warm and cold conditions **Trend:** No trend	S.LR.15.1; S.LR.15.2
Groundfish	WCGBTS, 2019	Benthic	**Status:** Some variability in composition **Trend:** Stable overall	S.LR.15.3; S.LR.15.4; App.E.10.5
Benthic community	CBNMS, 2020, 2021a	Benthic	**Status:** Building knowledge of new areas **Trend:** Increasing with more surveys	S.LR.15.5; App.E.15.1; App.E.15.2

Macroinvertebrates	Graiff et al., 2019; Graiff and Lipski, 2020a	Benthic	**Status:** Varies at sites/habitats but appears stable **Trend:** No trend data	App.E.15.3; App.E.15.5
Benthic fish	Graiff et al., 2019; Graiff and Lipski, 2020a	Benthic	**Status:** Appears stable and varies at sites/habitats **Trend:** No trend data	App.E.15.4; App.E.15.6
Seabirds	ACCESS, 2021	Pelagic	**Status:** Appears stable, variability with seasons **Trend:** Stable	S.LR.15.6; App.E.15.7
Data gaps	Investigation of unexplored areas of the sanctuary; long-term trend data to understand baseline conditions			

CBNMS maintains a species inventory database that documents all species with a verified observation in the sanctuary. The species list is the most comprehensive overview of species richness in the sanctuary. A total of 1,820 species have been documented to date, including: 19 species of marine mammals, 254 species of fish (42 of these are rockfish in the genus *Sebastes*), 74 species of seabirds, and at least 1,200 species of invertebrates.

Zooplankton

Zooplankton, such as amphipods, copepods, decapods, and euphausiids (krill), are primary foods for many of the sanctuary's seabird, marine mammal, and fish populations. Net tow sampling has been conducted in the upper 50 meters of the CBNMS water column since 2004 at predetermined stations (as part of ACCESS). Analysis of samples from 2004–2015 indicated that average zooplankton abundance (number per cubic meter) has increased since 2009 (Figure S.LR.15.1). The highest abundances were seen in 2011, 2014, and 2015. Krill and copepods usually dominate the community, but during the 2014 to 2015 heatwave, there were large increases in other zooplankton, including gelatinous zooplankton (doliolids and salps), which dominated the samples during those years (Elliott et al., 2020).

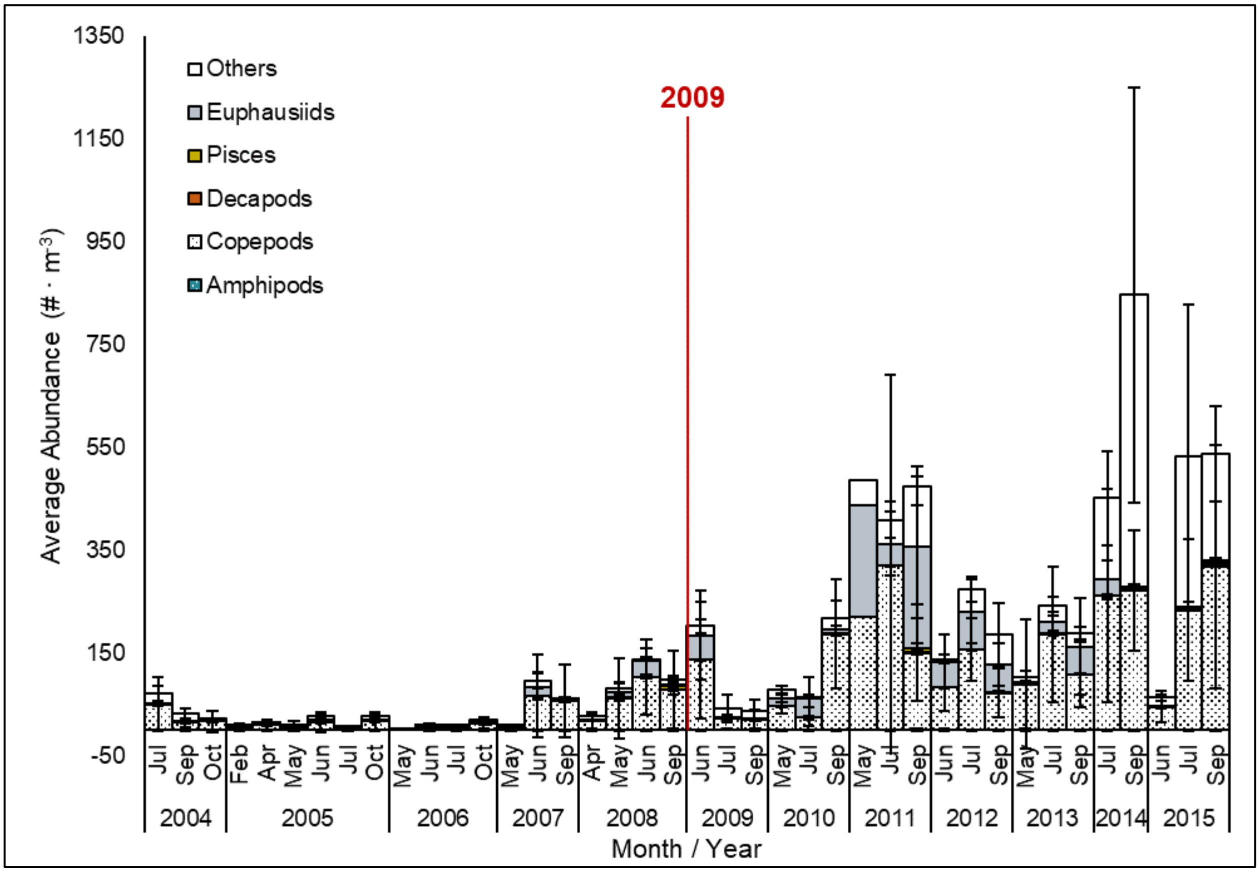


Figure S.LR.15.1. Average abundance (number per cubic meter) and standard deviation of zooplankton groups collected in the upper 50 meters of the water column at CBNMS ACCESS stations from 2004–2015. The vertical red line indicates the year of the last condition report (2009). Pisces, decapods, and amphipods are present in smaller numbers compared to "others," euphausiids, and copepods, and appear negligible in the graph. Source: ACCESS, 2021; Image: Elliott et al., 2020

Natural and climate change-related variation in ocean conditions influences zooplankton communities. As part of ACCESS, zooplankton are sampled using hoop nets in the spring and summer months (April–July). Similarities in zooplankton species composition between sample years were analyzed using non-metric multidimensional scaling (Figure S.LR.15.2). The analysis revealed changes in community composition during the study period. The years 2004–2006 were warm, followed by a cooler period from 2007–2013, each characterized by different relative abundances and productivity in the zooplankton community. The larger and more variable 2007–2013 cluster was attributed to changes in mid-2009 from colder to warmer conditions, which changed zooplankton community structure (Fontana et al., 2016). The North Pacific heatwave occurred in 2014–2015, producing assemblages dominated by tunicates. Such shifts can have large impacts on predator species. Years that had high gelatinous zooplankton abundance corresponded to low baleen whale density (Elliott et al., 2019; Figure S.LR.13.2, Figure S.LR.13.3).

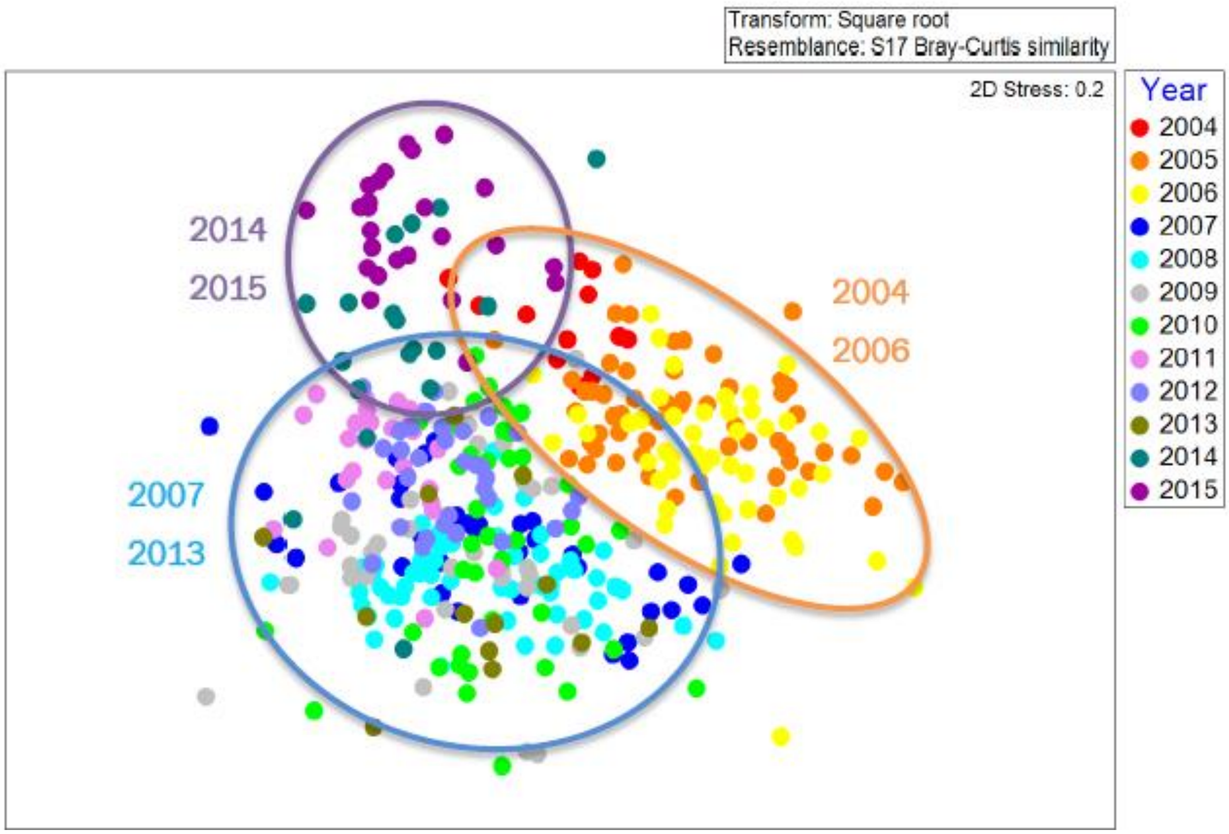


Figure S.LR.15.2. Non-metric multi-dimensional scaling plot for zooplankton species found in net tow samples (points) collected during spring and summer (April–July) ACCESS cruises in 2004–2015. The species composition of each net tow sample was used to calculate the Bray-Curtis similarity index. Samples with similar species in similar abundances are closer together on the plot, while samples that are more dissimilar in species composition and abundances are farther apart. See Figure S.LR.15.1 for zooplankton groups per sampling year. Source: ACCESS, 2021; Image: Elliott et al., 2020

Groundfish

Groundfish include more than 90 different types of roundfish, flatfish, rockfish, sharks, and skates off the West Coast. Groundfish primarily live on or near the seafloor and are fished year-round with a variety of gear types. NMFS conducts the West Coast Groundfish Bottom Trawl Survey to collect fishery-independent data used for stock assessments and groundfish management. Data are collected on the abundance, spatial distribution, sex, length, maturity, weight, and age of groundfish in trawlable shelf and slope habitats along the U.S. West Coast. Trawl datasets from the continental shelf and slope in CBNMS were derived from the West Coast Groundfish Bottom Trawl Survey (WCGBTS, 2019) and analyzed by CCIEA based on the analytical approaches used in NOAA's California Current Ecosystem Status Report (Harvey et al., 2021). To estimate species density, the number of species per trawl (species per area) was calculated and shows similar means in 2003–2008 and 2009–2019. Spatially, in the last five years, the number of species caught on the CBNMS shelf declined (greater than 1.0 standard deviation of the full time series) and the number of species caught on the CBNMS slope was stable (Figure S.LR.15.3).

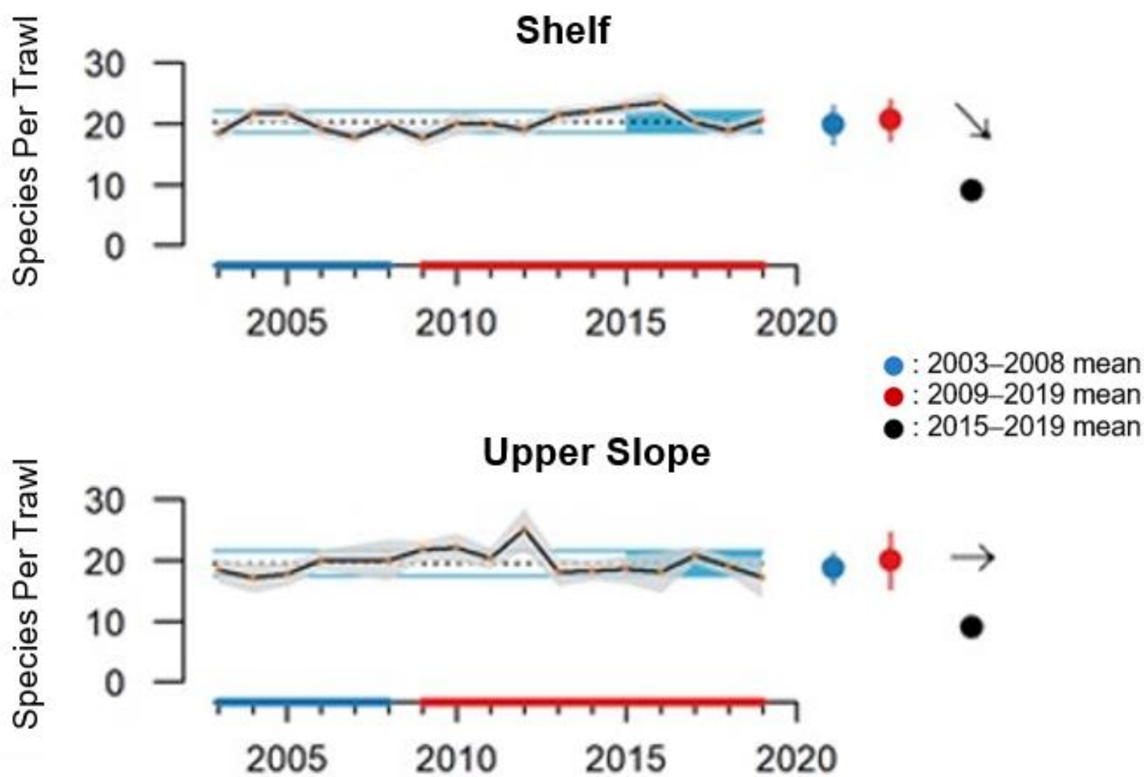


Figure S.LR.15.3. Number of species per trawl collected during the West Coast Groundfish Bottom Trawl Survey from 2003–2019 in CBNMS shelf and upper slope habitats. Horizontal dotted and blue lines behind the data indicate the mean and standard deviation, respectively, of the full time series. The gray shading indicates ± 1.0 standard error. The blue and red dots indicate the mean and 95% confidence interval from 2003–2008 and 2009–2019, respectively. The black dots indicate the recent mean (2015–2019) is within 1.0 standard deviation of the long-term mean (2003–2019), and the arrows indicate the trend from 2015–2019 decreased more than 1.0 standard deviation (shelf) or remained stable (upper slope) compared to the full time series. Image: CCIEA

The mean trophic level of species caught during the West Coast Groundfish Bottom Trawl Survey in CBNMS was also analyzed. Trophic level refers to the position of a given species in a food chain and indicates where species procure energy. The lowest trophic level is composed of primary producers (algae, phytoplankton), the next trophic level is composed of organisms that feed on primary producers, and the highest levels are top predators. Mean trophic level (MTL) is a biomass-weighted average of trophic levels of species that can indicate changes in trophic structure. Mean MTL was similar for the 2003–2008 and 2009–2019 time periods. On the CBNMS continental shelf, MTL ranged from 3.55 to 3.92 and, while variable, MTL was stable over the last five years and was similar to the long-term mean. On the upper CBNMS slope, MTL ranged from 3.51 to 3.83. MTL declined from 2015 to 2019 by more than one standard deviation of the long-term mean, reaching its lowest point across the time series (Figure S.LR.15.4). On the slope, the abundance of many species varied over the last five years. High-trophic-level species like lingcod (*Ophiodon elongatus*) and petrale sole (*Eopsetta jordani*) declined over the last five years on the upper slope, while some lower-trophic-level species like Dover sole (*Microstomus pacificus*) and shortspine thornyhead (*Sebastolobus alascanus*) increased. The combined effects of these changes likely caused the change in MTL on the upper slope.

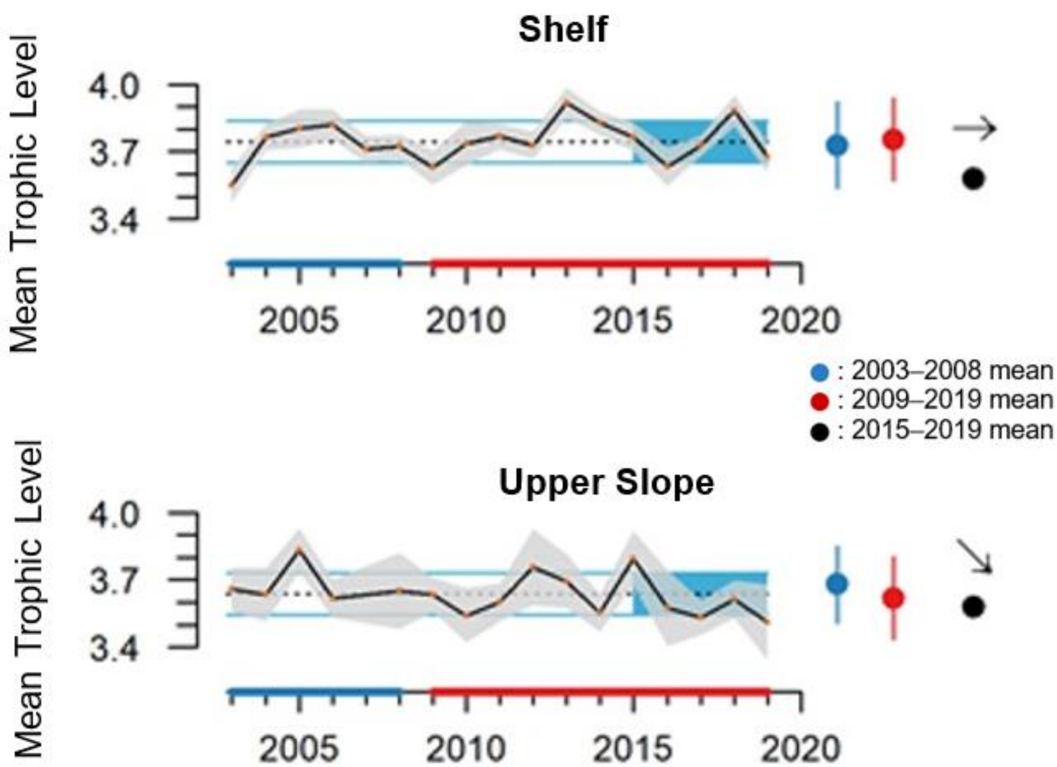


Figure S.LR.15.4. Mean trophic level (biomass-weighted average of trophic levels of species) of groundfish species caught during the West Coast Groundfish Bottom Trawl Survey from 2003–2019 in shelf and upper slope habitats in CBNMS. Horizontal dotted and blue lines behind the data indicate the mean and standard deviation of the full time series. The gray shading indicates ± 1.0 standard error. The blue and red dots indicate the mean and 95% confidence interval from 2003–2008 and 2009–2019, respectively. The black dots indicate the recent mean (2015–2019) is within 1.0 standard deviation of the long-term mean (2003–2019) and the arrows indicate the trend from 2015–2019 was stable (shelf) or decreased more than 1.0 standard deviation (upper slope) compared to the full time series. Image: CCIEA

Benthic Community

Focused effort on species identification in recent years has led to new observations and new range extensions, made possible by improved technologies like high-definition cameras and enhanced lighting and prioritization of new areas of seafloor added to the sanctuary in 2015 (see Figure App.E.15.1, Figure App.E.15.2). New species observations are extremely valuable for tracking long-term changes in community composition.

A New Coral

During an ROV cruise on Cordell Bank in 2018 aboard the NOAA ship *Bell M. Shimada*, a specimen of a small, yellow coral was collected (under sanctuary permit CBNMS-2014-001), identified, and described as a new species, *Chromoplexaura cordellbankensis* (Williams & Breedy, 2019; Figure S.LR.15.5a). *Chromoplexaura cordellbankensis* was thought to be a new record for CBNMS; however, a subsequent review of still images taken from submersible dives at Cordell Bank in 2004 indicates a similar-looking coral that may have been overlooked because of its small size, sparse occurrence, and the limited resolution of the expedition's standard definition video. *Chromoplexaura cordellbankensis* was observed on numerous ROV transects conducted on Cordell Bank in 2017, but attempts to collect a specimen were unsuccessful at that time (Graiff et. al., 2019).

New information about the deep habitats in CBNMS was collected when ONMS collaborated with the Ocean Exploration Trust in 2017 and 2019 to survey the sanctuary using ROV *Hercules* and the exploration vessel *Nautilus*. Many of the species observed in 2017 were found at depths between 740 and 2,700 meters and were new records for the sanctuary; 31 coral taxa and 11 sponge taxa were previously unknown in CBNMS (Graiff & Lipski, 2020b). Notably, the corkscrew coral *Radicipes stonei* was determined to be a range extension from the Aleutian Islands, Alaska (R. Cordeiro/Universidade Federal Rural de Pernambuco & G. Williams/California Academy of Sciences, personal communication, May 17, 2018). A sponge specimen collected at 2,220 meters was described as a new species, *Farrea cordelli* (Reiswig, 2020; Figure S.LR.15.5b).

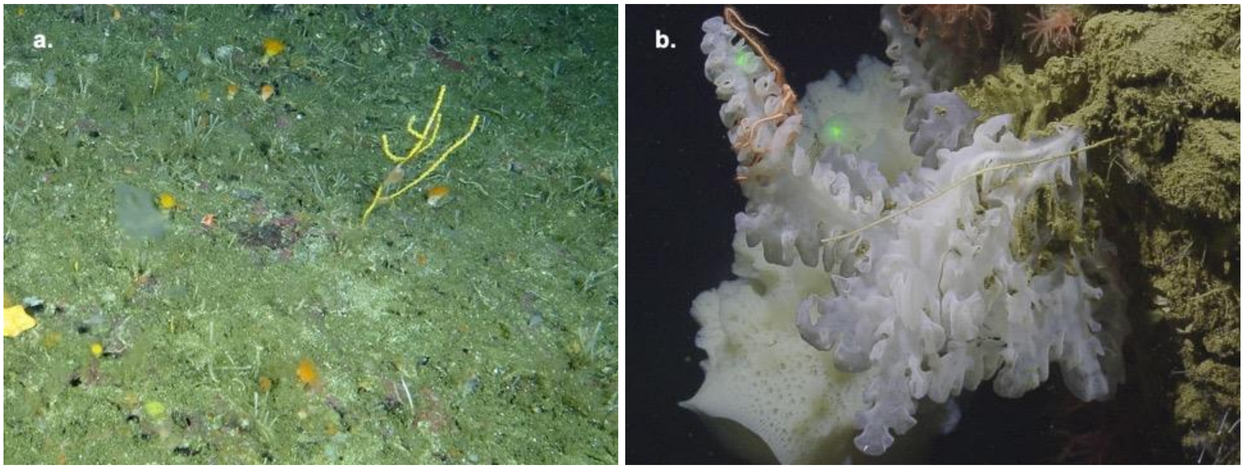


Figure S.LR.15.5. (a) *Chromoplexaura cordellbankensis*, a new gorgonian species and (b) the new sponge species, *Farrea cordelli*, collected at 2,220 m. Photos: (a) NOAA/Marine Applied Research and Exploration, (b) Ocean Exploration Trust/NOAA

New knowledge was gained about the geographical and depth ranges for many sponges. The sponge *Cladorhiza bathycrinoides* was previously known from the Sea of Okhotsk (Pacific coast of the Kurile Islands); the observation of a *C. bathycrinoides* specimen in CBNMS was an astonishing extension of ats least 6,382 kilometers from its previously known geographic range. The stalked sponge, *Caulophacus (Caulophacus) schulzei,* is known to have a wide distribution that includes the Tasman Sea, northern Peru, Ecuador, the Gulf of Panama, central California, and the Bering Sea, at depths of 3,183–4,510 meters. A specimen collected in CBNMS represented a northward range extension of 353 kilometers from Point Conception, California, and also resulted in the first *in situ* image of the species. The barrel-shaped sponge, *Rhabdocalyptus dawsoni,* is well known in the CBNMS region, with a distribution from southern California to Cape Spencer, Alaska, and probably into the Bering Sea at depths of 10–437 meters. However, the *R. dawsoni* specimen collected from CBNMS extended the depth distribution over fivefold, from 437 to 2,113 meters (Reiswig, 2020).

The deepest visual surveys in the sanctuary were conducted in Bodega Canyon (3,318 m) in 2019. Collections of stalked glass sponges (pending identification) and sea pens previously unknown to CBNMS were made (CBNMS, 2019). The depth distribution for at least 13 corals and nine sponges documented in 2019 were the deepest yet recorded in CBNMS. The first record of the tube worm *Lamellibranchia* sp. in CBNMS was also made (at 1,790–1,822 m in an area informally known as "Box canyon"), indicating the presence of methane seeps. All of these new and exciting findings about the benthic biodiversity in CBNMS can be attributed to advancements in technology and the addition of new areas to explore.

The most comprehensive benthic datasets are those from Cordell Bank itself. Benthic survey technologies and methods used on the bank have evolved from submersibles to ROVs, making direct comparisons of the respective datasets difficult. To assess recent biodiversity of the bank's coral, sponge, and fish communities, diversity indices, including species richness, Shannon diversity index, and Pielou's evenness index, were calculated from ROV data collected in 2017 and 2018 (CBNMS, 2021). On a spatial scale, biodiversity on Cordell Bank was similar across sampling sites, and will continue to be monitored during future surveys to establish longer-term trend data (see Figure App.E.15.3, Figure App.E.15.4). Biodiversity trend data are limited. Repeated surveys of designated "fixed" sites on the bank's shallowest reef tops will allow tracking of long-term changes in benthic communities. A comparison of diversity metrics of corals, sponges, and fish at the fixed site North Point indicated similar richness, diversity, and evenness in 2017 and 2018 (see Figure App.E.15.5, Figure App.E.15.6).

Seabirds

Over 50 seabird species have been observed feeding in or near CBNMS. These species include those that breed locally and highly migratory open-ocean species. Seabird species composition and abundances have been recorded annually since 2004 as a part of ACCESS. Diversity of seabirds quantified on transects in CBNMS and GFNMS were calculated for spring (May and June), summer (July and August), and fall (September and October) cruises (Figure S.LR.15.6). Overall, seabird diversity was stable from 2009–2019, and variation was likely attributable to natural processes associated with oceanographic seasonality.

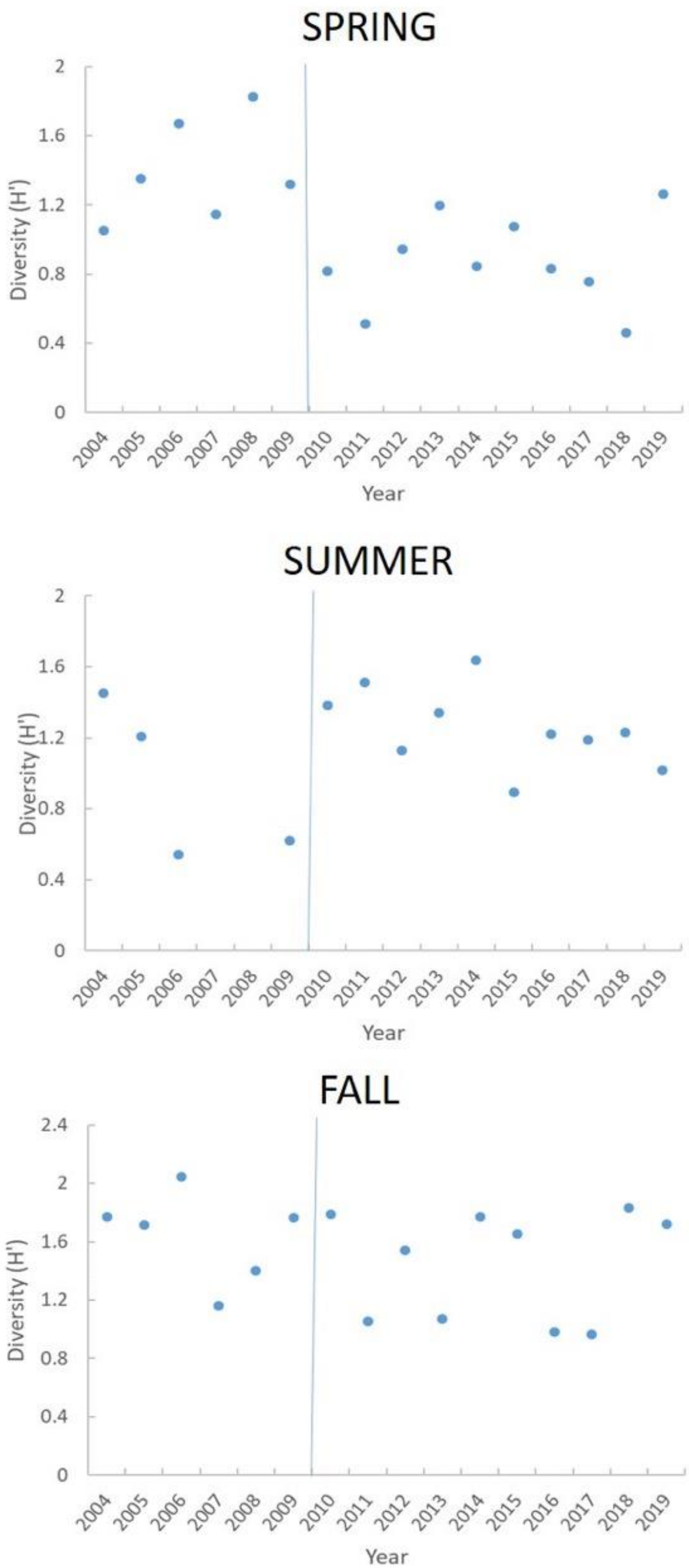


Figure S.LR.15.6. Diversity of seabirds observed during ACCESS cruises in spring, summer, and fall from 2004–2019. The vertical blue line represents the date of the previous condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science/NOAA

Conclusion

The status of biodiversity improved since the 2009 report, largely due to stable diversity for groundfish, benthic invertebrates, and seabird communities in the sanctuary. Natural variation in ocean conditions influences zooplankton diversity and abundance. Notably, zooplankton communities appear to have recovered to typical biodiversity after marine heatwave-induced changes. Time series data are available for indicator groups, but there is no historical information older than 20 years to better understand changes relative to “pristine” conditions, and there is no clear evidence of improving or worsening trends. Advancements in benthic survey technologies have allowed for more effective exploration in the sanctuary, resulting in new species records, identification of new species, and discovery of range and depth extensions, leading to an improved understanding of sanctuary biodiversity.

Status and Trends of Maritime Heritage Resources

The Maritime Heritage Resources section of this report addresses the condition and threats to heritage resources in the sanctuary. Maritime heritage can encompass a wide variety of cultural, archaeological, and historical resources. Archaeological and historical resources are material evidence of past human activities and include vessels, aircraft, structures, habitation sites, and objects created or modified by humans. Cultural resources may include specific locations associated with traditional beliefs or where a community has traditionally carried out economic, artistic, or other cultural practices important to maintaining its historic identity. The majority of existing site information currently describes shipwreck (archaeological/historical) resources. Question 16 assesses the integrity of known maritime heritage resources in the sanctuary. The integrity of a heritage resource refers to its ability to convey information about the past, and can be impacted by both natural events and human activities. Archaeological integrity is generally linked to the condition of the resource, whereas historical significance may rely on other factors.

Table S.MHR.16.1. 2009 and 2009–2021 condition report ratings for the maritime heritage question.

2009 Condition Report Questions	2009 Rating	2009–2021 Condition Report Questions	2009–2021 Condition Report Rating
15. Maritime archaeological resource integrity	?	16. Maritime heritage resource integrity	Undetermined ▼

Question 16: What is the condition of known maritime heritage resources and how is it changing?[20]

Undetermined ▼

Status Description: The status is undetermined.

Rationale: The status rating is undetermined. The one maritime heritage resource documented to be sunk within the sanctuary, the ex-USS *Stewart* (DD-224), has not been specifically located or assessed since it sank in 1946 within what is now the sanctuary (see Sanctuary Setting for more information). It is assumed that the ship has deteriorated to some degree as a result of being submerged in the Pacific Ocean; accordingly, the trend for the condition of the shipwreck is thought to be worsening, most likely due to natural processes, though it is possible the condition may be somewhat influenced by human activities (see question 5 in this report). Note that a confidence score was not assigned to status and trend rating for this question because an actual assessment has not yet been conducted; also, subject matter external experts were not consulted on these ratings.

Findings From the 2009 Condition Report

In the 2009 condition report, this question was also rated undetermined (Table S.MHR.16.1), but for a different reason—there were no documented underwater archaeological sites known to exist within sanctuary boundaries. At the time of the 2009 condition report, the ex-USS *Stewart* (DD-224) was not located within sanctuary boundaries; however, documents indicate that the shipwreck is now within CBNMS following NOAA's expansion of the sanctuary's boundaries in 2015.

New Information in the 2009–2021 Condition Report

Historic conditions on ex-USS *Stewart* (DD-224), a U.S. Navy destroyer, were documented prior to and at the time that it was used in 1946 by the Navy as a target ship (Figure S.MHR.16.1). Records include archival documents, articles, books, news stories, and photographs, and this information serves as a baseline for understanding the ship's condition when it sank in May 1946.

While the vessel did suffer damages and underwent repairs earlier in its history (Klar, 1989), during its service under the Japanese Imperial Navy flag, there were further repairs and modifications, including raising the vessel from a sunken dry dock and repairing battle damage. During its conversion into a Japanese patrol boat, significant changes were made, including trunking the front funnels together into one stack, lowering the stacks, altering the bridge and other structures, and changing the guns and some of the equipment (Edwards, 2010; Tamura, 2015). Once recovered by the U.S. Navy at Hiro Bay, the Navy determined there were health and safety issues on the vessel. It was rat infested, in decrepit condition, dirty, rusty, and had Japanese characters painted on the bulkheads and doors. The Navy had the Japanese clean,

---

[20] A workshop was not convened for the question that asks "what is the condition of known maritime heritage resources and how is it changing?" Archaeological experts with the ONMS Maritime Heritage Program and CBNMS internally evaluated this question. These subject matter experts have been monitoring existing archaeological sites along the West Coast since the 1980s.

paint, and fumigate it (Edwards, 2010; Klar, 1990). Only two boilers were working. On the way back to the U.S, the ship suffered a series of problems, such as mechanical issues with fuel pumps, engine and generator failures, and multiple parted towlines (Edwards, 2010; Klar, 1990). En route to Hawai‘i, a Navy tug accidentally buckled the ship’s starboard well deck bulkhead with its port anchor (Klar, 1990). It arrived in San Francisco Bay in April 1946 and was towed to a dock in Oakland. Due to a lack of available documentation, it is unknown if parts of the ship, its equipment, or contents were salvaged for reuse or disposal.

Figure S.MHR.16.1. Ex-USS *Stewart* (DD-224) on May 24, 1946, just before being sunk. Photo: Official U.S. Navy Photograph, National Archives and Records Administration

On May 24, 1946, the ship was intentionally sunk by the Navy for target practice. Navy patrol craft 799 pumped twelve 40-mm and 17 three-inch shells into the ship from a range of 300 yards after five navy fighter planes fired 18 rockets and thousands of rounds of .50 caliber machine gun bullets at the ship. With gaping holes opened in the side, the ship sank (Associated Press, 1946). Despite this, based on the photographs taken at the time, the ship, though on fire, appeared largely intact, though missing its weapons and radar, as it sank 38.7 miles west of Bodega Head in about 6,000 feet of water (Naval History and Heritage Command, 2021a, 2021b; ONMS, 2014b). *Stewart* has not been assessed since its sinking in 1946 and therefore its integrity is undetermined.

Though the integrity of the wreck has not been determined, the trend for the shipwreck's condition is assumed to be worsening. Physical forces have likely acted upon the ship due to sinking thousands of feet from the surface then contacting submerged lands. Additionally, over 75 years of continued submersion in the ocean has most likely degraded the shipwreck's components via interaction of biological, physical, and chemical processes. As described earlier in this report, a number of variables influence the condition of metal shipwrecks (Wright, 2016), including metal composition, pH, dissolved oxygen, temperature, salinity, and water movement, among others (North & Macleod, 1987). While the chemical makeup of the environment surrounding a submerged site is a primary factor in its preservation, the impacts of ocean acidification on metal corrosion rates, potential effects on organic materials, and implications for artifact stability and equilibrium are not yet well understood (Dunkley, 2015). The water chemistry at a given site affects the corrosion of the metal parts of a shipwreck, which occurs at different rates for different metals, and the amount and rate of concretions and microbial activity must also be considered in determining corrosion for a specific shipwreck (Moore, 2015). Zinc and wrought iron corrodes before metals such as aluminum and brass. Steel is fairly susceptible to corrosion, but these rates are lower in deep/cold water environments (Hoyt, 2020). More acid-soluble metals, such as copper or its alloys, will have a greater sensitivity to ocean acidification, as the alkalinity of seawater hydrolyzes acidic corrosion products, forming patinas that protect the metal surface—a process inhibited by increased acidity (Spalding, 2011). The depth where the ship sank (around 6,000 feet below the surface) suggests that overall microbial activity is likely limited and concretion may not be as prevalent in comparison to shallower shipwrecks (Hoyt, 2020). The deep location of this shipwreck precludes direct disturbance by human activity such as commercial and recreational fishing (bottom trawls do not reach this deep), inadvertent damage by recreational divers, looting, or vessel anchorings.

Conclusion

Although the status of the ex-USS *Stewart* is undetermined, the condition is assumed to be worsening, albeit at a slow pace. ONMS prioritizes the preservation of maritime heritage resources for the benefit of current and future generations and recognizes, as a matter of policy and practice, that *in situ* preservation is a widely accepted approach for resource protection. Notwithstanding the unknown current condition of the shipwreck, it likely continues to retain cultural and historical significance and educational value. Remains of the ship and any ship artifacts, depending on physical condition, may also retain those qualities, along with archaeological value.

Status and Trends of Ecosystem Services

This section summarizes the status and trends of ecosystem services. Virtual expert workshops were convened by CBNMS staff on various dates from May–June, 2021 to discuss seven ecosystem services: commercial harvest, consumptive recreation, non-consumptive recreation, science, education, heritage, and sense of place (see Appendices B and C). It is important to note that, in general, the assessments of the status and trends of key indicators in CBNMS are for the period from 2009–2021. During the virtual workshops, indicators for each topic were presented, accompanied by datasets ONMS compiled prior to the meeting. Attendees were then asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest any additional datasets that may be relevant. Once all datasets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by characterizing: (1) the sources of information they used to make judgments; and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence ratings. Appendix C provides a detailed description of the report development methods.

The following responses for each ecosystem service summarize the key indicators, supporting data sets, and rationale for each status and trend rating. Where published or additional information exists, the reader is provided with appropriate references and web links. Workshop discussions and ratings were based on data available at the time (e.g., through summer 2021). However, in some instances, sanctuary staff later reevaluated and/or incorporated newly available data in order to more accurately describe the current status and trends of resources. Situations where post-workshop rating decisions were made and/or data were used by sanctuary staff to support a rating, but were not presented or discussed during the workshop, are noted in the text.

Ecosystem Services: A Brief Introduction

Ecosystem services are the benefits that humans receive from natural and cultural resources. Generally, the taxonomy of the Millennium Ecosystem Assessment (2005) is used in ONMS condition reports. The Millennium Ecosystem Assessment (2005) was an initiative of the United Nations to assess ecosystem services, including cultural, provisioning, regulating, and supporting services. Categories of ecosystem services include “final” services, which are directly valued by people, and “intermediate” services, which are ecological functions that support final services (Boyd & Banzhaf, 2007). In ONMS condition reports, only final ecosystem services are rated, which is consistent with the anthropogenic focus of the reports and highlights priority management successes and challenges in sanctuaries. The complete definitions of ecosystem services considered by ONMS are included in Appendix B.

Intermediate and Final Ecosystem Services

There are two categories of ecosystem services: intermediate and final. Ecosystem services that are evaluated in condition reports are final ecosystem services. Intermediate services support other ecosystem services, whereas a good/service must be directly enjoyed by a person to be considered a final ecosystem service. For example, nutrient balance leads to clearer water and higher visibility for snorkeling and scuba diving. Nutrient balance is an intermediate service that supports the final ecosystem service of non-consumptive recreation via snorkeling and scuba diving.

Ecosystem Services That May Be Considered in ONMS Condition Reports

Provisioning (material benefits)

1. Commercial harvest — The capacity to support commercial market demand for seafood products
2. Subsistence harvest — The capacity to support non-commercial demand for food and utilitarian products
3. Drinking water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash
4. Ornamentals — Resources collected for decorative, aesthetic, or ceremonial purposes
5. Biotechnology — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use
6. Renewable energy — Use of ecosystem-derived materials or processes for the production of energy

Cultural (non-material benefits)

7. Consumptive recreation — Recreational activities that result in the removal of or harm to natural or cultural resources
8. Non-consumptive recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources
9. Science — The capacity to acquire and contribute information and knowledge
10. Education — The capacity to acquire and provide intellectual enrichment
11. Heritage — Recognition of historical and heritage legacy and cultural practices
12. Sense of Place — Aesthetic attraction, spiritual significance, and location identity

Regulating (buffers to change)

13. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Notably, some consider consumptive recreational fishing as a provisioning service, but it is included here as a cultural ecosystem service. Also, even though biodiversity was listed as an ecosystem service by the Millennium Ecosystem Assessment (2005), ONMS decided to remove it, recognizing that biodiversity is an attribute of the ecosystem on which many final ecosystem services depend (e.g., recreation, harvest); therefore, it is addressed in the State of the Resources section of this report. Lastly, although ONMS listed climate stability as an ecosystem service in 2015, it is no longer considered an ecosystem service in ONMS condition reports because national marine sanctuaries are not large enough to influence climate stability on a large scale (Fisher & Turner, 2008; Fisher et al., 2009).

For CBNMS, seven of the 13 final ecosystem services were: commercial harvest, consumptive recreation, non-consumptive recreation, science, education, heritage, and sense of place. The other six ecosystem services were evaluated by staff, but were determined to not be applicable to the site.

Ecosystem Services Indicators

The status and trends of ecosystem services are best evaluated using a combination of three types of indicators: economic, non-economic, and resource. Economic indicators may include direct measures of use (e.g., person-days of recreation, catch levels) that result in spending, income, jobs, gross regional product, tax revenues, and non-market economic values (the difference between what people pay to use a good/service and what they would be willing to pay). Non-economic indicators can be used to complement economic indicators and include importance-satisfaction ratings for natural and cultural resources, facilities and services for recreation uses, limits of acceptable change for resource conditions, social values and preferences (measured by polls), social vulnerability indicators, perceptions of resource conditions in the present and expectations for the future, and access to resources. Finally, resource indicators are considered in determining status and trend ratings for each ecosystem service. Resource indicators are used to determine if current levels of use are sustainable or are causing resource degradation. If resources cannot support levels of use, this may downgrade a rating that may otherwise be higher based on economic and non-economic indicators alone. Together, these three types of indicators are considered when assessing the status and trends of ecosystem services in national marine sanctuaries.

Provisioning Services (Material Benefits)

Commercial Harvest

The capacity to support commercial market demands for seafood products[21]

Fair

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Some fisheries in CBNMS have been impacted by changing environmental conditions, including ocean temperature shifts and algal blooms, as well as management interventions, such as fishery closures to mitigate whale entanglement risk.

Commercial harvest is defined as the capacity to support commercial market demand for seafood products. These products may include fish, shellfish, other invertebrates, roe, and algae. In CBNMS, commercially targeted species include Dungeness crab, Chinook salmon, and multiple groundfish species, among others (Table ES.CH.1). Data suggest a decline in commercial harvest for several of these species in recent years. Declines in harvest seem to be driven by both environmental conditions and management regulations. For example, commercial Dungeness crab seasons have been curtailed due to elevated levels of domoic acid, as well as the need to mitigate entanglement risk for whales. At the same time, performance of other fisheries has improved in recent years as management interventions, like the Pacific Fishery Management Council's rebuilding plan for over-harvested groundfish stocks, have taken effect. Given that the performance of some fisheries is compromised and additional management actions may be warranted, the status of commercial harvest in CBNMS was rated fair. The commercial harvest trend was rated mixed to reflect varying trends in the stocks of commercially targeted species.

Table ES.CH.1. Summaries for the key indicators related to commercial harvest that were discussed during the June 30, 2021 virtual workshop.

Indicator	Data Source	Data Summary	Figures and Tables
Commercial landings by species	CDFW, 2020a	**Status:** Dungeness crab, Chinook salmon, sablefish, Dover sole, and petrale sole were the top five landed species from 2013–2018. **Trend:** Dungeness crab and sablefish varied, salmon and Dover sole declined, and petrale sole improved slightly.	Table ES.CH.2; Figure ES.CH.2
Fishing vessels and hours	United States Coast Guard, 2021	**Status:** Most activity, regardless of gear type, was concentrated at the eastern boundary of CBNMS. **Trend:** There was an apparent increase in activity over time; however, AIS requirements have changed.	Figure App.F.CH.1

[21] Because of a limited number of experts available to provide input, staff rated this service after the workshop. Therefore, a confidence rating was not assigned.

Indicator	Data Source	Data Summary	Figures and Tables
Fishing vessels and hours	Global Fishing Watch, 2021	**Status:** Most activity, regardless of gear type, was concentrated at the eastern boundary of CBNMS. **Trend:** There was an apparent increase in activity over time; however, AIS requirements have changed. Trawling activity seemed to be fairly stable over time.	Figure App.F.CH.2
Rockfish populations	Pacific Fishery Management Council, 2020	**Status:** Species recovered or were recovering. **Trend:** Increasing population size	Figure S.LR.13.3
Juvenile rockfish	WCGBTS, 2019	**Status:** Abundance is similar to historical levels. **Trend:** Peaks from 2014–2016	Figure App.E.13.6
Rockfish survey data	WCGBTS, 2019	**Status:** Abundance is similar to historical levels. **Trend:** Peaks from 2014–2016	Figure S.LR.13.4
Benthic fish (bank)	CBNMS, 2020	**Status:** Abundance is similar to historical levels. **Trend:** No trend data	Figure App.E.13.7; Figure App.E.13.8; Figure App.E.13.9
Benthic fish and invertebrates (shelf)	CBNMS, 2020	**Status:** Abundance is similar to historical levels. **Trend:** No quantitative trend data, appeared stable	Figure App.E.13.10
Chinook salmon	ONMS, 2014b	**Status:** Threatened **Trend:** California Coastal evolutionarily significant unit was slowly increasing	Figure ES.CH.4
Data gaps	Direct measurements of fishing effort in CBNMS		

The top 10 species by harvest revenue are presented in Table ES.CH.2. Values for harvest revenue and pounds landed represent five-year averages from 2015–2019. The top 10 species harvested from CBNMS[22] were Dungeness crab, Chinook salmon, sablefish, petrale sole, dover sole, longspine thornyhead, market squid, shortspine thornyhead, chilipepper rockfish, and hagfish (CDFW, 2020a). These 10 species accounted for nearly 97% of the total value and 93% of the total pounds landed in the sanctuary from 2015 to 2019. California halibut, which was ranked 11th in overall harvest revenue from 2015 to 2019, was frequently in the top 10 most valuable species for individual years (CDFW, 2020a). While not a significant component of the fishery during the study period, species like Pacific sardine (commercial harvest closed in 2015) and albacore tuna occurred episodically, as they are strongly influenced by oceanographic conditions (Miller et al., 2017; Giron-Nava et al., 2021).

[22] Landings data were available at the level of CDFW's statistical fishing blocks, which are 10 minutes by 10 minutes in resolution. Annual catch and harvest revenue were estimated by grouping the 39 fishing blocks that best correspond to the sanctuary area.

Table ES.CH.2. Top 10 species in CBNMS by harvest revenue (annual average, 2015–2019). Source: CDFW, 2020a

Rank	Species	Harvest Revenue (2021 dollars)	Pounds Landed
1	Dungeness crab	$1,001,530	298,158
2	Chinook salmon	$552,786	90,387
3	Sablefish	$436,353	147,460
4	Petrale sole	$58,587	49,220
5	Dover sole	$56,478	133,925
6	Longspine thornyhead	$36,277	83,885
7	Market squid	$32,343	101,099
8	Shortspine thornyhead	$27,594	21,052
9	Chilipepper rockfish	$15,974	26,949
10	Hagfish	$14,214	19,522

To summarize landings by gear type, commercial records for specific fishing gears were grouped according to the methods described in Leeworthy et al. (2013). Table ES.CH.3 shows a summary of gear types ranked by five-year average harvest revenue from 2015 to 2019. Pot or trap gear, which is employed in the Dungeness crab fishery, accounted for the largest amount of harvest revenue from species captured in the sanctuary (CDFW, 2020a). Pot/trap gear ranked second in terms of pounds landed from the sanctuary, with around 333,000 pounds landed annually. More biomass was landed by trawl gear, which accounted for nearly 364,000 pounds annually (CDFW, 2020a). Following pot/trap gear, the next most valuable commercial gear types by harvest revenue were trolling gear, longlines, trawls, and purse seines. Table ES.CH.3 also summarizes the average annual number of vessels that reported catch with each gear type from 2015–2019, along with standard deviations. Since vessels may report catch using multiple gear types, a single vessel may be counted in multiple gear categories. More vessels reported using trolling gear than any other gear type, followed by pots/traps (CDFW, 2020a). These two gear types also exhibited the highest degree of variability in the number of vessels employing them. Although trawls captured more biomass than any other gear type, relatively few vessels (an annual average of 3.6) reported using trawl gear. An annual average of 21.4 vessels reported catch by hook and line, and an average of 13 vessels reported catch by longlines (CDFW, 2020a).

Table ES.CH.3. Summary of landings and number of vessels by gear type, 2015–2019. Source: CDFW, 2020a

Rank	Gear Type	Harvest Revenue (2021 dollars)	Pounds Landed	Average Number of Vessels	Standard Deviation
1	Pots/traps	$ 1,037,086	333,022	54	18.7
2	Troll	$ 550,630	90,406	72.6	40.1
3	Longlines	$ 368,938	118,155	13	4.3
4	Trawl	$ 256,170	363,961	3.6	0.9
5	Purse seine	$ 61,104	193,005	1	0
6	Other seine/dip nets	$ 41,558	87,088	1.3	0.6
7	Hook/line	$ 39,388	12,307	21.4	7.1
8	Hookah/diving	$ 2,717	429	1	0

Based on VMS records, fishing activity within CBNMS was concentrated in the eastern part of the sanctuary, where the majority of fishing for Dungeness crab and Chinook salmon occurs (National Centers for Coastal Ocean Science [NCCOS], 2020a). The number of commercial trips reporting catch in CBNMS varied without trend from 2012 to 2020 (CDFW, 2020a). No direct measure of fishing effort in the sanctuary was found, although estimating effort for certain fisheries may be possible using VMS records. This presents a data gap, as catch trends cannot be scaled by level of effort (i.e., CPUE cannot be calculated) to indicate trends in the local abundance of target species. Grouping together catch records for all species, there was a statistically significant increase in the total weight landed from CBNMS from 1994 (the first year for which catch records were available) to 2020 (Mann-Kendall test: $\tau = 0.328$, $p = 0.017$; Figure ES.CH.1). This trend is driven, in part, by high harvest years for market squid, Dungeness crab, and groundfish caught by trawl during and after 2010 (Figure ES.CH.2; CDFW, 2020a). From 2012 to 2020, total pounds landed appeared to decline, but the trend was not statistically significant at the 5% level (generalized linear model: coefficient = -73,255, $p = 0.12$; Figure ES.CH.1).

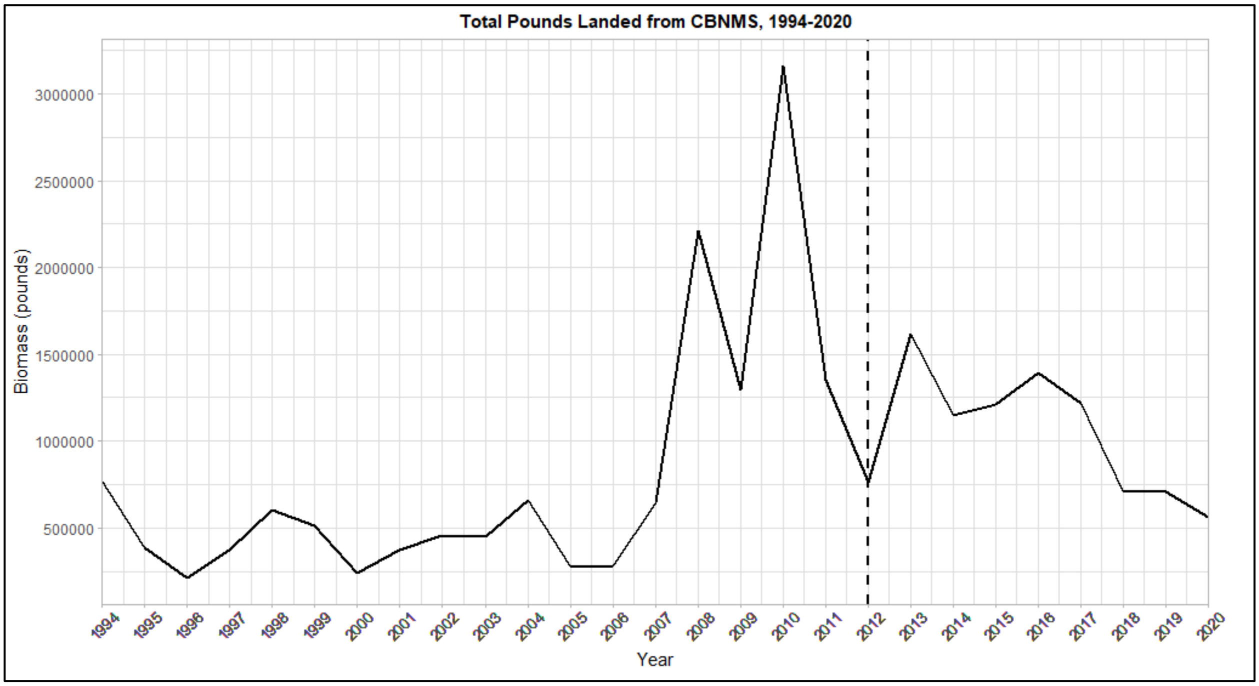


Figure ES.CH.1. Total pounds landed from CBNMS from 1994–2020. Source: CDFW, 2020a

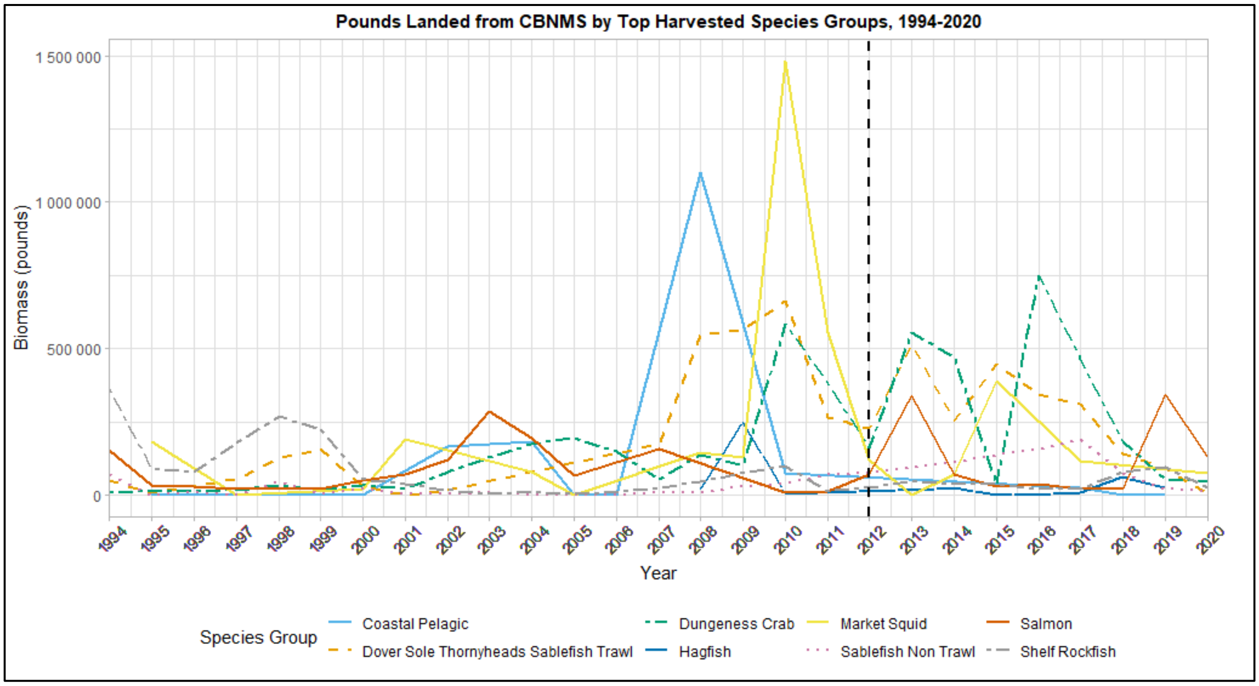


Figure ES.CH.2. Pounds landed from CBNMS by species group from 1994–2020. Source: CDFW, 2020a

The Dungeness crab fishery has been subject to several management actions in recent years. During the 2012–2020 period, there were relatively high Dungeness crab landings in 2013 and 2016 (CDFW, 2020a; Figure ES.CH.3). In 2015, landings decreased to a time series low as elevated levels of domoic acid, a neurotoxin produced by HABs, triggered health advisories and fishery closures for Dungeness crab (California Ocean Science Trust, 2016). Following another peak in 2016, landings decreased to low levels in 2019 and 2020. The fishery was subject to delays and closures in 2019, 2020, and 2021 due to elevated risk of whale and sea turtle entanglement in gears used by the fleet (CDFW, 2019, 2020b, 2021b, 2021c). Another concern for the fishery is ocean acidification, which reduces prey availability, inhibits larval development, and leaves freshly molted crabs vulnerable for a longer period of time (ONMS, 2020c; National Marine Sanctuary Foundation, 2019). The fishery closes during the molting season between August and December, and ocean acidification could lengthen the time needed for closures and reduce the number of crabs reaching adulthood (National Marine Sanctuary Foundation, 2019). Despite these concerns, population estimates indicated that the West Coast Dungeness crab population is stable or increasing (NOAA Fisheries, 2020b; Richerson et al. 2020).

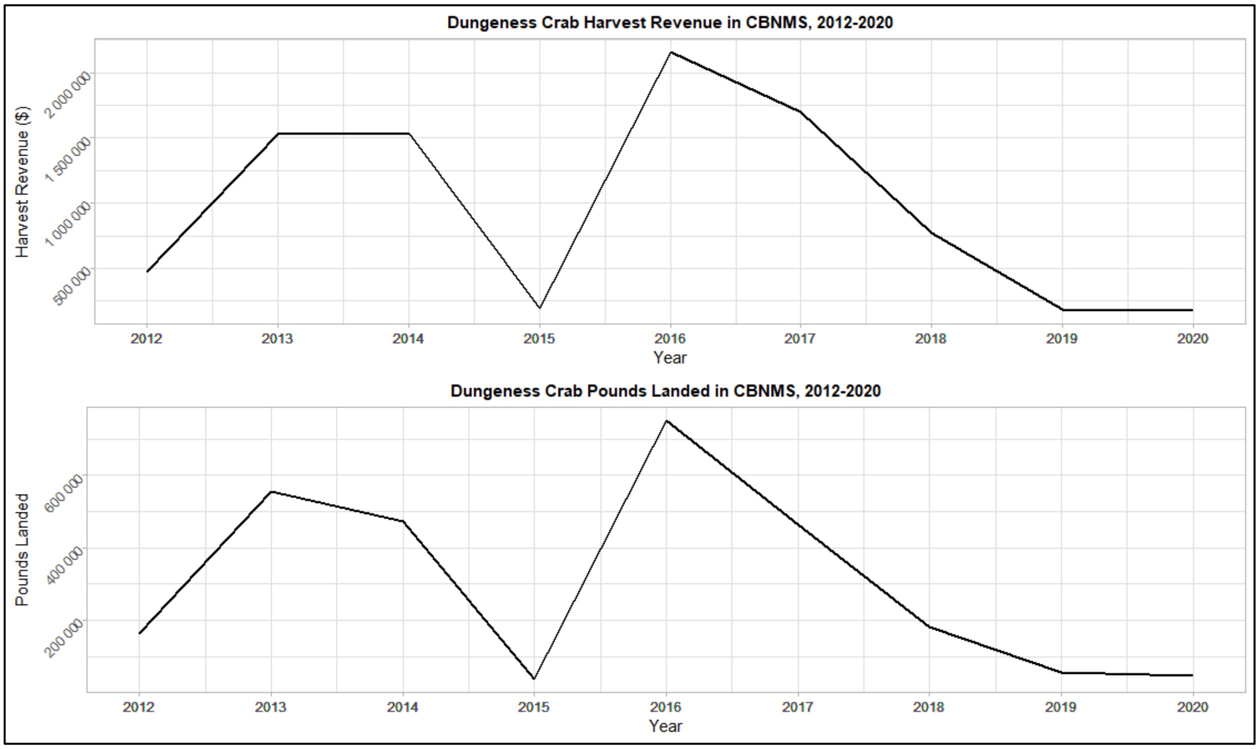


Figure ES.CH.3. Dungeness crab harvest revenue and pounds landed in CBNMS, 2012–2020. Source: CDFW, 2020a

From 2012 through 2020, Chinook salmon harvest peaked in 2013 and 2019 at over 340,000 pounds (CDFW, 2020a; Figure ES.CH.4). Those bumper years were interrupted by a period of low harvest from 2014 to 2018. The Chinook salmon observed in CBNMS belong primarily to the Sacramento River stock. However, other evolutionarily significant units are dependent on sanctuary waters for part of their life cycles as well. Together, these evolutionarily significant units include California Coastal Chinook (threatened, no trend), Central Valley spring-run

Chinook (threatened, stable/increasing trend), Central Valley fall and late-fall Chinook (species of concern, undetermined trend), and Sacramento River winter-run Chinook (endangered, increasing trend; ONMS, 2014b; CDFW, 2023; NMFS, 2016a, 2016b; NOAA Fisheries, 2020c). The harvest trends depicted in Figure ES.CH.4 track closely with trends in statewide harvest, as well as the observed Sacramento Index, a metric representing the total number of adult fall-run Chinook salmon in the ocean that will be harvested or that will escape to spawn in the Central Valley (FISHBIO, 2020; Pacific Fishery Management Council, 2020a).

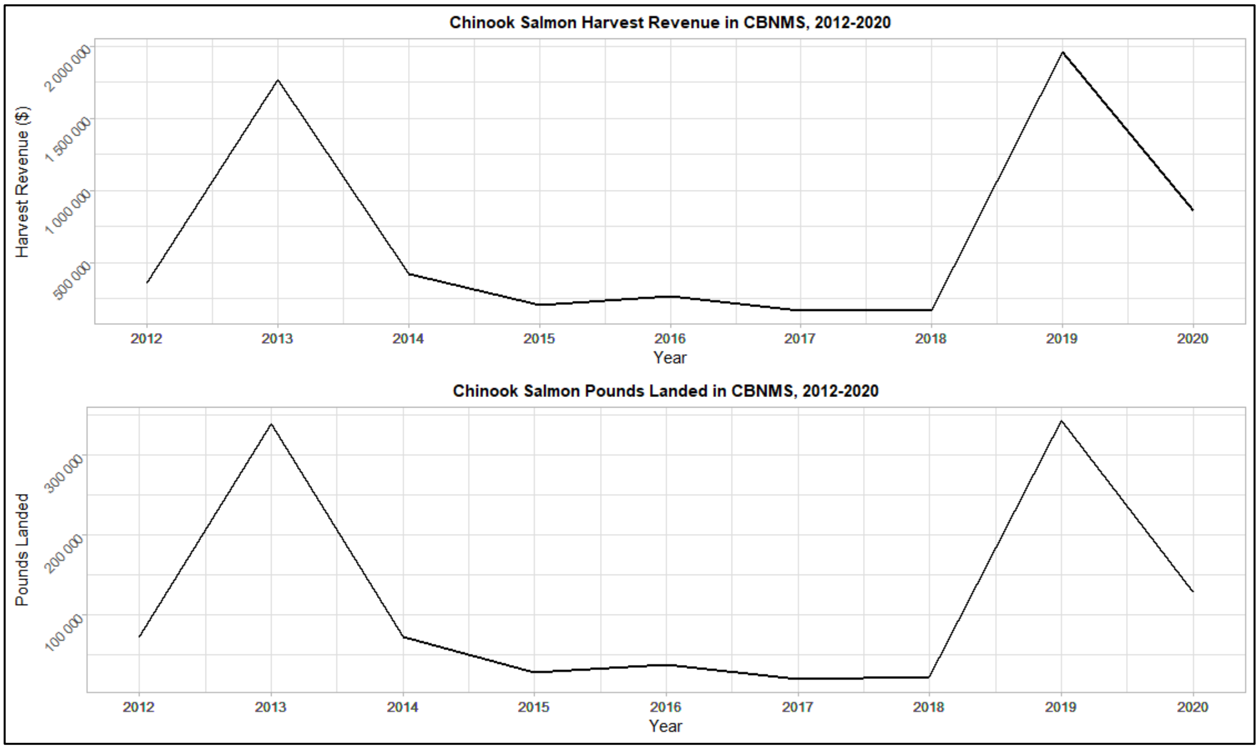


Figure ES.CH.4. Chinook salmon harvest revenue and pounds landed from CBNMS, 2012–2020. Source: CDFW, 2020a

Shelf rockfish landings in CBNMS varied without trend over the 2012–2020 period, peaking in 2019 at over 95,000 pounds (CDFW, 2020a). A number of rockfish stocks declined from the 1980s through the early 2000s as a result of fishing pressure and periodic, environmentally driven recruitment failure (Sanctuary Integrated Monitoring Network, 2020). Commercial fishing has since been limited in several areas of CBNMS as part of the Pacific Fishery Management Council's groundfish rebuilding plan (Pacific Fishery Management Council, 2020b). These closed areas include both Essential Fish Habitat Conservation Areas, which are closures to limit habitat impacts from bottom trawl gear other than demersal seines, and Rockfish Conservation Areas, which are areas where fishing for groundfish is prohibited for three modes of fishing: trawl, non-trawl, and recreational (CBNMS, 2020; ONMS, 2009). Currently, nine of 10 West Coast groundfish stocks are considered rebuilt since being declared overfished or depleted in 1999 (the exception is the yelloweye rockfish stock, which is rebuilding faster than expected; Pacific Fishery Management Council, 2021). The success of the groundfish rebuilding plan suggests potential for increased commercial groundfish harvest from CBNMS in the future.

Generally, fishery management affecting CBNMS has resulted in improvements. The collaborative Dungeness Crab Fishing Gear Working Group is developing measures—ranging from gear modifications to training to risk assessment tools—to reduce whale entanglements while minimizing costs to commercial fishers (California Ocean Protection Council, 2020). NOAA, through a cross-line-office initiative, has worked to develop and implement recovery actions for above-mentioned Chinook salmon evolutionarily significant units (NMFS, 2014). Fishery managers have demonstrated success in achieving the groundfish biomass targets outlined in the Pacific Fishery Management Council's rebuilding plan (Pacific Fishery Management Council, 2021).

Conclusion

While NMFS and CDFW management actions have improved stock levels, there remains a need to continue and improve in some areas of management; for example, restoration of impaired riverine and estuarine habitat, mitigation of human-wildlife conflict, such as reducing entanglement in fishing gear, and adaptation of fisheries management to increasing environmental variability (Brady et al., 2017). As a result, the status of commercial harvest in Cordell Bank was rated fair. The trend was rated mixed: several commercially important stocks are depleted, whereas others are stable or increasing.

Cultural Services (Non-Material Benefits)

Consumptive Recreation

Recreational activities that result in the removal of or harm to natural or cultural resources

Fair –

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: For species such as Chinook salmon, Dungeness crab, and the rockfish complex, enhancing existing management would help to improve resource conditions and satisfy demand. [23]

The status of consumptive recreation is fair and the trend is not changing. Consumptive recreation includes recreational activities that result in the removal of or damage to natural and cultural resources. For CBNMS, this activity is primarily recreational fishing, either by private/rental boats or by commercial passenger fishing vessels (CPFVs; Table ES.CR.1). NOAA Fisheries manages recreational fishing activities; these are not managed by CBNMS. CPFVs include both charter and party boats. The annual number of CPFV angler-days in CBNMS varied without trend from 2013–2019, with a relatively low level in 2016 (CDFW, 2021d; Figure ES.CR.2). The number of pleasure boat registrations in the study area[24] decreased significantly from 2013 to 2018 (California State Parks, 2021). Resource indicators for commonly targeted recreational species show mixed trends, with some depleted stocks undergoing recovery (see State of Living Resources chapter).

Table ES.CR.1. Summaries for the key indicators related to consumptive recreation that were discussed during the June 30, 2021 virtual workshop.

Indicator	Data Source	Data Summary	Figures and Tables
Top recreational for-hire species	CDFW, 2021d	**Status:** Dungeness crab, rockfish (unspecified, black, and blue) and Chinook salmon were the top species kept by CPFVs (2013–2018). **Trend:** The number of Chinook salmon kept by CPFVs showed a U-shaped trend. Overall, there was a slight increase in the number of unspecified rockfish kept, and the numbers of Dungeness crab, black rockfish, and blue rockfish varied without trend. Landings for all top species dipped between 2015–2017.	Table ES.CR.2; Figure ES.CR.1

[23] Because of a limited number of experts providing input, staff rated this service after the workshop. Therefore, a confidence rating was not assigned.

[24] The study area includes Mendocino, Sonoma, Marin, San Francisco, San Mateo, Contra Costa, and Alameda counties. See ONMS (2014).

Indicator	Data Source	Data Summary	Figures and Tables
Jobs, income, and GDP supported by CPFVs	CDFW, 2020a	**Status:** CPFVs continue to support a nominal amount of economic activity. **Trend:** Indicators of economic activity varied without trend, but economic activity in the study area (see Footnote 24) was lower from 2015–2017, consistent with state-level trends.	Table App.F.CR.1
Unique fishing vessels with AIS	United States Coast Guard, 2021	**Status:** On average from 2013–2019, there were around 48 fishing vessels using AIS in CBNMS each year, including commercial fishing vessels. **Trend:** The total number of unique fishing vessels and hours spent within CBNMS increased over the study period.	Figure S.HA.4.5
CPFV angler-days	CDFW, 2021d	**Status:** The number of CPFV angler-days in CBNMS ranged from roughly 200 to 550. **Trend:** No significant trend	Figure ES.CR.2
Rockfish populations	Pacific Fishery Management Council, 2020	**Status:** Species have recovered or are recovering. **Trend:** Increasing population size	Figure S.LR.13.3
Juvenile rockfish	WCGBTS, 2019	**Status:** Abundance is similar to historical levels. **Trend:** Peaks from 2014–2016	Figure App.E.13.6
Rockfish survey data	WCGBTS, 2019	**Status:** Abundance is similar to historical levels. **Trend:** Peaks from 2014–2016	Figure S.LR.13.4
Benthic fish (bank)	CBNM, 2020b	**Status:** Abundance is similar to historical levels. **Trend:** No trend data	Figure App.E.13.9
Benthic fish and inverts (shelf)	CBNMS, 2020	**Status:** Abundance is similar to historical levels. **Trend:** No quantitative trend data, appears stable	Figure App.E.13.10
Data gap	Potential users' knowledge, attitudes, and perceptions		

There are several types of boats that may be used in recreational fishing: private, rental, charter, and party boats. A private boat belongs to an individual, and is not for rent or use by paying passengers. A rental boat is rented by an individual, without a crew or guide. A CPFV falls within one of two categories: (1) a charter boat, which operates under charter for a specified price, time, etc.; (2) a party boat, which provides fishing space and privilege for a fee per recreational fisher (Leeworthy & Schwarzmann, 2015).

The top ten species kept by CPFVs are presented in Table ES.CR.2. During the study period, the most commonly kept species was Dungeness crab, followed by unspecified rockfish, Chinook salmon, and black rockfish. However, when considered together, the rockfish complex was the most landed recreational target by CPFVs. Blue rockfish and lingcod were also commonly captured in the sanctuary, along with canary rockfish, albacore tuna, white croaker, and striped bass.

Table ES.CR.2. Top 10 species kept by CPFVs from 2013–2018. Source: CDFW, 2021d

Species	Number Kept
Crab, Dungeness	1,730
Rockfish, unspecified	1,396
Salmon, Chinook	1,150
Rockfish, black	1,033
Rockfish, blue	684
Lingcod	522
Rockfish, canary	271
Tuna, albacore	190
Croaker, white	170
Bass, striped	168

Figure ES.CR.1 shows trends in the top five most kept species caught by CPFV anglers from 2013 to 2018. Low levels of Dungeness crab catch in 2015 and 2018 coincided with health advisories to avoid consumption of crab viscera due to high concentrations of domoic acid (Joint Committee on Fisheries and Aquaculture, 2016; CDFW, 2018; Figure ES.CR.1). In 2021, for the first time ever, recreational crabbers were prohibited from using traps during the Dungeness crab season in an effort to mitigate adverse interactions with whales and sea turtles; hoop nets and snares could still be used (CDFW, 2021b). Chinook salmon catch by CPFVs showed a gradual U-shaped trend over the study period, with higher levels of harvest in 2013 and 2018 (Figure ES.CR.1). Chinook salmon stocks found in the sanctuary (California Coastal, Central Valley spring-run, Central Valley fall and late-fall, and Sacramento River winter-run) were listed as either endangered, threatened, or species of concern, and stocks have shown mixed progress toward recovery (ONMS, 2014b; CDFW, 2023; NMFS, 2016a; NMFS, 2016b; NOAA Fisheries, 2020c).

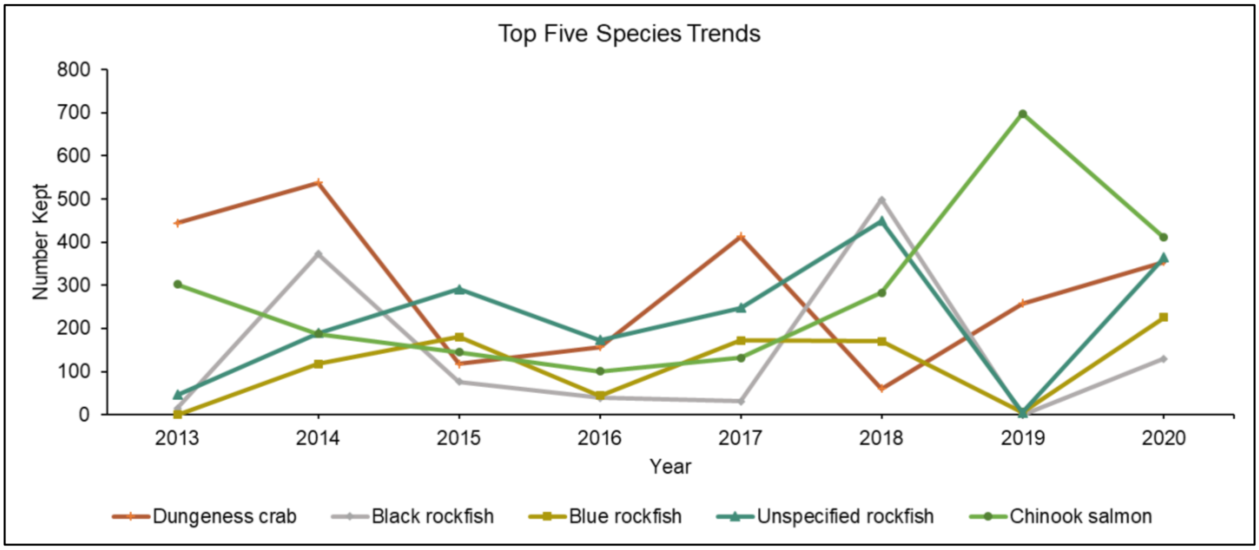


Figure ES.CR.1. Trends in top species kept by CPFVs from 2013–2018. Source: CDFW, 2021d

Catch of unspecified rockfish by CPFVs generally increased over the study period (Figure ES.CR.1). Black rockfish catch peaked in 2014 and 2018, with low levels of catch from 2015 to 2017 (Figure ES.CR.1). Blue rockfish catch varied without trend from 2014 to 2018, with relatively low catch by CPFVs reported in 2016 (Figure ES.CR.1). Much of Cordell Bank is closed to recreational fishing for rockfish (along with most other groundfish species), including in all waters less than 100 fathoms (50 C.F.R. § 660.360). According to the Pacific Fishery Management Council, nine of 10 West Coast groundfish stocks have recovered to target levels as defined in the Council's groundfish rebuilding plan (Pacific Fishery Management Council, 2021). The remaining stock, yelloweye rockfish, is recovering faster than expected (Pacific Fishery Management Council, 2021).

The 2016 fishing season was characterized by relatively low levels of CPFV catch for the top five most kept species. This corresponded with a decrease in effort that year, as measured by the number of CPFV angler-days inside CBNMS (Figure ES.CR.2). One explanation for low effort in 2016 is weather conditions: the winter season of 2016 had more hours under Small Craft Advisory conditions than any other season from 2009–2020 (National Data Buoy Center, 1971). Ocean conditions were also poor in 2016, with low productivity as a result of the prolonged marine heatwave that began in 2014. Two of the top recreational fisheries, Dungeness crab and salmon, had very poor years in 2016. Additionally, 2016 was an off year in terms of the economic contribution of CPFVs using the sanctuary—only $9,250 of income was generated by CPFV activity in the sanctuary in 2016 compared to a five-year average (2014–2018) of nearly $22,000 (see Table App.F.CR.1). Excluding 2016, the average economic contribution from 2014–2018 was roughly $24,900 in income.

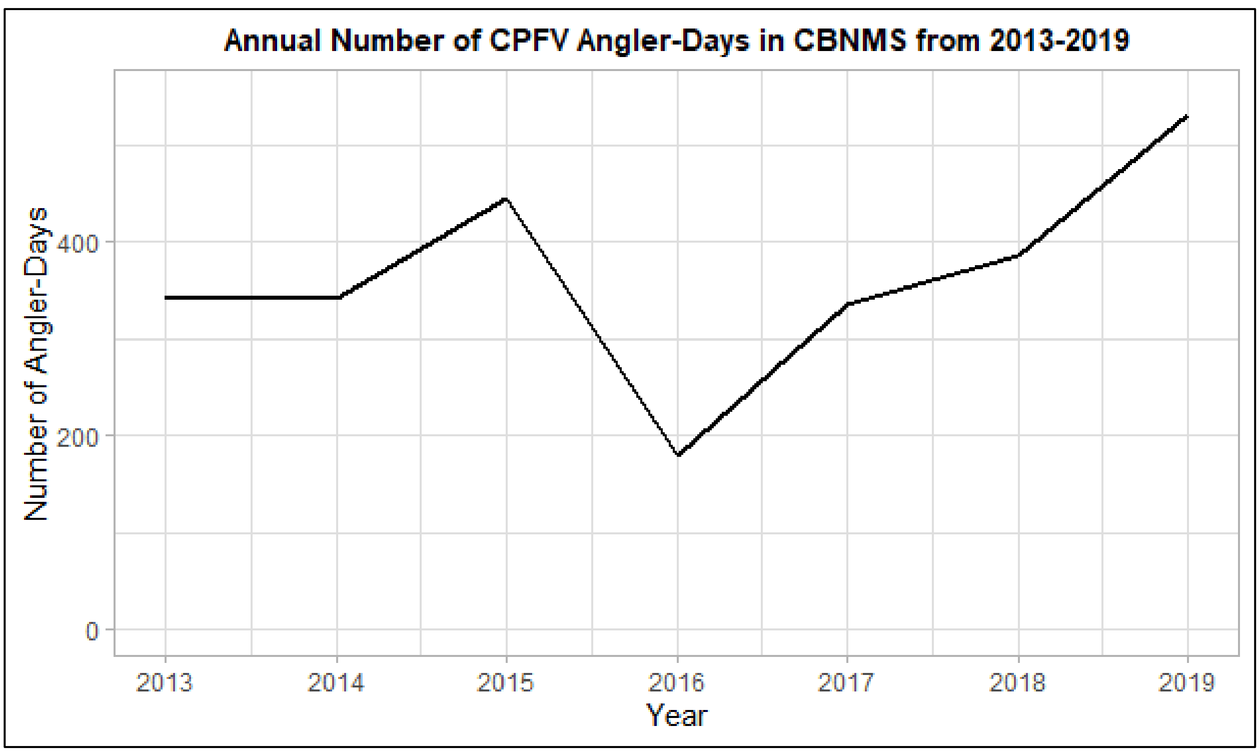


Figure ES.CR.2. Trends in CPFV effort (angler-days) in CBNMS from 2013–2019. Source: CDFW, 2021d

Information on fishing effort and catch by private and rental vessels within CBNMS is not presented in this report due to unexplained irregularities in the data. However, a prior ONMS study on recreational fishing from 2010 to 2012 found that recreational private/rental boat fishing in CBNMS accounted for an average of 0.5% of total person-days in District 4[25] and 0.1% of person-days in California (Leeworthy & Schwarzmann, 2015). The number of pleasure boat registrations within the CBNMS study area were analyzed as a proxy for trends in private/rental vessel fishing effort. The number of pleasure boat registrations in the study area decreased significantly from 2013 to 2018 by about 2700 vessels per year (California State Parks, 2021; generalized linear model, $p = 0.04$). Pleasure boat registrations declined from nearly 97,000 in 2013 to over 79,000 in 2018 (California State Parks, 2021). The largest single-year decline occurred between 2015 and 2016 (California State Parks, 2021).

One data gap in assessing the state of consumptive recreation in CBNMS is a lack of information on potential users' knowledge, attitudes, and perceptions. Among other things, this information would be useful for evaluating users' level of satisfaction with sanctuary resources and management, and for determining whether there is unmet demand for recreational fishing in CBNMS. Knowledge, attitudes, and perceptions data could also be used to identify barriers to accessing the ecosystem service (e.g., weather, cost, uncertainty over regulations) and develop target areas for improvement.

Conclusion

Important recreational fisheries within CBNMS are compromised. CBNMS can support recreational fishing indirectly by promoting a healthy ecosystem (e.g., by managing impacts to habitat and water quality) and coordinating outreach efforts. However, many actions that could support the ecosystem service are the authority of fishery management bodies (Pacific Fishery Management Council, NMFS, CDFW) or environmental agencies that manage watersheds. While NMFS and the Pacific Fishery Management Council have made progress rebuilding rockfish populations following historical declines, recreational fishing opportunities for rockfish remain limited within CBNMS. CDFW is working to reduce entanglement risk for large whales; however, the recreational Dungeness crab fishery may continue to face closures until significant strides are made. Additional management actions in riverine systems, particularly habitat restoration and improved flow conditions, could enhance prospects for the Chinook salmon fishery in CBNMS. For these reasons, the status of consumptive recreation in CBNMS was determined to be fair.

CPFV effort has varied without trend over the study period, while the number of pleasure boat registrations within the study area has declined slightly. Improvements in technologies like offshore vessels and navigational aids may partially offset access challenges created by weather and rough conditions. The trend in consumptive recreation in the sanctuary was therefore rated as stable.

---

[25] The sanctuary is located within District 4 (San Francisco District) of the state of California, for purposes of the California Recreational Fisheries Survey. District 4 includes Sonoma, Marin, San Francisco, and San Mateo counties on the coast and the eight counties surrounding San Francisco and San Pablo bays (Alameda, Contra Costa, Solano, Sonoma, Marin, San Francisco, San Mateo, and Santa Clara counties; CDFW, 2020c).

Non-Consumptive Recreation

Recreational activities that do not result in intentional removal of or harm to natural or cultural resources

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: Public access to CBNMS can be challenging due to extreme and unpredictable weather conditions, offshore location, lack of infrastructure, and limited number of tour operators. However, despite these challenges, businesses and individuals in the area are performing acceptably, and there is still demand to travel to the sanctuary. Populations of certain species that are of interest to wildlife viewers, like humpback and blue whales and some seabirds, are compromised. The worsening trend was driven by extreme weather conditions, which have impacted the number of wildlife viewing businesses operating in the sanctuary.

Recreational activities that do not result in the intentional removal of, or damage to, natural and heritage resources are considered non-consumptive. The status of non-consumptive recreation in CBNMS is good/fair, and the trend is worsening. The primary non-consumptive recreational activities in or adjacent to CBNMS are wildlife viewing, especially whale and bird watching, and boating (Table ES.NCR.1). CBNMS is located offshore, precluding shore-based or nearshore recreational activities in the sanctuary. Recreational diving is not recommended or common at CBNMS due to the depth of reef areas and the site's extreme, variable weather and ocean conditions.

Table ES.NCR.1. Summaries for the key indicators related to non-consumptive recreation that were discussed during the May 21, 2021 virtual workshop.

Indicator	Data Source	Habitat	Data Summary	Figures and Tables
Reported seabird sightings	eBird, 2021	Pelagic	**Status:** The most commonly sighted species were sooty shearwaters, western gulls, pink-footed shearwaters, common murres, and California gulls. **Trend:** Sightings have increased in recent years for the top five most sighted species in CBNMS.	Figure ES.NCR.1
Number of eBird observers	eBird, 2021	Pelagic	**Status:** From 2015–2019, an annual average of around 4,000 eBird observers reported sightings in CBNMS. **Trend:** The number of eBird observers with reports in CBNMS increased from 2009–2020.	Figure ES.NCR.2; Figure ES.NCR.3

Indicator	Data Source	Habitat	Data Summary	Figures and Tables
Distance traveled by vessels in CBNMS	USCG, 2021	Pelagic	**Status:** Pleasure boats, recreational vessels, and sailing vessels traveled an average of around 2,800 nm per year from 2009–2020. **Trend:** Distance traveled in CBNMS by pleasure boats and sailing vessels increased in recent years, excluding 2020, but this may be a result of more vessels carrying AIS. Distance traveled by passenger vessels declined from 2009–2020.	Figure App.F.NCR.1; Figure App.F.NCR.2
Whale populations	Carretta et al., 2020	Pelagic	**Status:** Endangered and threatened species **Trend:** Minor population increases, facing threats	Table S.LR.13.2
Whale density models	Becker et al., 2020	Pelagic	**Status:** High density of blue and humpback whales in CBNMS **Trend:** No trend data	Figure App.E.13.1
Whale density (ACCESS)	ACCESS, 20221	Pelagic	**Status:** Blue and humpback whales are common in CBNMS and GFNMS **Trend:** Increasing density of whales	Figure S.LR.13.1; Figure S.LR.13.2
Seabirds	ACCESS, 2021	Pelagic	**Status:** Cassin's auklet, black-footed albatross, sooty shearwaters, and pink-footed shearwaters are common in CBNMS and GFNMS **Trend:** Variable, no trend	Figure App.E.13.2–Figure App.E.13.5
Data gaps	A better understanding of demand for and constraints on non-consumptive recreation			

CBNMS offers unique opportunities for wildlife viewing. A wide variety of whales, pinnipeds, seabirds, and sea turtles can be viewed throughout the sanctuary seasonally. Higher numbers of cetaceans, including whales and dolphins, are present from June through November. Resident and migratory seabirds use the site's productive waters, drawing in birders from around the world. As of 2021, following an owner's retirement, there is only one operation offering regular (once a year) trips to CBNMS, down from two in previous years. As with many activities in CBNMS, wildlife viewing is constrained by variable offshore conditions like unpredictable and occasionally extreme weather, including wind, fog, and rough seas. From 2009–2020, 45% of days in CBNMS had Small Craft Advisory conditions for at least an hour (National Data Buoy Center, 1971). Thirty-six percent of days had Small Craft Advisory conditions for at least four hours (National Data Buoy Center, 1971). Unpredictable weather creates a barrier for small businesses, like charter operations, which face substantial revenue losses due to canceled trips (D. Gurrola/Dominican University of California & S. Allen/National Park Service (retired), personal communication, May, 21, 2021).

Whale Alert is a free app that allows users to report whale sightings, which are then logged in a central database (Whale Alert West Coast, 2021). As a voluntary reporting system, Whale Alert data do not provide information on the true abundance of whales in CBNMS; however, it can give some indication of whale watching in the sanctuary. From 2016 to 2020, there was an average of one whale sighting in CBNMS reported annually. This represents a decline from 2014, when there were nine (Whale Alert, 2020). These sightings are predominantly of blue and humpback whales. According to habitat-based density estimates for cetaceans in the California Current Ecosystem, there is a high, increasing density of blue and humpback whales in CBNMS (Becker et al., 2020; ACCESS, 2020). Other commonly sighted marine mammals near the sanctuary include Pacific white-sided dolphins, Dall's porpoise, and fur seals.

Bird watching is another popular activity in CBNMS. At least 75 species of seabirds have been documented in the sanctuary, including some migrating from as far as Alaska, Hawai'i, Australia, New Zealand, and South America (CBNMS, 2023). From 2009 to 2020, the top five bird species reported on the popular birding app eBird (2021) in CBNMS were sooty shearwaters, western gulls, pink-footed shearwaters, common murres, and California gulls (Figure ES.NCR.1). Species like Cassin's auklets, black-footed albatross, sooty shearwaters, and pink-footed shearwaters are common in CBNMS, and their populations have varied without trend in recent years (ACCESS, 2020). The number of annual bird sightings on eBird has increased in recent years (Figure ES.NCR.3), but this is driven in part by an increase in the number of eBird users (eBird, 2021). The number of individual eBird observers has increased significantly from 2009–2020 by close to 500 individuals per year (generalized linear model; $p < 0.001$; Figure ES.NCR.2).

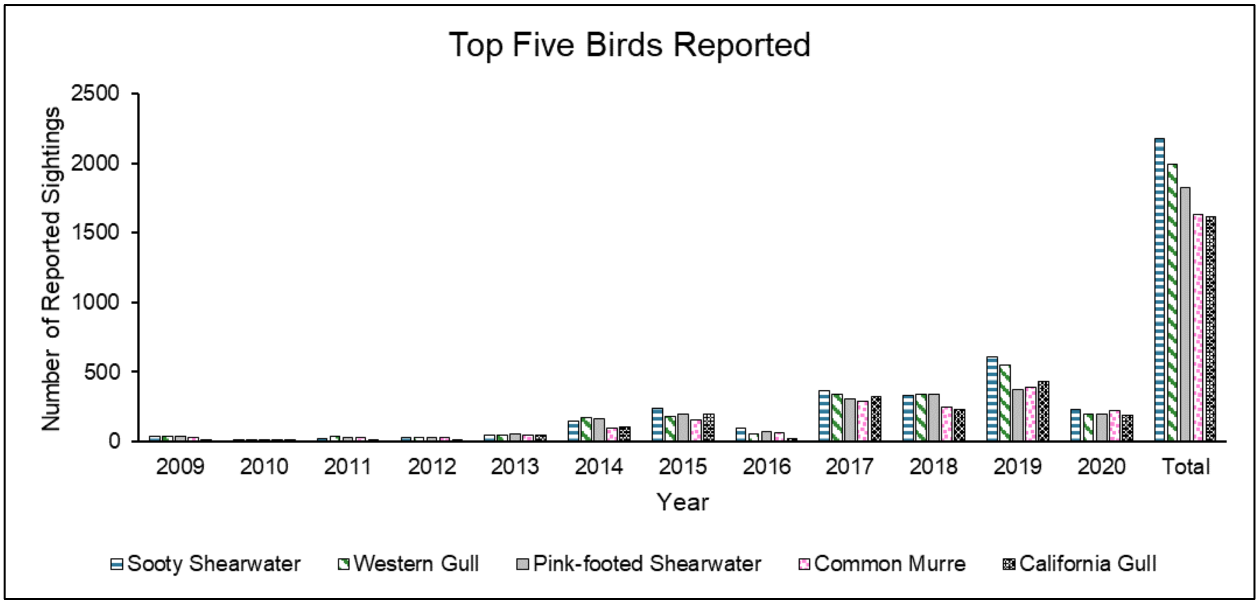


Figure ES.NCR.1. Top five seabird species reported by eBird users in CBNMS, 2009–2020. Reported sightings of these five species have increased in recent years. Source: eBird, 2021; Image: NCCOS

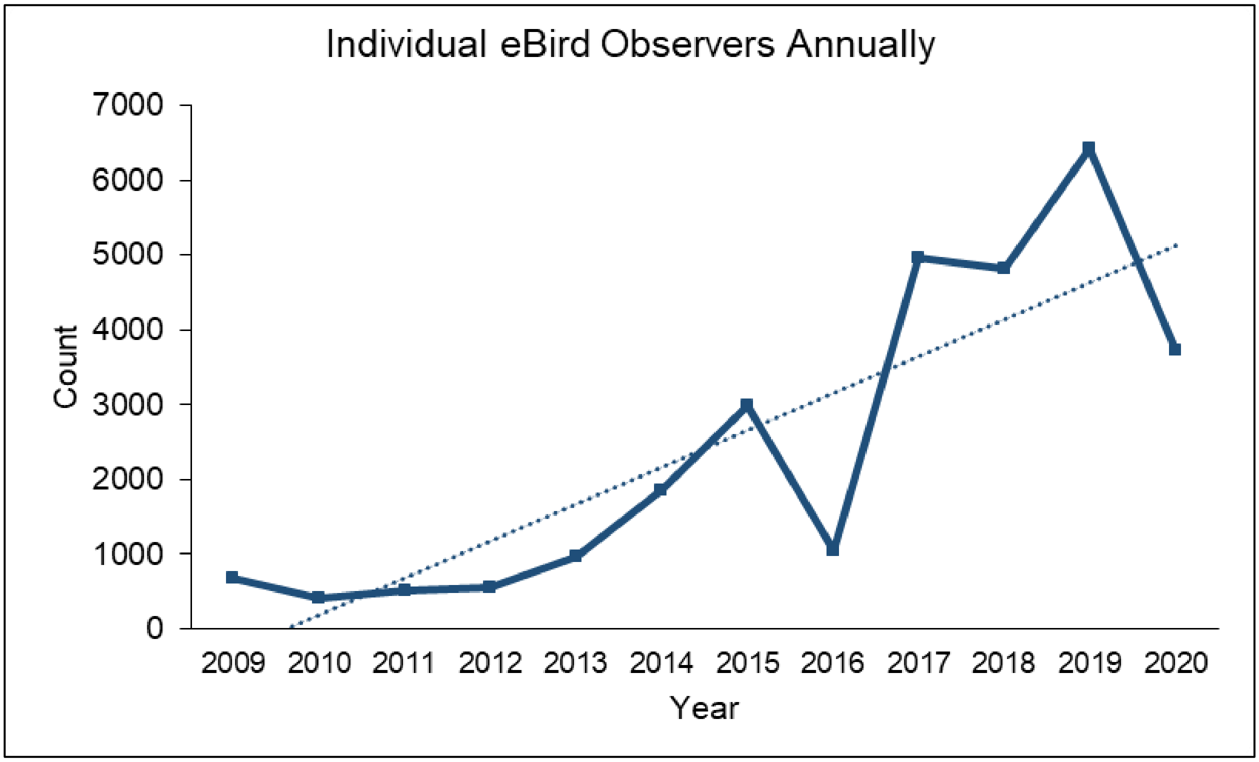


Figure ES.NCR.2. Number of unique eBird observers annually from 2009–2020. The number of eBird users reporting bird sightings near CBNMS has increased by around 500 individuals per year over the time period (dotted trendline). These counts may include eBird users traveling through the study area by cruise ship. Users logging bird sightings in CBNMS on multiple eBird accounts will be counted more than once, resulting in an overestimate of the true number of users. Source: eBird, 2021; Image: NCCOS

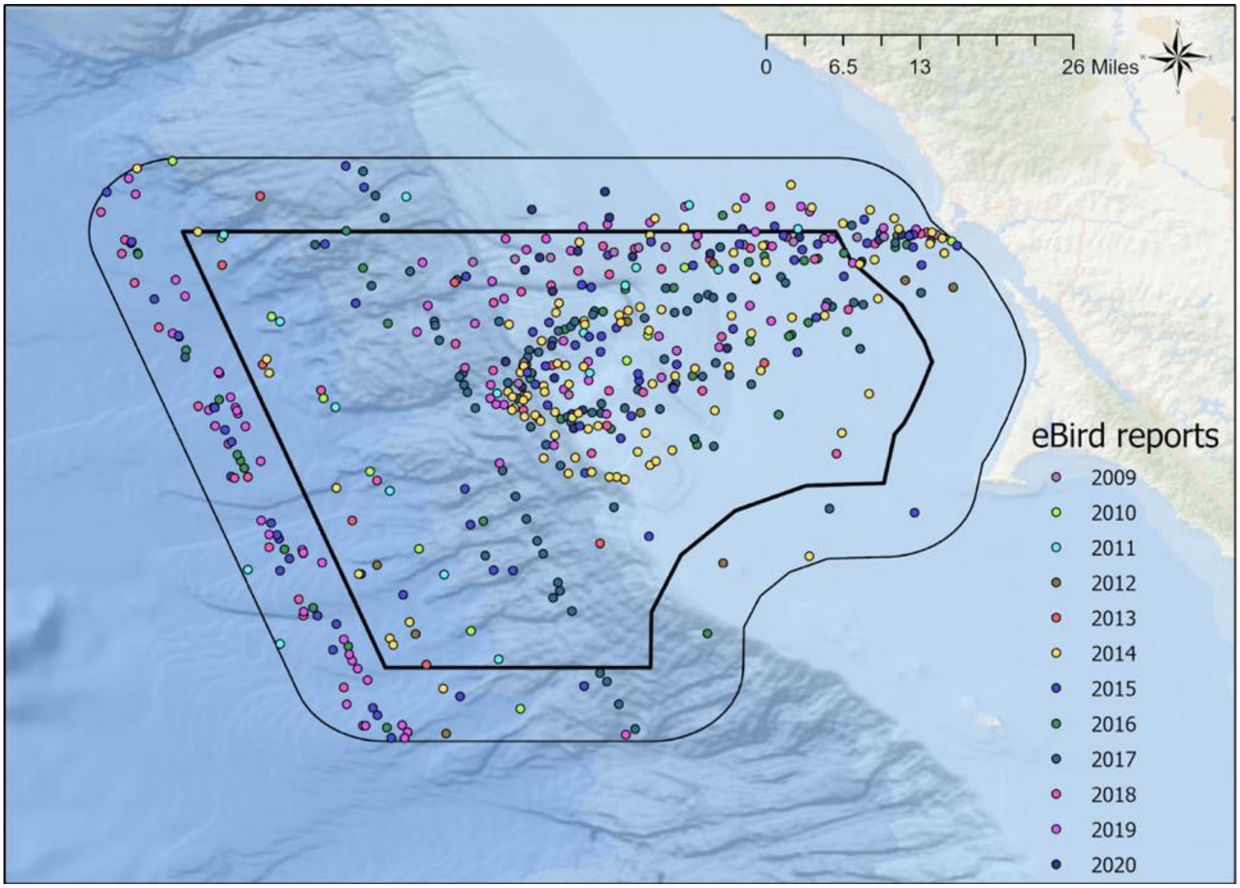


Figure ES.NCR.3. eBird reports in CBNMS with a 10 km buffer around the sanctuary, 2009–2020. Source: eBird, 2021; Image NCCOS

Recreational boating is another non-consumptive activity in CBNMS. Recreational traffic tends to be concentrated toward the eastern, nearshore portion of the sanctuary. From 2009–2020, non-consumptive recreation vessels traveled a total of 33,789 miles in CBNMS (NCCOS, 2020). Those vessels comprised 13% of the total number of unique vessels in the sanctuary (471 pleasure craft, 412 recreational vessels, 274 sailboats, and 2 diving operations out of 8,275 total unique vessels). The distance traveled by pleasure craft and sailing vessels carrying AIS was stable from 2009–2014, increased from 2014–2019, and then decreased in 2020 (NCCOS, 2020). However, the rate of AIS use by private vessels likely increased over that time, which may account for the increase in distance traveled observed from 2014–2019 and may not reflect an increase in the true distance traveled. Passenger vessels, including cruise ships and charter operations, also provide opportunities for non-consumptive recreation. Passenger vessels make up 2% of the total number of unique vessels and 3% of the total distance traveled in CBNMS (22,459 nm out of 898,369 nm). Passenger vessel activity is concentrated in highly trafficked areas and tends to follow more distinct pathways than pleasure craft vessels. Distance traveled by passenger vessels remained relatively stable from 2009–2018 and declined drastically in 2020, during the COVID-19 pandemic (NCCOS, 2020).

Conclusion

Non-consumptive recreation in CBNMS was rated good/fair with a worsening trend. CBNMS continues to provide opportunities to view marine mammals, sea turtles, and seabirds, although some wildlife populations that frequent or reside in the sanctuary remain compromised. Though there was no clear trend in the number of hours under Small Craft Advisory conditions (2009–2021; National Data Buoy Center, 1971), there was consensus among workshop experts that weather conditions are worsening. The number of wildlife tours operating within the sanctuary has declined, largely due to the challenges of scheduling tours around extreme weather conditions. In the past, CBNMS partnered with a non-profit organization to host field trips to the sanctuary from Bodega Bay, but those trips were discontinued due to financial constraints and at-sea liability. Based on public interest and participation in that program, it is likely that more people would visit and view wildlife in the sanctuary if more tours were available. Currently, with fewer tours operating, there are fewer opportunities for the public to experience non-consumptive recreation in CBNMS.

Science

The capacity to acquire and contribute information and knowledge

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: Compared to some other national marine sanctuaries, the ability of CBNMS to support science is constrained by challenges associated with accessing the sanctuary, particularly for students and external researchers. These challenges include the sanctuary's remote offshore location, frequently rough sea conditions, and inconsistent access to a research vessel. In addition, the small number of science staff and limited funding hinder the ability of CBNMS to expand its science program and develop new partnerships. Though these limitations led to a rating of fair, the trend was rated as improving, primarily because the expansion of the sanctuary has spurred additional research activity.

Science as an ecosystem service is defined as the capacity to acquire and contribute information and knowledge. National marine sanctuaries serve as natural laboratories that support researchers from a variety of institutions and provide opportunities to apply scientific information to resource management. Science in the sanctuary can be evaluated by examining the number and type of research cruises taking place, research permits that are issued, number of partners that the sanctuary collaborates with, and publications focused on the sanctuary (Table ES.S.1).

Table ES.S.1. Summaries for the key indicators related to science that were discussed during the May 26, 2021 virtual workshop.

Indicator	Source	Data Summary
Research cruises	CBNMS, 2021b	Total of 77 research cruises providing data to CBNMS from 2009–2021
Research permits	CBNMS, 2021c	37 research permits for research in the sanctuary from 2009–2021
Partners		At least 16 partners and collaborators working in the sanctuary
Publications	Literature search	Total of 147 publications on the sanctuary
Limitations		Limitations on access to the sanctuary; staffing and support for science; and ability to support students and external researchers

The waters around CBNMS have a rich history of science and exploration, dating to before its designation as a sanctuary. In the years since the last condition report, CBNMS has continued to support this ecosystem service with cruises, permits, partnerships, and publications.

There have been 77 research cruises since 2009 that have generated data or information to which CBNMS has access (CBNMS, 2021b). The majority of these (85%) were led or co-led by CBNMS and its partners, and the remainder were led solely by partners. This is an indication of both the strong scientific presence of CBNMS, but also the challenges for external researchers to work in the area, partially due to the sanctuary's remote location. In contrast to many other sanctuaries, CBNMS is not located in close proximity to a multitude of academic and research institutions. Still, CBNMS has developed strong relationships with at least 16 partners and collaborators from universities, government, and non-profit organizations.

From 2010 to 2019, CBNMS issued 37 research permits to its own staff or to other researchers to conduct work in the sanctuary that would otherwise violate a sanctuary regulation, such as disturbance of the seafloor and discharge of materials (CBNMS, 2021c). Not all research requires a permit, so the number of permits issued does not provide a full count of the projects conducted within the sanctuary. An increase in permits issued, which numbered three in the year before the 2015 expansion and nine in 2019, is a result of the increase in area in which research permits are required, as well as increasing awareness over time about sanctuary permit requirements.

These expeditions, projects, and partnerships have resulted in over 140 publications on CBNMS, including articles, dissertations and theses, conference proceedings, presentations, and other reports.

However, there are significant barriers for CBNMS to support this ecosystem service. The sanctuary's offshore location, lack of a shoreline and associated infrastructure, inaccessibility to non-technical divers, challenging sea conditions, need for a medium to large vessel, transit time of 1–3+ hours (depending on location), and the limited number of scheduled trips are all factors that limit the ability of researchers to conduct work in the sanctuary. For partners and other researchers, the limited number of research institutions nearby and the limited opportunities for undergraduate and graduate students to access the sanctuary also reduce the amount of scientific work in the sanctuary. In addition, the small number of CBNMS science staff, a lack of discretionary funds, and limited access to the ONMS research vessel *Fulmar* (homeported in Monterey Bay, California), reduce the ability of CBNMS to conduct its own research. There are few other vessels in the area capable of supporting scientific research in the sanctuary. These limitations and challenges have been fairly consistent throughout the time period 2009–2021.

Conclusion

In summary, although CBNMS has consistently supported science, limited staffing, financial support, access to vessels, and challenging weather and ocean conditions make working in the sanctuary difficult. As a result of these challenging conditions, CBNMS has been understudied compared to nearby coastal regions. Nevertheless, the uniquely productive ecosystem continues to attract interest from students and researchers in a variety of disciplines, ranging from physical oceanography to fisheries to ornithology, and CBNMS will continue attempts to increase scientific endeavors. There remains much to learn about the species inhabiting the sanctuary, as well as transient species benefiting from the high productivity around the bank, and how they may deal with changes in physical and chemical conditions. In benthic habitats, further exploration, characterization, and continued monitoring is needed. Although over 90% of the sanctuary seafloor is mapped for bathymetry, only a small percentage has been visually surveyed, and questions remain about the species and habitats in the sanctuary. In addition, repeated monitoring is needed to understand changes over time and in response to management actions. In pelagic habitat, continued monitoring of climate indicators and ocean noise is needed. Understanding the biological response to physical and chemical conditions is critical to effective management. The condition report identified data gaps in understanding the impacts of human activities, other stressors, and contaminants, and a lack of long-term monitoring led to an ability to determine trends in many parameters. In addition, information on factors that would enhance the number of researchers working and/or projects conducted in the sanctuary is needed. Data gaps should be further assessed during management plan development.

Education

The capacity to acquire and provide intellectual enrichment

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: There was high confidence and support among workshop participants for CBNMS education efforts, programs, and outcomes to date; however, but the lack of labor and sustained funding for education and outreach has prevented this service from meeting some community needs.

Education as an ecosystem service is defined as the capacity to acquire and provide intellectual enrichment. At CBNMS, the status of education was rated good/fair with an improving trend. CBNMS is a place of national, regional, and local significance. CBNMS staff engage audiences through education and outreach using a variety of methods (Table ES.E.1).

Table ES.E.1. Summaries for the key indicators related to education that were discussed during the May 27, 2021 virtual workshop.

Description of Program	Key Indicators Used to Determine Status and Trend
Exhibits bring CBNMS to the people through high-quality visuals in partner institutions that increase awareness about the sanctuary and increase ocean and climate literacy.	Visitorship and quality of experience at CBNMS exhibits created in partnership with sanctuary staff
CBNMS-staff-led field excursions promote adult learning opportunities and improve awareness about ocean ecology and encourage ocean stewardship.	Participation and quality of experience during CBNMS-led excursions
Distance learning and telepresence experiences improve awareness about the sanctuary and ocean ecology to school groups and the general public.	Number of distance learning and telepresence outreach programs
Social media and websites improve awareness about the existence of the sanctuary, the purpose of its designation, and its ecology.	Number of people reached
Outreach programs include a monthly radio program, presentations to community groups, exhibitions at community events, printed products, and films/videos. These products provide opportunities to communicate about the sanctuary with broad audiences.	Invitations and participation in outreach events
Formal education curricula and training programs train educators about CBNMS curriculum resources and the sanctuary ecosystem.	The number of teachers reached through workshops (and quality of their experience) and indication of intent to incorporate into classroom curriculum

Student in-person programming increases awareness about national marine sanctuaries and ocean literacy among students.	The number of students reached by programs
Learning opportunities for volunteers and interns advance skills students need to pursue careers related to national marine sanctuaries and provide opportunities for motivated community members to contribute their skills and efforts to support CBNMS programming.	The number of interns and volunteers CBNMS has hosted
Data gaps	Effectiveness of information in exhibits; long-term data on how teachers use information from teacher workshops over time; identification of targeted audiences for resource protection issues

Opportunities for intellectual enrichment through experiencing the sanctuary first-hand is limited by the site's entirely offshore location, as well as limited staff capacity (only one staff member focused on education). However, the education and outreach programs at CBNMS, which create awareness about the sanctuary and enhance ocean and climate literacy and stewardship, have expanded since 2009, largely through partnerships and collaborations. While many products and programs have been created or launched efficiently, the ability to expand existing and add new programs is difficult due to a lack of resources. To help increase intellectual enrichment, CBNMS has created many virtual opportunities for learning about the sanctuary.

Sanctuary Exhibits

Because CBNMS is entirely offshore, bringing the sanctuary to people in communities on land through permanent and traveling exhibits has been a key strategy for increasing awareness about the sanctuary's existence. There are six permanent exhibit locations (Table ES.E.2). Exhibits highlight the biodiversity above and below the sanctuary's surface with educational and interpretive panels, photos, videos, and, in some cases, interactive elements. Visitors to these exhibits totaled 3,799,914 between 2009 and 2020, with an increasing trend, until closures due to the COVID-19 pandemic began in 2020.

Point Reyes National Seashore has three visitor centers, two of which feature sanctuary-specific exhibits (Figure ES.E.1). At the Point Reyes Lighthouse Visitor Center, visitors can view educational and interpretive panels outside the center. When touring inside, they can view immersive and accurate painted murals depicting habitats in the sanctuary and view life-size models of marine life, along with sweeping views of the ocean. At the Bear Valley Visitor Center, visitors can view educational panels, lifelike models of marine life, and a video highlighting underwater video footage taken during research missions to the sanctuary. From 2009–2020, over 3 million people visited these National Park Service visitor centers where sanctuary educational and interpretive exhibits are located. The Oakland Museum of California hosted over 400,000 visitors from 2013–2020, including docent-led student programs. This museum hosts the largest of all CBNMS exhibits and highlights the sanctuary through video, models, educational panels, and a hands-on exhibit on ocean plastics. The museum also has a traveling photo exhibit about the sanctuary featuring high-quality images of sanctuary life. This exhibit reached over 7,000 visitors. The Bodega Marine Lab (with exhibit panels around aquariums) and Gualala Point Regional Park Visitor Center (with high-quality photos, a map, and a video) each have exhibits that feature CBNMS, and collectively hosted over 100,000 visitors. In summary, by partnering with other agencies and institutions, 3,799,914 people had the opportunity to view CBNMS exhibits between 2009 and 2020.

> *"I want to go there again because I can tell my family about [Cordell Bank]. I could tell them that I like a sea animal that lives there, like the California [sea] cucumber."* – Christian, Oakland Museum of California CBNMS exhibit visitor

> *"This is a superb exhibit showcasing the miracle of diverse life here at home on our beautiful planet. May it inspire those who view it to act with an ocean-conscious mind to protect, preserve, and appreciate the paradise we live in. The selection of photographs is absolutely incredible."* – CBNMS traveling photo exhibit guest logbook entry

Table ES.E.2. Total visitors per exhibit location from year of exhibit installation to 2020. Source: CBNMS and exhibit partner locations.

Exhibit Location (Focal Sanctuary Site[s])	Year Opened	Total Visitors from Year Opened to 2020
Point Reyes National Seashore Bear Valley Visitor Center (CBNMS and GFNMS)	2007	2,880,772
Bodega Marine Lab (CBNMS and GFNMS)	2008	92,968 (faculty, students, visiting students, public programs, docent-led tours)
Oakland Museum of California (CBNMS)	2013	432,350 (docent-led tours, student programs, general public)
CBNMS traveling photo exhibit (CBNMS)	2013	7023 (opening events, student programs, special events)
Gualala Point Regional Park Visitor Center (CBNMS and GFNMS)	2015	16,034 (public visitors, student programs)
Point Reyes National Seashore Lighthouse Visitor Center (CBNMS and GFNMS)	2016	370,767

Figure ES.E.1. The Ocean Exploration Center at Point Reyes National Seashore Lighthouse Visitor Center provides a windowed portal to both GFNMS and CBNMS with murals, models, and a hands-on touch station depicting habitats in sanctuary waters right off Point Reyes National Seashore. Photo: T. Chartier

CBNMS-Staff-Led Field Excursions

CBNMS is entirely offshore, and due to its often rough sea conditions, there is limited recreational access to enjoy wildlife watching. For over a decade, CBNMS co-hosted an annual field seminar with Point Reyes National Seashore Association's Field Seminar program, which consisted of a half-day classroom event with informative lectures, followed by a full-day boat trip to the sanctuary.

> *"This gave me an appreciation of Cordell Bank and why it is a national marine sanctuary, what wonderful marine wildlife we have off our coast, and [why it] must be protected.*" – Field seminar participant

Between 2009–2016, 121 seminar participants visited the sanctuary. These trips greatly enhanced appreciation and awe for the sanctuary and provided unique photography opportunities. Due to changes in the association's management of field seminars and because sea conditions are physically challenging, the trips were discontinued in 2017. In addition to the physical challenges of accessing the sanctuary, the program is costly even when conditions are amenable, presenting equity challenges, as only those with the financial means to participate can join the trip. Additionally, many participants often experience sea sickness while on the boat, which can result in a negative association with the sanctuary (J. Stock/NOAA, personal communication, May 27, 2021).

Distance Learning and Telepresence

With technology expanding and becoming more available in the last decade, CBNMS was able to take advantage of telepresence opportunities that accompany research expeditions. Telepresence technology allows CBNMS staff on research vessels to connect with audiences on land via internet connections. The Ocean Exploration Trust partnered with West Coast sanctuaries in 2017 and 2019. Aboard Ocean Exploration Trust's exploration vessel *Nautilus*, the CBNMS team conducted "ship-to-shore" telepresence interactions with schools and museums, social media users, and live stream viewers. These interactions had a wide reach; people around the world viewed the live broadcast and asked questions through Ocean Exploration Trust's platform (Table ES.E.3). Sixty-seven ship-to-shore video-based interactions occurred between CBNMS staff and schools and museums on land between 2017 and 2019 (each research cruise was one week in length) and reached 2,439 students, teachers, and museum/aquarium visitors. Social media outreach on Facebook, Twitter, and Instagram during these expeditions resulted in 678,564 social media content reaches (Table ES.E.3).

In addition to at-sea telepresence opportunities, CBNMS staff have also presented numerous online webinars targeting educators and the interested public. Webinar and digital classroom technology has allowed CBNMS staff to interact with students in a "virtual classroom visit" or distance learning format, presenting on topics ranging from sanctuary science to ocean and climate literacy. However, staff time is limited to meet the needs of communities, and training and mentoring interns and volunteers to fill the gap is time consuming, and these positions are usually short term.

Table ES.E.3. CBNMS outreach during Ocean Exploration Trust explorations in 2017 and 2019. Source: S. Wishnak/Ocean Exploration Trust, personal communication, October 30, 2019

Metric	Count
Number of live "ship to shore" interactions	67
Number of people reached during ship-to-shore interactions	2,439
Facebook reach during ship-to-shore interactions	260,995
Twitter reach during ship-to-shore interactions	327,200
Instagram reach during ship-to-shore interactions	90,369

Social Media and Websites

Social media can be a useful digital media platform to convey information about the sanctuary to the general public. Analytics of CBNMS social media use began in 2015. Information from 2015 to 2020 shows users and interactions via Twitter and Facebook increased (Figure ES.E.2, Figure ES.E.3). While statistics indicate exposure to the content, they do not provide information about its impact on viewers. That information can only be collected through a public survey, which is beyond the current capacity of CBNMS.

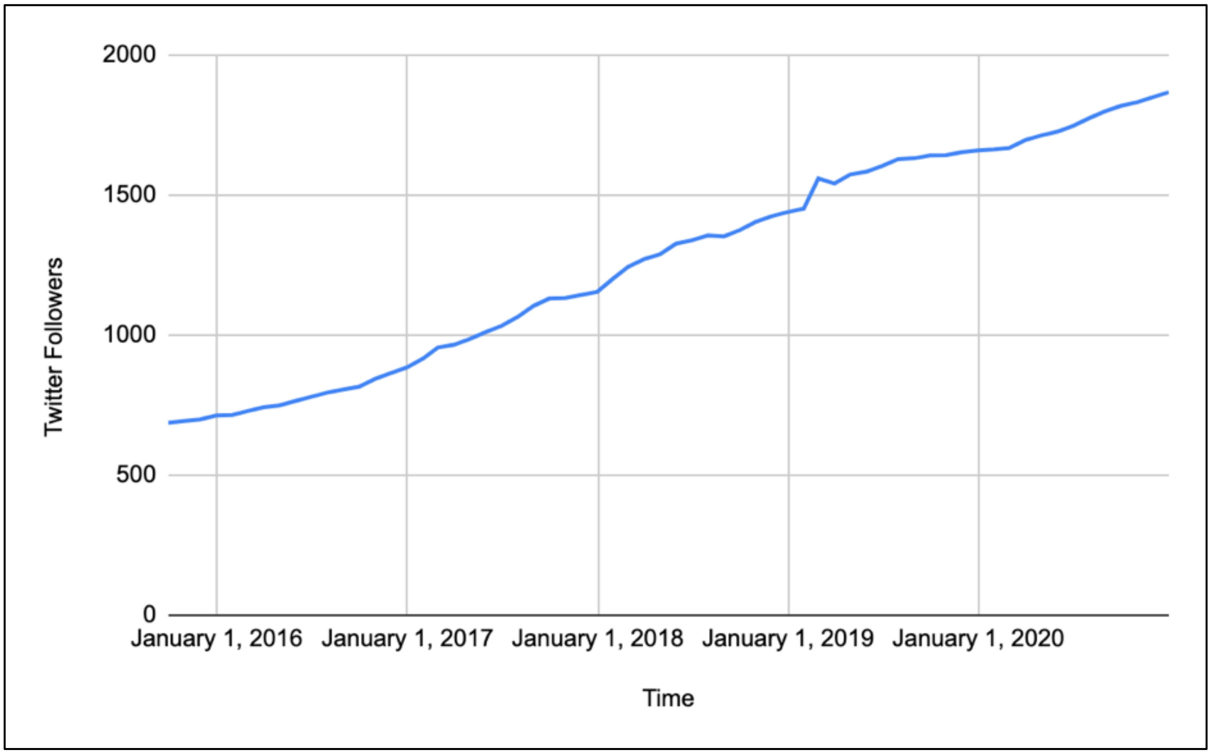


Figure ES.E.2. The number of Twitter page followers has steadily increased since the page was created in 2016. Source: Twitter, 2020

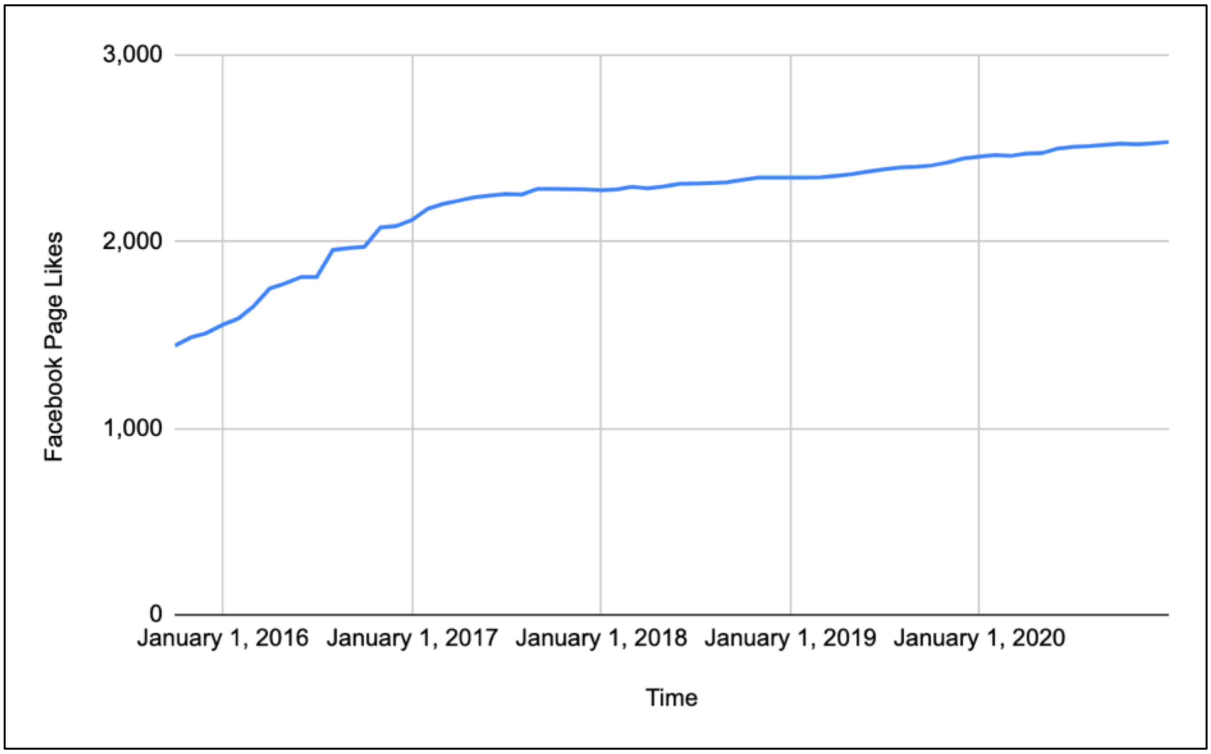


Figure ES.E.3. The number of Facebook likes per year has increased since the page was created in 2016. Source: Facebook, 2020

Multimedia Outreach

Public engagement, using a variety of multimedia, such as sanctuary print products, media, and videos, are meant to provide opportunities for a user to learn about the sanctuary and be inspired (Table ES.E.4). The intention is to empower users to further share or teach about the information they informally learned. Videos include those produced by ONMS and disseminated via its website and social media; videos shown at events, such as film festivals and in visitor centers; and externally produced films, such as a recent South Florida Public Broadcasting Service series about national marine sanctuaries that was distributed to public broadcasting stations nationwide and shown in film festivals. Since 2009, demand for print products has decreased substantially as digital media has increased in popularity (J. Stock/NOAA, personal communication, May 27, 2021).

CBNMS staff have reached audiences via radio as well. *Ocean Currents*, a radio program hosted by CBNMS staff live on KWMR, Community Radio for West Marin, California focuses on ocean-themed topics, with a strong focus on local sanctuary issues, bringing awareness of these issues to the coastal broadcast area. Each broadcast is also streamed live on the internet and saved as a downloadable podcast on the sanctuary website, potentially reaching a wider audience. The *Ocean Currents* broadcast has aired monthly since 2006 (with the exception of a hiatus starting in 2020 due to the COVID-19 pandemic) and during that time has produced over 120 live programs. “Podcast Connect” monitors podcast usage on Apple devices. These data show that between 2009–2020, there were 2,900 listeners, 1,600 engaged listeners (meaning they listened to some or all of the episode), and 29,428 total plays of episodes. There are limited data available for usage outside of Apple devices. The program has received many accolades, including numerous positive customer comments and ratings in iTunes, with an average 5 star rating (out of 5). One review states:

> *“This is a fantastic podcast for anyone that lives on the Pacific coast and for anyone that is concerned about the health of our ocean. Jennifer does an incredible job at bringing important coastal issues to the pod. Her interviews and guests do more than provide knowledge and insights, the inspire action!!” – SF Sean, March 15, 2019*

CBNMS has also created exhibits at community events to share sanctuary information with special event audiences. But because these events require planning and staff time, CBNMS has had to decline numerous invitations to participate in special events due to staffing limitations. Examples of events at which CBNMS had an interactive presence are: Bodega Bay Fish Fest, Earth Day, Ocean Film Festivals, World Ocean Day, Sharktoberfest, Earth Fest, and Get Into Your Sanctuary Day (J. Stock/NOAA, personal communication, May 27, 2021).

Table ES.E.4. Summary of outreach products for online, print, media, and film mediums.

Outreach Product	Audience	Examples
Online platforms	Public	CBNMS website, social media platforms
Media	Public	Featured articles in press (radio, television, print, web)
Film	Public	*Earth is Blue* films, South Florida Public Broadcasting Service film/*Changing Seas*, film festival viewings, film panel discussions with CBNMS staff
Community events	Public	CBNMS outreach presence at Bodega Bay Fish Fest, Earth Day, Ocean Film Festivals, World Ocean Day, Sharktoberfest, Earth Fest, Get into your Sanctuary Day, and others
Print products	Public, teachers	CBNMS brochure, posters, informational handouts

Formal Education Curriculum and Training Programs

CBNMS has worked with other national marine sanctuaries and partners to create high-quality curricula, educator training, and other programs to help bring sanctuary messaging and ocean and climate case studies into classrooms. These products have a long life span when they get in the hands of teachers. CBNMS has led teacher professional development courses to expose teachers to these resources. Between 2009 and 2020, CBNMS staff led training and workshops for teachers that varied from 2 to 40 hours over the course of a year. These professional development trainings reached 411 total teachers. Table ES.E.5 provides a summary of some CBNMS curriculum products.

Table ES.E.5. Curriculum products CBNMS has developed that focus on ocean issues through case studies associated with the sanctuary.

Curriculum Product	Topic	Additional Information	Reach
West Coast Deep-Sea Community Curriculum	Includes images from CBNMS ROV transects and background information about deep-sea habitats	Promoted to teachers via workshops, no data on use by teachers	1. Live webinar presentations about the curriculum reached 350 people 2. Reached 50 different teachers through teacher workshops 3. Reached 150 students during in-class presentations using the resource

Dungeness Crab Communication Toolkit	West-Coast-wide focus, ocean acidification and Dungeness crab	Use at sanctuary workshops and in outreach products	1. Live webinar presentations reached 200 people 2. Reached 40 different teachers through teacher workshops using resources in toolkit 3. 12,000 page views, 2,606 downloads of fact sheet, 495 downloads of PowerPoint presentation, 683 downloads of infographic, 151 downloads of the reference list, 193 downloads of the crab/ocean acidification reference list, 203 downloads of the PowerPoint script, 167 downloads of the B-roll
Winged Ambassadors	Albatrosses, upwelling, marine protected areas, seafloor features, ocean plastic ingestion/health effects		1. Curriculum downloaded by 5,278 teachers from 38 countries, reaching 358,787 students 2. Evaluation report in 2015 demonstrated how lessons supported ocean literacy 3. 15 presentations and trainings featuring Winged Ambassadors for teacher professional development

Student Programming

The CBNMS educator has worked with partners to offer immersive beach experiences that include a pre-activity, field trip to a beach, and post-activity. The pre-activity typically includes a classroom visit (either in person or virtual) by the sanctuary educator, who engages students through use of photos, videos, stories, and data in order to create excitement about the field trip and awareness of some of the concepts.

A significant partnership with the Oakland Museum of California has allowed CBNMS to engage with traditionally underrepresented communities in science. CBNMS worked with the museum to create a permanent gallery about the sanctuary that opened in 2013. The museum also created and continues to lead an elementary school program called Under the Sea: Exploring Cordell Bank National Marine Sanctuary, where students engage in a classroom activity at the museum, then experience a docent-led tour of sanctuary exhibits. Between 2013 and 2019, this program served 8,214 students, teachers, and chaperones.

> *"We discovered something new—the Cordell Bank exhibit reinforced the concept of the food web and some geography through maps. Doing the dissection was a great new experience!"* – Teacher evaluation after field trip

This partnership creates an opportunity for students who do not live along the coast to learn about the ocean in a museum through engaging exhibits and vivid imagery.

Supporting Volunteers and Interns

CBNMS staff have supported nine undergraduate and graduate interns by providing professional development opportunities through projects that enhance sanctuary education and outreach efforts. Increasing opportunities for typically underrepresented people in sciences is a NOAA priority.

CBNMS had 23 volunteers from 2009–2020 that supported various education and outreach programs. Volunteers created material for the *Ocean Currents* radio program, transcribed programs to increase accessibility, edited and archived video footage, and created listening guides. Requests for internship and volunteer opportunities have increased between 2009 and 2020 as students seek to build skills and experience with NOAA and ONMS. While the management plan prioritized development of a broad volunteer program, CBNMS did not have the staffing or financial resources to do it. Most volunteers and interns have helped with specific projects with a specific timeframe.

Limitations and Challenges

CBNMS is entirely offshore and surrounded on three sides by another national marine sanctuary that is adjacent to the shoreline. Access to the sanctuary is extremely difficult due to challenging sea conditions, lack of available and capable vessels to go offshore, and travel distance and time to the sanctuary. Therefore, creating a community identity and following of supporters is challenging. With only one federal employee, CBNMS chose to experiment with multiple types of engagement opportunities; however, to manage all the communication, training, outreach, and education needs for the sanctuary, the ability to sustain, grow, and add new programs is very limited, despite requests from the community for additional engagement.

The accomplishments to date have been extensive and have had a far reaching impact. Without either additional resources or a reduction in the variety of educational opportunities, the ability to expand is constrained. Volunteers and interns, while supportive for a short period of time, require training and ongoing supervision. Experts also noted that one staff member is not enough to reach the diverse audiences of the local sanctuary community, let alone at a national scale. While the management plan prioritized a variety of education and outreach programs and priorities, the site did not have enough staffing resources to carry out some of the strategies on an ongoing basis and focused on programs and products that had the most ongoing impact and broadest reach with the staffing resources available.

Conclusion

Overall, education and outreach efforts have increased the reach of CBNMS in the last 10 years through products like exhibits, signage, and digital media, and have had direct impact with students and teachers. Feedback from teachers regularly emphasizes the importance of CBNMS providing content via training to teachers and to students to both increase their awareness about the regional ocean environment and to build their personal connection to it. The investments made in exhibits have had the longest lasting impact on the local community and have strengthened partnerships. CBNMS has had the greatest educational reach through exhibits. Opportunistic virtual programming through live research expeditions also have a big impact, generating a high reach in a short period of time.

Heritage

Recognition of historical and heritage legacy and cultural practices

Status Description: The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.

Rationale: The heritage of CBNMS includes commercial and recreational fishing, science and exploration, and the presence of maritime heritage (archaeological, cultural, historical properties) resources. The quality of information related to recent fishing and science activities within CBNMS is high, but other heritage activities lack information. There is currently no information that suggests a connection of Indigenous peoples specifically to the sanctuary prior to contemporary usage of motorized fishing vessels in the region, though there are demonstrated connections to coastal and ocean resources in the general region. In addition, the expansion of the sanctuary in 2015 increased the area where sanctuary maritime heritage resources may be located and increased the coastal area where communities may have connections to the sanctuary. However, information about maritime heritage resources in the sanctuary and its historical and heritage legacy in the broader sanctuary community are areas for further investigation.

The heritage ecosystem service is defined as the recognition of historical and heritage legacy and cultural practices. This includes the shared history of the sanctuary and the communities around it, including present day and ancient cultures. Humans may benefit from both tangible and intangible aspects of heritage. Heritage may be reflected through modern-day economies, celebrations or recognition of past events, cultural landscapes, and community values. Commercial fishing, recreational fishing, science and exploration, interpretation of maritime heritage resources, and cultural connections were considered in rating this service (Table ES.H.1). The status was rated as fair with an improving trend. The fair rating was based on evidence of a strong science heritage, but also changes to fishing heritage due to changes in the type of fishing allowed, as well as a need for the site to put effort into gaining better understanding of cultural connections, including ancient connections. The improving trend is due to the sanctuary expansion in 2015 that resulted in more area for connections to maritime heritage resources and to coastal communities, as well as a shift in ONMS mission focus to include a more holistic consideration of cultural landscapes, rather than solely focusing on tangible maritime archaeological resources.

Table ES.H.1. Summaries for the key indicators related to heritage that were discussed during the May 26, 2021 virtual workshop.

Indicator	Data Summary
Commercial fishing	CBNMS plays a role in local commercial fishing heritage; this has changed over time with regulations.
Recreational fishing	CBNMS plays a role in local recreational fishing heritage; this has changed over time with regulations. Sea and weather conditions also limit some recreational users.

Science and exploration (historic)	Historic exploration and mapping was key to documentation of Cordell Bank.
Science and exploration (70s–80s)	Pioneering scuba surveys in the 1970s and 1980s led to the designation of the sanctuary and greatly expanded knowledge about Cordell Bank.
Science and exploration (2000s)	New technologies and imagery, science programs
Science and exploration (modern)	New technologies and rigorous monitoring are expanding knowledge about CBNMS, including the expansion area, and informing management.
Maritime archaeological resources	One known maritime archaeological resource exists in the sanctuary. There could be undiscovered resources. The sanctuary interprets and protects maritime heritage resources.
Indigenous communitycultural heritage	ONMS is currently working to expand its knowledge of historical and present day connections of Indigenous peoples to CBNMS.
Data gaps	Information about maritime heritage resources in the sanctuary; information about the sanctuary's historical and heritage legacy in the broader sanctuary community; past or present cultural connections of Indigenous communities to the sanctuary specifically, prior to contemporary usage of motorized fishing vessels

Fishing

Commercial and recreational fishing is part of the heritage of CBNMS. Fishing activity in CBNMS primarily originates from Bodega Bay and San Francisco. Occasionally, other boats from Half Moon Bay, Fort Bragg, and Oregon will access the sanctuary. As the closest port to the sanctuary, Bodega Bay has the strongest connection to the sanctuary and the town is defined by fishing-related activities. It has a tourism draw as a small working fishing town, the restaurants advertise and sell locally caught seafood, and the marina and associated businesses rely on the fishing activity. As the sanctuary is a minimum of six miles from the port, not all fishing vessels from Bodega Bay will enter the sanctuary, as many of the small boats will stay close to shore in GFNMS.

Commercial fishing in the sanctuary primarily targets crab, sablefish, groundfish, and salmon. The Pacific Fishery Management Council closed Cordell Bank and some of the surrounding areas to fishing in 2005–2006 to protect stocks and allow them to recover. Therefore, the role that CBNMS has been able to play in the local commercial fishing industry and its ability to support commercial fishing heritage has changed over time. During the assessment period for this condition report, spatial closures remained in place for most of the time period and some stocks have recovered. In 2020, some changes to Essential Fish Habitat were made, and the Rockfish Conservation Area was reopened to trawling.

Recreational fishing (see consumptive recreation ecosystem service) has a heritage component as well. Dating back to the late 1800s, recreational fishing at Cordell Bank was historically very popular, with news articles reporting large catches (R. Schwemmer/NOAA, personal communication, May 12, 2020). The Pacific Fishery Management Council closed Cordell Bank to all bottom contact recreational and commercial fishing in 2005–2006 through implementation of the “Cordell Bank Closed Area” Rockfish Conservation Area. There is an exception for “other flatfish” in this area. There is also a Cordell Bank Essential Fish Habitat Conservation Area to 50 fathoms on Cordell Bank that prohibits bottom contact gear from recreational and commercial fishing (see Figure App.E.10.2). Recreational fishing for crab and salmon are currently allowed in the sanctuary. However, access to the sanctuary from small boats can be difficult due to its offshore location and frequently rough seas. CBNMS has supported fishing as part of the heritage of the area by protecting the resources. The restrictions implemented by the Pacific Fishery Management Council have allowed the stocks to largely recover to management targets, but not pristine conditions.

Science and Exploration

CBNMS has a legacy of science and exploration dating back to long before it was a sanctuary. George Davidson discovered the bank in 1853, and it was mapped by Edward Cordell in 1869 using lead line. In the late 1800s, some of the earliest research cruises on the west coast of the U.S. collected dredge samples at Cordell Bank, which are archived at the Smithsonian Institution. In 1977, Cordell Expeditions, led by Robert Schmeider, conducted the first scuba dives on the bank. Subsequent trips were made through 1986, during which photos and specimens were collected and the bank was mapped (Schmieder, 1991; Figure ES.H.1). These early specimens, along with those collected more recently in the sanctuary, are archived in the research collections at the California Academy of Sciences in San Francisco, preserving a record of findings from the sanctuary (California Academy of Sciences, 2022). The images collected by Cordell Expeditions were the first underwater photos of Cordell Bank and were instrumental in gaining support for the designation of the sanctuary in 1989. After the sanctuary was established, a science program was developed. Eventually, the submersible *Delta*, and later an ROV, were used by CBNMS to explore the seafloor (Figure ES.H.2). CBNMS also began a pelagic monitoring program, first called Cordell Bank Ocean Monitoring Program, that focused on CBNMS and then merged into the larger ACCESS program with GFNMS and Point Blue Conservation Science. Other science projects have been added recently, including acoustic and oceanographic studies, in partnership with many collaborators. These efforts are preserved in mission documentation, archived data, and publications, and are part of the heritage of the area. They are also used in the story of CBNMS shared in public presentations, media, exhibits, and videos. Large-scale science projects not primarily focused on CBNMS but collecting data in and around the sanctuary, such as the long-term monitoring project CalCOFI, also contribute information that help scientists understand how sanctuary conditions compare to and are influenced by larger-scale patterns.

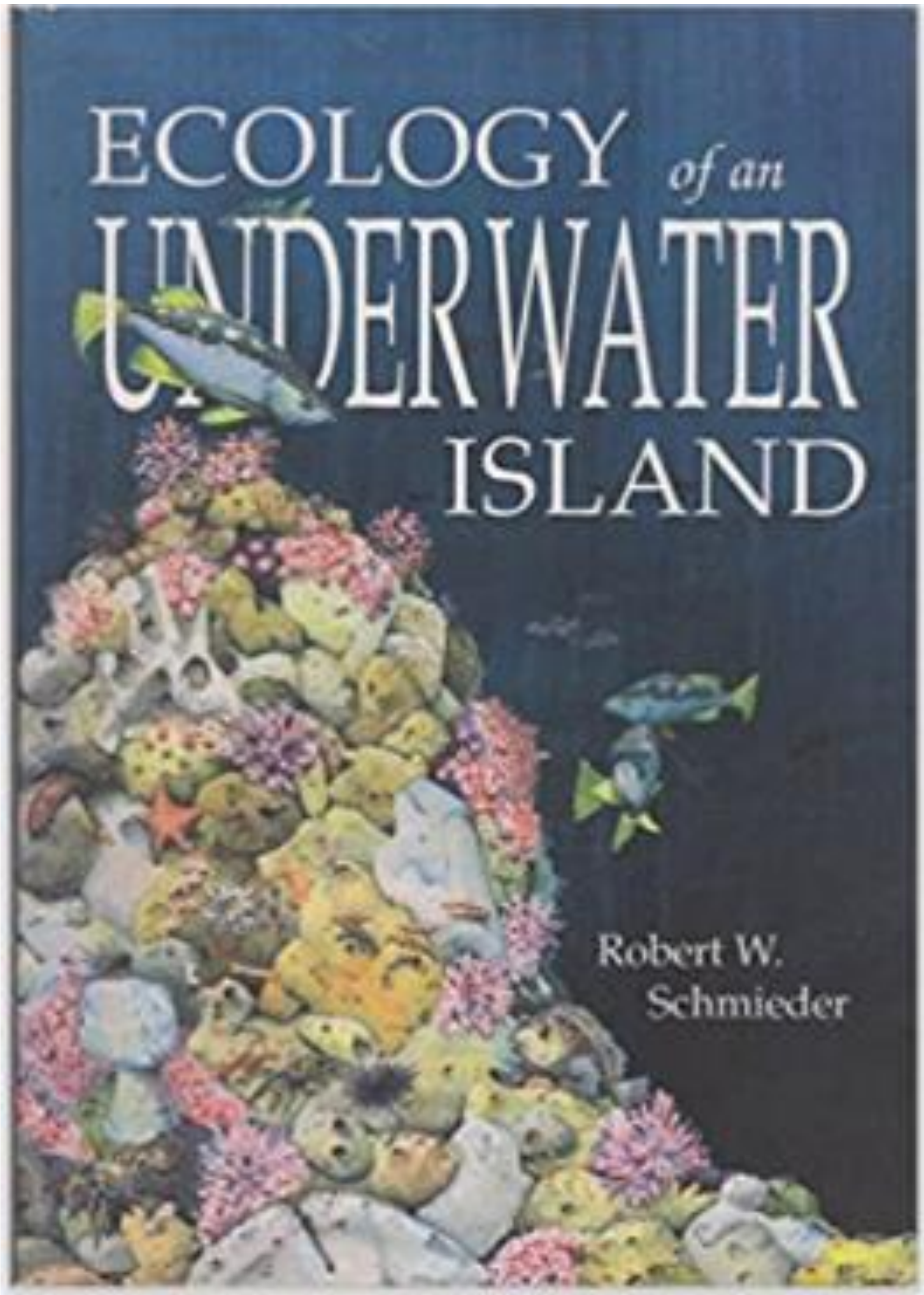


Figure ES.H.1. The findings from the historic dives at Cordell Bank by Cordell Expeditions are documented in *Ecology of an Underwater Island*. Image: Schmieder, 1991

Figure ES.H.2. Surveys of Cordell Bank were made using the submersible *Delta* from 2000–2005. Image: NOAA

Interpreting the Heritage of Maritime Archaeological Resources

There is one suspected shipwreck in CBNMS, the ex-USS *Stewart*, a U.S. Navy destroyer craft (R. Schwemmer/NOAA, personal communication, May 12, 2021; Figure ES.H.3). Built in 1920, it operated in the Pacific in World War II, was captured by the Japanese in 1942, then recaptured by the U.S. in 1945. In 1946, the U.S. intentionally scuttled the vessel in what is now CBNMS, and it is thought to be in or near Bodega Canyon. Although the vessel has not been visually surveyed on the seafloor, CBNMS helps to support the heritage of this and other potential maritime heritage resources by sharing the history and interpretation of archaeological sites and protecting all shipwrecks and other maritime archaeological resources in the sanctuary. Other archaeological resources may be in the sanctuary and yet to be discovered. Both ONMS and CBNMS provide outreach and programming about maritime heritage in national marine sanctuaries.

Indigenous peoples on the west coast of North America had many connections to coastal and ocean resources in ancient times. Periods of lower sea level coincide with coastal migration and habitation, and research on paleo shorelines can shed light on past connections to now-submerged lands. However, at this time, the sanctuary is unaware of any information that suggests historical connections of Indigenous peoples to CBNMS specifically, prior to contemporary usage of motorized fishing vessels. There are possible contemporary connections between CBNMS and Indigenous tribes and nations, who may fish or recreate in the sanctuary.

Figure ES.H.3. The USS *Stewart* when it was in U.S. Navy service. Image: National Archives

Conclusion

Because of its offshore location, CBNMS may have less of a direct, strong heritage connection to nearby communities compared to some other national marine sanctuaries. However, CBNMS plays a role and supports the heritage of commercial and recreational fishing, science and exploration, and maritime heritage resources. The role that the sanctuary plays in supporting the heritage of fishing has changed over time. Because of regulations from other agencies designed to allow fish stocks to recover, there are fewer types of fishing opportunities available at the time of the report than in the past. Science and exploration have a strong foundation at CBNMS, and the sanctuary continues to support this ecosystem service. At this time, CBNMS is unaware of past or present cultural connections between Indigenous communities and the sanctuary specifically, prior to contemporary usage of motorized fishing vessels. Information about maritime heritage resources in the sanctuary and its historical and heritage legacy in the broader sanctuary community are areas for further academic study. The sanctuary expansion and commitment to a more comprehensive approach to maritime heritage to include cultural connections led to the improving trend rating.

Sense of Place

Aesthetic attraction, spiritual significance, and location identity

Status Description: The capacity to provide the ecosystem service is compromised, but performance is acceptable.

Rationale: Due to physical barriers to in-person access, CBNMS has focused on bringing the sanctuary to the people through various means. As unique and difficult to visit as it is, CBNMS has cultivated a sense of place through a small but dedicated group of ocean users and has extended that sense of place to others remotely through education and outreach programming. In addition, visual resources created over the years through photography and videography have greatly aided in building a sense of place for local, regional, national, and international audiences. However, a lack of labor and sustained funding for CBNMS education and outreach programs has limited the ability to serve the needs of the community.

Sense of place is the aesthetic and spiritual attraction, and level of recognition and appreciation, that humans derive from a location given efforts to protect its iconic elements. Designation as a national marine sanctuary indicates the special recognition and appreciation the American public has for protecting the sanctuary's resources. Sanctuary designation can inspire many things in people, from creation of arts to a change in perspective. Just knowing a place of such biodiversity and wildness exists often inspires support for conservation and protection efforts. CBNMS is not an easy place to visit and experience, but the small number of people that have had the opportunity to do so have developed a strong connection to, memory of, and reverence for the sanctuary. Sense of place for those unable to visit the sanctuary can be built through education and outreach programs.

Indicators used to rate sense of place at CBNMS included exhibits, film, outreach, first hand experiences in the sanctuary, books inspired by CBNMS, wildlife photography, and interest in engaging with the CBNMS mission. The sense of place created by these indicators is central to the CBNMS mission of conserving and protecting this special place.

Sense of place was rated good/fair with an improving trend. The advancement of technology has allowed for improved imagery (photos and video), which has helped CBNMS reach more people and create a sense of place remotely. Exhibits with partner institutions and the CBNMS traveling exhibit target audiences that can not easily access the sanctuary, but can remotely experience its beauty and wonder through images (see the education ecosystem service section for more detail regarding these initiatives). Films produced about the sanctuary have enhanced viewers' awareness about its biodiversity. Remote live broadcasts of seafloor exploration, transmitted digitally by satellite and internet to people at home, schools, and museum venues, have greatly aided in bringing the sanctuary to the people.

Bringing the Place to the People: Exhibits, Film, and Outreach Events

Exhibits reached over 3 million visitors from 2009–2020. These exhibits include a traveling photo exhibit that brings images from the sanctuary to various community venues in Marin, Sonoma, and Mendocino counties in California (Figure ES.SP.1, Figure ES.SP.2). Comments from the photo exhibit's logbook exude the enthusiasm and sense of place it inspires:

> *"Thank you for taking me where I never could have gone!! Protect more!"*
>
> *"Thanks for sharing that which I will not see in person. Beautiful"*
>
> *"Fantastic! We didn't even know this existed, but it was very educational! Thank you!"*

Figure ES.SP.1. Viewers look at photos as part of the CBNMS traveling photo exhibit. Photo: J. Stock/NOAA

Figure ES.SP.2. Images of the offshore CBNMS travel to various public locations to enhance awareness about the sanctuary and what it protects. Photo: J. Stock/NOAA

The sanctuary is featured in some ONMS-produced short films that circulate on social media. The Cordell Marine Sanctuary Foundation facilitated a partnership between CBNMS and the South Florida Public Broadcasting Service *Changing Seas* series that resulted in the creation of a film about CBNMS. This film aired on public broadcasting stations and at various ocean film festivals nationwide. CBNMS staff participated in panel discussions about the film and the sanctuary at different film festivals that highlighted the film.

While bringing people to the sanctuary is one way to develop a sense of place, it is expensive and often inconsistent given weather and ocean conditions. In addition, CBNMS-staff-led boat trips allow for only a small number of people (one boat trip can take up to 35 people at a time) to visit the sanctuary, most of whom are repeat visitors due to their high interest in wildlife watching. Accessing the sanctuary directly also presents equity challenges due to the cost, physical challenges, and offshore location. The sanctuary co-hosted an annual wildlife watching boat trip between 2009 and 2017, but due to various factors (primarily unpredictable weather and rough ocean conditions), this offering was discontinued. Prior to its cancellation, participants shared the following reactions to the trip:

> *"Thanks to the hydrophone, we were able to listen to sea lions barking underwater and dolphins! That was incredible!"*
>
> *"I will never forget the dolphins! A mega pod!"*

Outside of the field trips, CBNMS has received invitations from federal agencies, Bay Area museums, community events, and nonprofit organizations to participate in outreach events, give community talks and presentations, and host and lead outdoor events like coastal walks and wildlife watching boat trips on charter vessels, indicating a desire for organizations and agencies to promote the sanctuary.

Sense of Place for People Who Have Visited the Sanctuary

The few who have traveled to CBNMS overcame several challenges to seek out a firsthand visit to the sanctuary, including a limited number of suitable seaworthy vessels to charter and highly variable and at times challenging sea conditions. Despite these challenges, visitors to CBNMS have had unique and memorable firsthand experiences.

A team of volunteer divers called Cordell Expeditions dove on Cordell Bank in the early 1980s and discovered its biodiversity, leading to the sanctuary's designation in 1989. Oral history interviews conducted with these explorers revealed that their experience diving Cordell Bank and exploring its biodiversity was, for some, a highlight of their lives (NOAA Fisheries, 2021c). They also expressed appreciation for how CBNMS programs have developed and how their original explorations led to the conservation of such an important place:

> *"We could fill volumes of our life experiences of what we've done, and we've all lived fairly adventurous lives. But for me, Cordell Bank was the highlight of it all." – Dave Cassotta, NOAA Fisheries, 2021c*
>
> *"Cordell Bank, having the opportunity to dive there, help describe it, is the number one high point in my life, excluding family…It's a place that should not be forgotten. It*

> *should be kept in the limelight, keep the public aware of such a special place right off our coast, unlike any other." – Don Dvorak*

> *"Cordell Bank was for about ten years...my obsessive driving interest to see this project through to the establishment of a national marine sanctuary." – Dr. Robert Schmieder*

Some fishers refer to Cordell Bank as a revered place, not just for fishing, but for encounters with seabirds and marine mammals in the surrounding area. Technical divers have supported the sanctuary mission in recent years by contributing to research and education, acquiring photographs and video, or collecting samples. Such access requires a permit to place a temporary reference line that contacts the seafloor. Nonetheless, these divers have explored and contributed their findings to CBNMS for resource management purposes.

Visitors all share a common impression: while inaccessible to most, those who have experienced CBNMS through research, fishing, or wildlife viewing appreciate the sanctuary and its resources enough to find a way to access this special place, despite the hardships involved.

Sharing Sense of Place: Literature and Photos Shared About Cordell Bank

CBNMS has inspired the writing of at least four books. Avid pelagic wildlife enthusiasts also post their top photos of birds and whales on social media and web pages.

Books either featuring or referencing CBNMS:

- *Ocean Birds of the Nearshore Pacific* (Stallcup, 1990)
- *Ecology of an Underwater Island* (Schmieder, 1991)
- *Edward Cordell and the Discovery of Cordell Bank* (Schmieder, 2019)
- *The Whale that Lit the World* (Churchman, 2018)

Websites with images taken in CBNMS:

- *The Natural History of Bodega Head* blog (Sones, 2022)
- Bay Area Underwater Explorers (2013)
- Flickr (2022)
- *Debi's Shearwater's Journeys* blog (Shearwater, 2013)

People Who Want to Engage with the Sanctuary Mission

While CBNMS is offshore, away from land, and out of sight for most people, there are various groups of people who have sought association with CBNMS. CBNMS has historically been supported by a small staff, and thus relies on partners to increase awareness of the sanctuary within the regional community. For example, the Oakland Museum of California approached sanctuary staff to feature CBNMS in its Natural Sciences Gallery renovation. Point Reyes National Seashore invited sanctuary staff to collaborate on interpretive exhibits in key locations to promote awareness of CBNMS throughout this highly visited park. Members of the community who are CBNMS enthusiasts formed a non-profit organization, the Cordell Marine Sanctuary Foundation. Their mission is to support scientific research, education, and public awareness of the sanctuary. Over the years, potential volunteers have reached out wanting to help and get involved in the CBNMS mission. In addition, members of the public apply to the

Sanctuary Advisory Council as seats become available, wanting to learn more and support the sanctuary with input from their respective constituencies. While the overall number of people engaging with CBNMS has been small, the dedication and passion they have for this unique place is apparent through their engagement with the sanctuary and its programs.

Conclusion

Due to its physical barriers to in-person access, CBNMS has focused on bringing the sanctuary to the people through various means. As unique and difficult to visit as it is, CBNMS has cultivated a sense of place through a small but dedicated group of ocean users and has extended that sense of place to others remotely through education and outreach programming. Distance learning programs, including research expedition telepresence, and temporary and permanent exhibits have allowed thousands of people to gain a sense of appreciation and sense of place for the sanctuary without physically accessing it. The visual resources created over the years through photography and videography have greatly aided in building this sense of place for local, regional, national, and international audiences. A data gap that was identified was information to help the sanctuary better understand effective ways to build and measure sense of place with communities over time.

Response to Pressures

The Pressures section of this report describes a variety of issues and human activities occurring within and beyond CBNMS that warrant attention, tracking, study, assessment and analysis, and, in some cases, specific management actions. Addressing any of these issues requires participation by and coordination with a variety of agencies and organizations. CBNMS works with entities such as federal, state, and local government agencies and non-profit organizations that contribute to managing human activities and addressing marine conservation issues. The Sanctuary Advisory Council is the primary way that the sanctuary receives input from these groups and the public on management of the sanctuary (see text box).

Cordell Bank National Marine Sanctuary Advisory Council

The Sanctuary Advisory Council was established in 2001 under the authority of the National Marine Sanctuaries Act. It was formed to serve as a forum for consultation and deliberation among its members and as a source of advice and recommendations to the sanctuary superintendent. Advisory council seats are occupied by members representing research, conservation, maritime activities, fishing, education, the community at large, and two federal agency partners. In addition to providing advice as a body to the sanctuary superintendent, individual advisory council members act as liaisons between CBNMS and constituent groups.

For each of the main issues and human activities presented in the Pressures section of this report, this Response section provides a summary of related activities and management actions led or coordinated by CBNMS staff. The activities described below are not exhaustive of all the ways CBNMS serves the community and the marine ecosystems encompassed within the sanctuary, but highlight significant contributions that are responsive to known or emerging pressures. Changes to management actions are not recommended in this section; however, in 2024, CBNMS staff will begin updating the sanctuary's management plan, and this condition report's findings will serve as an important foundation on which to build new action plans designed to address priority needs.

Summary of Activities

Described below is a summary of activities CBNMS has completed since the last condition report that address the influential pressures discussed throughout this report.

Climate Change and Ocean Acidification

Climate change is a global issue, and while there are many agencies, organizations, and individuals responding to this threat at global, regional, and local scales, NOAA has been working to better understand and communicate how the sanctuary is affected by climate change and ocean acidification. Since the last condition report, the scale, magnitude, and impacts of climate change have become increasingly clear. The highlights summarized below focus on CBNMS and its partners' efforts to address climate change and ocean acidification in the sanctuary and surrounding region.

Conservation Science Program

To enable effective management, scientists characterize and seek to understand how the resources and habitats in the sanctuary are responding to changes in the climate and ocean while recognizing that the sanctuary is ecologically interconnected to the ocean and atmosphere regionally and globally. NOAA scientists, including CBNMS staff, have identified potential climate impacts and climate indicators and are monitoring many of these indicators through partnerships with non-profit organizations and universities in various long-term projects. Examples include ACCESS ecosystem monitoring, hypoxia monitoring, and the CBNMS Benthic Science Project (Table R.1). These projects support management of the sanctuary, and particularly its response to climate change, by providing data on the conditions of sanctuary resources (e.g., on the seafloor and in the pelagic zone) under varying ocean conditions. This information can be used in climate-related resource protection and management efforts. In addition, and described in further detail in the following subsections, information from these projects has been applied to other management issues.

Table R.1. Conservation science programs that monitor climate indicators and identify potential impacts.

Program Name	Partners/ Collaborators	Timeframe	Primary Indicators Measured	Outputs
ACCESS	GFNMS, Point Blue Conservation Science, University of California Davis Bodega Marine Laboratory	2004–present	Oceanography, acoustics, prey sampling, predator abundance and distribution (and others)	Annual ocean climate indicators reports compile time series data of variables and summarize responses to environmental conditions (Elliott et al., 2019). Data have been used to understand conditions in the sanctuary and local responses to events like the marine heatwave.
Cordell Bank hypoxia monitoring project	University of California Davis Bodega Marine Laboratory	2014–present	Dissolved oxygen, salinity, temperature	Summaries of seasonal and annual patterns of oceanographic conditions at Cordell Bank (Hewett et al., 2017)
CBNMS Benthic Science Program	California Academy of Sciences	2000–present	Abundance and distribution of benthic taxa	New explorations and characterizations of sanctuary habitat and environmental conditions (Graiff et al., 2019, Giraffe & Lipski, 2020a, 2020b; Lipski et al., 2018)

Management, Administration, and the Resource Protection Program

Several reports have been produced that help inform and guide CBNMS activities related to climate change. In addition, CBNMS staff members have participated in ONMS regional and national climate teams to plan and implement climate initiatives. These teams also worked to coordinate efforts to learn about and address climate change and ocean acidification with the NOAA Climate Program Office and NOAA Fisheries.

Reports relevant to CBNMS climate change efforts:

- *Climate Change Impacts: Report of a Joint Working Group of the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries Advisory Councils* (Largier et al., 2010)
- *Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region: Report of a Working Group of the Gulf of the Farallones National Marine Sanctuary Advisory Council* (Duncan et al., 2013; adopted by CBNMS Advisory Council)
- *Climate Change Vulnerability Assessment for the North-Central California Coast and Ocean* (Hutto et al., 2015)
- *Climate-Smart Adaptation for North-central California Coastal Habitats Report of the Climate-Smart Adaptation Working Group of the Greater Farallones National Marine Sanctuary Advisory Council* (Hutto, 2016; includes CBNMS)
- *Climate Change Impacts: Cordell Bank National Marine Sanctuary* (ONMS, 2020d)
- *Climate Change Impacts: National Marine Sanctuaries West Coast Region* (ONMS, 2021)

These reports laid the groundwork to understand potential climate change impacts to sanctuary resources, identify indicators to monitor, and assess and understand the vulnerability and adaptive capacity of sanctuary resources.

CBNMS also took a number of actions to improve the efficiency of its facilities and operations, including moving into newly renovated, energy-efficient office buildings that are outfitted with high thermal resistance insulation, dual pane windows, LED lighting, ultra-high-efficiency tankless water heaters, high-efficiency central propane furnaces, and solar electric panels. Staff also compost waste from meals and lease hybrid-electric government vehicles for work use.

Education and Outreach Program

To raise awareness about the threats and impacts of climate change, CBNMS staff have initiated a number of activities focused on climate change and ocean acidification, including web postings, symposiums, workshops, classroom curricula, field trips, telepresence and other virtual learning opportunities, social media, segments on a local radio show, exhibits, and short films.

Summary: Climate Change Response

Impacts of climate change on sanctuary resources, particularly those related to temperature, ocean acidification, and species composition, distribution, and abundance, have become more evident since the 2009 condition report and tend to follow trends observed globally. Though we have an improved understanding of those impacts through monitoring and research, management action has focused largely on increasing awareness of the issue among the public. Further work is needed to understand what additional management actions could be taken to directly address and mitigate resource impacts from climate change in the sanctuary.

Fishing

CBNMS does not manage fisheries, though it can restrict destructive fishing activities. Rather, federal fisheries in CBNMS are managed by NOAA Fisheries (NMFS) and the Pacific Fishery Management Council. State fisheries in CBNMS (e.g., Dungeness crab) are managed by CDFW. CBNMS staff work with these partners to address fishing-related pressures.

After a multi-year process, NMFS changed Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act, in Amendment 28 of the Pacific Coast Groundfish Fishery Management Plan in 2019. West-Coast-wide changes to descriptions and management measures for Essential Fish Habitat and to specific Essential Fish Habitat Conservation Areas were developed through a collaborative process among trawl fishers and scientists and managers from federal and state agencies and environmental organizations. The trawl Rockfish Conservation Area was also removed in federal waters off Oregon and California, re-opening these waters to fishing with groundfish bottom trawl gear. CBNMS scientists contributed information on habitats and species that had been observed in some of the areas within the sanctuary, and the information was used to identify areas that eventually gained protection. The Essential Fish Habitat Conservation Areas in CBNMS currently comprise 170 square miles of benthic habitat protected from bottom trawl gear other than demersal seines. Within the sanctuary, the Essential Fish Habitat changes opened 19 square miles of primarily sandy-mud habitat on the continental shelf to bottom trawl fishing that were historically productive fishing grounds, while closing 19 square miles of shelf and slope habitat composed of hard and mixed substrate. It modified the boundaries of the existing Cordell Bank Biogenic Essential Fish Habitat Conservation Area, by extending it to protect new areas from bottom trawling while removing trawling restrictions from other areas, and also established a new Essential Fish Habitat Conservation Area, Gobbler's Knob. Following these changes to habitat protections, CBNMS identified new areas to survey to assess the impacts of fishing and protections.

CBNMS management considers potential impacts to fishing and other human activities prior to taking certain actions, such as revising the CBNMS management plan and finalizing regulations. For example, prior to the expansion of the sanctuary in 2015, ONMS studied the economic impacts the expansion would have on the commercial and recreational fisheries in CBNMS. An environmental impact statement was also compiled that reviewed the status of and projected impacts the expansion would have on living resources, commercial fishing, and recreation in the then-proposed expansion area (ONMS, 2014b). In brief, the environmental impact statement found that the expansion of sanctuary boundaries would not negatively affect living resources, commercial fishing, and recreation. Similarly, NOAA projected impacts of certain USCG vessel and training-related discharges on fishing in the expanded portion of the sanctuary in an environmental assessment and proposed rule prior to release of the final decision in 2018. NOAA determined that the impacts to natural resources, historic resources, and human uses (including fishing) would not be significant.

To ensure that sanctuary interests and regulations are considered in fisheries management and enforcement, CBNMS staff have built productive working relationships with fishery management agencies and other organizations with fishing interests. In particular, staff have worked closely with law enforcement partners and with the Pacific Fishery Management Council. Staff provide training on sanctuary regulations for enforcement officers and alert enforcement officers about potential or actual regulatory violations in the sanctuary. This has led to a collaborative enforcement approach, with law enforcement personnel from multiple agencies who are well-informed about and able to enforce sanctuary regulations. Staff regularly provide written and oral overview reports to the Pacific Fishery Management Council to keep them informed about surveys and assessments in West Coast national marine sanctuaries, allowing the council to incorporate that information into its actions. CBNMS also issues permits to allow for specified fisheries research activities within the sanctuary, such as groundfish stock assessments that disturb submerged lands or testing new fisheries assessment methods. By permitting these activities, CBNMS supports effective, data-driven fisheries management.

NOAA Fisheries and fishing stakeholders have seats on the Sanctuary Advisory Council, where they advise the sanctuary superintendent on issues related to sanctuary management and serve as liaisons to the community. These representatives regularly communicate fisheries updates to the council and weigh in on management actions that could affect fisheries and the fishing community.

Education and Outreach Programs

CBNMS seeks to raise awareness about how the sanctuary can support healthy fisheries. CBNMS staff have provided topical, fishing-specific outreach at local festivals, such as the Bodega Bay Fishermen's Festival. A toolkit was created and distributed through symposia, workshops, and on the web about how ocean acidification affects Dungeness crabs. Segments on a local radio show have featured interviews with guests about fishing, conservation, and management of fished species, among other topics. Fishing is featured in the CBNMS exhibit at the Oakland Museum of California. CBNMS has also worked to install interpretive exhibit panels about sanctuary resources at popular local fishing spots. Through these outreach efforts, CBNMS has reached people who otherwise may not be engaged on these issues.

Summary: Fishing Response

The sanctuary has taken actions to understand the impacts of fisheries on habitats and living resources, to inform fisheries management actions, and to educate the public about the importance of healthy ecosystems. The sanctuary benefits from many positive interactions and support from the fishing community. At the same time, the status and trends section of this report identified areas where fishing is impacting habitats and living resources. Data gaps that were noted included limited data availability and analysis of impacts and long-term trends.

Vessel Use

Noise

Following several high-profile ship strikes to whales in 2009, CBNMS began to study how vessels impact wildlife in the sanctuary. Ocean noise was identified as a potential vessel impact to whales, and in 2012, the CBNMS and GFNMS advisory councils recommended action to reduce vessel strike and acoustic impacts. In response, CBNMS began studying ocean noise in the sanctuary in 2015. In partnership with Oregon State University, NMFS, and NOAA's Pacific Marine Environmental Laboratory, CBNMS deployed a NOAA noise reference station to establish a baseline record of the soundscape of the sanctuary. The equipment has been serviced every two years and is still recording. Analysis of the first two years of data shows that low-frequency sound in the sanctuary is dominated by ships and baleen whales (Haver et al., 2020). These baseline data enable researchers and managers to understand the level of noise in the sanctuary, whether ocean noise is a threat to sanctuary wildlife, and effectiveness of any future management actions to reduce noise pollution. Other acoustic research in the sanctuary includes a NMFS project to deploy drifting acoustic buoys in partnership with CBNMS scientists. These buoys record sound at higher frequencies than the noise reference station and can be deployed beyond the geographic listening range of the noise reference station. Higher-frequency recordings provide information about species in the sanctuary such as beaked whales, but also about human activities occurring in the sanctuary (e.g., small vessel use) that could cause acoustic impacts to wildlife. In addition to working to understand the sanctuary's soundscape, CBNMS is engaged in regional, national, and international partnerships that explore possible management efforts, particularly related to reducing shipping noise.

In addition, CBNMS has raised awareness to the public about the issue of ocean noise by creating videos and web stories and participating in interviews with the media.

Ship Strikes

In response to the high-profile ship strikes to whales that occurred in 2009, and the subsequent advisory council recommendations mentioned in the previous section, CBNMS worked with USCG, NOAA Fisheries, and the IMO from 2010–2012 to modify the San Francisco TSS, including the northern lane in CBNMS, to improve safe navigation and reduce the co-occurrence of whales and ships transiting the sanctuary. As a result, the lanes were modified in 2014 from a funnel shape to straight lanes, and the northern lane through the sanctuary was lengthened and redirected. Beginning in 2010, CBNMS and GFNMS began to request that vessel traffic voluntarily slow down in the San Francisco TSS. Since 2015, CBNMS and GFNMS have worked together to implement a consistent annual voluntary vessel speed reduction in the San Francisco TSS from May 1 to November 15, during which cooperation level is tracked and reported to shipping companies. Beginning in May 2022, the voluntary slowdown extended through all of CBNMS and GFNMS and the end date was extended from November 15 to December 15 to further protect whales. As of 2021, the cooperation level with the voluntary request was 63% (Table R.2). In addition, CBNMS has partnered with GFNMS, Channel Islands National Marine Sanctuary, Bay Area Air Quality Management District, Air Pollution Districts of Santa Barbara and Ventura, EPA, California Marine Sanctuary Foundation, Greater Farallones Association, and the Volgenau Family Foundation to offer a monetary incentive program for ships to slow down in the TSS. Shipping companies register in advance and pledge to cooperate with the slow down request in exchange for funds. As of 2021, the cooperation level with the incentivized request was 60%. The population of ships engaged in the two programs (voluntary and incentivized) differs, leading to the different levels of cooperation. Since 2019, staff from CBNMS and GFNMS began evaluating additional actions that could be taken to further reduce ship strike risk.

Table R.2. Percent cooperation (percent of distance (nautical miles) traveled) with the voluntary vessel speed reduction program in the San Francisco TSS from all vessels 300 gross register tonnage or more, by year. Source: NOAA, 2021c

Region	2017	2018	2019	2020	2021
San Francisco Bay Region	45%	45%	58%	64%	63%

Information from sanctuary science projects has been incorporated in ship strike reduction efforts. ACCESS data on the distribution and abundance of whales and prey were used to identify habitat use hotspots (Rockwood et al., 2020a). This information was then used to identify where whales are most at risk of ship strikes and what management efforts might be most effective in reducing the risk of ship strikes (Rockwood et al., 2020b). Modeling analysis indicates that ship strike risk was reduced by 9–13% depending on species and year during May, June, July, and September in 2016–2017 as a result of speed reductions (Rockwood et al., 2020b). The noise reference station analysis provided new information about whale presence during times of the year when visual surveys were lacking, and this information was used in considerations of the timing and duration of annual voluntary vessel speed reduction (Haver et al., 2020).

CBNMS has also sought to raise awareness about the risk of ship strikes to whales through web sites and media outreach.

Spills and Discharges

CBNMS regulations prohibit the discharge of material or matter into the sanctuary to reduce pollution. When the sanctuary was expanded in 2015, the regulation was applied to the new area following a review of the impacts to living resources, fisheries, and military activities. There are exemptions for discharge from lawful fishing and certain USCG activities, including training. In 2018, CBNMS and GFNMS completed an environmental assessment of the USCG discharge exemption and concluded that although there may be impacts to water quality, the impacts would not be significant.

CBNMS staff members have worked with enforcement partners, including the NOAA Office of Law Enforcement and USCG, to ensure that those charged with enforcing sanctuary regulations are familiar with them and up to date on any issues. This includes ensuring pump-out facilities are in working order and training boarding officers, wardens, and rangers. CBNMS works closely with these enforcement partners when any issues arise. As a result of regulations and enforcement, NOAA settled a lawsuit against a cruise ship company in 2021 for illegally discharging material into the sanctuary.

Summary: Vessel Response

CBNMS has responded to the impacts of vessels on sanctuary habitats and living resources by increasing our understanding of ocean noise, reducing the risk of ship strikes to whales, and enforcing prohibitions on vessel spills and discharges. The status and trends section of this report identifies several areas where vessel impacts are a concern, which factored into ratings. Continued tracking of vessel use and analysis of trends, enforcement efforts, and passive acoustic monitoring is still needed. Management actions have reduced the risk to whales to some extent, but conservation targets have not been met, and cooperation with voluntary programs has leveled off. Further understanding of ship strike risk and possible management actions is needed.

Marine Debris

As noted above, regulations prohibit discharge of marine debris into the sanctuary; however, marine debris can enter the sanctuary through the loss of fishing gear, boating equipment, and research equipment. Also, litter from land or vessels outside the sanctuary, as well as materials in wastewater, including microplastics and microfibers, can enter the sanctuary. CBNMS staff record observations of marine debris during ACCESS and benthic surveys (see Figures App.E.10.5, App.E.10.6, App.E.10.7). These records have led to targeted removals of lost fishing gear, including crab pots at the surface and nets on the seafloor, to reduce entanglement and ghost fishing. CBNMS staff help to support and coordinate with other agencies and responders on entanglement, strandings, and necropsies. Outreach efforts by CBNMS staff aim to raise awareness about the impacts of marine debris on albatross that feed in the sanctuary. Programs with school groups, curricula, and exhibits have focused on actions students can take at schools and on local beaches to keep marine debris out of the watershed.

Summary: Marine Debris Response

CBNMS has worked to reduce the impacts of marine debris in the sanctuary by recording the locations of marine debris, supporting programs to reduce wildlife impacts from marine debris, and raising awareness about the issue. In the State section of this report, marine debris was noted to have impacts on water quality, habitat, and living resources. Continued monitoring to assess long-term trends and more information about microplastics were identified as needs.

Concluding Statement from Cordell Bank National Marine Sanctuary Superintendent Maria Brown

This is the first time CBNMS will have a condition report that provides a snapshot of the status and trends of human activities and sanctuary resources, as well as the importance of the sanctuary for providing ecosystem services, prior to developing a management plan. CBNMS's first condition report, published in 2009 when the sanctuary was 529 square miles in size, provides a reference point, but not a direct comparison for assessing the status and trends within the sanctuary. The sanctuary expanded in 2015 to 1,286 square miles, adding more habitat, with new areas to characterize and monitor.

The 2009–2021 condition report establishes a baseline for the expanded CBNMS. The data presented will guide recommendations for research and monitoring; education and outreach; and policies and programs in the next CBNMS management plan. The executive summary provides a succinct overview of these findings and a summary of the overall condition of CBNMS.

The development of a condition report is an important tool in a site's management process. The report summarizes the health of the ecosystem and community engagement through activities such as whale and seabird watching cruises, recreational fishing, and commercial fishing within that ecosystem over the last 10 or more years. Through extensive data collection and analysis, CBNMS staff and 92 people supported the review and report development of the status and trends of and pressures on focal species, habitats, and ecosystem services, as well as sanctuary management responses to those pressures. This information will guide Sanctuary Advisory Council recommendations and future management actions to maintain or improve the health of the sanctuary. CBNMS is scheduled to start the management plan review process in 2024 and will provide multiple opportunities for public engagement over the multi-year planning process.

Thank you to all who made the CBNMS condition report possible. Your data, participation, reviews, and expertise are instrumental in informing and guiding future management actions to maintain and improve the health of the sanctuary.

With gratitude,

Maria Brown

Acknowledgements

The production of this report would not have been possible without the participation and contributions of federal and state agencies, academic and non-governmental organizations, consortia, partners, and researchers. With gratitude, we recognize these individuals, who participated in meetings and workshops, contributed information, reviewed drafts, and/or provided general support to this effort:

Alvaro Jaramillo, Amy Freitag, Andrew Leising, Bella Mayorga, Ben Becker, Benjamin Rubinoff, Brady Phillips, Brian Johnson, Caitlin Evans, Carol Preston, Chris Harvey, Chris Hendry, Chrissy Piotrowski, Christine Beekman, Dan Dorfman, Dan Howard, Daniel Studt, David Dann, Dayna McLaughlin, Denise Greig, Dick Ogg, Doreen Gurrola, Elaine Dolcini, Ellie Jones, Gary Williams, George Clyde, Giselle Samonte, Grace Bottitta-Williamson, Greg Ruiz, Greg Williams, Hans Van Tilburg, Heidi Burkart, Henry Ruhl, Irma Cuevas, Jaime Jahncke, Jan Roletto, Jarrod Santora, Jeff Dorman, Jennifer Brown, Jennifer Selgrath, Jenny Hartigan, Jim Barry, Joe Hoyt, John Berge, John Calambokidis, John Largier, Jordan Stout, Justin Holl, Karen Reyna, Karin Forney, Karina Nielsen, Kathryn Lohr, Keeley Kent, Kelly Andrews, Laura Rogers-Bennett, Leila Hatch, Leslie Adler-Ivanbrook, Lindsey Peavey Reeves, Maria Brown, Marisol Garcia-Reyes, Meghan Marrero, Meredith Elliott, Michael Cummings, Michael Murphy, Morgan Patton, Nick Tolimieri, Nicole Raineault, Noah Wagner, Peter Winch, Richard Ogg, Robert Schwemmer, Robert Van Syok, Ryan Shea, Samara Haver, Sandi Funke, Sara Hutto, Sarah Allen, Sarah Hameed, Steven Bograd, Tom Laidig, Tom Lambert, Tracy Hajduk, Vanessa Zubkousky-White, Vernon Smith, and Will Klajbor.

ONMS is indebted to the thoughtful peer reviewers of this document: Ben Becker, Kristy Wallmo, and Virginia Selz.

Finally, we are also grateful to Kathryn Lohr for providing copy edits and Dayna McLaughlin for design and layout of the final report.

Literature Cited

Applied California Current Ecosystem Studies. (2020). *Tracking ocean climate*. http://www.accessoceans.org/?page_id=77

Applied California Current Ecosystem Studies. (2021). *Survey data, 2005–2019* [Unpublished data set]. https://data.caloos.org/#module-metadata/f712b555-d8ff-4345-83e4-9de2a337c7a4

Arthur, C., Baker, J., Bamford, H. (Eds.). (2009). *Proceedings of the international research workshop on the occurrence, effects, and fate of microplastic marine debris*. Technical Memorandum NOS-OR&R-30. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Marine Debris Program. https://repository.library.noaa.gov/view/noaa/2509

Asche, F., Eggert, H., Oglend, A., Roheim, C. A., & Smith, M. D. (2022). Aquaculture: Externalities and policy options. *Review of Environmental Economics and Policy*, *16*(2), 282–305. https://doi.org/10.1086/721055

Associated Press. (1946, May 26). Tough old ship sent to bottom: Heavier guns used after rockets fail. *San Bernardino Sun*, 52.

Avio, C. G., Gorbi, S., & Regoli, F. (2017). Plastics and microplastics in the oceans: From emerging pollutants to emerged threat. *Marine Environmental Research*, *128*, 2–11. https://doi.org/10.1016/j.marenvres.2016.05.012

Baldassare, M., Bonner, D., Lawler, R., & Thomas, D. (2021). *Californians and the environment*. Public Policy Institute of California. https://www.ppic.org/wp-content/uploads/ppic-statewide-survey-californians-and-the-environment-july-2021.pdf

Basu, N., Scheuhammer, A. M., Bursian, S. J., Elliott, J., Rouvinen-Watt, K. & Chan, H. M. (2007). Mink as a sentinel species in environmental health. *Environmental Research*, *103*(1), 130–144. https://doi.org/10.1016/j.envres.2006.04.005

Bay Area Underwater Explorers. (2013). *Bay Area Underwater Explorers Cordell Project*. https://www.baue.org/projects/cordell/

Becker, E. A., Forney, K. A., Miller, D. L., Fiedler, P. C., Barlow, J., & Moore, J. E. (2020). *Habitat-based density estimates for cetaceans in the California Current Ecosystem based on 1991–2018 survey data*. Technical Memorandum NMFS-SWFSC-638. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center. https://swfsc-publications.fisheries.noaa.gov/publications/CR/2020/2020Becker1.pdf

Bednaršek, N., Feely, R. A., Reum, J. C. P., Peterson, B., Menkel, J., Alin, S. R., & Hales, B. (2014). *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1785), 20140123. https://doi.org/10.1098/rspb.2014.0123

Bednaršek, N., Feely, R. A., Tolimieri, N., Hermann, A. J., Siedlecki, S. A., Waldbusser, G. G., McElhany, P., Alin, S. R., Klinger, T., Moore-Maley, B., & Pörtner, H. O. (2017). Exposure history determines pteropod vulnerability to ocean acidification along the U.S. West Coast. *Scientific Reports*, *7*, 4526. https://doi.org/10.1038/s41598-017-03934-z

Bednaršek, N., Feely, R. A., Beck, M. W., Alin, S. R., Siedlecki, S. A., Calosi, P., Norton, E. L., Saenger, C., Štrus, J., Greeley, D., Nezlin, N. P., Roethler, M., & Spicer, J. I. (2020). Exoskeleton dissolution with mechanoreceptor damage in larval Dungeness crab related to severity of present-day ocean acidification vertical gradients. *Science of The Total Environment*, *716*, 136610. https://doi.org/10.1016/j.scitotenv.2020.136610

Bejarano, A. C., Gulland, F. M., Goldstein, T., St. Leger, J., Hunter, M., Schwacke, L. H., VanDolah, F. M., & Rowles, T. K. (2008). Demographics and spatio-temporal signature of the biotoxin domoic acid in California Sea Lion (*Zalophus californianus*) stranding records. *Marine Mammal Science*, *24*(4), 899–912. https://doi.org/10.1111/j.1748-7692.2008.00224.x

Benson, S. R., Forney, K. A., Harvey, J. T., Carretta, J. V., & Dutton, P. H. (2007a). Abundance, distribution, and habitat of leatherback turtles (*Dermochelys coriacea*) off California, 1990−2003. *Fishery Bulletin*, *106*, 337–347. https://spo.nmfs.noaa.gov/content/abundance-distribution-and-habitat-leatherback-turtles-dermochelys-coriacea-california-1990

Benson, S. R., Dutton, P. H., Hitipeuw, C., Samber, B., Bakarbessy, J., & Parker, D. (2007b). Post-nesting migrations of leatherback turtles (*Dermochelys coriacea*) from Jamursba-Medi, Bird's Head Peninsula, Indonesia. *Chelonian Conservation and Biology*, *6*(1), 150−154. https://doi.org/10.2744/1071-8443(2007)6[150:PMOLTD]2.0.CO;2

Benson, S. R., Eguchi, T., Foley, D. G., Forney, K. A., Bailey, H., Hitipeuw, C., Samber, B. P., Tapilatu, R. F., Rei, V., Ramohia, P., Pita J., & Dutton, P. H. (2011). Large-scale movements and high-use areas of western Pacific leatherback turtles, *Dermochelys coriacea*. *Ecosphere*, *2*(7), art84. https://doi.org/10.1890/ES11-00053.1

Benson, S. R., Forney, K. A, Moore, J. E., LaCasella E. L., Harvey J. T., & Carretta, J. V. (2020). A long-term decline in the abundance of endangered leatherback turtles, *Dermochelys coriacea*, at a foraging ground in the California Current Ecosystem. *Global Ecology and Conservation*, *24*, e01371. https://doi.org/10.1016/j.gecco.2020.e01371

Bode, A., Botas, J. A., & Fernandez, E. (1997). Nitrate storage by phytoplankton in a coastal upwelling environment. *Marine Biology*, *129*, 399–406. https://doi.org/10.1007/s002270050180

Bograd, S. J., Buil, M. P., Di Lorenzo, E., Castro, C. G., Schroeder, I. D., Goericke, R., Anderson, C. R., Benitez-Nelson, C., & Whitney, F. A. (2015). Changes in source waters to the Southern California Bight. *Deep Sea Research Part II: Topical Studies in Oceanography*, 112, 42–52. https://doi.org/10.1016/j.dsr2.2014.04.009

Bond, N. A., Cronin, M. F., Freeland, H., & Mantua, N. (2015). Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophysical Research Letters*, *42*(9), 3414–3420. https://doi.org/10.1002/2015GL063306

Boulougouris, E. (2021, April 1). How container ships got so big, and why they're causing problems. *The Maritime Executive*. https://maritime-executive.com/editorials/op-ed-no-need-to-scrap-megamax-boxships-after-suez-canal-grounding

Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, *63*(2–3), 616–626. https://doi.org/10.1016/j.ecolecon.2007.01.002

Brady, R. X., Alexander, M. A., Lovenduski, N. S., & Rykaczewski, R. R. (2017). Emergent anthropogenic trends in California Current upwelling. *Geophysical Research Letters*, *44*(10), 5044–5052. https://doi.org/10.1002/2017GL072945

Breitburg, D. L., Salisbury, J., Bernhard, J. M., Cai, W. J., Dupont, S., Doney, S. C., Kroeker, K.J., Levin, L.A., Long, W.C., Milke, L.M., Miller, S.H., Phelan, B., Passow, U., Seibel, B.A., Todgham, A.E., &

Tarrant, A. M. (2015). And on top of all that…Coping with ocean acidification in the midst of many stressors. *Oceanography*, *28*(2), 48–61. https://dx.doi.org/10.5670/oceanog.2015.31

Bricker, S. B., Clement, C. G., Pirhalla, D. E., Orlando, S. P., & Farrow, D. R. G. (1999). *National estuarine eutrophication assessment: Effects of nutrient enrichment in the nation's estuaries*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. https://repository.library.noaa.gov/view/noaa/1693

Brookens, T. J., Harvey, J. T., & O'Hara, T. M. (2007). Trace element concentrations in the Pacific harbor seal (*Phoca vitulina richardii*) in central and northern California. *Science of the Total Environment*, *372*(2–3), 676–692. https://doi.org/10.1016/j.scitotenv.2006.10.006

Brookens, T. J., O'Hara, T. M., Taylor, R. J., Bratton, G. R., & Harvey, J. T. (2008). Total mercury body burden in Pacific harbor seal, *Phoca vitulina richardii*, pups from central California. *Marine Pollution Bulletin*, *56*(1), 27–41. https://doi.org/10.1016/j.marpolbul.2007.08.010

Buesseler, K. O., Jayne, S. R., Fisher, N. S., Rypina, I. I., Baumann, H., Baumann, Z., Breier, C. F., Douglass, E. M., George, J., Macdonald, A. M., Miyamoto, H., Nishikawa, J., Pike, S. M., & Yoshida, S. (2012). Fukushima-derived radionuclides in the ocean and biota off Japan. *Proceedings of the National Academy of Sciences*, *109*(16), 5984–5988. https://doi.org/10.1073/pnas.1120794109

Buesseler, K., Dai, M., Aoyama, M., Benitez-Nelson, C., Charmasson, S., Higley, K., Maderich, V., Masqué, P., Morris, P. J., Oughton, D., & Smith, J. N. (2017). Fukushima Daiichi-derived radionuclides in the ocean: Transport, fate, and impacts. *Annual Review of Marine Science*, *9*, 173–203. https://doi.org/10.1146/annurev-marine-010816-060733

Bullard, S. G., Lambert, G., Carman, M. R., Byrnes, J., Whitlatch, R. B., Ruiz, G., Miller, R. J., Harris, L., Valentine, P. C., Collie, J. S., Pederson, J., McNaught, D. C., Cohen, A. N., Asch, R. G., Dijkstra, J., & Heinonen, K. (2007). The colonial ascidian *Didemnum* sp. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. *Journal of Experimental Marine Biology and Ecology*, *342*(1), 99–108. https://doi.org/10.1016/j.jembe.2006.10.020

Bureau of Ocean Energy Management & National Oceanic and Atmospheric Administration. (2021). *Marine cadastre*. https://marinecadastre.gov/

Calambokidis, J., & Barlow, J. (2020). *Updated abundance estimates for blue and humpback whales along the U.S. West Coast using data through 2018*. Technical Memorandum NMFS-SWFSC-634. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center. https://repository.library.noaa.gov/view/noaa/27104

California Academy of Sciences. (2022). *Invertebrate zoology collection* [Data set]. https://researcharchive.calacademy.org/research/izg/iz_coll_db/Index.asp

California Air Resources Board. (2020). California Air Resources Board. Retrieved from https://ww2.arb.ca.gov/ghg-inventory-graphs. Accessed July 22, 2020.

California Department of Public Health. (2020a). *Domic acid in crabs, 2003–2020* [Data set]. California Department of Public Health, Food and Drug Branch. https://www.cdph.ca.gov/Programs/CEH/DFDCS/pages/fdbprograms/foodsafetyprogram/domoicacid.aspx

California Department of Public Health. (2020b). *Paralytic shellfish poisoning toxins and domoic acid, 1991–2020* [Unpublished data set].

California Department of Fish and Wildlife. (2018). Southern commercial Dungeness crab season delayed in ocean waters north of Bodega Head due to public health hazard. *California Department of Fish and Wildlife News*. https://cdfgnews.wordpress.com/2018/11/09/southern-commercial-dungeness-crab-season-delayed-in-ocean-waters-north-of-bodega-head-due-to-public-health-hazard/

California Department of Fish and Wildlife. (2019). California commercial Dungeness crab season will close statewide April 15, 2019. *Marine Management News*. https://cdfwmarine.wordpress.com/2019/04/02/california-commercial-dungeness-crab-season-will-close-statewide-april-15-2019/

California Department of Fish and Wildlife. (2020a). *California commercial landing receipt data, 1994–2020* [Unpublished data set].

California Department of Fish and Wildlife. (2020b). *Declaration of Fishery Season Delay in the Commercial Dungeness Crab Fishery due to Risk of Marine Life Entanglement*. Sacramento, CA. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=184803&inline

California Department of Fish and Wildlife. (2020c). *California Recreational Fisheries Survey - Additional information*. https://wildlife.ca.gov/Conservation/Marine/CRFS/Additional-Information

California Department of Fish and Wildlife. (2021a). *Marine Life Management Act*. https://wildlife.ca.gov/Conservation/Marine/MLMA

California Department of Fish and Wildlife. (2021b). *New recreational Dungeness crab fishery regulations adopted to manage entanglement risk for whales and sea turtles*. https://wildlife.ca.gov/News/new-recreational-dungeness-crab-fishery-regulations-adopted-to-manage-entanglement-risk-for-whales-and-sea-turtles

California Department of Fish and Wildlife. (2021c). *CDFW announces start of commercial crab fishery and recreational use of crab traps in fishing zone 3*. https://wildlife.ca.gov/News/cdfw-announces-start-of-commercial-crab-fishery-and-recreational-use-of-crab-traps-in-fishing-zone-3

California Department of Fish and Wildlife. (2021d). *California passenger fishing vessel data* [Unpublished data set].

California Department of Fish and Wildlife. (2023). *Chinook salmon*. https://wildlife.ca.gov/Conservation/Fishes/Chinook-Salmon

California Environmental Data Exchange Network. (2021). *Contaminant Tissue Data, 2009-2010*. https://ceden.waterboards.ca.gov/AdvancedQueryTool

California Natural Diversity Database. (2023). *State and federally listed endangered and threatened animals of California*. California Department of Fish and Wildlife. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109405&inline

California Ocean Protection Council. (2020). *California Dungeness Crab Fishing Gear Working Group*. https://www.opc.ca.gov/whale-entanglement-working-group/

California Ocean Science Trust. (2016). *Frequently asked questions list: Harmful algal blooms and California fisheries*. https://www.oceansciencetrust.org/wp-content/uploads/2016/07/HABs-and-Fisheries-FAQ-List-2016-.pdf

California State Parks. (2021). *California vessel registration reports*. Division of Boating and Waterways. https://dbw.parks.ca.gov/?page_id=29371

Campbell, M. D., Patino, R., Tolan, J., Strauss, R., & Diamond, S. L. (2010). Sublethal effects of catch-and-release fishing: Measuring capture stress, fish impairment, and predation risk using a condition index. *ICES Journal of Marine Science*, *67*(3), 513–521. https://doi.org/10.1093/icesjms/fsp255

Carlton, J. T., Chapman, J. W., Geller, J. B., Miller, J. A., Carlton, D. A., McCuller, M. I., Treneman, N. C., Steves, B. P., & Ruiza, G. M. (2017). Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography. *Science*, *357*(6358), 1402–1406. https://doi.org/10.1126/science.aao1498

Carreiro-Silva, M., Ocaña, O., Stankovic, D., Sampaio, I., Porteiro, F. M., Fabri, M., & Stefanni, S. (2017). Zoantharians (Hexacorallia: Zoantharia) associated with cold-water corals in the Azores region: New species and associations in the deep sea. *Frontiers in Marine Science*, *4*, 88. https://doi.org/10.3389/fmars.2017.00088

Carretta, J. V., Muto, M. M., Wilkin, S., Greenman, J., Wilkinson, K., Deangelis, M., Viezbicke, J., & Jannot, J. (2016). *Sources of human-related injury and mortality for U.S. Pacific west coast marine mammal stock assessments, 2010–2014*. Technical Memorandum NMFS-SWFSC-554. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center. https://repository.library.noaa.gov/view/noaa/8703

Carretta, J. V., Muto, M. M., Greenman, J., Wilkinson, K., Lawson, D., Viezbicke, J.,& Jannot, J. (2017). *Sources of human-related injury and mortality for U.S. Pacific west coast marine mammal stock assessments, 2011–2015*. Technical Memorandum NMFS-SWFSC-579. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center. https://repository.library.noaa.gov/view/noaa/14800

Carretta, J. V., Oleson, E. M., Forney, K. A, Muto, M. M., Weller, D. W., Lang, A. R., Baker, J., Hanson, B., Orr, A. J., Barlow, J., Moore, J. E., & Brownell, R. L., Jr. (2021). *U.S. Pacific marine mammal stock assessments: 2020*. Technical Memorandum NMFS-SWFSC-646. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center. https://doi.org/10.25923/r00a-m485

Cavole, L. M., Demko, A. M., Diner, R. E., Giddings, A., Koester, I., Pagniello, C. M. L. S., Paulsen, M., Ramirez-Valdez, A., Schwenck, S. M., Yen, N. K., Zill, M. E., & Franks, P. J. S. (2016). Biological impacts of the 2013–2015 warm-water anomaly in the northeast Pacific: Winners, losers, and the future. *Oceanography*, *29*(2), 273–285. http://www.jstor.org/stable/24862690

Center for Biological Diversity v. NOAA Fisheries, Case No. 3:21-cv-345 (U.S. District Court for the Northern District of California, 2021). https://biologicaldiversity.org/programs/oceans/pdfs/CA_whales_and_ship_strike_complaint_2021_01_14.pdf

Chan, F., Barth, J. A., Blanchette, C. A., Byrne, R. H., Chavez, F., Cheriton, O., Feely, R. A., Friederich, G., Gaylord, B., Gouhier, T., Hacker, S., Hill, T., Hofmann, G., McManus, M. A., Menge, B. A., Nielsen, K. J., Russell, A., Sanford, E., Sevadjian, J., & Washburn, L. (2017). Persistent spatial structuring of coastal ocean acidification in the California Current System. *Scientific Reports*, *7*, 2526. https://doi.org/10.1038/s41598-017-02777-y

Churchman, J. (2018). *The whale that lit the world*. Morrisville, NC: Lulu Press, Inc.

Communities for a Better Environment, Center for Biological Diversity, San Francisco Baykeeper, Friends of the Earth, & Sierra Club. (2019). *Comments on San Francisco Bay to Stockton Navigation Improvement Project Draft Environmental Impact Statement*.

Convention on Biological Diversity. (2006). *Article 2. Use of terms*. United Nations Environment Programme. https://www.cbd.int/convention/articles/?a=cbd-02

Cooper, H. L., Potts, D. C., & Paytan, A. (2017). Effects of elevated pCO_2 on the survival, growth, and moulting of the Pacific krill species, *Euphausia pacifica*. *ICES Journal of Marine Science*, *74*(4), 1005–1012. https://doi.org/10.1093/icesjms/fsw021

Cordell, J. R., Lawrence, D. J., Ferm, N. C., Tear, L. M., Smith, S. S., & Herwig, R. P. (2008). Factors influencing densities of non-indigenous species in the ballast water of ships arriving at ports in Puget Sound, Washington, United States. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *19*(3), 322–343. https://doi.org/10.1002/aqc.986

Cordell Bank National Marine Sanctuary. (2014). *Climate change*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/assessment/pdfs/cbnms_climate_change_2014.pdf

Cordell Bank National Marine Sanctuary. (2019). *Cordell Bank remotely operated vehicle exploratory surveys on deep slope habitat, Cruise NA116, 2019* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.

Cordell Bank National Marine Sanctuary. (2020). *Benthic monitoring* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.

Cordell Bank National Marine Sanctuary. (2021a). *Cordell Bank remotely operated vehicle surveys on continental shelf soft sediment habitat, 2017–2018* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.

Cordell Bank National Marine Sanctuary. (2021b). *Analysis of Cordell Bank National Marine Sanctuary cruise register database* [Unpublished data]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.

Cordell Bank National Marine Sanctuary. (2021c). *Analysis of Office of National Marine Sanctuaries permit database* [Unpublished data]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries.

Cordell Bank National Marine Sanctuary. (2023). *Seabirds*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. https://cordellbank.noaa.gov/about/seabirds.html

Croll, D. A., Marinovic, B., Benson, S., Chavez, F. P., Black, N., Ternullo, R., & Tershy, B. R. (2005). From wind to whales: Trophic links in a coastal upwelling system. *Marine Ecology Progress Series*, *289*, 117–130. https://doi.org/10.3354/meps289117

Croxall, J. P., Butchart, S. H. M., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., & Taylor, P. (2012). Seabird conservation status, threats and priority actions: A global assessment. *Bird Conservation International*, *22*(1), 1–34. https://doi.org/10.1017/S0959270912000020

Davis, J. A., May, M. D., Greenfield, B. K., Fairey, R., Roberts, C., Ichikawa, G., Stoelting, M. S., Becker, J. S. & Tjeerdema, R. S. (2002). Contaminant concentrations in sport fish from San Francisco Bay, 1997. *Marine Pollution Bulletin*, *44*(10), 1117–1129. https://doi.org/10.1016/S0025-326X(02)00166-2

Davis, J. A., Ross, J. R. M., Bezalel, S. N., Hunt, J. A., Melwani, A. R., Allen, R. M., Ichikawa, G., Bonnema, A., Heim, W. A., Crane, D., Swenson, S., Lamerdin, C., Stephenson, M., & Schiff, K. (2010). *Contaminants in fish from the California coast, 2009–2010: Summary report on a two-year screening survey*. California State Water Resources Control Board. https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/coast_study/bog2012may/coast2012report.pdf

Dayton, P. K. (1972). Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. In B. C. Parker (Ed.), *Proceedings of the colloquium on conservation problems in Antarctica* (pp. 81–96). Allen Press.

Dekeling, R. P. A., Tasker, M. L., Van der Graaf, A. J., Ainslie, M. A., Anderson, M. H., André, M., Borsani, J. F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S. P., Sigray, P., Sutton, G., Thomsen, F.,...Young, J. V. (2014). *Monitoring guidance for underwater noise in European seas, part II: Monitoring guidance specifications*. Publications Office of the European Union. https://doi.org/10.2788/27158

deRivera, C. E., Ruiz, G., Crooks, J., Wasson, K., Lonhart, S., Fofonoff, P., Steves, B., Rumrill, S., Brancato, M. S., Pegau, S., Bulthuis, D., Preisler, R. K., Schoch, C., Bowlby, E., DeVogelaere, A., Crawford, M., Gittings, S., Hines, A., Takata, L.,...Powell, S. (2005). *Broad-scale non-indigenous species monitoring along the West Coast in national marine sanctuaries and national estuarine research reserves*. Report to National Fish and Wildlife Foundation. https://repository.library.noaa.gov/view/noaa/10712

Di Lorenzo, E., Schneider, N., Cobb, K. M., Franks, P. J. S., Chhak, K., Miller, A. J., McWilliams, J. C., Bograd, S. J., Arango, H., Curchister, E., Powell, T. M., & Rivière, P. (2008). North Pacific Gyre Oscillation links ocean climate and ecosystem change. *Geophysical Research Letters*, *35*(8), L08607. https://doi.org/10.1029/2007GL032838

Di Lorenzo, E., & Mantua, N. (2016). Multi-year persistence of the 2014/15 North Pacific marine heatwave. *Nature Climate Change*, *6*, 1042–1047. https://doi.org/10.1038/nclimate3082

Diaz, R., Hastings, S., Fowler, A., & Marks, L. (2018). *Preventing the spread of the invasive alga* Undaria pinnatifida *in the Santa Barbara Channel region: Management options and case studies*. Prepared for National Oceanic and Atmospheric Administration, Channel Islands National Marine Sanctuary.

Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2009). Ocean acidification: The other CO_2 problem. *Annual Review of Marine Science*, *1*, 169–192. https://doi.org/10.1146/annurev.marine.010908.163834

Dore, J. E., Lukas, R., Sadler, D. W., Church, M. J., & Karl, D. M. (2009). Physical and biogeochemical modulation of ocean acidification in the central North Pacific. *Proceedings of the National Academy of Sciences*, *106*(30), 12235–12240. https://doi.org/10.1073/pnas.090604410

Duncan, B. E., Higgason, K. D., Suchanek, T. H, Largier, J., Stachowicz, J., Allen, S., Bograd, S., Breen, R., Gellerman, H., Hill, T., Jahncke, J., Johnson, R., Lonhart, S., Morgan, S., Roletto, J., & Wilkerson, F. (2014). *Ocean climate indicators: A monitoring inventory and plan for tracking climate change in the north-central California coast and ocean region*. Report of a Working Group of the Gulf of the Farallones National Marine Sanctuary Advisory Council. Marine Sanctuaries Conservation Series ONMS-14-09. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries.

https://farallones.noaa.gov/manage/climate/pdf/GFNMS-Indicators-Monitoring-Plan-FINAL.pdf

Dunkley, M. (2015). Climate is what we expect, weather is what we get: Managing the potential effects of climate change on underwater cultural heritage. In W. Willems & H. van Shaik (Eds.), *Water and heritage: Material, conceptual, and spiritual connections* (pp. 217–230). Leiden: Sidestone Press.

eBird. (2021). *eBird basic dataset* [Data set]. The Cornell Lab of Ornithology. https://ebird.org/science/use-ebird-data

Edwards, P. M. (2010). *Between the lines of World War II: Twenty-one remarkable people and events*. Jefferson, NC: McFarland & Company, Inc.

Elliott, M., & Jahncke, J. (2019). *Ocean climate indicators status report: 2018*. Report to collaborators at Cordell Bank and Greater Farallones national marine sanctuaries. Point Blue Conservation Science. http://www.accessoceans.org/wp-content/uploads/2019/12/Ocean-Climate-Indicators-Report-2018.pdf

Elliott, M., Lipski, D., Roletto, J., Warzybok, P., & Jahncke, J. (2020). *Ocean climate indicators status report: 2019*. Point Blue Conservation Science. http://www.accessoceans.org/wp-content/uploads/2020/07/Ocean_Climate_Indicators_Report_2019.pdf

Endres, S., Maes, F., Hopkins, F., Houghton, K., Mårtensson, E. M., Oeffner, J., Quack, B., Singh, P., & Turner, D. (2018). A new perspective at the ship-air-sea-interface: The environmental impacts of exhaust gas scrubber discharge. *Frontiers in Marine Science*, *5*, 139. https://doi.org/10.3389/fmars.2018.00139

Environmental Research Division. (2022). *Upwelling indices*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries, Southwest Fisheries Science Center. https://oceanview.pfeg.noaa.gov/products/upwelling/cutibeuti

Esri. (2014). *World ocean base* [Data set]. https://www.arcgis.com/home/item.html?id=1e126e7520f9466c9ca28b8f28b5e500%2F

Fabry, V. J., Seibel, B. A., Feely, R. A., & Orr, J. C. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science*, *65*(3), 414–432. https://doi.org/10.1093/icesjms/fsn048

Facebook. (2020). *CBNMS account analytics* [Unpublished data set].

Federal Geographic Data Committee. (2012). *Coastal and marine ecological classification standard*, version 4.0. Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee.

Federal Reserve Bank of Minneapolis. (2022). *Consumer Price Index, 1913–*. https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator/consumer-price-index-1913-

Feely, R. A., Sabine, C. L., Hernandez-Ayon, J. M., Ianson, D., & Hales, B. (2008). Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science*, *320*(5882), 1490–1492. https://doi.org/10.1126/science.1155676

Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., Hill, T. M., Gaylord, B.,Sanford, E., Byrne, R. H., Sabine, C. L., Greeley, D., & Juranek, L. (2016). Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science*, *183*(A), 260–270. https://doi.org/10.1016/j.ecss.2016.08.043

Felis, J. J., Adams, J., Hodum, P. J., Carle, R. D., & Colodro, V. (2019). Eastern Pacific migration strategies of pink-footed shearwaters *Ardenna creatopus*: Implications for fisheries interactions and international conservation. *Endangered Species Research*, *39*, 269–282. https://doi.org/10.3354/esr00969

Field, J. C., Miller, R. R., Santora, J. A., Tolimieri, N., Haltuch, M. A., Brodeur, R. D., Auth, T. D., Dick, E. J., Monk, M. H., & Wells, B. K. (2021). Spatiotemporal patterns of variability in the abundance and distribution of winter-spawned pelagic juvenile rockfish in the California Current. *PloS ONE*, *16*(5), e0251638. https://doi.org/10.1371/journal.pone.0251638

FISHBIO. (2020). *Better than expected: The 2019 salmon season*. https://fishbio.com/field-notes/the-fish-report/better-expected-2019-salmon-season

Fisher, B., & Turner, R. K. (2008). Ecosystem services: Classification for valuation. *Biological Conservation*, *141*(5), 1167–1169. https://doi.org/10.1016/j.biocon.2008.02.019

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, *68*(3), 643–653. https://doi.org/10.1016/j.ecolecon.2008.09.014

Fisher, J. L., Peterson, W. T., & Rykaczewski, R. R. (2015). The impact of El Niño events on the pelagic food chain in the northern California Current. *Global Change Biology*, *21*(12), 4401–4414. https://doi.org/10.1111/gcb.13054

Fleming, A. H., Clark, C. T., Calambokidis, J., & Barlow, J. (2016). Humpback whale diets respond to variance in ocean climate and ecosystem conditions in the California Current. *Global Change Biology*, *22*(3), 1214–1224. https://doi.org/10.1111/gcb.13171

Flickr. (2022, January 18). *Photos*. https://www.flickr.com/search/?text=cordell%20bank

Fofonoff, P. W., Ruiz, G. M., Steves, B., Simkanin, C., & Carlton, J. T. (2018). *California Non-native Estuarine and Marine Organisms (Cal-NEMO) System*. http://invasions.si.edu/nemesis/

Fontana, R. E., Elliott, M. L., Largier, J. L., & Jahncke, J. (2016). Temporal variation in zooplankton abundance and composition in a strong, persistent coastal upwelling region. *Progress in Oceanography*, *142*, 1–16. https://doi.org/10.1016/j.pocean.2016.01.004

Food and Agriculture Organization of the United Nations. (2020). *The state of world fisheries and aquaculture 2020: Sustainability in action*. https://doi.org/10.4060/ca9229en

Ford, R. G., Ainley, D. G., Casey, J. L., Keiper, C. A., Spear, L. B., & Ballance, L. T. (2004). The biogeographic pattern of seabirds in the central portion of the California Current. *Marine Ornithology*, *32*, 77–96.

Free, C. M., Moore, S. K., & Trainer, V. L. (2022). The value of monitoring in efficiently and adaptively managing biotoxin contamination in marine fisheries. *Harmful Algae*, *114*, 102226. https://doi.org/10.1016/j.hal.2022.102226

Frey, M. A., Simard, N., Robichaud, D. D., Martin, J. L., & Therriault, T. W. (2014). Fouling around: Vessel sea-chests as a vector for the introduction and spread of aquatic invasive species. *Management of Biological Invasions*, *5*(1), 21–30. http://dx.doi.org/10.3391/mbi.2014.5.1.02

Frisk, G. V. (2012). Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends. *Scientific Reports*, *2*, 437. https://doi.org/10.1038/srep00437

Froehlich, H. E., Gentry, R. R., Lester, S. E., Cottrell, R. S., Fay, G., Branch, T. A., Gephart, J. A., White, E. R., & Baum, J. K. (2021). Securing a sustainable future for U.S. seafood in the wake of a global crisis. *Marine Policy*, *124*, 104328. https://doi.org/10.1016/j.marpol.2020.104328

Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin*, *92*(1–2), 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

García-Reyes, M., & Largier, J. (2010). Observations of increased wind-driven coastal upwelling off central California. *Journal of Geophysical Research: Oceans*, *115*(C4), C04011. https://doi.org/10.1029/2009JC005576

García-Reyes, M., & Largier, J. L. (2012). Seasonality of coastal upwelling off central and northern California: New insights, including temporal and spatial variability. *Journal of Geophysical Research: Oceans*, *117*(C3), C03028. https://doi.org/10.1029/2011JC007629

García-Reyes, M., Largier, J. L., & Sydeman, W. J. (2014). Synoptic-scale upwelling indices and predictions of phyto- and zooplankton populations. *Progress in Oceanography*, *120*, 177–188. https://doi.org/10.1016/j.pocean.2013.08.004

Gatehouse Maritime. (2022). *Vessel tracking, 2021* [Unpublished data set].

Gentemann, C. L., Fewings, M. R., & García-Reyes, M. (2017). Satellite sea surface temperatures along the West Coast of the United States during the 2014–2016 northeast Pacific marine heat wave. *Geophysical Research Letters*, *44*(1), 312–319. https://doi.org/10.1002/2016GL071039

Gephart, J. A., Froehlich, H. E., & Branch, T. A. (2019). To create sustainable seafood industries, the United States needs a better accounting of imports and exports. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(19), 9142–9146. https://doi.org/10.1073/pnas.1905650116

Gerhart, D. J. (1990). Fouling and gastropod predation: Consequences of grazing for a tropical octocoral. *Marine Ecology Progress Series*, *62*, 103–108.

Giron-Nava, A., Ezcurra, E., Brias, A., Velarde, E., Deyle, E., Cisneros-Montemayor, A. M., Munch, S. B., Sugihara, G., & Aburto-Oropeza, O. (2021). Environmental variability and fishing effects on the Pacific sardine fisheries in the Gulf of California. *Canadian Journal of Fisheries and Aquatic Sciences*, *78*(5), 623–630. https://doi.org/10.1139/cjfas-2020-0010

Global Fishing Watch. (2021). *Total fishing hours for all gear types, 2012–2020* [Data set]. Copyright 2021, Global Fishing Watch, Inc. Accessed on June 17, 2021. https://globalfishingwatch.org/data-download/datasets/public-fishing-effort

Gobler, C. J. (2020). Climate change and harmful algal blooms: Insights and perspective. *Harmful Algae*, *91*, 101731. https://doi.org/10.1016/j.hal.2019.101731

Goh, N. K. C., Ng, P. K. L., & Chou, L. M. (1999). Notes on the shallow water gorgonian-associated fauna on coral reefs in Singapore. *Bulletin of Marine Science*, *65*(1), 259–282.

Gómez, C. E., Wickes, L., Deegan, D., Etnoyer, P. J., & Cordes, E. E. (2018). Growth and feeding of deep-sea coral *Lophelia pertusa* from the California margin under simulated ocean acidification conditions. *PeerJ*, *6*, e5671. https://doi.org/10.7717/peerj.5671

Graiff, K., Lipski, D., Howard D., & Carver, M. (2019). *Benthic community characterization of the mid-water reefs of Cordell Bank*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/docs/2017-cb-benthic-community.pdf

Graiff, K., & Lipski, D. (2020a). *Characterization of Cordell Bank, and continental shelf and slope: 2018 ROV surveys*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/docs/20200709-characterization-of-cordell-bank-and-continental-shelf-and-slope.pdf

Graiff, K., & Lipski, D. (2020b). *First characterization of deep-sea habitats in Cordell Bank National Marine Sanctuary: E/V* Nautilus *2017*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/docs/20200709-first-characterization-of-deep-sea-habitats-in-cordell-bank-national-marine-sanctuary.pdf

Graiff, K., & Lipski, D. (2023). *Second characterization of deep-sea habitats in Cordell Bank National Marine Sanctuary: E/V Nautilus 2019* [Manuscript in review]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary.

Gruber N., Hauri, C., Lachkar, Z., Loher, D., Frölicher, T. L., & Plattner, G. (2012). Rapid progression of ocean acidification in the California Current System. *Science*, *337*(6091), 220–223. https://doi.org/10.1126/science.1216773

Gulf of the Farallones National Marine Sanctuary. (2014). *Final management plan*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmsfarallones.blob.core.windows.net/farallones-prod/media/archive/manage/pdf/expansion/GFNMS_FMP_12_04_14.pdf

Gulland, F. M., Baker, J., Howe, M., LaBrecque, E., Leach, L., Moore, S. E., Reeves, R. R., & Thomas, P. O. (2022). A review of climate change effects on marine mammals in United States waters: Past predictions, observed impacts, current research and conservation imperatives. *Climate Change Ecology*, *3*, 100054. https://doi.org/10.1016/j.ecochg.2022.100054

Hanyuda, T., Hansen, G. I., & Kawai, H. (2018). Genetic identification of macroalgal species on Japanese tsunami marine debris and genetic comparisons with their wild populations. *Marine Pollution Bulletin*, *132*, 74–81. https://doi.org/10.1016/j.marpolbul.2017.06.053

Hartwell, S. I. (2007). *Distribution of persistent organic contaminants in canyons and on the continental shelf off central California*. Technical Memorandum NOS NCCOS 58. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science. https://repository.library.noaa.gov/view/noaa/16893

Hartwell, I. (2008). *Contaminants in sediments of the central California continental shelf and slope* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment.

Harvey, C. J., Garfield, N., Williams, G. D., Tolimieri, N. (Eds.). (2021). *Ecosystem status report of the California Current for 2020–21: A summary of ecosystem indicators compiled by the California Current Integrated Ecosystem Assessment Team*. Technical Memorandum NMFS-NWFSC-170. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center. https://doi.org/10.25923/x4ge-hn11

Hassellöv, I., Turner, D. R., Lauer, A., & Corbett, J. J. (2013). Shipping contributes to ocean acidification. *Geophysical Research Letters*, *40*(11), 2731–2736. https://doi.org/10.1002/grl.50521

Hatch, L., Clark, C., Merrick, R., Van Parijs, S., Ponirakis, D., Schwehr, K., Thompson, M., & Wiley, D. (2008). Characterizing the relative contributions of large vessels to total ocean noise fields: A case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. *Environmental Management*, *42*(5), 735–752. https://doi.org/10.1007/s00267-008-9169-4

Haugan, P. M., & Drange, H. (1996). Effects of CO_2 on the ocean environment. *Energy Conversion and Management*, *37*(6–8), 1019–1022. https://doi.org/10.1016/0196-8904(95)00292-8

Haver, S. M., Rand, Z., Hatch, L. T., Lipski, D., Dziak, R. P., Gedamke, J., Haxel, J., Heppell, S. A., Jahncke, J., McKenna, M. F., Mellinger, D. K., Oestreich, W. K., Roche, L., Ryan, J., & Van Parijs, S. M. (2020). Seasonal trends and primary contributors to the low-frequency soundscape of the Cordell Bank National Marine Sanctuary. *The Journal of the Acoustical Society of America*, *148*(2), 845–858. https://doi.org/10.1121/10.0001726

Haver, S. M., Adams, J. D., Hatch, L. T., Van Parijs, S. M., Dziak, R. P., Haxel, J., Heppell, S. A., McKenna, M. F., Mellinger, D. K., & Gedamke, J. (2021). Large vessel activity and low-frequency sound benchmarks in United States waters. *Frontiers in Marine Science*, 8, 669528. https://doi.org/10.3389/fmars.2021.669528

Hewett, K., Lipski, D., & Largier, J. (2017). *Hypoxia in Cordell Bank National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic andAtmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary and University of California, Davis, Bodega Marine Lab. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/archive/science/hypoxia_052417.pdf

Hobday, A. J., Alexander, L. V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C., Benthuysen, J. A., Burrows, M. T., Donat, M. G., Feng, M., Holbrook, N. J., Moore, P. J., Scannell, H. A., Sen Gupta, A., & Wernberg, T. (2016). A hierarchical approach to defining marine heatwaves. *Progress in Oceanography*, *141*, 227–238. https://doi.org/10.1016/j.pocean.2015.12.014

Hodgson, E. E., Kaplan, I. C., Marshall, K. N., Leonard, J., Essington, T. E., Busch, D. S.,Fulton, E. A., Harvey, C. J., Hermann, A. J., & McElhany, P. (2018). Consequences of spatially variable ocean acidification in the California Current: Lower pH drives strongest declines in benthic species in southern regions while greatest economic impacts occur in northern regions. *Ecological Modelling*, *383*, 106–117. https://doi.org/10.1016/j.ecolmodel.2018.05.018

Hornberger, M. I., Luoma, S. N., van Geen, A., Fuller, C., & Anima, R. (1999). Historical trends of metals in the sediments of San Francisco Bay, California. *Marine Chemistry*, *64*(1–2), 39–55. https://doi.org/10.1016/S0304-4203(98)80083-2

Huang, B., Liu, C., Banzon, V. F., Freeman, E., Graham, G., Hankins, B., Smith, T. M., & Zhang, H. (2020). *NOAA 0.25-degree daily optimum interpolation sea surface temperature (OISST)*, Version 2.1 (202009). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Environmental Information. https://doi.org/10.25921/RE9P-PT57

Hutto, S. V., Higgason, K. D., Kershner, J. M., Reynier, W. A., & Gregg, D. S. (2015). *Climate change vulnerability assessment for the north-central California coast and ocean*. Marine Sanctuaries Conservation Series ONMS-15-02. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/vulnerability-assessment-gfnms.pdf

Hutto, S. V. (Ed.). (2016). *Climate-smart adaptation for north-central California coastal habitats*. Report of the Climate-Smart Adaptation Working Group of the Greater Farallones National Marine Sanctuary Advisory Council. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. http://climate.calcommons.org/sites/default/files/Climate-Smart%20Adaptation%20Report_March%202016.pdf

Hyrenbach, K. D., Keiper, C., Allen, S. G., Ainley, D. G., & Anderson, D. J. (2005). Use of marine sanctuaries by far-ranging predators: Commuting flights to the California Current System by breeding

Hawaiian albatrosses. *Fisheries Oceanography*, *15*(2), 95–103. https://doi.org/10.1111/j.1365-2419.2005.00350.x

Intergovernmental Panel on Climate Change (2019). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley (Eds.). https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation, and vulnerability; Contribution of working group II to the sixth assessment report of the Intergovernmental Panel on Climate Change*. H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, &B. Rama (Eds.). Cambridge, UK and New York, NY: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Irvine, L. M., Mate, B. R., Winsor, M. H., Palacios, D. M., Bograd, S. J., Costa, D. P., & Bailey, H. (2014). Spatial and temporal occurrence of blue whales off the U.S. West Coast, with implications for management. *PLoS ONE*, *9*(7), e102959. https://doi.org/10.1371/journal.pone.0102959

Ito, T., Minobe, S., Long, M. C., & Deutsch, C. (2017). Upper ocean O_2 trends: 1958–2015. *Geophysical Research Letters*, *44*(9), 4214–4223. https://doi.org/10.1002/2017GL073613

Jacox, M. G., Hazen, E. L., Zaba, K. D., Rudnick, D. L., Edwards, C. A., Moore, A. M., & Bograd, S. J. (2016). Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events. *Geophysical Research Letters*, *43*(13), 7072–7080. https://doi.org/10.1002/2016GL069716

Jacox, M. G., Edwards, C. A., Hazen, E. L., & Bograd, S. J. (2018). Coastal upwelling revisited: Ekman, Bakun, and improved upwelling indices for the U.S. West Coast. *Journal of Geophysical Research: Oceans*, *123*(10), 7332–7350. https://doi.org/10.1029/2018JC014187

Jägerbrand, A. K., Brutemark, A., Barthel Svedén, J., & Gren, I. M. (2019). A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of The Total Environment*, *695*, 133637. https://doi.org/10.1016/j.scitotenv.2019.133637

Jahncke, J., Saenz, B. L., Abraham, C. L., Rintoul, C., Bradley, R. W., & Sydeman, W. J. (2008). Ecosystem responses to short-term climate variability in the Gulf of the Farallones, California. *Progress in Oceanography*, *77*(2–3), 182–193. https://doi.org/10.1016/j.pocean.2008.03.010

Jaradat, O. A. (2018). *Trends in container terminal infrastructure and technology*. National Academy of Engineering. https://www.nae.edu/183189/Trends-in-Container-Terminal-Infrastructure-and-Technology#:~:text=Since%201968%20container%2Dcarrying%20capacity,or%20more%20(figure%202).

Jensen, C. M., Hines, E., Holzman, B. A., Moore, T. J., Jahncke, J., & Redfern, J. V. (2015). Spatial and temporal variability in shipping traffic off San Francisco, California. *Coastal Management*, *43*(6), 575–588. https://doi.org/10.1080/08920753.2015.1086947

Johnstone, J. A., & Mantua, N. J. (2014). Atmospheric controls on northeast Pacific temperature variability and change, 1900–2012. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(40), 14360–14365. https://doi.org/10.1073/pnas.1318371111

Joint Committee on Fisheries and Aquaculture. (2016). *August 10, 2016 progress reports on crab season, domoic acid and disaster declaration*. California State Legislature. https://fisheries.legislature.ca.gov/content/august-10-2016-progress-reports-crab-season-domoic-acid-and-disaster-declaration

Karras, G. (2019). *Expert report of Greg Karras regarding the draft integrated general reevaluation report and environmental impact statement, San Francisco Bay to Stockton, California Navigation Study, for the San Francisco Bay to Stockton, California Navigational Improvement Project*. https://s3-us-west-2.amazonaws.com/s3-wagtail.biolgicaldiversity.org/documents/Expert_Report_of_G_Karras_on_SF_Bay_to_Stockton_Navigational_Improvement.pdf

Keeling, R. F., Körtzinger, A., & Gruber, N. (2010). Ocean deoxygenation in a warming world. *Annual Review of Marine Science*, *2*, 199–229. https://doi.org/10.1146/annurev.marine.010908.163855

Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., Cook, G. S., Lorenz, J. J., & Boyer, J. N. (2013). The EBM-DPSER conceptual model: Integrating ecosystem services into the DPSIR framework. *PLoS ONE*, *8*(8), e70766. https://doi.org/10.1371/journal.pone.0070766

Keller, A. A., Ciannelli, L., Wakefield, W. W., Simon, V., Barth, J. A., & Pierce, S. D. (2015). Occurrence of demersal fishes in relation to near-bottom oxygen levels within the California Current large marine ecosystem. *Fisheries Oceanography*, *24*(2), 162–176. https://doi.org/10.1111/fog.12100

Keller, A. A., Fruh, E. L., Johnson, M. M., Simon, V., & McGourty, C. (2010). Distribution and abundance of anthropogenic marine debris along the shelf and slope of the U.S. West Coast. *Marine Pollution Bulletin*, *60*(5), 692–700. https://doi.org/10.1016/j.marpolbul.2009.12.006

Kintisch, E. (2015). 'The Blob' invades Pacific, flummoxing climate experts. *Science*, *348*(6230), 17–18. https://doi.org/10.1126/science.348.6230.17

Klar, J. W. (1989). World War II operational history of "USS *Stewart*" (DD-224). *Warship International*, *26*(2), 139–167. https://www.jstor.org/stable/44892087

Klar, J. W. (1990). USS DD-224 (ex-*Stewart*)—the voyage home. *Warship International*, *27*(1), 74–82. https://www.jstor.org/stable/44891311

Klasing, S., & Brodberg, R. (2008). *Development of fish contaminant goals and advisory tissue levels for common contaminants in California sport fish: Chlordane, DDTs, dieldrin, methylmercury, PCBs, selenium, and toxaphene*. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Pesticide and Environmental Toxicology Branch. https://oehha.ca.gov/media/downloads/fish/report/atlmhgandothers2008c.pdf

Laist, D. W., Knowlton, A. R., Mead, J. G., Collet, A. S., & Podesta, M. (2006). Collisions between ships and whales. *Marine Mammal Science*, *17*(1), 35–75. https://doi.org/10.1111/j.1748-7692.2001.tb00980.x

Largier, J. L., Lawrence, C. A., Roughan, M., Kaplan, D. M., Dever, E. P., Dorman, C. E., Kudela, R. M., Bollens, S. M., Wilkerson, F. P., Dugdale, R.C., Botsford, L. W., Garfield, N., Kuebel Cervantes, B., & Koračin, D. (2006). WEST: A northern California study of the role of wind-driven transport in the productivity of coastal plankton communities. *Deep Sea Research Part II: Topical Studies in Oceanography, 53*(25–26), 2833–2849. https://doi.org/10.1016/j.dsr2.2006.08.018

Largier, J. L., Cheng, B. S., & Higgason, K. D. (Eds.). (2010). *Climate change impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries*. Report of a Joint Working Group of the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries Advisory Councils. Marine Sanctuaries Conservation Series ONMS-11-04. U.S. Department of Commerce, National Oceanic and

Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/gf_cbnms_climate_report.pdf

Largier, J., Cheng, B., & Higgason, K. (2011). *Climate change impacts: Gulf of the Farallones and Cordell Bank national marine sanctuaries; Report of a joint working group of the Gulf of the Farallones and Cordell Bank national marine sanctuaries advisory councils*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/gf_cbnms_climate_report.pdf

Largier, J. L. (2020, February). *Wind-modulated buoyancy current pulses associated with outflow from San Francisco Bay*. Oral presentation at American Geophysical Union Ocean Sciences Meeting, San Diego, California. https://agu.confex.com/agu/osm20/meetingapp.cgi/Paper/656550

Leeworthy, V. R., Jerome, D., & Schueler, K. (2013). *Technical appendix: Economic impact of the commercial fisheries on local county economies from catch in California national marine sanctuaries 2010, 2011 and 2012*. Marine Sanctuaries Conservation Series ONMS-13-07. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/techapp13.pdf

Leeworthy, V., & Schwarzmann, D. (2015). *Economic impact of the recreational fisheries on local county economies in Cordell Bank National Marine Sanctuary 2010, 2011 and 2012*. Marine Sanctuaries Conservation Series ONMS-2015-08. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/socioeconomic/cordellbank/pdfs/cbnms-rec-report.pdf

Lem, A., Bjørndal, T., & Lappo, A. (2014). *Economic analysis of supply and demand for food up to 2030—special focus on fish and fishery products*. Fisheries and Aquaculture Circular No. 1089. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i3822e/i3822e.pdf

Lipski, D., & K. Graiff. (2017). *Cordell Bank National Marine Sanctuary long-term benthic science strategy* [Unpublished report]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Cordell Bank National Marine Sanctuary.

Lipski, D., Williams, G., Howard, D., Stock, J., Roletto, J., Cochrane, G., Fish, C., & Graiff, K. (2018). Discovering the undersea beauty of Cordell Bank National Marine Sanctuary. In N. A. Raineault, J. Flanders, & A. Bowman (Eds.), New frontiers in ocean exploration: The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2017 field season (pp. 34–35). *Oceanography*, *31*(1), supplement. https://tos.org/oceanography/assets/docs/31-1_supplement.pdf

Longo, S. B. (2011). Global sushi: The political economy of the Mediterranean bluefin tuna fishery in the modern era. *Journal of World-Systems Research*, *17*(2), 403–427. https://doi.org/10.5195/jwsr.2011.422

Lonhart, S. I. (2012, September). Growth and distribution of the invasive bryozoan *Watersipora* in Monterey Harbor, California. In D. L. Steller & L. K. Lobel (Eds.), *Diving For Science 2012* (pp. 89–98). Proceedings of the American Academy of Underwater Sciences 31st Scientific Symposium, Dauphin Island, AL. https://nmsmontereybay.blob.core.windows.net/montereybay-prod/media/research/techreports/lonhart_2012.pdf

Lonhart, S. I., Jeppesen, R., Beas-Luna, R., Crooks, J. A., & Lorda, J. (2019). Shifts in the distribution and abundance of coastal marine species along the eastern Pacific Ocean during marine heatwaves from 2013 to 2018. *Marine Biodiversity Records*, *12*, 13. https://doi.org/10.1186/s41200-019-0171-8

Love, D. C., Asche, F., Conrad, Z., Young, R., Harding, J., Nussbaumer, E. M., Thorne-Lyman, A. L., & Neff, R. (2020). Food sources and expenditures for seafood in the United States. *Nutrients*, *12*(6), 1810. https://doi.org/10.3390/nu12061810

Lovelace, S., Fletcher, P., Dillard, M., Nuttle, W., Patterson, S., Ortner, P., Loomis, D., & Shivlani, M. (2013). *Selecting human dimensions indicators for South Florida's coastal marine ecosystem—Noneconomic indicators*. Marine and Estuarine Goal Setting for South Florida (MARES) white paper. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division.

Lu, L., Levings, C. D., & Piercey, G. E. (2007). *Preliminary investigation on aquatic invasive species of marine and estuarine macrobenthic invertebrates on floating structures in five British Columbia harbours*. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2814. Fisheries and Oceans Canada, Science Branch—Pacific Region, DFO-UBC Centre for Aquaculture and Environmental Research. https://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-4-2814-eng.pdf

Madigan, D. J., Baumann, Z., & Fisher, N. S. (2012). Pacific bluefin tuna transport Fukushima-derived radionuclides from Japan to California. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(24), 9483–9486. https://doi.org/10.1073/pnas.1204859109

Madigan, D. J., Baumann, Z., Snodgrass, O. E., Dewar, H., Berman-Kowalewski, M., Weng, K. C., Nishikawa, J., Dutton, P. H., & Fisher, N. S. (2017). Assessing Fukushima-derived radiocesium in migratory Pacific predators. *Environmental Science and Technology*, *51*(16), 8962–8971. https://doi.org/10.1021/acs.est.7b00680

Malone, T. C. (1980). Size-fractionated primary productivity of marine phytoplankton. In P. G. Falkowski (Ed.), *Primary productivity in the sea* (pp. 301–319). Boston, MA: Springer. https://doi.org/10.1007/978-1-4684-3890-1_17

Maloni, M., Paul, J. A., & Gligor, D. M. (2013). Slow steaming impacts on ocean carriers and shippers. *Maritime Economics and Logistics*, *15*, 151–171. https://doi.org/10.1057/mel.2013.2

Marchal, P., Andersen, B., Caillart, B., Eigaard, O., Guyader, O., Hovgaard, H., Iriondo, A., Le Fur, F., Sacchi, J., & Santurtún, M. (2006). Impact of technological creep on fishing effort and fishing mortality, for a selection of European fleets. *ICES Journal of Marine Science*, *64*(1), 192–209. https://doi.org/10.1093/icesjms/fsl014

Martin, M., Ichikawa, G., Goetzl, J., de los Reyes, M., & Stephenson, M. D. (1984). Relationships between physiological stress and trace toxic substances in the bay mussel, *Mytilus edulis*, from San Francisco Bay, California. *Marine Environmental Research*, *11*(2), 91–110. https://doi.org/10.1016/0141-1136(84)90025-4

McCabe, R. M., Hickey, B. M., Kudela, R. M., Lefebvre, K. A., Adams, N. G., Bill, B. D., Gulland, F. M. D., Thomson, R. E., Cochlan, W. P., & Trainer, V. L. (2016). An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters*, *43*(19), 10366–10376. https://doi.org/10.1002/2016GL070023

McClatchie, S., Goericke, R., Cosgrove, R., Auad, G., & Vetter, R. (2010). Oxygen in the Southern California Bight: Multidecadal trends and implications for demersal fisheries. *Geophysical Research Letters*, *37*(19), L19602. https://doi.org/10.1029/2010GL044497

McGowan, J. A., Cayan, D. R., & Dorman, L. M. (1998). Climate-ocean variability and ecosystem response in the northeast Pacific. *Science*, *281*(5374), 210–217. https://doi.org/10.1126/science.281.5374.210

McHuron, E. A., Castellini, J. M., Rios, C. A., Berner, J., Gulland, F. M. D., Greig, D. J., & O'Hara, T. M. (2019). Hair, whole blood, and blood-soaked cellulose paper-based risk assessment of mercury concentrations in stranded California pinnipeds. *Journal of Wildlife Diseases*, *55*(4), 823–833. https://doi.org/10.7589/2018-11-276

McKenna, M. F., Katz, S. L., Wiggins, S. M., Ross, D., & Hildebrand, J. A. (2012a). A quieting ocean: Unintended consequence of a fluctuating economy. *The Journal of the Acoustical Society of America*, *132*(3), EL169–EL175. https://doi.org/10.1121/1.4740225

McKenna, M. F., Ross, D., Wiggins, S. M., & Hildebrand, J. A. (2012b). Underwater radiated noise from modern commercial ships. *The Journal of the Acoustical Society of America*, *131*(1), 92–103. https://doi.org/10.1121/1.3664100

McKenna, M. F., Wiggins, S. M., & Hildebrand, J. A. (2013). Relationship between container ship underwater noise levels and ship design, operational and oceanographic conditions. *Scientific Reports*, *3*, 1760. https://doi.org/10.1038/srep01760

McKenna, M. F., Gabriele, C., & Kipple, B. (2017). Effects of marine vessel management on the underwater acoustic environment of Glacier Bay National Park, AK. *Ocean and Coastal Management*, *139*, 102–112. https://doi.org/10.1016/j.ocecoaman.2017.01.015

McKenna, M.F., Tetyana, M., Baumann-Pickering, S., Solsona Berga, A., Adams, J.D., Joseph, J., Kim, E.B., Kok, A.C.M., Lammers, M.O., Merkens, K., Pevey Reeves, L., Rowell, T.J., Ryan, J., Southall, B., Stimpert, A.K., Barkowski, J., Stanley, J.A., Thompson, M.A., Wall, C.C., Zang, E.J., and Hatch, L.T. (in review) Listening for Vessels to Understand Use and Reduce Impacts in U.S. National Marine Sanctuaries.

McLaskey, A. K., Keister, J. E., McElhany, P., Olson, M. B., Busch, D. S., Maher, M., & Winans, A. K. (2016). Development of *Euphausia pacifica* (krill) larvae is impaired under pCO_2 levels currently observed in the Northeast Pacific. *Marine Ecology Progress Series*, *555*, 65–78. https://doi.org/10.3354/meps11839

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: A framework for assessment*. Washington, DC: Island Press. https://millenniumassessment.org/en/Framework.html

Miller, I. M., Shishido, C., Antrim, L., & Bowlby, C. E. (2013). *Climate change and the Olympic Coast National Marine Sanctuary: Interpreting potential futures*. Marine Sanctuaries Conservation Series ONMS-13-01. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/ocms_cca.pdf

Miller, J. J., Maher, M., Bohaboy, E., Friedman, C. S., & McElhany, P. (2016). Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (*Cancer magister*). *Marine Biology*, *163*, 118. https://doi.org/10.1007/s00227-016-2883-1

Miller, R. R., Field, J. C., Santora, J. A., Monk, M. H., Kosaka, R., & Thomson, C. (2017). Spatial valuation of California marine fisheries as an ecosystem service. *Canadian Journal of Fisheries and Aquatic Sciences*, *74*(11), 1732–1748. https://doi.org/10.1139/cjfas-2016-0228

Moore, A. M., Edwards, C. A., Fiechter, J., Drake, P., Neveu, E., Arango, H. G., Gürol, S., & Weaver, A. T. (2013). A 4D-var analysis system for the California Current: A prototype for an operational regional ocean data assimilation system. In S. K. Park & L. Xu (Eds.), *Data assimilation for atmospheric, oceanic and hydrological applications*, Vol. II (pp. 345–366). Berlin: Springer.

Moore, J. D., III (2015). Long-term corrosion processes of iron and steel shipwrecks in the marine environment: A review of current knowledge. *Journal of Maritime Archaeology*, *10*, 191–204. https://doi.org/10.1007/s11457-015-9148-x

Moore, T. J., Redfern, J. V., Carver, M., Hastings, S., Adams, J. D., & Silber, G. K. (2018). Exploring ship traffic variability off California. *Ocean & Coastal Management*, *163*, 515–527. https://doi.org/10.1016/j.ocecoaman.2018.03.010

Morgan, L. E., & Chuenpagdee, R. (2003). *Shifting gears: Addressing the collateral impacts of fishing methods in U.S. waters*. Washington, DC: Island Press.

Multi-Agency Rocky Intertidal Network. (2023). *Overview: MARINe*. https://marine.ucsc.edu/overview/index.html

Munday, P. L., Dixson, D. L., McCormick, M. I., Meekan, M., Ferrari, M. C., & Chivers, D. P. (2010). Replenishment of fish populations is threatened by ocean acidification. *Proceedings of the National Academy of Sciences of the United States of American*, *107*(29), 12930–12934. https://doi.org/10.1073/pnas.1004519107

Murphy, E. J. (2001). Krill. In J. H. Steele (Ed.), *Encyclopedia of ocean sciences* (pp. 1405–1413). Amsterdam, Netherlands: Elsevier Science Ltd. https://doi.org/10.1006/rwos.2001.0201

National Aeronautics and Space Administration. (2020). *Ocean color web: MODIS-Aqua satellite images for diffusion attenuation coefficient at 490 nm, Pacific Northwest, 2002–2019* [Data set]. https://oceancolor.gsfc.nasa.gov/l3/

National Centers for Coastal Ocean Science. (2020a). *Vessel monitoring system data* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

National Centers for Coastal Ocean Science. (2020b). *Automatic identification system data* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

National Centers for Environmental Information (NCEI). (2020a). *Climate at a glance: Global time series; December temperature anomalies, 1880–2019* [Data set]. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/ocean/ann/6/1880-2019

National Centers for Environmental Information. (2020b). *Pacific Decadal Oscillation (PDO), 1980–2020* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://www.ncei.noaa.gov/pub/data/cmb/ersst/v5/index/ersst.v5.pdo.dat

National Centers for Environmental Information. (2020c). *Global ocean heat and salt content: Seasonal, yearly, and pentadal fields, 0–700 m* [Data set]. https://www.ncei.noaa.gov/access/global-ocean-heat-content/#null

National Data Buoy Center. (1971). *Station 46013* [Data set]. https://www.ndbc.noaa.gov/station_page.php?station=46013

National Marine Fisheries Service. (2014). *Recovery plan for the evolutionarily significant units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the distinct population segment of California Central Valley steelhead*. West Coast Region, California Central Valley Area Office. https://media.fisheries.noaa.gov/dam-migration/central_valley_salmonids_recovery_plan-accessible.pdf

National Marine Fisheries Service. (2016a). *2016 5-year review: Summary and evaluation of California Coastal Chinook salmon and Northern California steelhead*. West Coast Region. https://repository.library.noaa.gov/view/noaa/17016

National Marine Fisheries Service. (2016b). *5-year review: Summary and evaluation of Central Valley spring-run Chinook salmon evolutionarily significant unit*. West Coast Region. https://repository.library.noaa.gov/view/noaa/17018

National Marine Fisheries Service Office of Science and Technology. (2022). *Foreign trade* [Data set]. https://www.fisheries.noaa.gov/inport/item/3480

National Marine Fisheries Service, & U.S. Fish and Wildlife Service. (2020). *Endangered Species Act status review of the leatherback turtle (*Dermochelys coriacea*)*. Report to the National Marine Fisheries Service Office of Protected Resources and U.S. Fish and Wildlife Service. https://repository.library.noaa.gov/view/noaa/25629

National Marine Sanctuary Foundation. (2019). *Sea wonder: Dungeness crab*. https://marinesanctuary.org/blog/sea-wonder-dungeness-crab/

National Marine Sanctuary Program. (2004). *A monitoring framework for the National Marine Sanctuary System*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/library/national/swim04.pdf

National Oceanic and Atmospheric Administration. (2020a). *The Integrated Ecosystem Assessment approach*. https://www.integratedecosystemassessment.noaa.gov/about-iea/iea-approach

National Oceanic and Atmospheric Administration. (2020b). Carbon cycle. https://www.noaa.gov/education/resource-collections/climate/carbon-cycle

National Oceanic and Atmospheric Administration. (2021a). *The California Current marine heatwave tracker—blobtracker*. California Current Integrated Ecosystem Assessment. www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker

National Oceanic and Atmospheric Administration. (2021b). *The California Current marine heatwave tracker—an experimental tool for tracking marine heatwaves*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries, Southwest Fisheries Science Center, Environmental Research Division. https://oceanview.pfeg.noaa.gov/projects/mhw/sanctuaries

National Oceanic and Atmospheric Administration. (2021c). *Voluntary vessel speed reduction program percent cooperation* [Unpublished data set]. U.S. Department of Commerce.

National Park Service. (2021). *Vital signs monitoring*. https://www.nps.gov/im/vital-signs.htm

National Research Council. (2002). *Effects of trawling and dredging on seafloor habitat*. Washington, DC: National Academy Press.

National Research Council. (2003). *Ocean noise and marine mammals*. Washington, DC: National Academy Press.

Naval History and Heritage Command. (2021a). *80-G-702833 Ex-USS* Stewart. https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nara-series/80-g/80-G-700000/80-G-702833.html

Naval History and Heritage Command. (2021b). *80-G-702832 Ex-USS* Stewart. https://www.history.navy.mil/content/history/nhhc/our-collections/photography/numerical-list-of-images/nara-series/80-g/80-G-700000/80-G-702832.html

Neilson, J. L., Gabriele, C. M., Jensen, A. S., Jackson, K., & Straley, J. M. (2012). Summary of reported whale-vessel collisions in Alaskan waters. *Journal of Marine Sciences*, *2012*, 106282. https://doi.org/10.1155/2012/106282

Neville, D. R., Phillips, A. J., Brodeur, R. D., & Higley, K. A. (2014). Trace levels of Fukushima disaster radionuclides in East Pacific albacore. *Environmental Science and Technology, 48*(9)*,* 4739–4743. https://doi.org/10.1021/es500129b

Nevins, H., Hyrenbach, D., Keiper, C., Stock, J., Hester, M., & Harvey, J. (2005). Seabirds as indicators of plastic pollution in the North Pacific. *Plastic Debris Rivers to the Sea Conference*. Redondo Beach, CA.

NOAA Fisheries. (2020a). *Pacific Coast groundfish vessel monitoring program compliance guide*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://media.fisheries.noaa.gov/dam-migration/vms_complianceguide_may2020.pdf

NOAA Fisheries. (2020b). *West Coast Dungeness crab stable or increasing even with intensive harvest, research shows*. NOAA. Retrieved from https://www.fisheries.noaa.gov/feature-story/west-coast-dungeness-crab-stable-or-increasing-even-intensive-harvest-research-shows

NOAA Fisheries. (2020c). *Endangered winter-run Chinook salmon increase with millions of offspring headed to sea*. NOAA. Retrieved from https://www.fisheries.noaa.gov/feature-story/endangered-winter-run-chinook-salmon-increase-millions-offspring-headed-sea

NOAA Fisheries. (2021a). *2020 West Coast whale entanglement summary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://media.fisheries.noaa.gov/2021-03/2020_West_Coast_Whale_Entanglement_Summary.pdf?VersionId=null#:~:text=We%20confirmed%2017%20entangled%20whales,separate%20entanglements%20confirmed%20in%202020

NOAA Fisheries (2021b). Vessel monitoring system data, 2009-2019 [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

NOAA Fisheries. (2021c). *Voices oral history archives, 2009-2012* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://voices.nmfs.noaa.gov/

NOAA Fisheries. (2022a). *National stranding database, 1987–2020* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://mmhsrp.nmfs.noaa.gov/mmhsrp/

NOAA Fisheries. (2022b). *West Coast large whale entanglement response program*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/west-coast-large-whale-entanglement-response-program

NOAA Marine Debris Program. (2014a). *Entanglement: Entanglement of marine species in marine debris with an emphasis on species in the United States*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Response and Restoration. https://marinedebris.noaa.gov/entanglement-marine-species-marine-debris-emphasis-species-united-states

NOAA Marine Debris Program. (2014b). *Ingestion: Occurrence and health effects of anthropogenic debris ingested by marine organisms*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Response and Restoration. https://marinedebris.noaa.gov/occurrence-and-health-effects-anthropogenic-debris-ingested-marine-organisms

NOAA Northwest Fisheries Observation Science Program. (2021). *Survey data, 2002–2019* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries, Northwest Fisheries Science Center.

North, N. A., & Macleod, I. D. (1987). Corrosion of metals. In C. Pearson (Ed.), *Conservation of marine archaeological objects* (pp. 68–98). London: Butterworths.

Nuttle, W. K.,& Fletcher, P. J. (Eds.) (2013). *Integrated conceptual ecosystem model development for the Florida Keys/Dry Tortugas coastal marine ecosystem*. NOAA Technical Memorandum OAR-AOML101/NOS-NCCOS-161. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Ocean Protection Council. (2018). *2018–19 risk assessment and mitigation program (RAMP) overview*. California Dungeness Crab Fishing Gear Working Group. https://opc.ca.gov/webmaster/_media_library/2018/12/CAWorkingGroup_RAMPOverview_October2018.pdf

Ocean Exploration Trust, & Cordell Bank National Marine Sanctuary. (2017). *ROV* Hercules *survey, expedition at Cordell Bank National Marine Sanctuary, August 6–15, 2017* [Unpublished data set].

Office of General Counsel. (2021). *Civil administrative enforcement actions, January, 2021, through April 30, 2021*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://www.gc.noaa.gov/documents/2021/Enforcement-Actions-January-April-2021-6-2-2021.pdf

Office of National Marine Sanctuaries. (2009). *Olympic Coast National Marine Sanctuary condition report 2009*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/condition/pdfs/cbnms_conditionreport09.pdf

Office of National Marine Sanctuaries. (2014a). *Cordell Bank National Marine Sanctuary final management plan and environmental assessment*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/archive/management/cbnms_fmp_december_2014.pdf

Office of National Marine Sanctuaries. (2014b). *Cordell Bank and Gulf of the Farallones national marine sanctuaries expansion: Final environmental impact statement*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmscordellbank.blob.core.windows.net/cordellbank-prod/media/archive/management/cbnms_gfnms_feis_expansion_122014.pdf

Office of National Marine Sanctuaries. (2020a). *Climate change impacts: Cordell Bank National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://sanctuaries.noaa.gov/media/docs/20200820-climate-change-impacts-cordell-bank-national-marine-sanctuary.pdf

Office of National Marine Sanctuaries. (2020b). *Climate change and ocean acidification*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://sanctuaries.noaa.gov/science/sentinel-site-program/climate-change-ocean-acidification.html

Office of National Marine Sanctuaries. (2020c). *Fishing impacts: Cordell Bank*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://sanctuaries.noaa.gov/science/sentinel-site-program/cordell-bank/fishing-impacts.html

Office of National Marine Sanctuaries. (2020d). *Climate change impacts: Cordell Bank National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National

Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/20200820-climate-change-impacts-cordell-bank-national-marine-sanctuary.pdf

Office of National Marine Sanctuaries. (2021). *Climate change impacts: National marine sanctuaries West Coast Region*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/20210520-wcr-climate-impacts-profile.pdf

Office of National Marine Sanctuaries. (2022). *Our vision for America's treasured ocean places: A five-year strategy for the National Marine Sanctuary System*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2022-2027-a-5-yr-strategy-for-the-national-marine-sanctuary-system.pdf

Office of Response and Restoration. (2016). *How much oil is on that ship?* U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://response.restoration.noaa.gov/about/media/how-much-oil-ship.html

Office of Response and Restoration. (2021). *Incidents database, 2009–2021* [Data set]. https://incidentnews.noaa.gov/raw/index

Office of Science and Technology. (2022). *Foreign trade* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. https://www.fisheries.noaa.gov/inport/item/3480

Ohlendorf, H. M., Custer, T. W., Lowe, R. W., Rigney, M., & Cromartie, E. (1988). Organochlorines and mercury in eggs of coastal terns and herons in California, USA. *Colonial Waterbirds*, *11*(1), 85–94. https://doi.org/10.2307/1521173

Osborne, E. B., Thunell, R. C., Gruber, N., Feely, R. A., & Benitez-Nelson, C. R. (2020). Decadal variability in twentieth-century ocean acidification in the California Current Ecosystem. *Nature Geoscience*, 13, 43–49. https://doi.org/10.1038/s41561-019-0499-z

Pacific Fishery Management Council. (2020a). *Managing Pacific coast fisheries*. https://www.pcouncil.org

Pacific Fishery Management Council. (2020b). *Pacific Coast Groundfish Fishery Management Plan*. https://www.pcouncil.org/documents/2020/11/groundfish-fmp-appendix-f-overfished-species-rebuilding-plans.pdf/

Pacific Fishery Management Council. (2021). *Council news: Rigorous management practices have led to successful rebuilding of several West Coast groundfish stocks*. https://www.pcouncil.org/council-news-rigorous-management-practices-have-led-to-successful-rebuilding-of-several-west-coast-groundfish-stocks/

Pacific Marine Environmental Laboratory, National Marine Fisheries Service, Office of National Marine Sanctuaries, & Natural Resource Stewardship and Science Directorate. (2014). *NOAA Ocean Noise Reference Station Network raw passive acoustic data* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Environmental Information; Oceanic and Atmospheric Research; National Ocean Service & U.S. Department of Interior, National Park Service. https://doi.org/10.7289/V5M32T0D

Paine, R. T. (1966). Food web complexity and species diversity. *The American Naturalist*, *100*(910), 65–75.

Paine, R. T. (1969). A note on trophic complexity and community stability. *The American Naturalist*, *103*(929), 91–93. https://doi.org/10.1086/282586

Parker, R. W., & Tyedmers, P. H. (2015). Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. *Fish and Fisheries*, *16*(4), 684–696. https://doi.org/10.1111/faf.12087

Pederson, J., Carlton, J. T., Bastidas, C., David, A., Grady, S., Green-Gavrielidis, L., Hobbs, N., Kennedy, C., Knack, J., McCuller, M., O'Brien, B., Osborne, K., Pankey, S., & Trott, T. (2021). 2019 rapid assessment survey of marine bioinvasions of southern New England and New York, USA, with an overview of new records and range expansions. *BioInvasions Records*, *10*(2), 277–237. https://doi.org/10.3391/bir.2021.10.2.01

Piatt, J. F., Sydeman, W. J., & Wiese, F. (2007). Introduction: A modern role for seabirds as indicators. *Marine Ecology Progress Series*, *352*, 199–204. https://doi.org/10.3354/meps07070

Piatt, J. F., Parrish, J. K., Renner, H. M., Schoen, S. K., Jones, T. T., Arimitsu, M. L., Kuletz, K. J., Bodenstein, B., García-Reyes, M., Duerr, R. S., Corcoran, R. M., Kaler, R. S. A., McChesney, G. J., Golightly, R. T., Coletti, H. A., Suryan, R. M., Burgess, H. K., Lindsey, J., Lindquist, K...& Sydeman, W. J. (2020). Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014–2016. *PloS ONE*, *15*(1), e0226087. https://doi.org/10.1371/journal.pone.0226087

Ray, G. L. (2005). *Invasive marine and estuarine animals of California*. U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory. https://apps.dtic.mil/sti/pdfs/ADA441862.pdf

Redfern, J. V., Hatch, L. T., Caldow, C., DeAngelis, M. L., Gedamke, J., Hastings, S., Henderson, L., McKenna, M. F., Moore, T. J., & Porter, M. B. (2017). Assessing the risk of chronic shipping noise to baleen whales off Southern California, USA. *Endangered Species Research*, *32*, 153–167. https://doi.org/10.3354/esr00797

Redfern, J. V., Becker, E. A., & Moore, T. J. (2020). Effects of variability in ship traffic and whale distributions on the risk of ships striking whales. *Frontiers in Marine Science*, *6*, 793. https://doi.org/10.3389/fmars.2019.00793

Reiswig, H. M. (2020). Report of *Cladorhiza bathycrinoides* Koltun (Demospongiae) from North America and a new species of *Farrea* (Hexactinellida) among sponges from Cordell Bank, California. *Zootaxa,* 4747(3), 562–574. https://doi.org/10.11646/zootaxa.4747.3.9

Responsive Management. (2009). *Monterey Bay area residents' opinions on the management of the Monterey Bay National Marine Sanctuary*. Report for the Alliance of Communities for Sustainable Fisheries. https://nmsmontereybay.blob.core.windows.net/montereybay-prod/media/sac/2009/082109/acsf_report1.pdf

Richardson, W. J., Greene, C. R., Jr., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise*. San Diego, CA: Academic Press. https://doi.org/10.1016/C2009-0-02253-3

Richerson, K., Punt, A. E., & Holland, D. S. (2020). Nearly a half century of high but sustainable exploitation in the Dungeness crab (*Cancer magister*) fishery. *Fisheries Research*, *226*, 105528. https://doi.org/10.1016/j.fishres.2020.105528

Rickard, J. (2019). *USS* Stewart *(DD-224)*. HistoryOfWar.org. http://www.historyofwar.org/articles/weapons_USS_Stewart_DD224.html

Rockman, M., Morgan, M., Ziaja, S., Hambrecht, G. & Meadow, A. (2016). *Cultural resources climate change strategy*. U.S. Department of Interior, National Park Service, Cultural Resources, Partnerships, and Science and Climate Change Response Program. https://www.nps.gov/subjects/climatechange/upload/NPS-2016_Cultural-Resoures-Climate-Change-Strategy.pdf

Rockwood, R. C., Elliott, M. L., Saenz, B., Nur, N., & Jahncke, J. (2020a). Modeling predator and prey hotspots: Management implications of baleen whale co-occurrence with krill in Central California. *PLoS ONE*, *15*(7), e0235603. https://doi.org/10.1371/journal.pone.0235603

Rockwood, R. C., Adams, J., Silber, G., & Jahncke J. (2020b). Estimating effectiveness of speed reduction measures for decreasing whale-strike mortality in a high-risk region. *Endangered Species Research*, 43, 145–166. https://doi.org/10.3354/esr01056

Roemmich, D., & McGowan, J. (1995). Climatic warming and the decline of zooplankton in the California Current. *Science*, *267*(5202), 1324–1326. https://doi.org/10.1126/science.267.5202.1324

Rossi, T., Nagelkerken, I., Pistevos, J. C. A., & Connell, S. D. (2016). Lost at sea: Ocean acidification undermines larval fish orientation via altered hearing and marine soundscape modification. *Biology Letters*, *12*(1), 20150937. https://doi.org/10.1098/rsbl.2015.0937

Ruiz, G. M., Rawlings, T. K., Dobbs, F. C., Drake, L. A., Mullady, T., Huq, A., & Colwell, R. R. (2000). Global spread of microorganisms by ships. *Nature*, *408*, 49–50. https://doi.org/10.1038/35040695

Ryan, J. P., Joseph, J. E., Margolina, T., Hatch, L. T., Azzara, A., Reyes, A., Southall, B. L., DeVogelaere, A., Peavey Reeves, L. E., Zhang, Y., Cline, D. E., Jones, B., McGill, P., Baumann-Pickering, S., & Stimpert, A. (2021). Reduction of low-frequency vessel noise in Monterey Bay National Marine Sanctuary during the COVID-19 pandemic. *Frontiers in Marine Science*, *8*, 587. https://doi.org/10.3389/fmars.2021.656566

San Francisco Estuary Institute. (2021). *Contaminant tissue data, 2009–2010* [Data set]. https://cd3.sfei.org/

Sanctuary Integrated Monitoring Network. (2020). *Fishes: CBNMS*. https://sanctuarysimon.org/cordell-bank-nms/fishes/

Sanctuary Integrated Monitoring Network. (2021). *Explore California sanctuaries*. https://sanctuarysimon.org

Sanford, E., Sones, J. L., García-Reyes, M., Goddard, J. H., & Largier, J. L. (2019). Widespread shifts in the coastal biota of northern California during the 2014–2016 marine heatwaves. *Scientific Reports*, *9*, 4216. https://doi.org/10.1038/s41598-019-40784-3

Santora, J. A., Ralston, S., & Sydeman, W. J. (2011). Spatial organization of krill and seabirds in the central California Current. *ICES Journal of Marine Science*, *68*(7), 1391–1402. https://doi.org/10.1093/icesjms/fsr046

Santora, J. A., Mantua, N. J., Schroeder, I. D., Field, J. C., Hazen, E. L., Bograd, S. J., Sydeman, W. J., Wells, B. K., Calambokidis, J., Saez, L., Lawson, D., & Forney, K. A. (2020). Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. *Nature Communications*, *11*, 536. https://doi.org/10.1038/s41467-019-14215-w

Schmieder, R. W. (1991). *Ecology of an underwater island*. Walnut Creek, CA: Cordell Expeditions.

Schmieder, R. W. (2019). *Edward Cordell and the discovery of Cordell Bank*. New York, NY: Springer International Publishing.

Scholz, A., Mertens, M., & Steinback, C. (2005). The OCEAN framework—Modeling the linkages between marine ecology, fishing economy, and coastal communities. In D. Wright & A. Scholz (Eds.), *Place* *matters: Geospatial tools for marine science, conservation, and management in the Pacific Northwest* (pp. 70–91). Corvallis, OR: Oregon State University Press.

Shaffer, S. A., Tremblay, Y., Weimerskirch, H., Scott, D., Thompson, D. R., Sagar, P. M., Moller, H., Taylor, G. A., Foley, D. G., Block, B. A., & Costa, D. P. (2006). Migratory shearwaters integrate oceanic resources across the Pacific Ocean in an endless summer. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(34), 12799–12802. https://doi.org/10.1073/pnas.0603715103

Shearwater, D. (2013). Debi Shearwater's journeys. *Blogger*. https://shearwaterjourneys.blogspot.com/search?q=cordell+bank

Sigray, P., Borsani, J. F., Le Courtois, F., Andersson, M., Azzellino, A., Castellote, M., Ceyrac, L., Dekeling, R., Haubner, N., Hegarty, M., Hedgeland, D., Juretzek, C., Kinneging, N., Klauson, A., Leaper, R., Liebschner, A., Maglio, A., Mihanović, H., Mueller, A…& Weilgart, L. (2021). *Assessment framework for EU threshold values for continuous underwater sound: Recommendations from the technical group on underwater noise*. European Commission. https://ec.europa.eu/environment/marine/pdf/Doc%202%20-%20TG%20Noise%20DL3%20-%20AF%20for%20EU%20TV%20for%20continuous%20noise.pdf

Silber, G. K., Slutsky, J., & Bettridge, S. (2010). Hydrodynamics of a ship/whale collision. *Journal of Experimental Marine Biology and Ecology*, *391*(1–2), 10–19. https://doi.org/10.1016/j.jembe.2010.05.013

Silva, P. C., Woodfield, R. A., Cohen, A. N., Harris, L. H., & Goddard, J. H. R. (2002). First report of the Asian kelp *Undaria pinnatifida* in the northeastern Pacific Ocean. *Biological Invasions*, *4*, 333–338. https://doi.org/10.1023/A:1020991726710

Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., O'Keeffe, E., Parker, S., Johansson, L., Aldous, L., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D. S., Ng, S., Agrawal, A., Winebrake, J. J., Hoen, M…& Pandey, A. (2015). *Third IMO greenhouse gas study 2014*. London, UK: International Maritime Organization.

Sones, J. (2022). The natural history of Bodega Head. *Blogger*. https://bodegahead.blogspot.com/

Southwest Fisheries Science Center. (2021). Rockfish Recruitment and Ecosystem Assessment Survey from 2012 to 2018 [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Centers for Environmental Information. https://www.fisheries.noaa.gov/inport/item/17408

Spalding, M. J. (2011). Perverse sea change: Underwater cultural heritage in the ocean is facing chemical and physical changes. *Cultural Heritage and Arts Review*, *2*(1), 12–16.

Stallcup, R. (1990). *Ocean birds of the nearshore Pacific: A guide for the sea-going naturalist*. Stinson Beach, CA: Point Reyes Bird Observatory.

Stallcup, R. (2010). *The amazing seabirds of Cordell Bank National Marine Sanctuary*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program. https://repository.library.noaa.gov/view/noaa/2619

Stramma, L., & Schmidtko, S. (2019). Global evidence of ocean deoxygenation. In D. Laffoley & J. M. Baxter (Eds.), *Ocean deoxygenation: Everyone's problem; Causes, impacts, consequences and solutions* (pp. 25–36). International Union for Conservation of Nature. https://portals.iucn.org/library/sites/library/files/documents/02.1%20DEOX.pdf

Sumaila, U. R., Teh, L., Watson, R., Tyedmers, P., & Pauly, D. (2008). Fuel price increase, subsidies, overcapacity, and resource sustainability. *ICES Journal of Marine Science*, *65*(6), 832–840. https://doi.org/10.1093/icesjms/fsn070

Surface Water Ambient Monitoring Program. (2021). *Contaminant tissue data, 2009–2010* [Data set]. https://gispublic.waterboards.ca.gov/swamp-data/

Sutton, R., Franz, A., Gilbreath, A., Lin, D., Miller, L., Sedlak, M., Wong, A., Box, C., Holleman, R., Munno, K., Zhu, X., & Rochman, C. (2019). *Understanding microplastic levels, pathways, and transport in the San Francisco Bay region*. San Francisco Estuary Institute. https://www.sfei.org/sites/default/files/biblio_files/Microplastic%20Levels%20in%20SF%20Bay%20-%20Final%20Report.pdf

Tamura, T. (2015). The career of the imperial Japanese Navy patrol boat No. 102 (ex-USS *Stewart*, DD-224). *Warship International*, *52*(3), 227–254. https://www.jstor.org/stable/i40207516

Tanaka, K. R., & Van Houtan, K. S. (2022). The recent normalization of historical marine heat extremes. *PLOS Climate*, *1*(2), e0000007. https://doi.org/10.1371/journal.pclm.0000007

Tans, P., & Keeling, R. (2021). *Trends in atmospheric carbon dioxide: Mauna Loa, Hawaii* [Data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Global Monitoring Laboratory, Earth System Research Laboratories. https://gml.noaa.gov/ccgg/trends/data.html

Tasker, M. L., Amundin, M., André, M., Hawkins, A., Lang, W., Merck, T., Scholik-Schlomer, A., Teilmann, J., Thomsen, F., Werner, S., & Zakharia, M. (2010). *Marine strategy framework directive: Task group 11 report; Underwater noise and other forms of energy*. Publications Office of the European Union. https://doi.org/10.2788/87079

Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Björn, A., Rowland, S. J., Thompson, R. C., Galloway, T. S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P. H., Tana, T. S., Prudente, M., Boonyatumanond, R., Zakaria, M. P., Akkhavong, K…& Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2027–2045. http://doi.org/10.1098/rstb.2008.0284

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at sea: Where is all the plastic? *Science*, *304*(5672), 838. http://doi.org/10.1126/science.1094559

Tiwari, M., Wallace, B. P., & Girondot, M. (2013). Dermochelys coriacea *(West Pacific Ocean subpopulation)*. The IUCN Red List of Threatened Species 2013, e.T46967817A46967821. https://doi.org/10.2305/IUCN.UK.2013-2.RLTS.T46967817A46967821.en

Twitter. (2020). *CBNMS account analytics* [Unpublished data set].

U.S. Bureau of Economic Analysis. (2020). *Personal income by county, metro, and other areas* [Data set]. U.S. Department of Commerce. https://www.bea.gov/data/income-saving/personal-income-county-metro-and-other-areas

U.S. Coast Guard. (2020). *Marine Information for Safety and Law Enforcement casualty and pollution incidents database, 2010–2020* [Unpublished data set].

U.S. Coast Guard. (2021). *Vessel traffic service vessel monitoring data, 2005–2017* [Unpublished data set].

U.S. Energy Information Administration. (2022). *Petroleum and other liquids: Weekly retail gasoline and diesel prices* [Data set]. https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm

U.S. Environmental Protection Agency. (2021). *Greenhouse Gas Reporting Program (GHGRP): Emissions by location*. https://www.epa.gov/ghgreporting/ghgrp-emissions-location

University of California Davis Bodega Marine Laboratory, Cordell Bank National Marine Sanctuary. (2021). *Dissolved oxygen and other oceanographic measurements at Cordell Bank, 2014–2021* [Unpublished data set].

University of California Santa Cruz. (2016). *UCSC CCS 2016a historical reanalysis physical ROMS model output on sigma levels* [Data set]. https://oceanmodeling.ucsc.edu:8443/thredds/CCSRA2016a_phys_agg_catalog_slevs.html

Van Hoomissen, S., Gulland, F. M. D., Greig, D. J., Castellini, M., & O'Hara, T. M. (2015). Blood and hair mercury concentrations in the Pacific harbor seal (*Phoca vitulina richardii*) pup: Associations with neurodevelopmental outcomes. *EcoHealth*, *12*, 490–500. https://doi.org/10.1007/s10393-015-1021-8

Vaquer-Sunyer, R., & Duarte, C. M. (2008). Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(40), 15452–15457. https://doi.org/10.1073/pnas.080383310

Vos, E., & Reeves, R. R. (2005). *Report of an international workshop: Policy on sound and marine mammals, 28–30 September 2004, London, England*. Marine Mammal Commission. https://www.mmc.gov/wp-content/uploads/finalworkshopreport.pdf

Wall, C. C., Haver, S. M., Hatch, L. T., Miksis-Olds, J., Bochenek, R., Dziak, R. P., & Gedamke, J. (2021). The next wave of passive acoustic data management: How centralized access can enhance science. *Frontiers in Marine Science*, *8*, 703682. https://doi.org/10.3389/fmars.2021.703682

Washington State Department of Ecology. (1996). *Guidelines for determining oil spill volume in the field: Terminology, ranges, estimates, and experts*. Olympia, WA: Department of Ecology Distribution Center. https://apps.ecology.wa.gov/publications/documents/96250.pdf

Wasmund, N., Kownacka, J., Göbel, J., Jaanus, A., Johansen, M., Jurgensone, I., Lehtinen, S., & Powilleit, M. (2017). The diatom/dinoflagellate index as an indicator of ecosystem changes in the Baltic Sea 1: Principle and handling instruction. *Frontiers in Marine Science*, *4*, 22. https://doi.org/10.3389/fmars.2017.00022

West Coast Groundfish Bottom Trawl Survey. (2019). *Survey data, 2012–2018* [Unpublished data set]. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Fisheries, Northwest Fisheries Science Center, Fishery Resource Analysis and Monitoring Division.

Whale Alert West Coast. (2021). *About us*. http://westcoast.whalealert.org/

Whale Alert. (2020). *Whale map: San Francisco region* [Data set]. https://geo.pointblue.org/whale-map/index.php?nms=gof

White, E. R., Froehlich, H. E., Gephart, J. A., Cottrell, R. S., Branch, T. A., Agrawal Bejarano, R., & Baum, J. K. (2021). Early effects of COVID-19 on US fisheries and seafood consumption. *Fish and Fisheries*, *22*(1), 232–239. https://doi.org/10.1111/faf.12525

White House Office of Management and Budget. (2004). *Final information quality bulletin for peer review*. https://georgewbush-whitehouse.archives.gov/omb/memoranda/fy2005/m05-03.pdf

Wilcox, C., Van Sebille, E., & Hardesty, B. D. (2015). Threat of plastic pollution to seabirds is global, pervasive, and increasing. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(38), 11899–11904. https://doi.org/10.1073/pnas.1502108112

Williams, G. C., & Breedy, O. (2019). A new species of gorgonian octocoral from the mesophotic zone off the central coast of California, Eastern Pacific, with a key to related regional taxa (Anthozoa, Octocorallia, Alcyonacea). *Proceedings of the California Academy of Sciences*, *65*(6), 143–158.

Wolf, S. G., Sydeman, W. J., Hipfner, J. M., Abraham, C. L., Tershy, B. R., & Croll, D. A. (2009). Range-wide reproductive consequences of ocean climate variability for the seabird Cassin's auklet. *Ecology*, *90*(3), 742–753. https://doi.org/10.1890/07-1267.1

Wright, J. (2016). Maritime archaeology and climate change: An invitation. In: *Journal of Maritime Archaeology*, *11*, 255–270. https://doi.org/10.1007/s11457-016-9164-5

Zabel, R. W., Harvey, C. J., Katz, S. L., Good, T. P., & Levin, P. S. (2003). Ecologically sustainable yield. *American Scientist*, *91*, 150–157. https://www.jstor.org/stable/27858183

Zabin, C. J., Ashton, G. V., Brown, C. W., & Ruiz, G. M. (2009). Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. *Aquatic Invasions*, *4*(3), 429–434. https://doi.org/10.3391/ai.2009.4.3.1

Zabin, C. J., Marraffini, M., Lonhart, S. I., McCann, L., Ceballos, L., King, C., Watanabe, J., Pearse, J. S., & Ruiz, G. M. (2018). Non-native species colonization of highly diverse, wave swept outer coast habitats in Central California. *Marine Biology*, *165*, 31. https://doi.org/10.1007/s00227-018-3284-4

Appendix A: Questions and Rating Schemes for Status and Trends of Sanctuary Resources

Below are descriptions of the questions and possible responses used to report the condition of sanctuary resources in condition reports for all national marine sanctuaries. ONMS and subject matter experts use this guidance, as well as their own understanding of the condition of resources, to make judgments about the status and trends of sanctuary resources.

The resource questions derive from the National Marine Sanctuary System's mission (Office of National Marine Sanctuaries, 2022) and a system-wide monitoring framework (National Marine Sanctuary Program, 2004) developed to ensure the timely flow of data and information to those responsible for managing and protecting resources in the ocean and coastal zone, and to those that use, depend on, and study sanctuary resources. The resource questions are used to guide ONMS and its partners at each unit in the sanctuary system in the development of sanctuary condition reports. Evaluations of resource status and trends are based on the interpretation of quantitative and, when necessary, non-quantitative assessments and observations by scientists, managers, and users.

In 2012, ONMS reviewed and edited the resource questions and their possible responses that were developed for the first round of condition reports (drafted between 2007 and 2014; National Marine Sanctuary Program, 2004). The questions that follow are revised and improved versions of those original questions. Although all questions have been edited to some degree, both in their description and status ratings, the nature and intent of most questions have not changed. Five questions, however, are either new or are significantly altered and are therefore not directly comparable to the original questions posed in the first round of condition reports. For these, a new baseline will need to be established.

- In the Water Quality section, one climate change question was added. This was necessary to address the increasing awareness and attention to the issue following the original design of the condition report process, which began in 2002.
- Two Habitat questions were combined due to feedback received during the development of the first round of reports. A single question regarding the "integrity of major habitat types" has been created and combines prior questions that separately inquired about non-biogenic and biogenic habitats. Experience showed that experts considered the condition of certain species (e.g., kelp, corals, and seagrass) critical to their assessment of most habitat, including those often considered non-biogenic; thus separating the two provided little added value.
- Among the Living Marine Resources questions, one used in the first round of condition reports was removed entirely. It asked about "the status of environmentally sustainable fishing." It was removed for a variety of reasons. First, it was the only question focused on a single, specific human activity rather than a particular resource. Second, considerations of fishing activity are already included in the question regarding "human activities that may influence living resources." Finally, living resources that would

provide a basis for judgment for this question are typically considered as part of other living resource questions, and need not be covered twice. Another change to the Living Marine Resources questions pertains to the question about the "health of key species," which was previously addressed in a single question, but is now split into two. The first asks specifically about the status of "keystone and foundation" species, the second about "other focal species." In both cases, the health of any species of interest can be considered in the judgment of status and trends.

- One of the initial questions addressed potential environmental hazards presented by heritage resources like shipwrecks. While the assessment of such threats is important, it was decided that the question was more appropriately addressed in the water quality and habitat contaminant questions rather than apply specifically to historic maritime properties. Therefore, the question was removed from the Maritime Heritage Resources section of the report and the subject is discussed in the context of other questions.

Ratings for a number of questions depend on judgments of the “ecological integrity” within a national marine sanctuary. This is because one of the foundational principles behind the establishment of sanctuaries is to protect ocean ecosystems. The term ecological integrity is used to imply “the presence of naturally occurring species, populations and communities, and ecological processes functioning at appropriate rates, scales, and levels of natural variation, as well as the environmental conditions that support these attributes” (modified from national park vital signs monitoring [National Park Service, 2021]). Sanctuaries have ecological integrity when they have their native components intact, including abiotic components (i.e., the physical forces and chemical elements, such as water), biotic elements (such as habitats), biodiversity (i.e., the composition and abundance of species and communities), and ecological processes (e.g., competition, predation, symbioses). For purposes of this report, the level of integrity that is judged to exist is based on the extent to which humans have altered specific components of the system, and the effect of that change on the ability of an ecosystem to resist continued change and recover from it. The statements for many questions are intended to reflect this judgment. Reference is made in the rating system to “near-pristine” conditions, for which this report would imply a status as near to an unaltered ecosystem as can reasonably be presumed to exist, recognizing that there are virtually no ecosystems on Earth completely free from human influence.

Not all questions, however, use ecological integrity as a basis for judgment. One focuses on the impacts of water quality factors on human health. Two questions rate the status of keystone and key species compared with that expected in an unaltered ecosystem. One rates maritime heritage resources based on their historical, archaeological, scientific, and educational value. Finally, four ask specifically about the levels of ongoing human activities (i.e., pressures) that could affect resource condition.

During workshops in which status and trends are rated, subject matter experts discuss each resource question and relevant indicators, available data, literature (e.g., published scientific studies, reports), and experience associated with the topic. They then discuss the statements provided as options for judgments about status; these statements have been customized for each question. Once a particular statement is agreed upon, a color code and status rating (e.g., good, fair, poor) is assigned. Experts can also decide that the most appropriate rating is “N/A” (i.e., the question does not apply), “undetermined” (i.e., resource status is undetermined due to a paucity of relevant information), or “mixed” (i.e., conflicting signals from indicators prevent the selection of a single status rating). A subsequent discussion is then held about the trend. Conditions are determined to be improving, remaining the same, or worsening over the time since the production of the prior condition report. Symbols used to indicate trends are the same for all questions: “▲”—conditions appear to be improving; “▬”—conditions do not appear to be changing; “▼”—conditions appear to be worsening; “▲▼”—conditions appear to be mixed; “?”—trend is undetermined; “N/A”—the question does not apply.

Human Drivers

1. What are the states of influential human drivers and how are they changing?

Driving forces are those characteristics of human societies that influence the nature and extent of pressures on resources. They are the underlying cause of change in coastal marine ecosystems, as they determine human use. Drivers are influenced by demographics (e.g., age structure, population, etc.), demand, economic circumstances, industrial development patterns, business trends, and societal values. They operate at global, regional, and local scales. Examples include increasing global demand for agricultural commodities, which increases the use of chemicals that degrade coastal water quality; difficult economic times that reduce fishing efforts for a period of time within certain regions; or local construction booms that alter recreational visitation trends. Other drivers could be the demands that govern trends, such as global greenhouse gas generation, regional shipping or offshore industrial development, local recreation and tourism, fishing, port improvement, manufacturing, and age-specific services (e.g., retirement). Each of these, in turn, influences certain pressures on natural and cultural resources.

Integrated into this question should be consideration of societal values, which include such matters as levels of conservation awareness, political leanings, opinion about environmental issues relative to other concerns, or changing opinions about the acceptability of specific behaviors (e.g., littering, fishing). Understanding these values gives one a better understanding of the likely future trends in drivers and pressures, as well as the nature of the societal tradeoffs in different uses of the ecosystem resources (e.g., the effects of multiple changing drivers on each other and the resources they affect). This can better inform policy and management responses and education and outreach efforts that are designed to change societal values with the intention to change drivers and reduce pressures.

In rating the status and trends for drivers, the following should be considered:

- the main driving forces behind each pressure affecting natural resources and the environment
- the best available indicators of each driving force
- the status and trend of each driving force
- societal values behind each driving force
- the best indicators of societal values
- the status and trend of societal values

Rating	Status Description
Good	Few or no drivers occur that have the potential to influence pressures in ways that will negatively affect resource qualities.
Good/Fair	Some drivers exist that may influence pressures in ways expected to degrade some attributes of resource quality.
Fair	Selected drivers are influencing pressures in ways that cause measurable resource impacts.
Fair/Poor	Selected drivers are influencing pressures in ways that result in severe impacts that are either widespread or persistent.
Poor	Selected drivers are influencing pressures in ways that result in severe, persistent, and widespread impacts.

Human Dimensions

2. What are the levels of human activities that may adversely influence water quality and how are they changing?

Among the human activities in or near sanctuaries that affect water quality are those involving direct discharges and spills (vessels, onshore and offshore industrial facilities, public wastewater facilities), those that contribute contaminants to groundwater, stream, river, and water control discharges (agriculture, runoff from impermeable surfaces through storm drains, conversion of land use), and those releasing airborne chemicals that subsequently deposit via particulates at sea (vessels, land-based traffic, power plants, manufacturing facilities, refineries). In addition, dredging and trawling can cause resuspension of contaminants in sediments. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
Good	Few or no activities occur that are likely to negatively affect water quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade water quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

3. What are the levels of human activities that may adversely influence habitats and how are they changing?

Human activities that degrade habitat quality do so by affecting structural (physical), biological, oceanographic, acoustic, or chemical characteristics of the habitat. Structural impacts, such as removal or mechanical alteration of habitat, can result from various fishing methods (e.g., trawls, traps, dredges, longlines, and even hook-and-line in some habitats), dredging of channels and harbors, dumping dredge spoil, grounding of vessels, anchoring, laying pipelines and cables, installing offshore structures, discharging drill cuttings, dragging tow cables, and placing artificial reefs. Removal or alteration of critical biological components of habitats can occur due to several of the above activities, most notably trawling, groundings, and cable drags. Marine debris, particularly in large quantities (e.g., lost gill nets and other types of fishing gear), can degrade both biological and structural habitat components. Changes in water circulation often occur when channels are dredged, fill is added, coastlines are armored or other construction takes place. Management actions such as beach wrack removal or sand replenishment on high public-use beaches, may impact the integrity of the natural ecosystem. Alterations in circulations can lead to changes in food delivery, waste removal, water quality (e.g., salinity, clarity and sedimentation), recruitment patterns, and a host of other ecological processes. Chemical alterations most commonly occur following spills and can have both acute and chronic impacts. Many of these activities can be controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
Good	Few or no activities occur that are likely to negatively affect habitat quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade habitat quality.
Fair	Selected activities have caused measurable resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

4. What are the levels of human activities that may adversely influence living resources and how are they changing?

Human activities that degrade the condition of living resources do so by causing a loss or reduction of one or more species, by disrupting critical life stages, by impairing various physiological processes, or by promoting the introduction of non-indigenous species or pathogens. (Note: Activities that impact habitat and water quality may also affect living resources. These activities are dealt with in the following human activity questions, and some may be repeated here as they also directly affect living resources).

For most sanctuaries, recreational or commercial fishing and collecting have direct effects on animal or plant populations, either through removal or injury of organisms. Related to this, lost fishing gear can cause extended periods of loss for some species through entanglement and "ghost fishing." In addition, some fishing techniques are size-selective, resulting in impacts to particular life stages. High levels of visitor use in some places also cause localized depletion, particularly in intertidal areas or on shallow coral reefs, where collecting and trampling can be chronic problems.

Mortality and injury to living resources has also been documented from cable drags (e.g., towed barge operations), dumping spoil or drill cuttings, vessel groundings, or repeated anchoring. Contamination caused by acute or chronic spills or increased sedimentation to nearshore ecosystems from road developments in watersheds (including runoff from coastal construction or highly built coastal areas), discharges by vessels, or municipal and industrial facilities can make habitats unsuitable for recruitment or other ecosystem services (e.g., as nurseries or spawning grounds). And while coastal armoring and construction can increase the availability of surfaces suitable for hard bottom species, the activity may disrupt recruitment patterns for other species (e.g., intertidal soft bottom animals), and natural habitat may be lost.

Oil spills (and spill response actions), discharges, and contaminants released from sediments (e.g., by dredging and dumping) can all cause physiological impairment and tissue contamination. Such activities can affect all life stages by direct mortality, reducing fecundity, reducing disease resistance, loss as prey and disruption of predator-prey relationships, and increasing susceptibility to predation. Furthermore, bioaccumulation results in some contaminants moving upward through the food chain, disproportionately affecting certain species.

Activities that promote the introduction of non-indigenous species include bilge discharges and ballast water exchange, commercial shipping and vessel transportation. Intentional or accidental releases of aquarium fish and plants can also lead to introductions of non-indigenous species.

Many of these activities are controlled through management actions in order to limit their impact on protected resources.

Rating	Status Description
Good	Few or no activities occur that are likely to negatively affect living resource quality.
Good/Fair	Some potentially harmful activities exist, but they have not been shown to degrade living resource quality.
Fair	Selected activities have caused measurable living resource impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

5. What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Some human activities threaten the archaeological or historical condition of maritime heritage resources. Archaeological or historical condition is compromised when elements are moved, removed, or otherwise damaged. Threats come from looting, inadvertent damage by recreational divers, improper research methods, vessel anchorings and groundings, and commercial and recreational fishing activities, among others. Other human activities may alter or damage heritage resources by impacting the landscape or viewshed of culturally significant places or locations. Many of these activities can be controlled through management actions in order to limit their impact to maritime heritage resources.

Rating	Status Description
Good	Few or no activities occur at maritime heritage resource sites that are likely to adversely affect their condition.
Good/Fair	Some potentially damaging activities exist, but they have not been shown to degrade maritime heritage resource condition.
Fair	Selected activities have caused measurable impacts to maritime heritage resources, but effects are localized and not widespread or persistent.
Fair/Poor	Selected activities have caused severe impacts that are either widespread or persistent.
Poor	Selected activities have caused severe, persistent, and widespread impacts.

Water Quality

6. What is the eutrophic condition of sanctuary waters and how is it changing?

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. It is usually caused by an increase in the amount of nutrients (largely nitrogen and phosphorus) being discharged to the water body. As a result of accelerated algal production, a variety of interrelated impacts may occur, including nuisance and toxic algal blooms, depleted dissolved oxygen, and loss of submerged aquatic vegetation (Bricker et al., 1999). Indicators commonly used to detect eutrophication and associated problems include nutrient concentrations, chlorophyll content, rates of water column or benthic primary production, benthic algae cover, algae bloom frequency and intensity, oxygen levels, and light penetration.

Eutrophication of sanctuary waters can impact the condition of other sanctuary resources. Nutrient enrichment often leads to plankton and/or algae blooms. Blooms of benthic algae can affect benthic communities directly through space competition. Indirect effects of overgrowth and other competitive interactions (e.g., accumulation of algal-sediment mats) often lead to shifts in dominance in the benthic assemblage, oxygen depletion, etc. Disease incidence and frequency can also be affected by algae competition and changes in the chemical environment along competitive boundaries. Blooms can also affect water column conditions, including light penetration and plankton availability, which can alter pelagic food webs. HABs, some of which are exacerbated by eutrophic conditions, often affect other living resources, as biotoxins are consumed or released into the water and air, or decomposition depletes oxygen concentrations.

Rating	Status Description
Good	Eutrophication has not been documented, or does not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Eutrophication is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
Fair	Eutrophication has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Eutrophication has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Eutrophication has caused severe degradation in most if not all attributes of ecological integrity.

7. Do sanctuary waters pose risks to human health and how are they changing?

Human health concerns are generally aroused by evidence of contamination (usually bacterial or chemical) in bathing waters or seafood intended for consumption. They also arise when harmful algal blooms are reported or when cases of respiratory distress or other disorders attributable to harmful algal blooms increase dramatically. Any of these conditions should be considered in the course of judging the risk to humans posed by waters in a marine sanctuary.

Some sanctuaries may have access to specific information about beach closures and seafood contamination. In particular, beaches may be closed when criteria for water safety are exceeded. Shellfish harvesting and fishing may be prohibited when contaminant or biotoxin loads or infection rates exceed certain levels. Alternatively, seafood advisories may also be issued, recommending that people avoid or limit intake of particular types of seafood from certain areas (e.g., when ciguatera poisoning is reported). Any of these conditions, along with changing frequencies or intensities, can be important indicators of human health problems and can be characterized using the descriptions below.

Rating	Status Description
Good	Water quality does not appear to have the potential to negatively affect human health.
Good/Fair	One or more water quality indicators suggest the potential for human health impacts but human health impacts have not been reported.
Fair	Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.
Fair/Poor	Water quality problems have caused severe impacts that are either widespread or persistent.
Poor	Water quality problems have caused severe, persistent, and widespread human impacts.

8. Have recent, accelerated changes in climate altered water conditions and how are they changing?

The purpose of this question is to capture shifts in water quality, and associated impacts on sanctuary resources, due to climate change. Though temporal changes in climate have always occurred on Earth, evidence is strong that changes over the last century have been accelerated by human activities. Indicators of climate change in sanctuary waters include water temperature, acidity, sea level, upwelling intensity and timing, storm intensity and frequency, changes in erosion and sedimentation patterns, and freshwater delivery (e.g., rainfall patterns). Climate-related changes in one or more of these indicators can impact the condition of habitats, living resources, and maritime archaeological resources in sanctuaries.

Increasing water temperature has been linked to changing growth rates, reduced disease resistance, and disruptions in symbiotic relationships (e.g., bleaching on coral reefs), and changes in water temperature exposure may affect a species' resistance or the capacity to adapt to disturbances. Acidification can affect the survival and growth of organisms throughout the food web, as well as the persistence of skeletal material after death (through changes in rates of dissolution and bioerosion). Recent findings also suggest acidification impacts at sensory and behavioral levels, which can alter vitality and species interactions. Sea level change alters habitats, as well as their use and persistence. Variations in the timing and intensity of upwelling is known to change water quality through factors such as oxygen content and nutrient flow, further disrupting food webs and the natural functioning of ecosystems. Changing patterns and intensities of storms alter community resistance and resilience within ecosystems that have, over long periods of time, adapted to such disturbances. Altered rates and volumes of freshwater delivery to coastal ecosystems affects salinity and turbidity regimes and can disrupt reproduction, recruitment, growth, disease incidence, phenology, and other important processes.

Rating	Status Description
Good	Climate-related changes in water conditions have not been documented or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Climate-related changes are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Climate-related changes have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Climate-related changes have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Climate-related changes have caused severe degradation in most if not all attributes of ecological integrity.

9. Are other stressors, individually or in combination, affecting water quality, and how are they changing?

The purpose of this question is to capture shifts in water quality due to anthropogenic stressors not addressed in other questions. For example, localized changes in circulation or sedimentation resulting from coastal construction or dredge spoil disposal can affect light penetration, salinity regimes, oxygen levels, productivity, waste transport, and other aspects of water quality that in turn influence the condition of habitats and living resources. Human inputs, generally in the form of contaminants from point or non-point sources, including fertilizers, pesticides, hydrocarbons, heavy metals, and sewage, are common causes of environmental degradation. When present in the water column, any of these contaminants can affect marine life by direct contact or ingestion, or through bioaccumulation via the food chain.

(Note: Over time, accumulation in sediments can sequester and concentrate contaminants. Their effects may manifest only when the sediments are resuspended during storm or other energetic events. In such cases, reports of status should be made under Question 11 — Habitat contaminants.)

Rating	Status Description
Good	Other stressors on water quality have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected stressors are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected stressors have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected stressors have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected stressors have caused severe degradation in most if not all attributes of ecological integrity.

Habitat

10. What is the integrity of major habitat types and how are they changing?

Ocean habitats can be categorized in many different ways, including water column characteristics, benthic assemblages, substrate types, and structural character. There are intertidal and subtidal habitats. The water column itself is one habitat type (Federal Geographic Data Committee, 2012). There are habitats composed of substrates formed by rocks or sand that originate from purely physical processes. And, there are certain animals and plants that create, in life or after their death, substrates that attract or support other organisms (e.g., corals, kelp, beach wrack, drift algae). These are commonly called biogenic habitats.

Regardless of the habitat type, change and loss of habitat is of paramount concern when it comes to protecting marine and terrestrial ecosystems. Of greatest concern to sanctuaries are changes to habitats caused, either directly or indirectly, by human activities. Human activities like coastal development alter the distribution of habitat types along the shoreline. Changes in water conditions in estuaries, bays, and nearshore waters can negatively affect biogenic habitat formed by submerged aquatic vegetation. Intertidal habitats can be affected for long periods by oil spills or by chronic pollutant exposure. Marine debris, such trash and lost fishing gear, can degrade the quality of many different marine habitats including beaches, subtidal benthic habitats, and the water column. Sandy seafloor and hard bottom habitats, even rocky areas several hundred meters deep, can be disturbed or destroyed by certain types of fishing gear, including bottom trawls, shellfish dredges, bottom longlines, and fish traps. Groundings, anchors, and irresponsible diving practices damage submerged reefs. Cables and pipelines disturb corridors across numerous habitat types and can be destructive if they become mobile.

Integrity of biogenic habitats depends on the condition of particular living organisms. Coral, sponges, and kelp are well known examples of biogenic habitat-forming organisms. The diverse assemblages residing within these habitats depend on and interact with each other in tightly linked food webs. They may also depend on each other for the recycling of wastes, hygiene, and the maintenance of water quality. Other communities that are dependent on biogenic habitat include intertidal communities structured by mussels, barnacles, and algae and subtidal hard-bottom communities structured by bivalves, corals, or coralline algae. In numerous open ocean areas drift algal mats provide food and cover for juvenile fish, turtles, and other organisms. The integrity of these communities depends largely on the condition of species that provide structure for them.

This question is intended to address acute or chronic changes in both the extent of habitat available to organisms and the quality of that habitat, whether non-living or biogenic. It asks about the quality of habitats compared to those that would be expected in near-pristine conditions (see definition above).

Rating	Status Description
Good	Habitats are in near-pristine condition.
Good/Fair	Selected habitat loss or alteration is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.
Fair	Selected habitat loss or alteration has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected habitat loss or alteration has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected habitat loss or alteration has caused severe degradation in most if not all attributes of ecological integrity.

11. What are contaminant concentrations in sanctuary habitats and how are they changing?

Habitat contaminants result from the introduction of unnatural levels of chemicals or other harmful material into the environment. Contaminants may be introduced through discrete entry locations, called point sources (e.g., rivers, pipes, or ships) and those with diffuse origins, called non-point sources (e.g., groundwater and urban runoff). Chemical contaminants themselves can be very specific, as in a spill from a containment facility or vessel grounding, or a complex mix, as with urban runoff. Familiar chemical contaminants include pesticides, hydrocarbons, heavy metals, and nutrients. Contaminants may also arrive in the form of materials that alter turbidity or smother plants or animals, therefore affecting metabolism and production.

This question is focused on risks posed primarily by contaminants within benthic formations, such as soft sediments, hard bottoms, or structure-forming organisms (see notes below). Not only are contaminants within benthic formations consumed or absorbed by benthic fauna, but resuspension due to benthic disturbance makes the contaminants available to water column organisms. In both cases contaminants can be passed upwards through the food chain. While the contaminants of most common concern to sanctuaries are generally pesticides, hydrocarbons, and nutrients, the specific concerns of individual sanctuaries may differ substantially.

Notes: 1) Contaminants in the water column addressed in the water quality section of this report should be cited, but details need not be repeated here; 2) many consider noise a pollutant, but in the interest of focusing here on more traditional forms of habitat degradation caused by contaminants, ONMS recommends addressing the impacts of acoustic pollution within the living resource section, most likely as it impacts key species.

Rating	Status Description
Good	Contaminants have not been documented, or do not appear to have the potential to negatively affect ecological integrity.
Good/Fair	Selected contaminants are suspected and may degrade some attributes of ecological integrity, but have not yet caused measurable degradation.
Fair	Selected contaminants have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected contaminants have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected contaminants have caused severe degradation in most if not all attributes of ecological integrity.

Living Resources

12. What is the status of keystone and foundation species and how is it changing?

Certain species are defined as "keystone" within ecosystems, meaning they are species on which the persistence of a large number of other species in the ecosystem depends (Paine, 1966). They are the pillars of community stability (among other things, they strongly affect both resistance and resilience) and their contribution to ecosystem function is disproportionate to their numerical abundance or biomass. Their impact is therefore important at the community or ecosystem level. Keystone species are often called "ecosystem engineers" and can include habitat creators (e.g., corals, kelp), predators that control food web structure (e.g., Humboldt squid, sea otters), herbivores that regulate benthic recruitment (e.g., certain sea urchins), and those involved in critical symbiotic relationships (e.g., cleaning or co-habitating species).

"Foundation" species are single species that define much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes (Dayton, 1972). These are typically dominant biomass producers in an ecosystem and strongly influence the abundance and biomass of many other species. Examples include krill and other zooplankton, kelp, forage fish, such as rockfish anchovy, sardine, and coral. Foundation species exhibit similar control over ecosystems as keystone species, but their high abundance distinguishes them.

Changes in either keystone or foundation species may transform ecosystem structure through disappearances of or dramatic increases in the abundance of dependent species. Not only do the abundances of keystone and foundation species affect ecosystem integrity, but measures of condition can also be important to determining the likelihood that these species will persist and continue to provide vital ecosystem functions. Measures of condition may include growth rates, fecundity, recruitment, age-specific survival, contaminant loads, pathologies (e.g., disease incidence, tumors, deformities), the presence and abundance of critical symbionts, or parasite loads.

Rating	Status Description
Good	The status of keystone and foundation species appears to reflect near-pristine conditions and may promote ecological integrity (full community development and function).
Good/Fair	The status of keystone or foundation species may preclude full community development and function, but has not yet led to measurable degradation.
Fair	The status of keystone or foundation species suggests measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	The status of keystone and foundation species suggests severe degradation in some but not all attributes of ecological integrity.
Poor	The status of keystone and foundation species suggests severe degradation in most if not all attributes of ecological integrity.

13. What is the status of other focal species and how is it changing?

This question targets other species of particular interest from the perspective of sanctuary management. These "focal species" may not be abundant or provide high value to ecosystem function, but their presence and health is important for the provision of other services, whether conservation, economic, or strategic. Examples include species targeted for special protection (e.g., threatened or endangered species), species for which specific regulations exist to minimize perturbations from human disturbance (e.g., touching corals, riding manta rays or whale sharks, disturbing white sharks, disturbing nesting birds), or indicator species (e.g., common murres as indicators of oil pollution). This category could also include so-called "flagship" species, which include charismatic or iconic species associated with specific locations, ecosystems or are in need of specific management actions, are highly popular and attract visitors or business, have marketing appeal, or represent rallying points for conservation action (e.g., humpback and blue whales, Dungeness crab).

Status of these other focal species can be assessed through measures of abundance, relative abundance, or condition, as described for keystone species. In contrast to keystone and foundation species, however, the impact of changes in the abundance or condition of focal species is more likely to be observed at the population or individual level, and less likely to result in ecosystem or community effects.

Rating	Status Description
Good	Selected focal species appear to reflect near-pristine conditions.
Good/Fair	Reduced abundances in selected focal species are suspected but have not yet been measured.
Fair	Selected focal species are at reduced levels, but recovery is possible.
Fair/Poor	Selected focal species are at substantially reduced levels, and prospects for recovery are uncertain.
Poor	Selected focal species are at severely reduced levels, and recovery is unlikely.

14. What is the status of non-indigenous species and how is it changing?

This question allows sanctuaries to report on the threat posed and impacts caused by non-indigenous species. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their native distributional range, having arrived there by human activity, either deliberate or accidental. Activities that commonly facilitate invasions include vessel ballast water exchange, restaurant waste disposal, and trade in exotic species for aquaria. In some cases, climate change has resulted in water temperature fluctuations that have allowed range extensions for certain species.

Non-indigenous species that have damaging effects on ecosystems are called "invasive" species. Some can be extremely destructive, and because of this potential, non-indigenous species are usually considered problematic and warrant rapid response after invasion. For those that become established, however, their impacts can sometimes be assessed by quantifying changes in affected native species. In some cases, the presence of a species alone constitutes a significant threat (e.g., certain invasive algae and invertebrates). In other cases, impacts have been measured, and may or may not significantly affect ecosystem integrity.

Evaluating the potential impacts of non-indigenous species may require consideration of how climate change may enhance the recruitment, establishment, and/or severity of impacts of non-indigenous species. Altered temperature or salinity conditions, for example, may facilitate the range expansion, establishment and survival of non-indigenous species while stressing native species, thus reducing ecosystem resistance. This will also make management response decisions difficult, as changing conditions will make new areas even more hospitable for non-indigenous species targeted for removal.

Rating	Status Description
Good	Non-indigenous species are not suspected to be present or do not appear to affect ecological integrity (full community development and function).
Good/Fair	Non-indigenous species are present and may preclude full community development and function, but have not yet caused measurable degradation.
Fair	Non-indigenous species have caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Non-indigenous species have caused severe degradation in some but not all attributes of ecological integrity.
Poor	Non-indigenous species have caused severe degradation in most if not all attributes of ecological integrity.

15. What is the status of biodiversity and how is it changing?

Broadly defined, biodiversity refers to the variety of life on Earth, and includes the diversity of ecosystems, species and genes, and the ecological processes that support them (Convention on Biological Diversity, 2006). This question is intended as an overall assessment of biodiversity compared to that expected in a near-pristine system (one as near to an unaltered ecosystem as people can reasonably expect, given that there are virtually no ecosystems completely free from human influence). It may include consideration of measures of biodiversity (usually aspects of species richness and evenness) and the status of functional interactions between species (e.g., trophic relationships and symbioses). Intact ecosystems require that all parts not only exist, but that they function together, resulting in natural symbioses, competition, predator-prey relationships, and redundancies (e.g., multiple species capable of performing the same ecological role). Intact structural elements, processes, and natural spatial and temporal variability are essential characteristics of community integrity and provide a natural adaptive capacity through resistance and resilience.

The response to this question will depend largely on changes in biodiversity that have occurred as a result of human activities that cause depletion, extirpation or extinction, illness, contamination, disturbance, and changes in environmental quality. Examples include collection of organisms, excessive visitation (e.g., trampling), industrial activities, coastal development, pollution, activities creating noise in the marine environment, and those that promote the spread of non-indigenous species.

Loss of species or changing relative abundances can be mediated through selective mortality or changing fecundity, either of which can influence ecosystem shifts. Human activities of particular interest in this regard are commercial and recreational harvesting. Both can be highly selective and disruptive activities, with a limited number of targeted species, and often result in the removal of high proportions of the populations, as well as large amounts of untargeted species (bycatch). Extraction removes biomass from the ecosystem, reducing its availability to other consumers. When too much extraction occurs, ecosystem stability can be compromised through long-term disruptions to food web structure, as well as changes in species relationships and related functions and services (e.g., cleaning symbioses). This has been defined as “ecologically unsustainable” extraction (Zabel et al., 2003).

Rating	Status Description
Good	Biodiversity appears to reflect near-pristine conditions and promotes ecological integrity (full community development and function).
Good/Fair	Selected biodiversity loss or change is suspected and may preclude full community development and function, but has not yet caused measurable degradation.
Fair	Selected biodiversity loss or change has caused measurable but not severe degradation in some attributes of ecological integrity.
Fair/Poor	Selected biodiversity loss or change has caused severe degradation in some but not all attributes of ecological integrity.
Poor	Selected biodiversity loss or change has caused severe degradation in most if not all attributes of ecological integrity.

Maritime Heritage Resources

16. What is the condition of known maritime heritage resources and how is it changing?

Maritime heritage resources are the wide variety of tangible and intangible elements (archaeological, cultural, historical properties) that reflect our human connections to Great Lakes and ocean areas.

Maritime heritage resources include archaeological and historical properties, and material evidence of past human activities, including vessels, aircraft, structures, habitation sites, and objects created or modified by humans. The condition of these resources in a marine sanctuary significantly affects their value for science and education, as well as the resource's eligibility for listing in the National Register of Historic Places. The "integrity" of archaeological/historical resources, as defined within the National Register criteria, refers to their ability to help scientists answer questions about the past through archaeological research. Historical significance of an archaeological resource depends on its integrity and/or its representativeness of past events that made a significant contribution to the broad patterns of history, its association with important persons, or its embodiment of a distinctive type or architecture.

Maritime heritage resources also include certain culturally significant resources, locations and viewsheds, the condition of which may change over time. Such resources, often more intangible in nature, may still be central to traditional practices and maintenance of cultural identity. The integrity of both cultural resources and cultural locations are included within the National Register criteria.

Section 110 of the National Historic Preservation Act requires federal agencies to inventory, assess, and nominate appropriate maritime heritage resources ("historic properties") to the National Register. The Maritime Cultural Landscape approach, adopted by the sanctuary system, provides a comprehensive tool for the assessment of archaeological, historical and cultural (maritime heritage) resources.

Assessments of heritage resources include evaluation of the apparent condition, which results from deterioration caused by human and natural forces (unlike questions about water, habitat, and living resources, the non-renewable nature of many heritage resources makes any reduction in integrity and condition, even if caused by natural forces, permanent). While maritime heritage resources have intrinsic value, these values may be diminished by changes to their condition.

Rating	Status Description
Good	Known maritime heritage resources appear to reflect little or no unexpected natural or human disturbance.
Good/Fair	Selected maritime heritage resources exhibit indications of natural or human disturbance, but there appears to have been little or no reduction in aesthetic, cultural, historical, archaeological, scientific, or educational value.
Fair	The diminished condition of selected maritime heritage resources has reduced, to some extent, their aesthetic, cultural, historical, archaeological, scientific, or educational value, and may affect the eligibility of some sites for listing in the National Register of Historic Places.
Fair/Poor	The diminished condition of selected maritime heritage resources has substantially reduced their aesthetic, cultural, historical, archaeological, scientific, or educational value, and is likely to affect their eligibility for listing in the National Register of Historic Places.
Poor	The degraded condition of known maritime heritage resources in general makes them ineffective in terms of aesthetic, cultural, historical, archaeological, scientific, or educational value, and precludes their listing in the National Register of Historic Places.

Appendix B: Definitions and Rating Scheme for Status and Trends of Ecosystem Services

The following describes the ecosystem services and possible responses that ONMS considers in condition reports for all national marine sanctuaries. ONMS and subject matter experts use this guidance to make judgments about the status and trends of sanctuary ecosystem services.

ONMS defines ecosystem services in a slightly more restrictive way than some other experts. Specifically, ecosystem services are defined herein as the benefits people obtain from nature through use, consumption, enjoyment, and/or simply knowing these resources exist (non-use). The descriptions below reflect this definition, and therefore, only these ecosystem services are evaluated in sanctuary conditions reports. Intermediate services are not evaluated in the Status and Trends of Ecosystem Services chapter of these reports. Intermediate services, while critical to ecosystem function, are not directly used, consumed, or enjoyed by humans and thus do not meet the ONMS condition report definition of ecosystem services. In other words, these intermediate services support ecosystems but are not final ecosystem services in and of themselves. As an example, biodiversity is often considered as an ecosystem service by experts in the field, but ONMS recognizes biodiversity as an intermediate service of the ecosystem on which many final ecosystem services depend (e.g., consumptive and non-consumptive recreation, commercial and subsistence harvest depend on the status and trend of biodiversity). For this reason, biodiversity is considered an intermediate ecosystem service and it is evaluated in the Status and Trends of Sanctuary Resources chapter of the report. Decomposition and carbon storage are examples of other intermediate services.

In addition, ONMS does not consider climate regulation or stabilization as ecosystem services in condition reports. The impacts of climate change on water quality, habitat, and living resources are considered separately in the Status and Trends of Sanctuary Resources chapter of the report. While sanctuaries are not large enough to influence climate stability, they may locally buffer climate-related factors, such as temperature change and ocean acidity; thus, the extent to which they may locally buffer climate-related factors is reflected in resource conditions in the Status and Trends of Sanctuary Resources chapter.

Finally, some ecosystem services may not be assessed by individual sanctuaries because the activities required to achieve them are prohibited (e.g., collection of ornamentals), the sanctuary is not mandated to manage a specific resource that provides a particular service (e.g., management of fisheries), or there is simply no related activity underway or expected (e.g., renewable energy production).

Below are brief descriptions of the ecosystem services that could be considered within each sanctuary condition report (more complete descriptions are provided below the list).

***Cultural* (non-material benefits)**

1. Consumptive recreation — Recreational activities that result in the removal of or harm to natural or cultural resources
2. Non-consumptive recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources
3. Science — The capacity to acquire and contribute information and knowledge
4. Education — The capacity to acquire and provide intellectual enrichment
5. Heritage — Recognition of historical and heritage legacy and cultural practices
6. Sense of Place — Aesthetic attraction, spiritual significance, and location identity

***Provisioning* (material benefits)**

7. Commercial Harvest — The capacity to support commercial market demands for seafood products
8. Subsistence Harvest — The capacity to support non-commercial harvesting of food and utilitarian products
9. Drinking water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash
10. Ornamentals — Resources collected for decorative, aesthetic, ceremonial purposes
11. Biotechnology — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use
12. Renewable energy — Use of ecosystem-derived materials or processes for the production of energy

***Regulating* (buffers to change)**

13. Coastal protection — Flow regulation that protects habitats, property, coastlines, and other features

Sanctuaries vary with regard to the ecosystem services they support. To rate the status and trend for each relevant ecosystem service, the following can be considered:

- the best available indicators for each ecosystem service (e.g., economic, human dimension non-economic, resource, traditional ecological knowledge)
- the status and direction of change of each ecosystem service
- the prioritization of each indicator
- whether economic indicators send a false signal about the status and trend of an ecosystem service (namely, conflicting ecological and economic indicators, suggesting that people are sacrificing natural capital for short-term economic gain)

The steps used to rate ecosystem services were adapted from a multi-year study, *Marine and Estuarine Goal Setting for South Florida*, of three south Florida marine ecosystems, including Florida Keys National Marine Sanctuary (Kelble et al., 2013). The study used integrated conceptual ecosystem models for each ecosystem under the DPSER Model (Nuttle & Fletcher, 2013) and evaluation of three types of indicators for each ecosystem service: 1) economic; 2) human dimension non-economic (Lovelace et al., 2013); and 3) resource.

The evaluation of ecosystem services should consider whether economic and non-economic indicators yield the same conclusions as resource indicators; this will enable consideration of the sometimes conflicting relationship between economic gain and the preservation of natural capital. For example, economic indicators (e.g., dive operator income) may suggest improving recreational services, while resource indicators (e.g., anchor damage to benthic habitat) suggest that natural resources are being sacrificed for short-term gain, thus making the activity unsustainable.

ONMS recognizes that the ecosystem services model is intentionally anthropocentric, designed to elicit a selected type of service-oriented rating useful in resource management decision-making. Connections between ecosystems, culture and heritage, and resource management are often complex, beyond the scope of the condition report. Collectively, stakeholders may have multiple worldviews and ecosystem values equally important to consider, and some ecosystem elements may not be appropriate to rate in the ecosystem services approach (e.g., aspects of heritage and sense of place). Sanctuaries may want to consider the option of including a "context-specific perspective" or narrative (as proposed in Diaz et al., 2018), without assigning a status or trend rating, for the purpose of providing appropriate information for management purposes. Cultural (non-material) ecosystem services are particularly intricate and have been undervalued in the past. Evaluators should remember that deliberative processes engaging local stakeholders and subject matter experts are critical, and adherence to the process demands both flexibility and creativity.

During workshops in which status and trends are determined, subject matter experts discuss each ecosystem service and relevant indicators, available data, literature (e.g., published scientific studies, reports), and experience associated with the topic. They then discuss the statements provided (see table below) as options for judgments about status. Once a particular statement is agreed upon, a color code and status rating (e.g., good, fair, poor) is assigned. Experts can also decide that the most appropriate rating is "N/A" (i.e., the ecosystem service does not apply), "undetermined" (i.e., ecosystem service status is undetermined due to a paucity of relevant information), or "mixed" (i.e., variation across indicators prevents the selection of a single status rating). A subsequent discussion is then held about the trend. Conditions are determined to be improving, remaining the same, or worsening in comparison to the results found in the first round of condition reports. Symbols used to indicate trends are the same for all ecosystem services: "▲"—conditions appear to be improving; "▬"—conditions do not appear to be changing; "▼"—conditions appear to be worsening; "▲▼"—conditions appear to be mixed; and "?"—trend is undetermined; "N/A"—the ecosystem service does not apply.

Rating Scheme for Ecosystem Services

Rating	Status Description
Good	The capacity to provide the ecosystem service has remained unaffected or has been restored.
Good/Fair	The capacity to provide the ecosystem service is compromised, but performance is acceptable.
Fair	The capacity to provide the ecosystem service is compromised, and existing management would require enhancement to enable acceptable performance.
Fair/Poor	The capacity to provide the ecosystem service is compromised, and substantial new or enhanced management is required to restore it.
Poor	The capacity to provide the ecosystem service is compromised, and it is doubtful that new or enhanced management would restore it.

Cultural (Non-Material Benefits)

Consumptive recreation — Recreational activities that result in the removal of or harm to natural or cultural resources

Perhaps the most popular activity that involves consumptive recreation is sport fishing from private boats and for-hire operations. Targeted species and bycatch are removed from the environment, and those that must be released due to regulations and prohibitions (e.g., undersized or out of season) sometimes die due to stress or predation. Nonetheless, fishing for consumptive purposes is a highly valued cultural tradition for many people, as well as a popular recreational activity. Other consumptive recreational activities include beachcombing, clam digs and shell collecting.

Indicators of status and trends for consumptive recreation often include levels of use (direct counts or estimates made from commercial vessel records and catch levels, and fishing license registrations) and production of economic value through job creation, income, spending, and tax revenue. Public polls can also be used to assess non-market indicators, such as importance and satisfaction, social values, willingness to pay, and facility and service availability.

Non-consumptive recreation — Recreational activities that do not result in intentional removal of or harm to natural or cultural resources

Recreational activities, including ecotourism and outdoor sports, are often considered a non-consumptive ecosystem service that provides desirable experiential opportunities. Non-consumptive recreational activities include those on shore or from private boats and for-hire operations, such as relaxing, exploring, diving and snorkeling, kayaking, birdwatching, surfing, sailing, and wildlife viewing. Activities that may have unintentional impacts on habitats or wildlife including catch-and-release fishing and tidepooling which could result in mortality or trampling, respectively, are also considered in this category.

It should be noted that private boating often includes both non-consumptive and consumptive recreational activities (e.g., snorkeling and fishing during a single trip). Thus, field and survey data can be ambiguous, reflecting the heterogeneous preferences of boaters. This also has implications for interpretations of data regarding attitudes and perceptions of management strategies and regulations to protect and restore natural and cultural resources.

Indicators used to assess status and trends in market values for recreation can include direct measures of use (e.g., person-days of use by type of activity) that result in spending, income, jobs, gross regional product, and tax revenues. They can also be non-market economic values (the difference between what people pay to use a good/service and what they would be willing to pay). The data can be used to estimate the value a consumer receives when using a good or service over and above what they pay to obtain the good or service. Indirect measures are also used. For example, populations and per capita incomes at numerous scales influence demand for recreational products and services. Fuel prices can even serve as indirect measures of recreational demand because the levels of use by some recreational users tracks fuel prices.

Science — The capacity to acquire and contribute information and knowledge

Sanctuaries serve as natural laboratories that can advance science and education. NOAA provides vessel support, facilities, and information that is valuable to the research community, including academic, corporate, non-governmental and government agency scientists, citizen scientists, and educators that instruct others using research. Sanctuaries serve as long-term monitoring sites, provide minimally disturbed focal areas for many studies, and provide opportunities to restore or maintain natural systems.

Status and trends for science can be assessed by counting and characterizing the number of research permits and tracking the accomplishments and growth of partnerships, activity levels of citizen monitoring, and participation of the research community in sanctuary management. The number and types of research cruises and other expeditions conducted can also provide useful indicators. Indirect indicators, such as per capita income and gross regional or national product, may be helpful as higher incomes and better economic conditions often result in higher investments in research and monitoring.

Education — The capacity to acquire and provide intellectual enrichment

As with science, national marine sanctuaries' protected natural systems and cultural resources attract educators at many levels for both formal and informal education. Students and teachers often either visit sanctuaries or use curricula and information provided by sanctuary educators.

The status and trends for education can be tracked by evaluating the number of educators and students visiting the sanctuary and visitor centers, the number of teacher trainings, use of sanctuary-related curricula in the classroom, and levels of activity in volunteer docent programs. The number of outreach offerings provided during sanctuary research and education expeditions can also be a good indicator. Education can also follow trends in populations and per capita income locally, regionally, and nationally. Populations create demand for services, and higher incomes lead to investment, making these useful indirect indicators.

Heritage — Recognition of historical and heritage legacy and cultural practices

The iconic nature of many national marine sanctuaries or particular places within them generally means that they have long been recognized, used, and valued. Communities developed around them, traveled through them, and depended on their resources. This shared history and heritage creates the unique cultural character of many present-day coastal communities, and can also be an important part of the current economy. Recognition of the past, including exhibits, artifacts, records, stories, songs, and chants provide not only a link to the history of these areas, but a way to better understand the maritime and cultural heritage within the environment itself. Tangible and intangible aspects of heritage blend together to contribute to the history and legacy of the place.

For some marine sanctuaries, vibrant and active indigenous cultures remain a defining and dominant element of the cultural heritage of these places. Not only are they a direct and priceless connection to the past, but they frame and influence modern-day economies, cultural landscapes, and conservation ethics and practices. Their very existence is intrinsic to the heritage of these places.

Given this broad range of cultural expression, benefits of heritage may take many forms. Additionally, cultural heritage resources will often be part of, or overlap with, other ecosystem service categories, and may be understood from multiple perspectives (such as, a living resource keystone species that may also be identified as a "cultural" keystone species, one of exceptional significance to a culture or a people). The Heritage ecosystem service category defines benefits from resources primarily attached to historical and heritage legacy and culture. Heritage resources, including certain living resources and traditional medicines, may also provide other benefits that can be addressed in other ecosystem service categories.

Economic indicators that reflect status and trends for heritage value as an ecosystem service may include spending, income, jobs, and other revenues generated from visitation, whether it is to dive on wreck sites or patronize museums and visitor centers where artifacts are displayed and interpreted. Non-market indicators, such as willingness to pay for protection of resources, activity levels for training and docent interpretation, and changes in threat levels (looting and damage caused by fishing), may also be considered. Sites may determine that some aspects of Heritage may simply not be ratable using the framework of condition reports.

Sense of place — Aesthetic attraction, spiritual significance, and location identity

A wide range of intangible meanings can be attributed to a specific place by people, both individually and collectively. Aesthetic attraction, spiritual significance, and location identity all influence our recognition and appreciation for a place, as well as efforts to protect its iconic elements.

Marine environments serve as places of aesthetic attraction for many people, and inspire works of art, music, architecture, and tradition. Many people also value particular places as sources of therapeutic rejuvenation and to offer a change of perspective. Aesthetic aspects are often reflected as motifs in books, film, artworks, and folklore and as part of national symbols, architecture, and advertising efforts. These elements of “place attachment” may develop and change over the short and long term.

Many people, families, and communities consider places as defining parts of their “self identity,” especially if they have lived there during or since childhood. The relationship between self/family/community and place can run very deep, particularly where lineage is place-based, with genealogy going back many generations. “Place identity” develops over the long term, and is often expressed in reciprocal human-ecosystem relationships, and locations associated with spiritual significance. The recognition of very long term place-based stewardship, sometimes in excess of 10,000 years, provides a unique aspect of place identity.

Many people even incorporate water or water-related activities as habitual or significant parts of their lives and cultures. Different factors are considered to measure/assess sense of place, including level of uniqueness, recognition, reputation, reliance, and appreciation for a place. Accounting for sense of place can provide strong incentives for conservation, preservation, and restoration efforts.

Despite its value as a cultural ecosystem service, it is difficult to quantify sense of place with direct measures. Examples of indicators may include the quality and availability of opportunities to support rituals, ceremonies and narratives and the level of satisfaction knowing that a place exists. Polls or surveys are often used to evaluate public opinions regarding economic and non-economic values of a place. Non-economic values may include existence or bequest value, which use surveys to estimate the value people would be willing to pay for resources to stay in a certain condition even though they may never actually use them. To comprehensively evaluate sense of place, sites may find it useful to consider subcategories such as place attachment and place identity. Furthermore, sites may determine that some aspects of Sense of Place may simply not be ratable using the framework of condition reports.

Provisioning (Material Benefits)

Commercial harvest — The capacity to support commercial market demands for seafood products

Humans consume a large variety and abundance of products originating from the oceans and Great Lakes for nutrition or for use in other sectors. This includes fish, shellfish, other invertebrates, roe, and algae. Seafood is one of the largest traded food commodities in the world. Commercial fishing provides food for domestic and export markets, sold as wholesale and retail for household, restaurant and institutional meals. Seafood based industries include those that fish and harvest directly from wild capture and cultivated resources, as well as other businesses with functions throughout the supply chain including production of commercial gear, processors, storage facilities, buyers, transport and market outlets.

Within this category we also include what many call artisanal fishing, which can include commercial sale, but is also conducted by individuals or small groups who live near their harvest sites and use small scale, low technology, low cost fishing practices. Their catch is usually not processed (although it may be smoked or canned), and is mainly for local consumption or sale.

Artisanal fishing uses traditional fishing techniques such as rod and tackle, fishing arrows and harpoons, cast nets, and sometimes small traditional fishing boats.

Fisheries located in national marine sanctuaries are usually encompassed by larger regional fisheries that are regulated by fisheries management plans. Fisheries management plans may include sanctuary-specific restrictions to protect sanctuary habitats, living resources, and archaeological resources, and to fulfill treaty obligations. Data that can be used to assess status and trends for this ecosystem service include: catch levels by species and species groups; and economic contributions in the form of sector-related jobs, income, sales, and tax revenue. Indirect measures include data on licensing, fleet size, fishing vessel types and sizes, days at sea, and commodity prices.

Subsistence harvest — The capacity to support non-commercial harvesting of food and utilitarian products

Subsistence harvesting is the practice of collecting marine resources (e.g., fish, shellfish, marine mammals, seabirds, roe, and algae) either for food or for creating products that are utilitarian in nature (e.g., traditional medicine, shelter, clothing, fuel and tools) that are not for sale or income generation. Subsistence is conducted principally for personal and family use, and sometimes for community use, and may be distributed through ceremony, sharing, gifting, and bartering. Some people depend on subsistence fishing for food security and may have few other sources of income to provision their food and nutrition needs. Harvesting for subsistence is also a cultural or traditional practice for some people. It typically operates on a smaller and more local scale than commercial fishing. Natural resources that support subsistence harvest may also be used as ceremonial regalia or for cultural traditions, and therefore support other ecosystem services, including Heritage, Sense of Place, and Ornamentals. Data from surveys, tribal and indigenous knowledge and the status of fishery stocks can be used to assess the status and trends of this service.

Drinking water — Providing water for human use by minimizing pollution, including nutrients, sediments, pathogens, chemicals, and trash

Clean water is considered a final ecosystem service when the natural environment is improving water quality for human consumption or other direct use (e.g., irrigation). Although sanctuary ecosystems often function to improve water quality, most do not result in the final ecosystem service of clean water for human use. For most natural resources, improving water quality in a sanctuary is a supporting or intermediate ecosystem service that may, for example, result in better water quality for fish species that are then enjoyed by commercial or recreational anglers, safer water in which to swim, or improved water clarity for diving. These are aspects of other final ecosystem services and the water quality itself is an indicator that is inherently important to them; however, ONMS does not include this aspect of clean water in condition reports because it would result in a double counting of its ecosystem service value. Instead, ONMS evaluates clean water as a final ecosystem service, where the natural environment is improving water for human consumption, such as drinking water, or for irrigation (e.g., through filtration or suitability for desalination). In this way, the benefits of management policies and actions that improve water quality are captured separately, but in relation to the relevant final ecosystem services they support.

Ornamentals — Resources collected for decorative, aesthetic, or ceremonial purposes

In sanctuaries where the collection of ornamental products is not prohibited or is allowed under permit, they are taken for their aesthetic or material value for artwork, souvenirs, fashion, handicrafts, jewelry, or display. This includes live animals for aquaria and trade, pearls, shells, corals, sea stars, furs, feathers, ivory, and more. Some, particularly animals for the aquarium trade, are sold commercially and can be valued like other commodities; others cannot. Some products may be decorative and relatively non-functional, others culturally significant and specifically functional, such as ceremonial regalia. Status and trends for the use of ornamentals can also be evaluated using indicators such as the number of permitted or other collectors, frequency and intensity of collection operations, and sales.

Biotechnology — Medicinal and other products derived or manufactured from sanctuary animals or plants for commercial use

Biochemical and genetic resources, medicines, chemical models, and test organisms are all potential products that can be derived or sourced from national marine sanctuaries. Biochemical resources include compounds extracted from marine animals and plants and used to develop or manufacture foods, pharmaceuticals, cosmetics, and other products (e.g., omega-3 fatty acids from fish oil, or microbes for spill or waste bioremediation). Genetic resources are the genetic content of marine organisms used for animal and plant breeding and for biotechnology. Natural resources can also be used as a model for new products (e.g., the development of fiber optic technology, based on the properties of sponge spicules). Items harvested for food consumption are evaluated in Commercial and Subsistence Harvest.

Collections of products for biotechnology applications may be allowed under permit, and sanctuary permit databases can also be used to gauge demand and collection activity within a given national marine sanctuary. The value of commercially sold products associated with biotechnology may also be available.

Renewable energy — Use of ecosystem-derived materials or processes for the production of energy

In the offshore environment, energy production sources are considered to be either non-renewable (oil and gas) or renewable (wind, solar, tidal, wave, or thermal). While oil and gas technically are ecosystem-sourced and may be renewable over a time frame measured in millions of years, as an ecosystem service, they are not subject to management decisions in human time frames; therefore, they are not considered an ecosystem service in this section. The activities and management actions related to hydrocarbon production are, however, considered elsewhere in condition reports, primarily with regard to resource threats, impacts, and protection measures.

In contrast, "renewable" forms of energy that depend on ecosystem materials and processes operating over shorter time periods are evaluated. Indicators of status and trends for these energy sources include the types and number of permitted or licensed experimental or permanent operations, energy production, revenues generated, and jobs created. Indirect indicators that inform trends and provide some predictive value include social and market trends, energy costs, and expected demand based on service market populations trends.

Regulating (Buffers to Change)

Coastal protection — Natural features that control water movement and/or wind energy, thus protecting habitat, property, heritage resources and coastlines

Coastal and estuarine ecosystems can buffer the potentially destructive energy of environmental disturbances, such as floods, tidal surges and storm waves, and wind. Wetlands, kelp forests, mangroves, seagrass beds, and reefs of various types all absorb some of the energy of local disturbances, protecting themselves, submerged habitats closer to shore, intertidal ecosystems, and emergent land masses. They also can trap sediments and promote future protection through shoaling. They can also become sources of sediments for coastal dunes and beaches that control flooding and protect coastal properties from wave energy and the impacts of sea-level rise.

The value of coastal protection can be estimated by evaluating the basis of the value of vulnerable coastal properties and infrastructure and modeled estimates of losses expected under different qualities of coastal ecosystems (replacement cost). Levels of historical change under different energy scenarios can be used to support these estimates. Public polls can also reveal information on willingness to pay that is used to value this service.

Appendix C: Methods for Report Development

The process for preparing national marine sanctuary condition reports involves a combination of accepted techniques for collecting and interpreting information gathered from subject matter experts. The approach varies somewhat from sanctuary to sanctuary in order to accommodate different styles for working with partners, however, all include the evaluation of ecosystem indicators which is a well-established method for tracking ecosystem conditions and trends with the purpose of informing ecosystem-based management. The assessment of sanctuary resources and ecosystem services include quantitative measures of ecosystem indicators derived from regional monitoring data, supplemented by qualitative interpretations derived from expert opinions and local knowledge. This approach allows for a transparent and repeatable process.

The first step to assess an ecosystem's condition and health (see Appendices A and B) is to select indicators that reflect the status and trends of key components of the ecosystem. These indicators should be representative of the entire socio-ecological system, including individual components like biophysical indices, human activity, and community vulnerability. Indicators should meet certain criteria in order to be considered usable and appropriate for the condition report. This includes long-term data availability, importance to the ecosystem and culture, responsiveness to changes in environmental conditions, measurability, relevance to sanctuary condition report questions, and responsiveness to management actions. The indicator selection process for the CBNMS condition report began with sanctuary staff conducting a literature review of previous work focused on indicators in the region. Sanctuary staff then reviewed and prioritized each indicator based on the criteria previously described.

Next, ONMS selected and consulted subject matter experts familiar with water quality, habitat, living resources, maritime heritage resources, and socioeconomics in the sanctuary. A list of experts who participated in the CBNMS condition report process is available in the Acknowledgements section of this report. A series of virtual workshops were held with these subject matter experts in March, April, and June, 2021 to discuss and evaluate the series of questions about each resource and ecosystem service: human activities, water quality, habitat, living resources, maritime heritage resources, and ecosystem services (commercial harvest, consumptive recreation, non-consumptive recreation, science, education, heritage, and sense of place). During the virtual workshops, experts were first introduced to the questions and ecosystem services (see Appendices A and B). Next, the indicators for each topic were presented, accompanied by datasets ONMS had collected prior to the meeting.

Attendees were then asked to review the indicators and datasets, identify data gaps or misrepresentations, and suggest any additional datasets that may be relevant. Once all datasets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. CBNMS's approach in working with workshop experts was closely related to the Delphi Method, a technique designed to organize group communication among a panel of geographically dispersed experts by using questionnaires, ultimately facilitating the formation of a group judgment. This method can be applied when it is necessary for decision makers to combine the testimony of a group of experts, whether in the form of facts, informed opinion, or both, into a single useful statement. The Delphi Method requires experts to respond to questions with a limited number of choices to arrive at the best-supported answers. Feedback to the experts allows them to refine their views, gradually moving the group toward the most agreeable judgment. In order to ensure consistency with the Delphi Method, a critical role of the facilitator was to minimize dominance of the discussion by a single individual or opinion (which often leads to "follow the leader" tendencies in group meetings) and to encourage the expression of honest differences of opinion. As discussions progressed, the group converged on an opinion for each rating that most accurately described the resource or ecosystem service condition. After an appropriate amount of time, the facilitator asked whether the group could agree on a rating for the question or ecosystem service, as defined by specific language linked to each rating (see Appendices A and B). If an agreement was reached, the result was recorded and the group moved on to consider the trend in the same manner. If agreement was not reached, the facilitator recorded the vote of individuals for each rating category and that information helped to inform the confidence scoring process.

After assigning status and trend ratings, experts were asked to assign a level of confidence for each value by: (1) characterizing the sources of information they used to make judgments; and (2) their agreement with the selected status and trend ratings. The evidence and agreement ratings were then combined to determine the overall confidence ratings, as described in the three steps outlined below.

Step 1: Rate Evidence

Consider three categories of evidence typically used to make status or trend ratings: (1) data, (2) published information, and (3) personal experience.

Limited	Medium	Robust
Limited data or published information, and little or no substantive personal experience.	Data available, some peer reviewed published information, or direct personal experience.	Considerable data, extensive record of publication, or extensive personal experience.

Step 2: Rate Agreement

Rate agreement among those participating in determining the status and trend rating, or if possible, within the broader scientific community. Levels of agreement can be characterized as “low,” “medium,” or “high.”

Step 3: Rate Confidence

Using the matrix below, combine ratings for both evidence and agreement to identify a level of confidence. Levels of confidence can be characterized as “very low,” “low,” “medium,” “high,” or “very high.”

Agreement ↑			
	“Medium” High agreement Limited evidence	“High” High agreement Medium evidence	“Very High” High agreement Robust evidence
	“Low” Medium agreement Limited evidence	“Medium” Medium agreement Medium evidence	“High” Medium agreement Robust evidence
	“Very Low” Low agreement Limited evidence	“Low” Low agreement Medium evidence	“Medium” Low agreement Robust evidence

Evidence (type, amount, quality, consistency) →

An initial draft of the report, written by ONMS, summarized information, expert opinions, and levels of confidence expressed by the experts. Comments, data, and citations received from the experts were included, as appropriate, in text supporting the ratings and compiled in three appendices. This initial draft was made available to contributing experts and data providers, which allowed them to review the content and determine if the report accurately reflected their input, identify information gaps, provide comments, or suggest revisions to the ratings and text.

Following the expert review, the document was sent to representatives of partner agencies for a second review. These representatives were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors. Upon receiving reviewer comments, ONMS revised the text and ratings as appropriate.

In August 2022, a draft final report was sent to three regional experts for a required external peer review. External peer review became a requirement when the White House Office of Management and Budget (OMB) issued a Final Information Quality Bulletin for Peer Review (OMB Bulletin) that established peer review standards to enhance the quality and credibility of the federal government’s scientific information (OMB, 2004). Along with other information, these standards apply to “influential scientific information,” which is information that can reasonably be determined to have a "clear and substantial impact on important public policies or private sector decisions" (OMB, 2004, p. 11). Condition reports are considered influential scientific information and are subject to the review requirements of both the Information Quality Act and the OMB Bulletin guidelines; therefore, every condition report is reviewed by a minimum of three individuals who are considered to be experts in their field, were not involved in the development of the report, and are not ONMS employees. Comments and recommendations of the peer reviewers were considered and incorporated, as appropriate, into the final text of this report. Furthermore, OMB Bulletin guidelines require that reviewer comments, names, and affiliations be posted on the agency website, http://www.cio.noaa.gov/.

Reviewer comments, however, are not attributed to specific individuals. Comments by the external peer reviewers are posted at the same time as the formatted final document.

In all steps of the review process, experts were asked to review the technical merits of resource ratings and accompanying text, as well as to point out any omissions or factual errors; however, the interpretation, ratings, and text in the condition report are the responsibility of, and receive final approval by, ONMS. To emphasize this important point, authorship of the report is attributed to ONMS; subject matter experts are not authors, though their efforts and affiliations are acknowledged in the report.

Cordell Bank National Marine Sanctuary Confidence Ratings from March, April, and June, 2021 Virtual Expert Workshops

Table App.C.1. A summary of confidence levels for CBNMS condition report ratings.

Question	Virtual Workshop Date	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Human Activities/Water Quality	June 29	Status: Good/Fair	Medium	High	High
		Trend: Not Changing	Medium	Medium	Medium
Human Activities/Habitat	June 29	Status: Fair	Robust	High	Very High
		Trend: Improving	Robust	High	Very High
Human Activities/Living Resources[26]	June 29	Status: Fair	Robust	High	Very High
		Trend: Undetermined	Robust	Medium	High
Human Activities/Maritime Heritage Resources[27]	N/A	Status: Good	N/A	N/A	N/A
		Trend: Undetermined	N/A	N/A	N/A

[26] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, “mixed,” was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data.
[27] A workshop was not convened for the question that asks “What are the levels of human activities that may adversely affect maritime heritage resources and how are they changing?” Archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject experts have been monitoring existing archaeological sites along the West Coast since the 1980s.

Question	Virtual Workshop Date	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Water Quality/Eutrophication	March 24	Status: Good	Limited	High	Medium
		Trend: Not Changing	Limited	High	Medium
Water Quality/Risk to Human Health	March 24	Status: Good/Fair	Medium	High	High
		Trend: Worsening	Limited	Medium	Low
Water Quality/Climate Change	March 26	Status: Fair	Robust	Medium	High
		Trend: Worsening	Limited	Medium	Low
Water Quality/Other Stressors	March 26	Status: Good/Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
Habitat/Integrity[28]	March 29	Status: Fair	Medium	Medium	Medium
		Trend: Undetermined	Limited	High	Medium
Habitat/Contaminants	March 29	Status: Undetermined	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
Living Resources/Keystone and Foundation Species	March 31	Status: Good/Fair	Medium	High	High
		Trend: Undetermined	Medium	High	High

[28] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, “mixed,” was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data.

Question	Virtual Workshop Date	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Living Resources/Other Focal Species[29]	March 31	Status: Fair	Medium	High	High
		Trend: Undetermined	Medium	Medium	Medium
Living Resources/Non-indigenous Species	April 7	Status: Good	Limited	High	Medium
		Trend: Undetermined	Limited	Low	Low
Living Resources/Biodiversity	April 7	Status: Good/Fair	Medium	High	High
		Trend: Not Changing	Medium	High	High
Maritime Heritage Resources/Integrity[30]	N/A	Status: Undetermined	N/A	N/A	N/A
		Trend: Worsening	N/A	N/A	N/A

[29] Experts assigned a trend rating of undetermined at the workshop. However, following the workshop, a new trend, "mixed," was introduced to the condition report rating scheme as a result of discussions with experts. ONMS staff determined that this new rating was more appropriate to apply to this question, based on the combination of trends from available data. Because of this new trend, the confidence score was also adjusted to high in order to reflect a higher level of expert agreement.

[30] A workshop was not convened for the question that asks "What is the condition of known maritime heritage resources and how is it changing?" Archaeological experts with the ONMS Maritime Heritage Program and CBNMS evaluated this question internally. These subject experts have been monitoring existing archaeological sites along the West Coast since the 1980s.

Ecosystem Services	**Virtual Workshop Date**	**Rating**	**Evidence (Limited, Medium, Robust)**	**Agreement (Low, Medium, High)**	**Confidence (Very Low, Low, Medium, High, Very High)**
Commercial Harvest[31]	June 30	Status: N/A	N/A	N/A	N/A
		Trend: N/A	N/A	N/A	N/A
Consumptive Recreation[32]	June 30	Status: N/A	N/A	N/A	N/A
		Trend: N/A	N/A	N/A	N/A
Non-Consumptive Recreation	May 21	Status: Good/Fair	Robust	High	Very High
		Trend: Worsening	Robust	High	Very High
Science	May 26	Status: Fair	Medium	High	High
		Trend: Improving	Medium	Medium	Medium
Education	May 27	Status: Good/Fair	Robust	High	Very High
		Trend: Improving	Robust	Medium	High
Heritage	May 26	Status: Fair	Medium	Medium	Medium
		Trend: Improving	Limited	Medium	Medium
Sense of Place	May 27	Status: Good/Fair	Medium	Medium	Medium
		Trend: Improving	Medium	High	High

31 Because of a limited number of experts providing input, staff rated this service after the workshop.
32 Because of a limited number of experts providing input, staff rated this service after the workshop.

Appendix D:
Comparing the 2009 and 2009–2021 Cordell Bank National Marine Sanctuary Condition Reports

Table App.D.1. 2009 (left) and 2009–2021 (right) status, trend, and confidence ratings for the human activities questions. The 2009 condition report ratings reflect the sanctuary prior to its expansion in 2015.

2009 Condition Report Questions	2009 Rating	2009–2021 Condition Report Questions	2009–2021 Condition Report Rating
N/A	N/A	1. Influential Drivers	Not rated
4. Human activities and water quality	?	2. Human activities and water quality	Good/Fair –
8. Human activities and habitat	▲	3. Human activities and habitat	Fair ▲
14. Human activities and living resources	▲	4. Human activities and living resources	Fair ▲▼
17. Human activities and maritime archaeological resources	?	5. Human activities and maritime heritage resources	Good ?
2. Eutrophic condition	–	6. Eutrophic condition	Good –
3. Human health risks	–	7. Human health risks	Good/Fair ▼
1. Multiple stressors (including climate)	?	8. Climate drivers	Fair ▼
		9. Other stressors	Good/Fair ?
5. Habitat abundance/distribution	–	10. Integrity of major habitats	Fair ▲▼
6. Condition of biologically structured habitat	?		
7. Contaminants	–	11. Contaminants	Undetermined ?
12. Status of key species	▲	12. Keystone & foundation species	Good/Fair ?
13. Condition/health of key species	–	13. Other focal species	Fair ▲▼

2009 Condition Report Questions	2009 Rating	2009–2021 Condition Report Questions	2009–2021 Condition Report Rating
11. Non-indigenous species	?	14. Non-indigenous species	Good ?
9. Biodiversity	▲	15. Biodiversity	Good/Fair –
15. Maritime archaeological resource integrity	?	16. Maritime heritage resource integrity	Undetermined ▼

Appendix E:
Additional State of the Resources Figures and Tables

Additional Pressures Figures

Question 3: What are the levels of human activities that may adversely influence habitats and how are they changing?

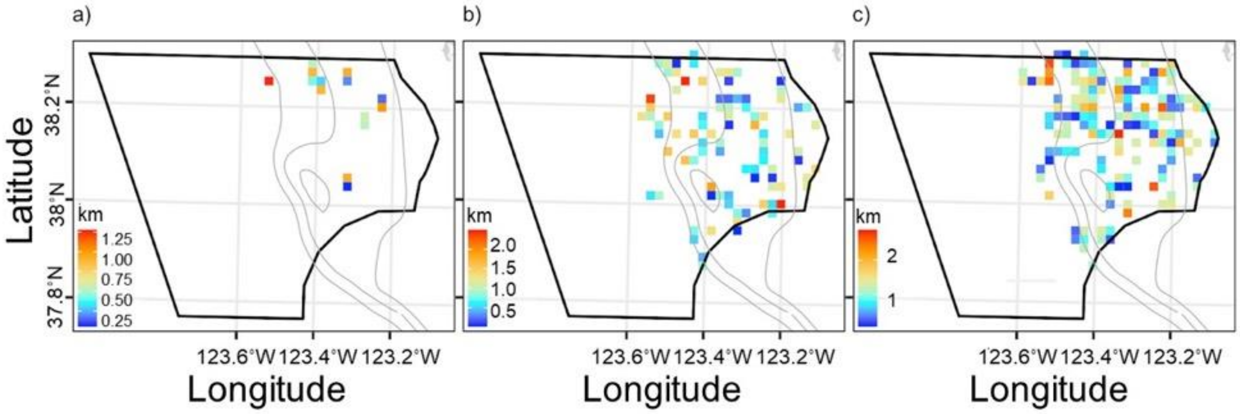


Figure App.E.3.1. Spatial representation of seafloor contact by bottom trawl gear from NOAA's Northwest Fishery Science Center Groundfish Survey within CBNMS, calculated from annual distances trawled within each 2x2 km grid cell from 2003–2019. (a) Distance trawled in 2019 (most recent year available). (b) Total sum of distance trawled from 2003–2008. (c) Total sum of distance trawled from 2009–2019. Gray lines represent 100-, 200-, and 500-m depth contours. Source: NOAA Northwest Fisheries Observation Science Program, 2021; Image: CCIEA

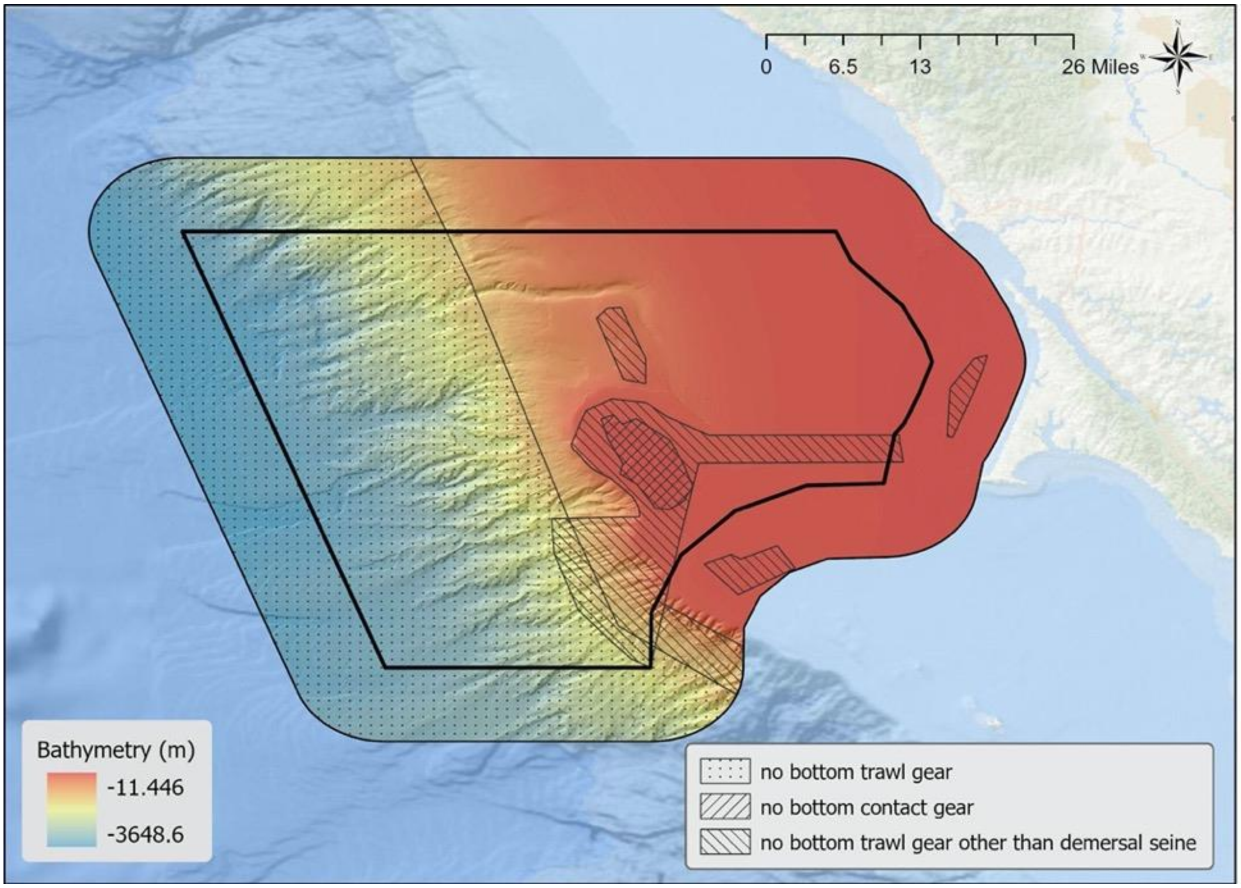


Figure App.E.3.2. CBNMS (heavier black outline) and surrounding area, illustrating bathymetry and the spatial distribution of fishing regulations. Source: Esri, 2014; Pacific Fishery Management Council, 2020a; Image: NCCOS

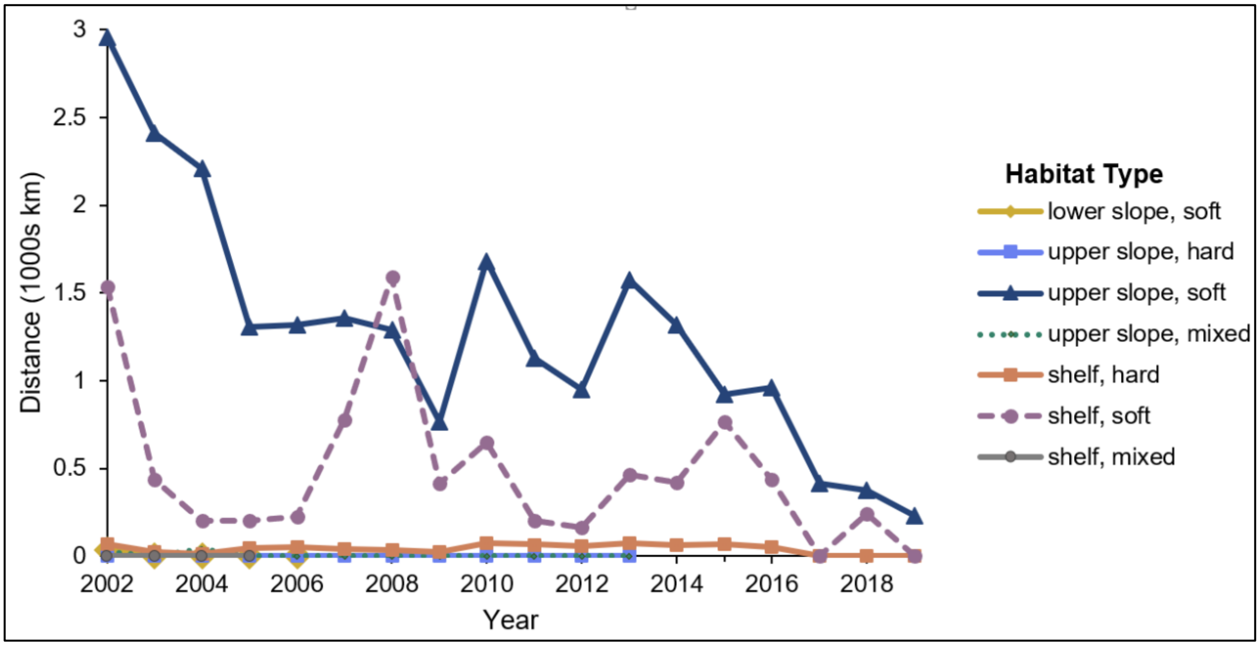


Figure App.E.3.3. Distance of seafloor contact among habitat types by bottom trawl gear from federal groundfish fisheries operating within the boundaries of CBNMS (2002–2019). Years with no data are due to no trawling in those years or because <3 vessels trawled in the spatial domain and data are thus confidential. Source: NOAA Northwest Fisheries Observation Science Program, 2021; Image: CCIEA

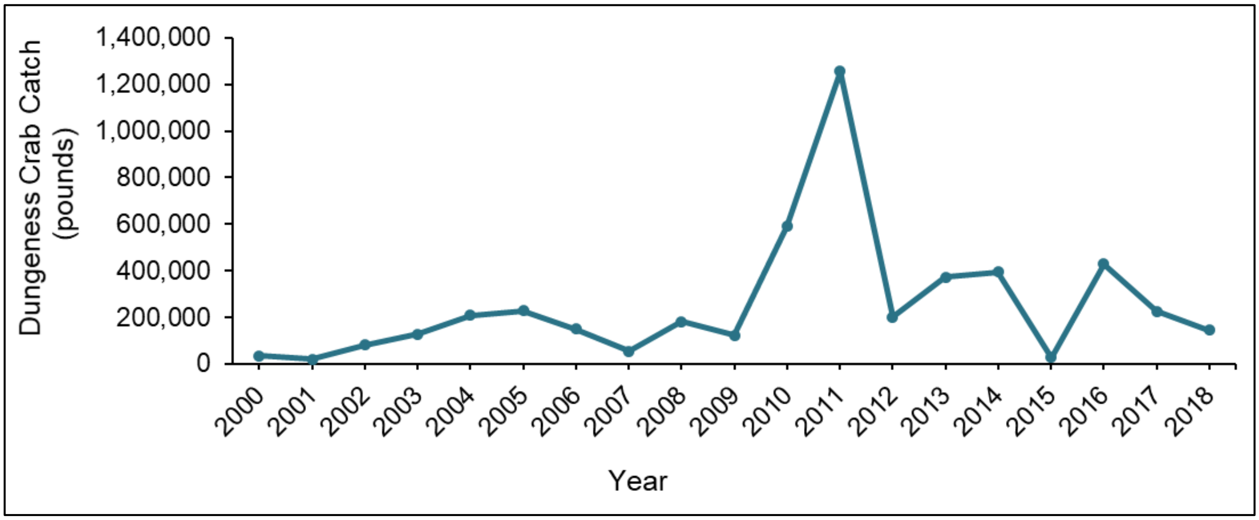


Figure App.E.3.4. Annual Dungeness crab catch in pounds from 2000–2018. Source: CDFW, 2020a; Image: NOAA

Additional Water Quality Figures and Tables

Question 6: What is the eutrophic condition of sanctuary waters and how is it changing?

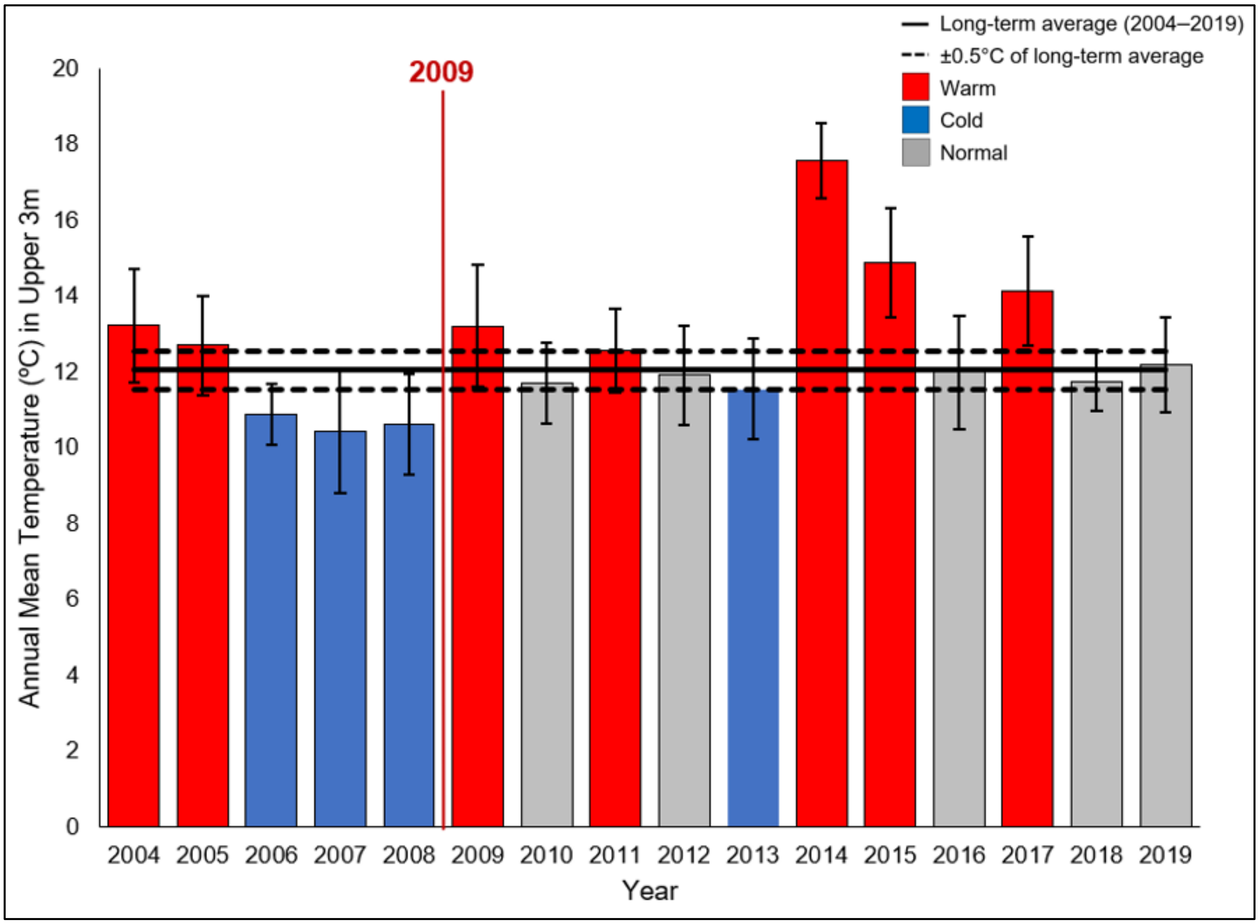


Figure App.E.6.1. Annual mean temperature in surface waters (mean ± standard deviation) measured at CBNMS during ACCESS cruises. Temperature was measured by a CTD recorder. Solid line represents the long-term average (2004–2019) and dotted lines represent +0.5 °C and -0.5 °C around long-term average. Red bars represent warm years (above +0.5 °C line), blue bars represent cold years (below -0.5 °C line), and gray bars represent normal years (within ±0.5 °C of long-term average). The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

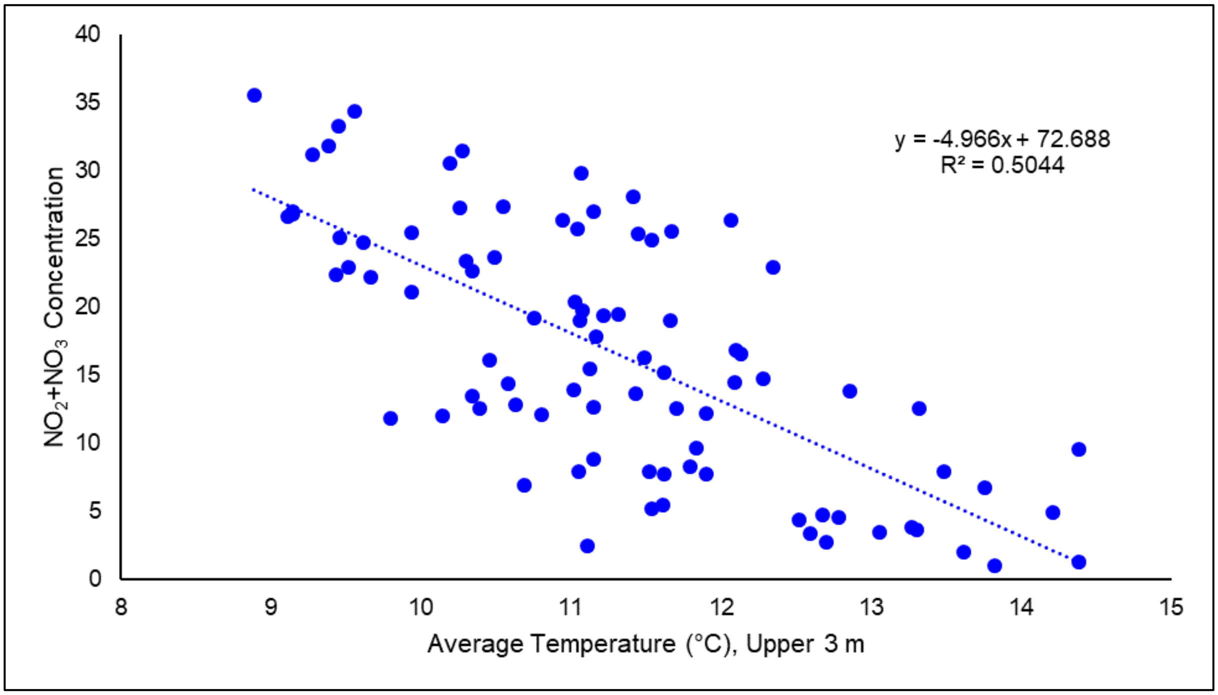


Figure App.E.6.2. The relationship between temperature and nitrates during cold periods in the upper 3 m at CBNMS ACCESS stations (i.e., CTD data with average temperature 0.5 °C below the long-term mean). Source: ACCESS, 2021; Image: Point Blue Conservation Science

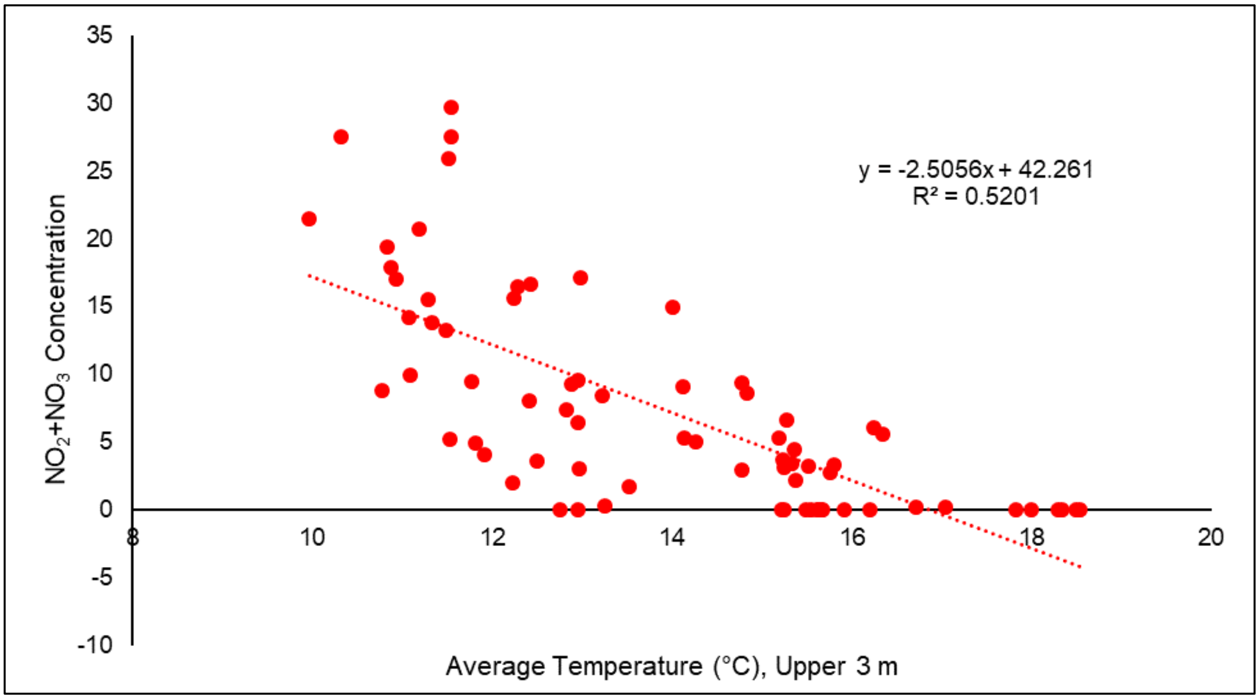


Figure App.E.6.3. The relationship between temperature and nitrates during warm periods in the upper 3 m at CBNMS ACCESS stations (i.e., CTD data with average temperature 0.5 °C above the long-term mean). Source: ACCESS, 2021; Image: Point Blue Conservation Science

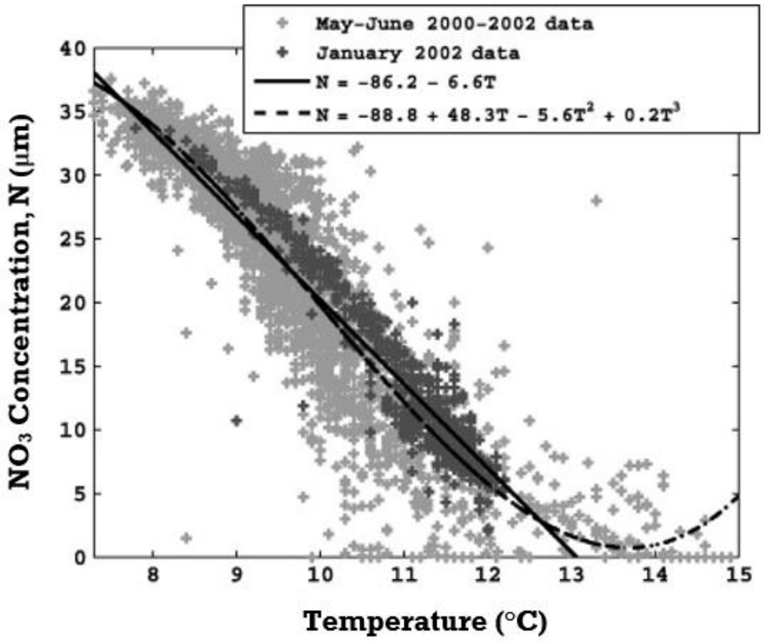


Figure App.E.6.4. Temperature vs. NO_3 concentration for water samples from the Wind Events and Shelf Transport program (Largier et al., 2006). Lines show a linear and a cubic polynomial fitting of the data. Image: García-Reyes et al., 2014

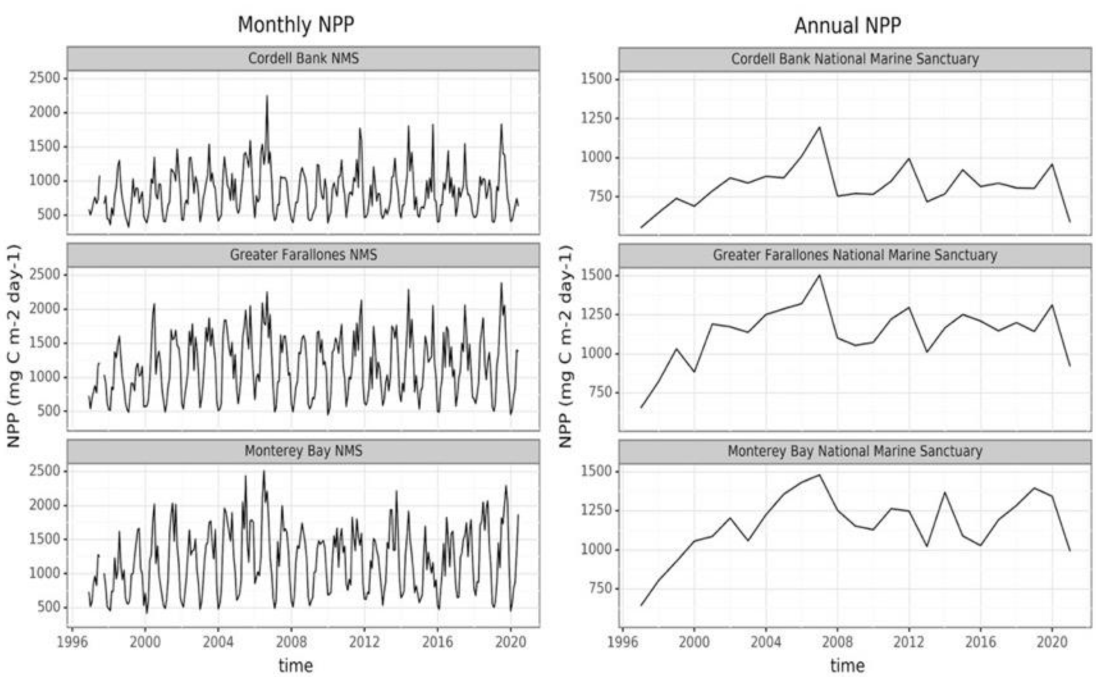


Figure App.E.6.5. Monthly and annual NPP for Cordell Bank, Greater Farallones, and Monterey Bay national marine sanctuaries. NPP estimates are calculated from the 5-day merged chlorophyll *a*, merged daily photosynthetically active radiation (from MODISA, MODIST, VIIRS-SNNP, VIIRS-JPSS1 satellite data) and daily SST-OI data. Source: Huang et al., 2020; Image: CenCOOS

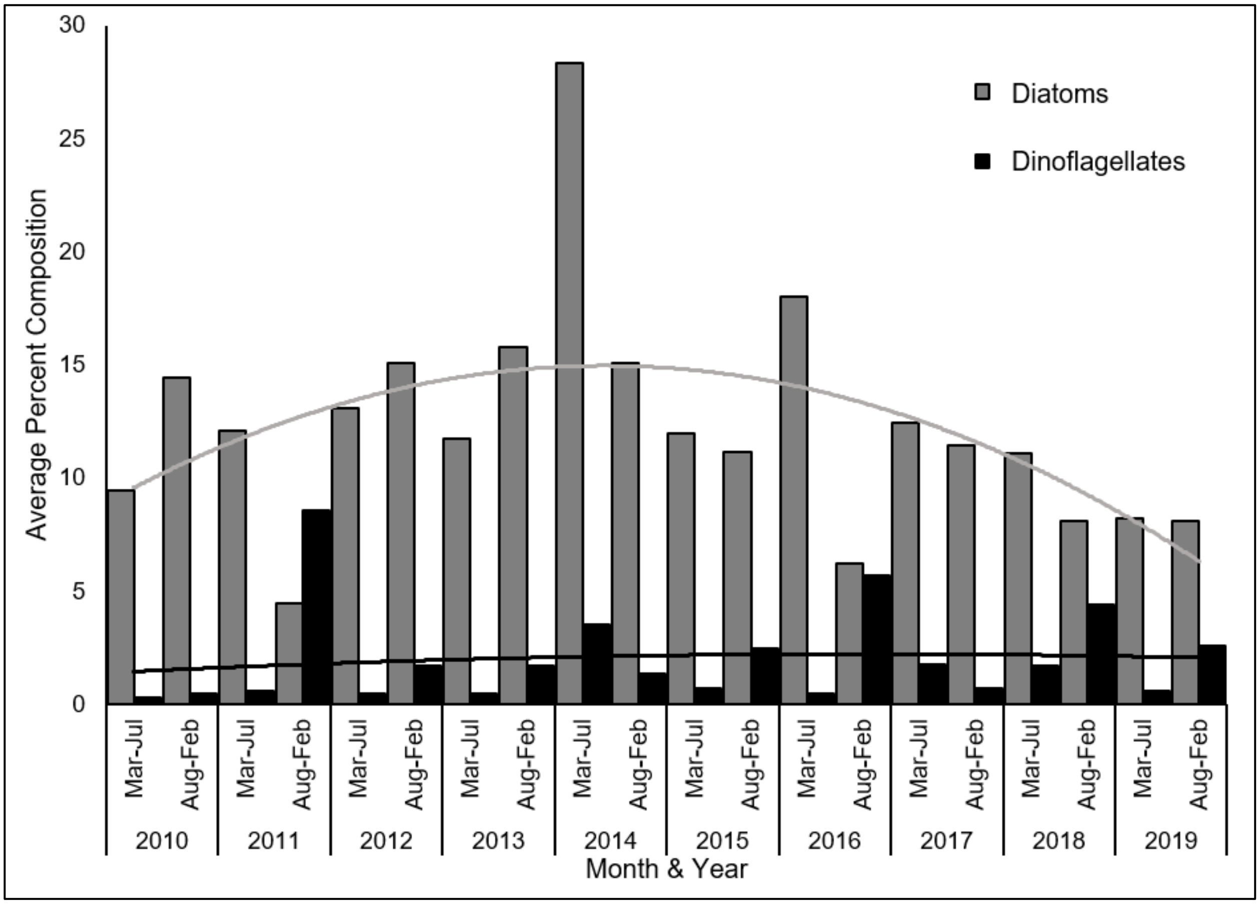


Figure App.E.6.6. Mean ratio of the percent composition of the number of individuals of dinoflagellates and diatoms found in phytoplankton samples in CBNMS. Phytoplankton samples were collected during ACCESS cruises and analyzed by the California Department of Public Health Biotoxin Monitoring Program. Data from stations N4-WN and N2-WN (nearshore), 4-E and 2-E (mid-shelf), and 4-W and 2-W (offshore) were used in these figures. No samples were collected nearshore in May 2011 or mid-shelf and offshore in June 2014. Source: ACCESS, 2021; Image: Point Blue Conservation Science

Question 7: Do sanctuary waters pose risks to human health and how are they changing?

Table App.E.7.1. Phytoplankton species collected during ACCESS cruises that can produce HABs.

Species
Alexandrium catenella
Alexandrium spp.
Cochlodinium spp.
Dinophysis acuminata
Dinophysis caudata
Dinophysis fortii
Dinophysis mitra
Dinophysis odiosa
Dinophysis rotundata
Dinophysis spp.
Dinophysis tripos
Gonyaulax spinifera
Gonyaulax spp.
Gonyaulax triacantha
Lingulodinium polyedrum
Prorocentrum gracile
Prorocentrum micans
Prorocentrum spp.
Protoperidinium bipes
Protoperidinium conicum
Protoperidinium divergens
Protoperidinium ovatulum
Protoperidinium ovum
Protoperidinium spp.
Pseudo-nitzschia spp.

Species
Pseudo-nitzschia delicatissima complex
Pseudo-nitzschia seriata complex

Table App.E.7.2. Number of California sea lions admitted to The Marine Mammal Center with signs of and/or positive tests for DA poisoning. The locations of these strandings ranged from San Mateo to Mendocino counties (including inside San Francisco Bay). Shaded boxes indicate years considered for this condition report.

Year	Number of Sea Lions
1998	2
1999	1
2000	12
2001	7
2002	7
2003	12
2004	5
2005	10
2006	22
2007	16
2008	13
2009	41
2010	6
2011	9
2012	4
2013	7
2014	12
2015	27
2016	12
2017	6
2018	10
2019	33
2020	20
Total	294

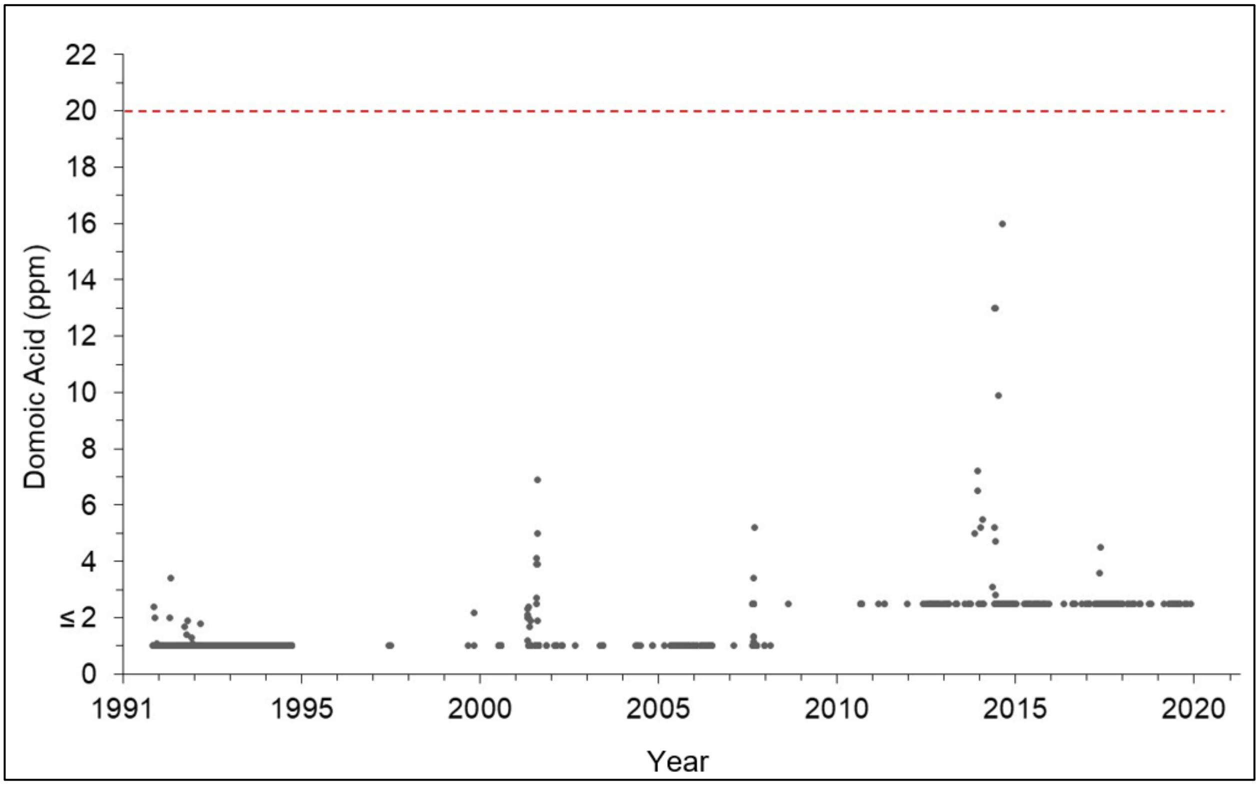


Figure App.E.7.1. DA in 1,694 bivalves (mussels, clams, oysters) taken coastally in Marin and Sonoma counties (including inside San Francisco Bay). Dashed red line indicates the action limit. Data provided by the California Department of Public Health, Environmental Management Branch. Note that there was a change in analytical techniques in 2008 that changed the lower reporting limit. No samples came from CBNMS. Source: California Department of Public Health, 2020b

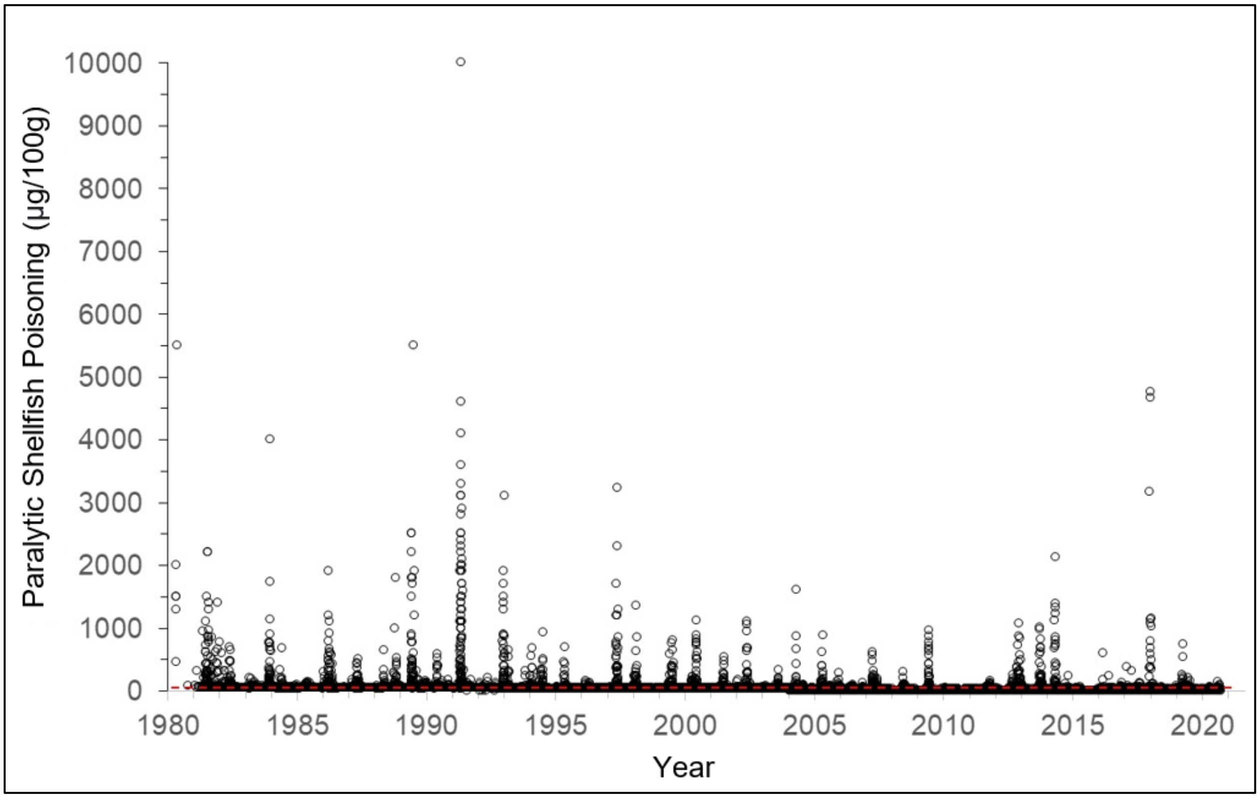


Figure App.E.7.2. Paralytic shellfish poisoning in 13,859 bivalves (mussels, clams, oysters) taken coastally in Marin and Sonoma counties (including inside San Francisco Bay). Dashed red line indicates the action limit. Data from California Department of Public Health, Environmental Management Branch. No samples came from CBNMS. Source: California Department of Public Health, 2020b

Question 8: Have recent, accelerated changes in climate altered water conditions and how are they changing?

Table App.E.8.1. Average, minimum, and maximum dissolved oxygen recorded by ROV *Hercules* while surveying the seafloor in 2017. Source: Ocean Exploration Trust & CBNMS, 2017

Dive	Site	Avg. O_2 (mg/L)	Min. O_2 (mg/L)	Max. O_2 (mg/L)	Min. Depth (m)	Max. Depth (m)
H1625	BC I	2.14	1.57	2.71	1660	2207
H1626	BC II	1	0.43	1.43	1205	1599
H1627	Box	2.86	2.14	3.43	1976	2737
H1628	SW CB I	0.43	0.29	0.57	1005	1126
H1629	SW CB II	0.29	0.29	0.29	866	988
H1630	BC III	0.43	0.14	0.71	744	1291

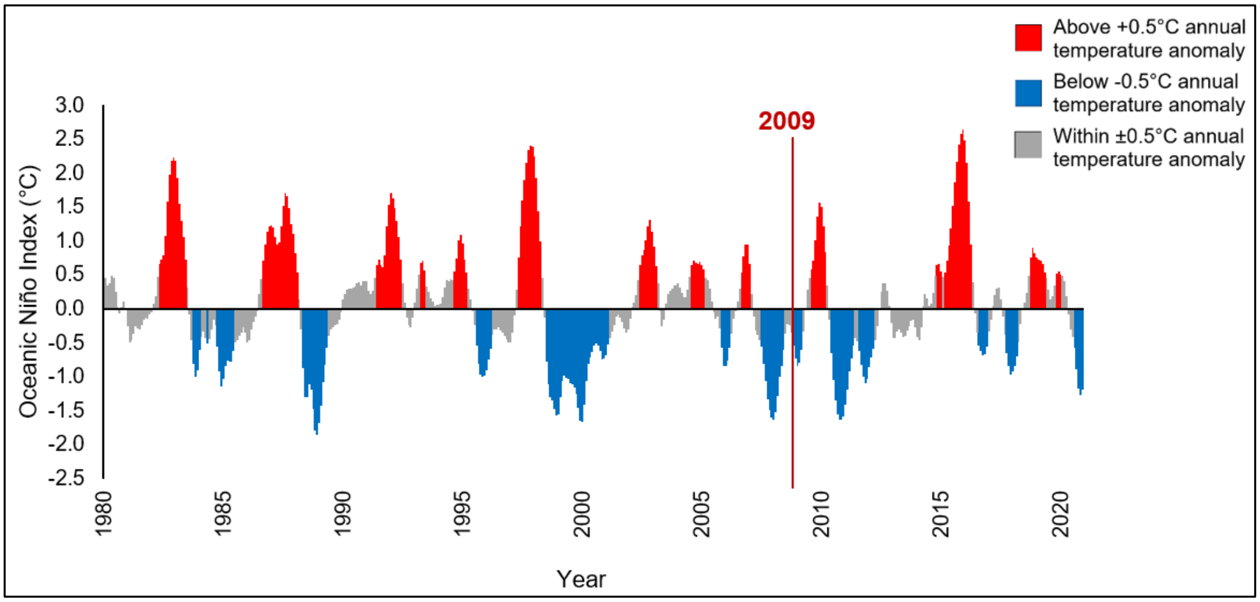


Figure App.E.8.1. Oceanic Niño Index, 1980–2020. Oceanic Niño Index is a three-month running mean of ERSST.v5 SST anomalies in the Niño 3.4 region (5 °N–5 °S, 120–170 °W). Red bars represent warm years (above +0.5 °C annual temperature anomaly), blue bars represent cold years (below -0.5 °C annual temperature anomaly), and gray bars represent normal years (within ±0.5 °C of long-term average). The vertical red line indicates the year of the last condition report (2009). Source: NCEI, 2020a; Image: Point Blue Conservation Science

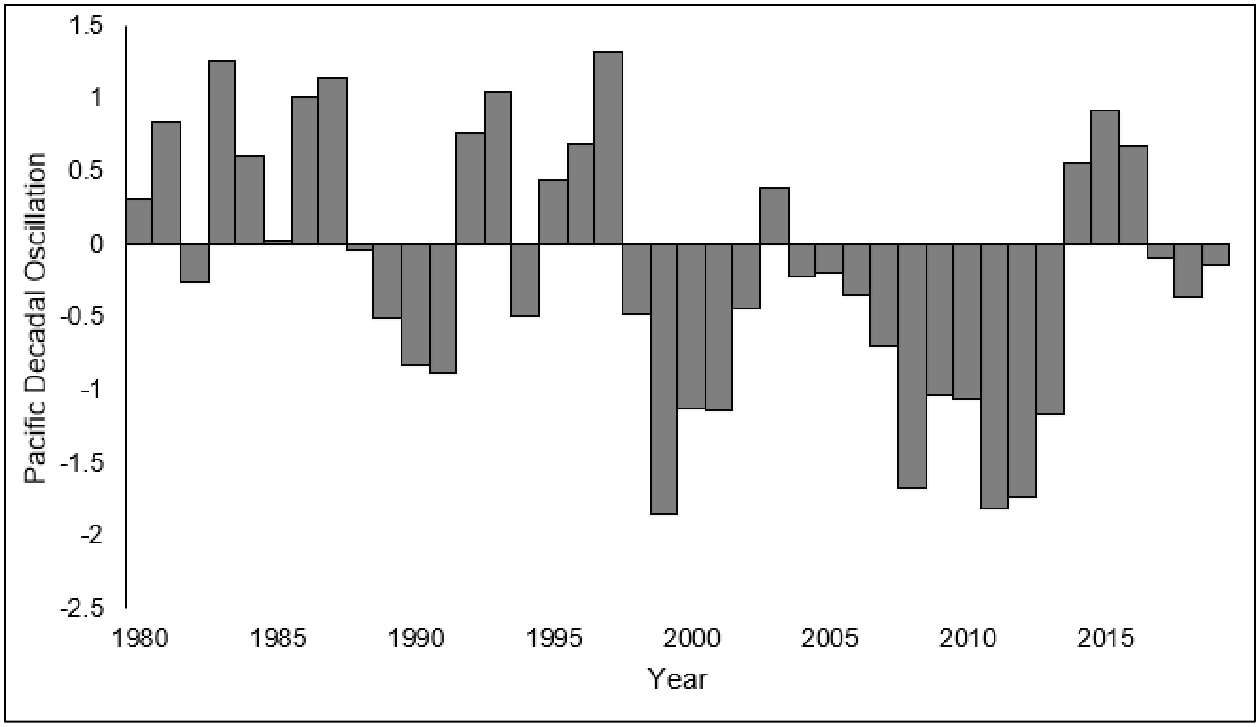


Figure App.E.8.2. Annual averages of the Pacific Decadal Oscillation, years 1980–2019. Line shows polynomial trend for 2009–2019. Source: NCEI, 2020b; Image: Point Blue Conservation Science

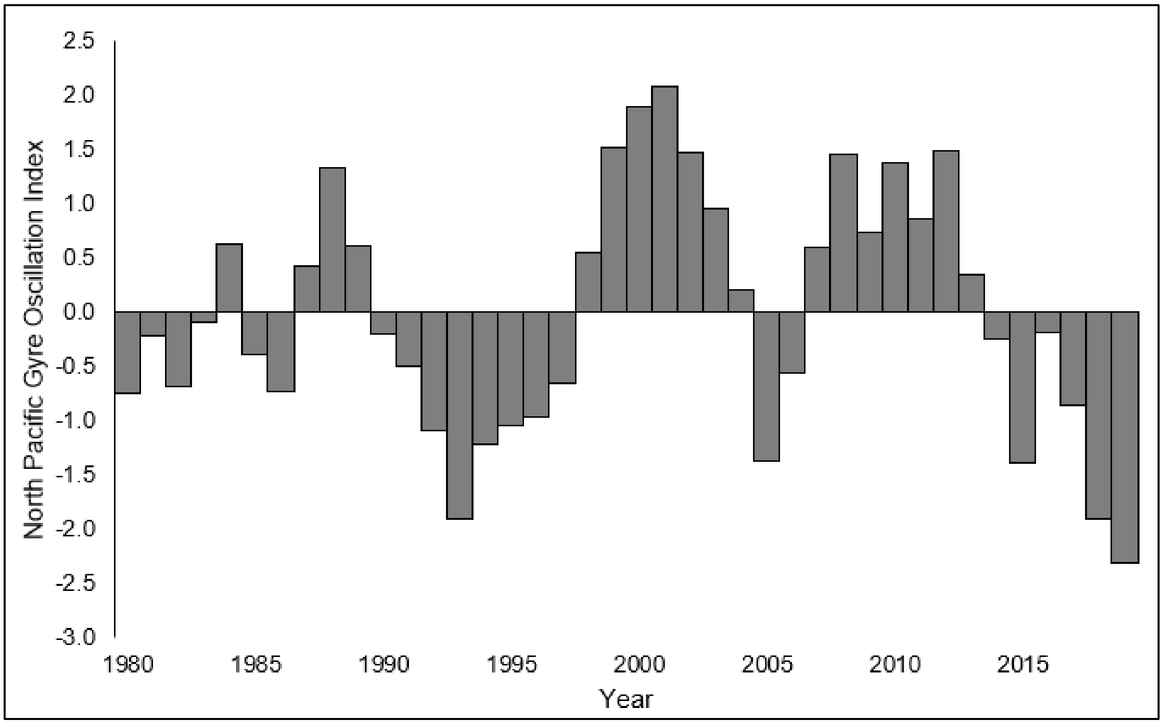


Figure App.E.8.3. Annual averages of the North Pacific Gyre Oscillation, years 1980–2019. Line shows polynomial trend for 2009–2019. Source: Di Lorenzo et al., 2008; Image: Point Blue Conservation Science

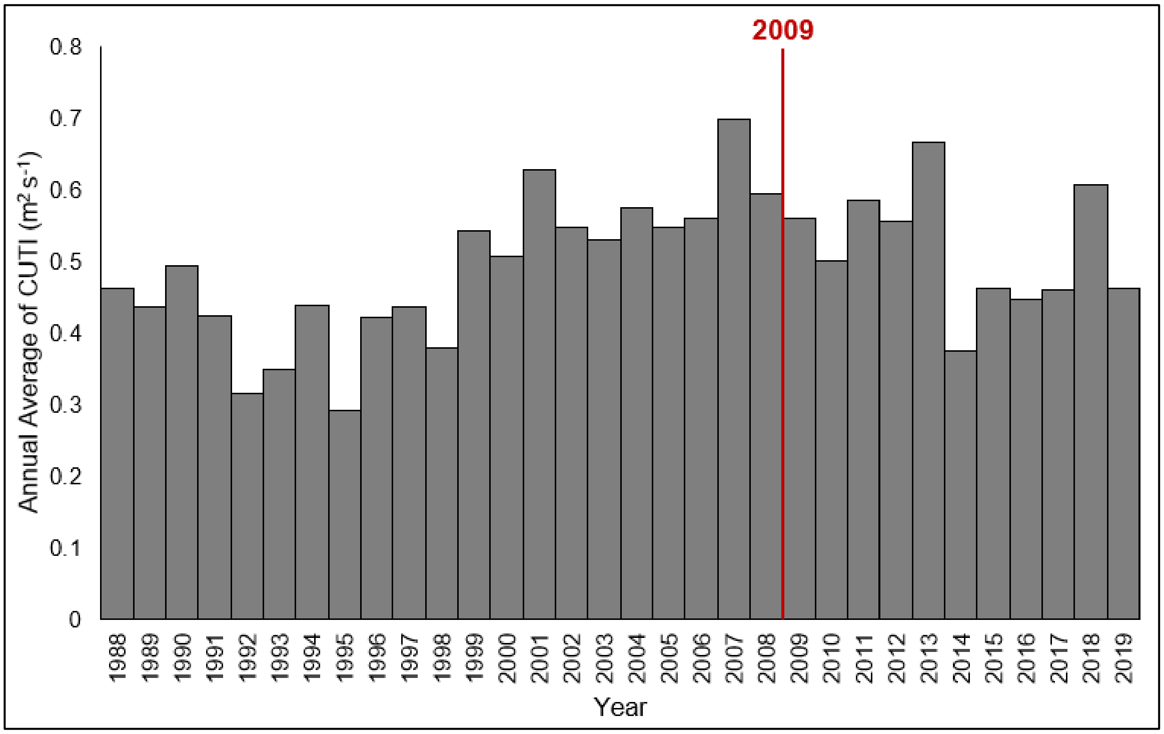


Figure App.E.8.4. Annual averages of the Coastal Upwelling Transport Index (CUTI), years 1988–2019. The vertical red line indicates the year of the last condition report (2009). Source: Jacox et al., 2018; Image: Point Blue Conservation Science

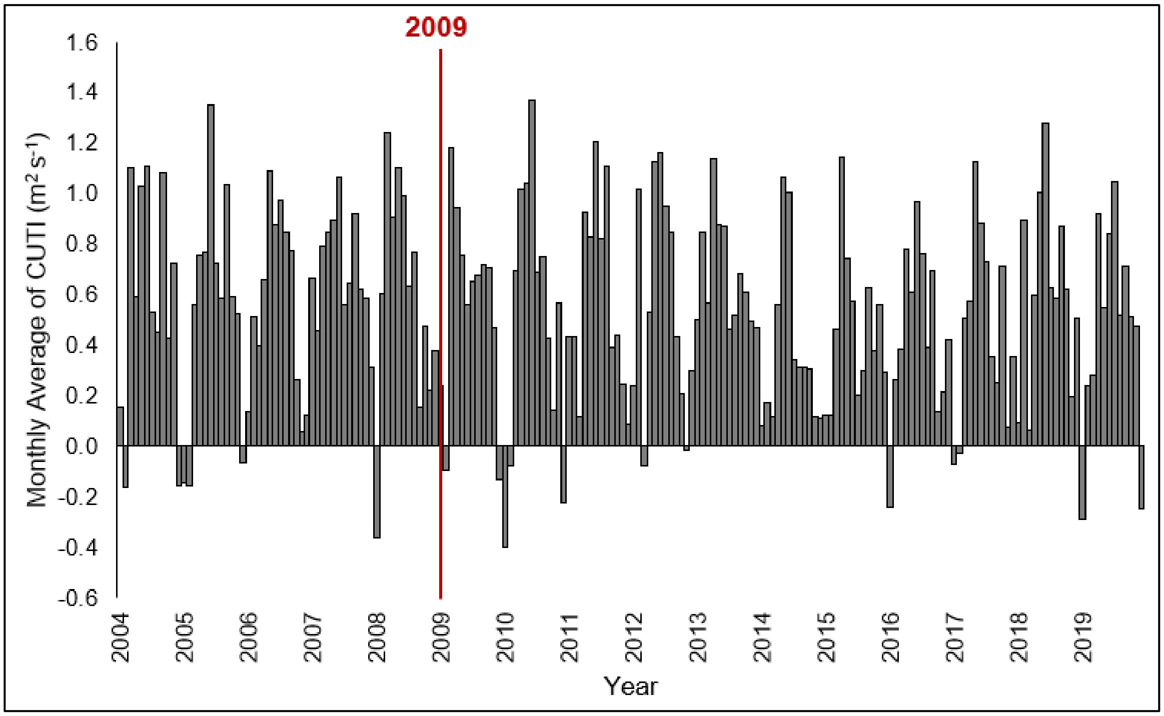


Figure App.E.8.5. Monthly values of the Coastal Upwelling Transport Index (CUTI), years 2004–2019. The vertical red line indicates the year of the last condition report (2009). Source: Jacox et al., 2018; Image: Point Blue Conservation Science

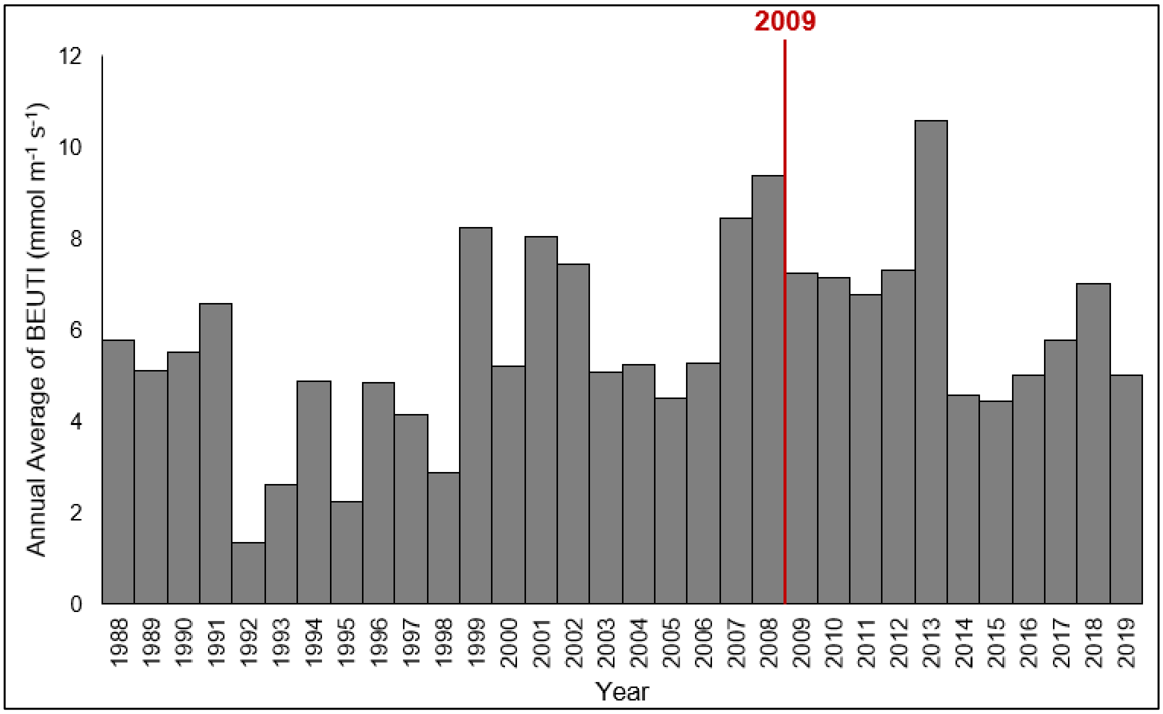


Figure App.E.8.6. Annual averages of the Biologically Effective Upwelling Transport Index (BEUTI), years 1988–2019. The vertical red line indicates the year of the last condition report (2009). Source: Jacox et al., 2018; Image: Point Blue Conservation Science

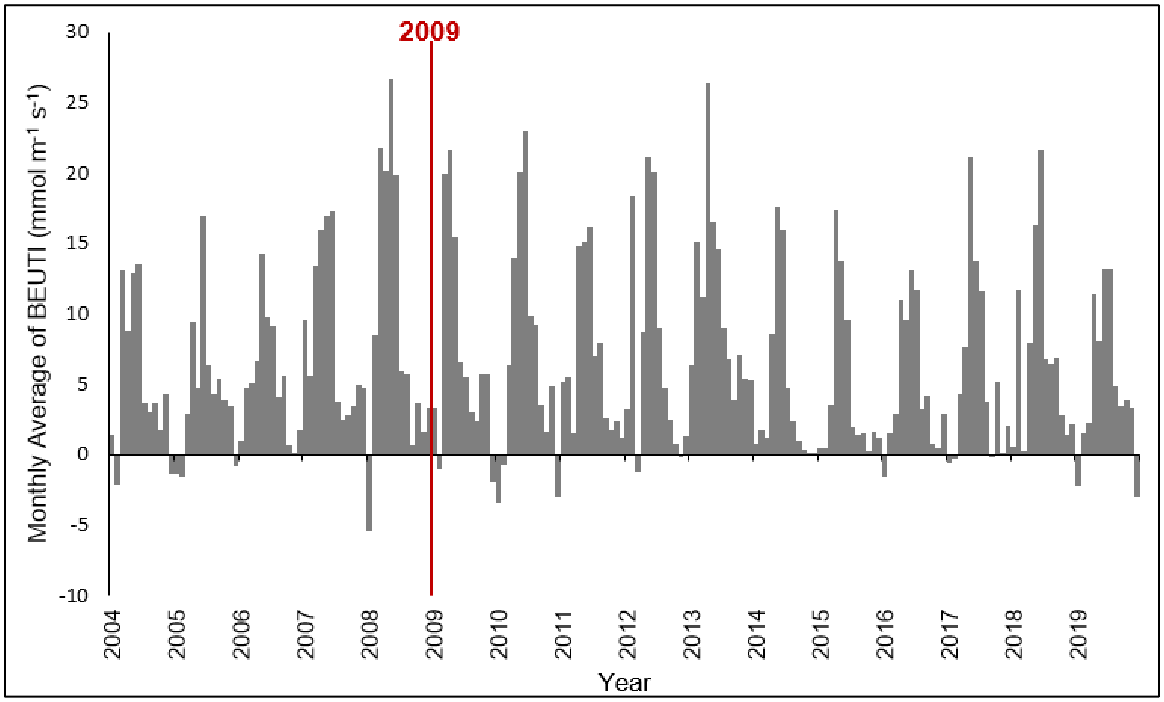


Figure App.E.8.7. Monthly values of the Biologically Effective Transport Index (BEUTI), years 2004–2019. The vertical red line indicates the year of the last condition report (2009). Source: Jacox et al., 2018; Image: Point Blue Conservation Science

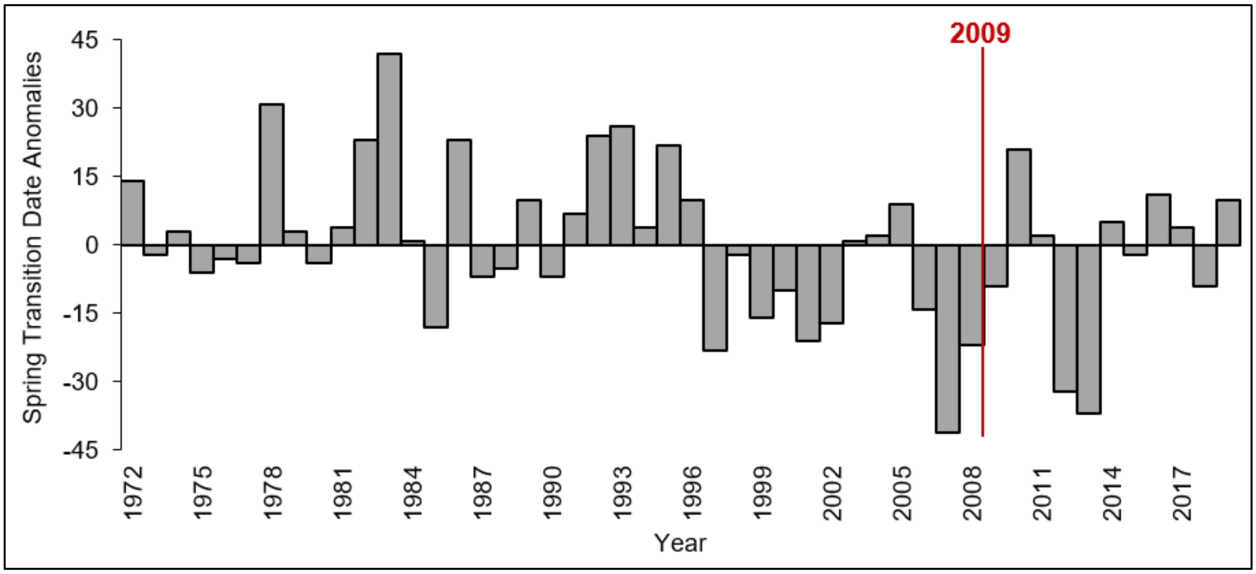


Figure App.E.8.8. Spring transition date anomalies determined from daily Bakun upwelling indices (averaged values from 36 °N and 39 °N), years 1972–2019. The vertical red line indicates the year of the last condition report (2009). Source: Jacox et al., 2018; Image: Point Blue Conservation Science

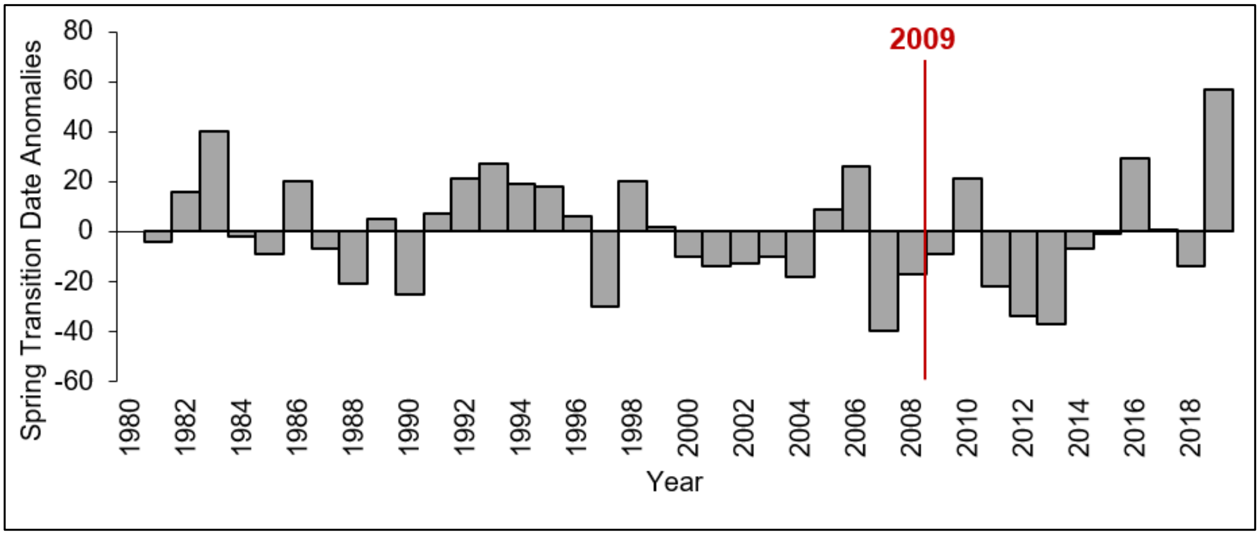


Figure App.E.8.9. Spring transition date anomalies determined from NOAA buoy data (46013), years 1972–2019. The vertical red line indicates the year of the last condition report (2009). Source: National Data Buoy Center, 1971; Image: Point Blue Conservation Science

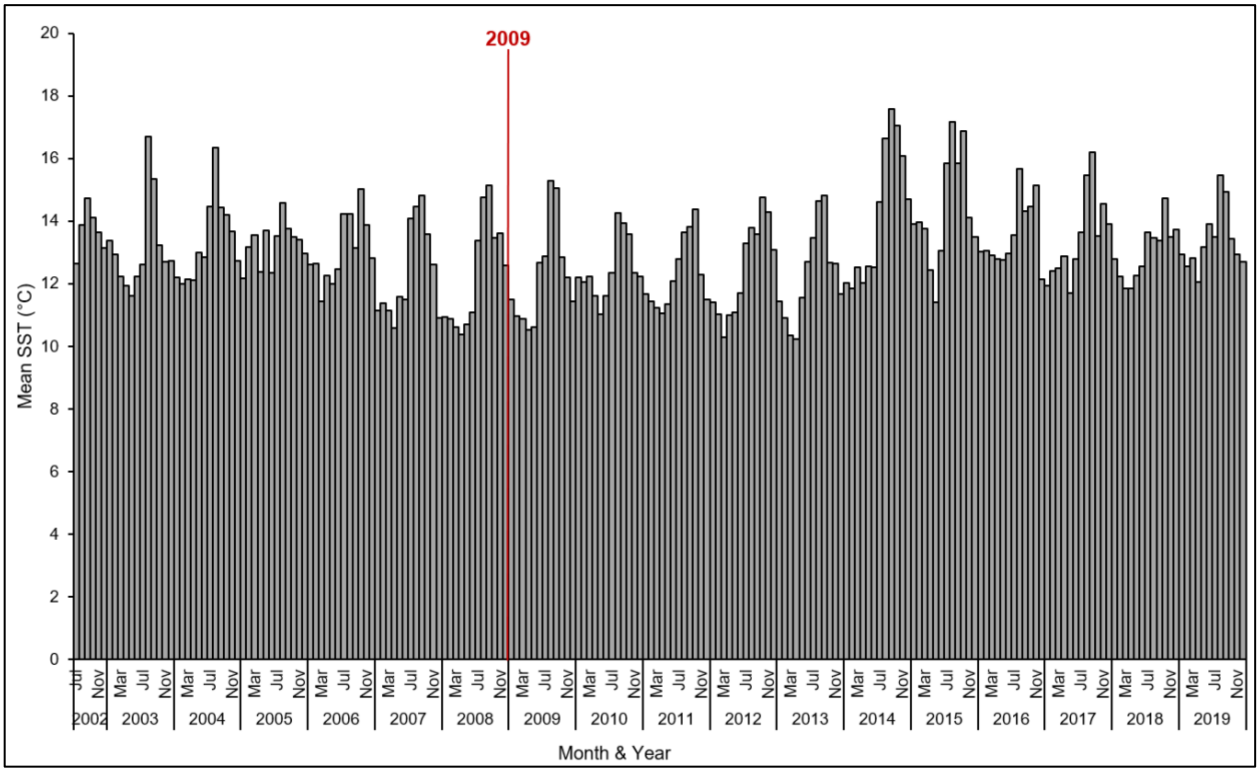


Figure App.E.8.10. Mean monthly sea surface temperature from Aqua MODIS 4 km satellite data for CBNMS region, 2002–2019. Line shows polynomial trend for 2009–2019. The vertical red line indicates the year of the last condition report (2009). Source: National Aeronautics and Space Administration, 2020; Image: Point Blue Conservation Science

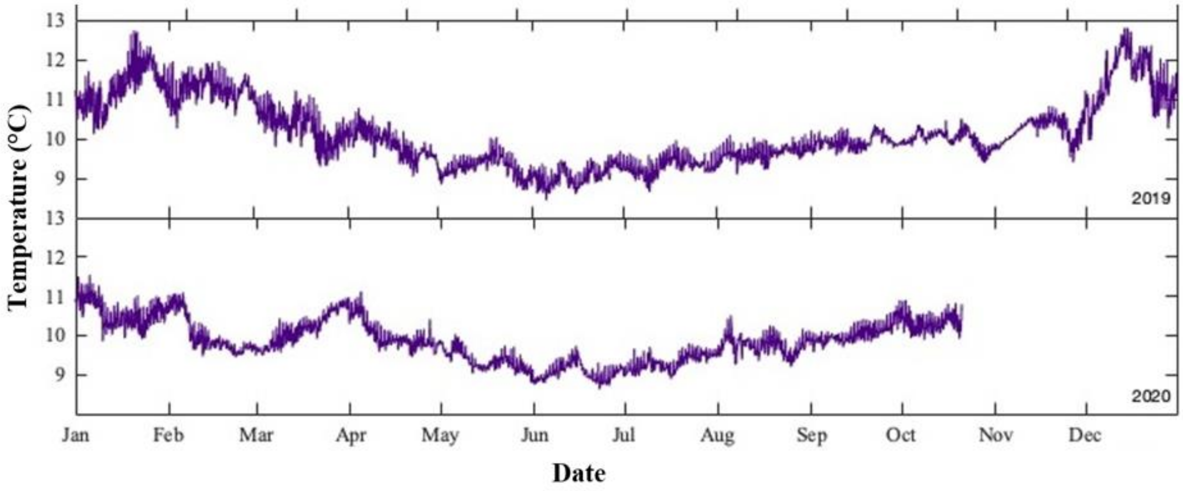


Figure App.E.8.11. Temperature at 80 meters depth on Cordell Bank mooring. Source: University of California Davis Bodega Marine Laboratory & CBNMS, 2021; Image: University of California Davis Bodega Marine Laboratory

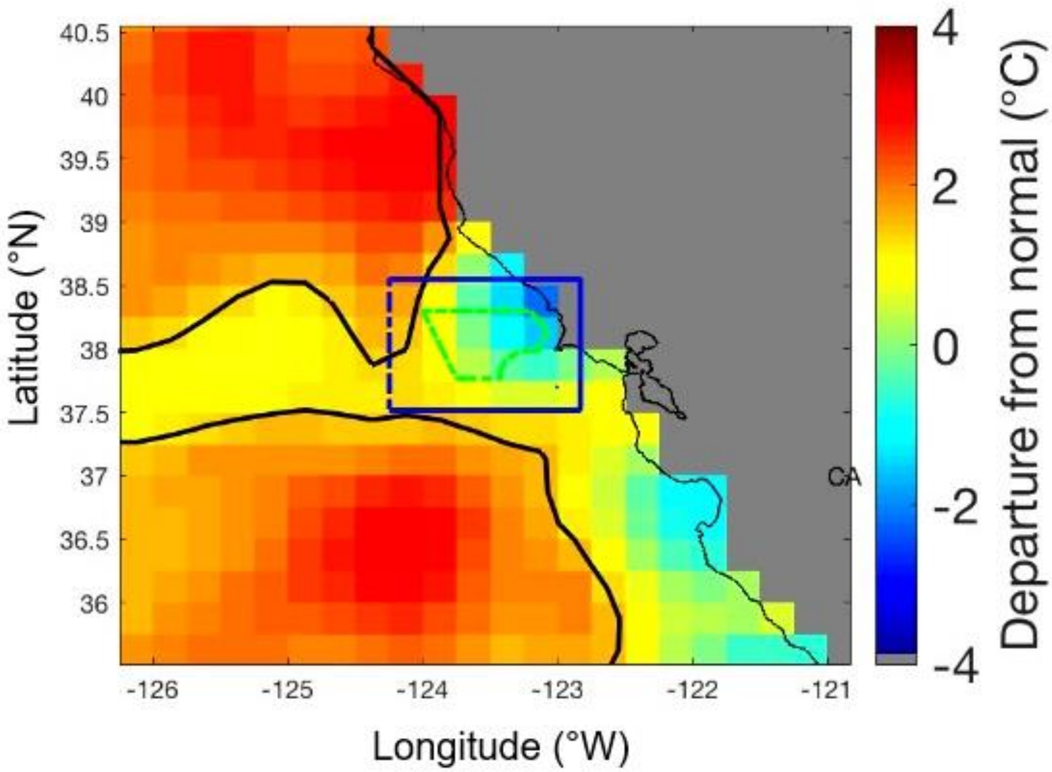


Figure App.E.8.12. Temperature anomalies on September 26, 2020. Source: Huang, et al., 2020; Image: Andrew Leising/NOAA

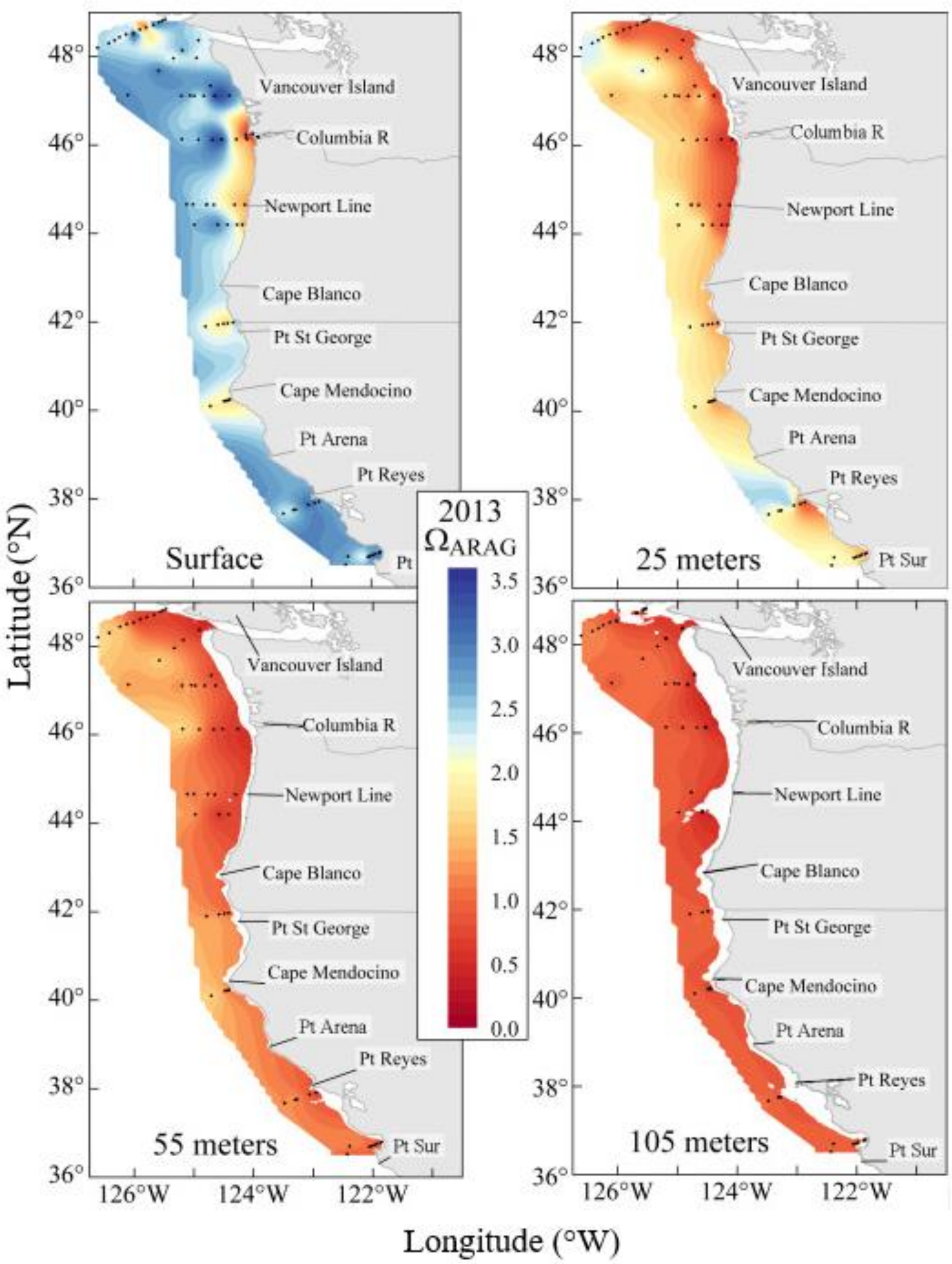


Figure App.E.8.13. Aragonite saturation state at the surface, 25 m, 55 m, and 105 m depth during the 2013 West Coast survey. Image: Feely et al., 2016

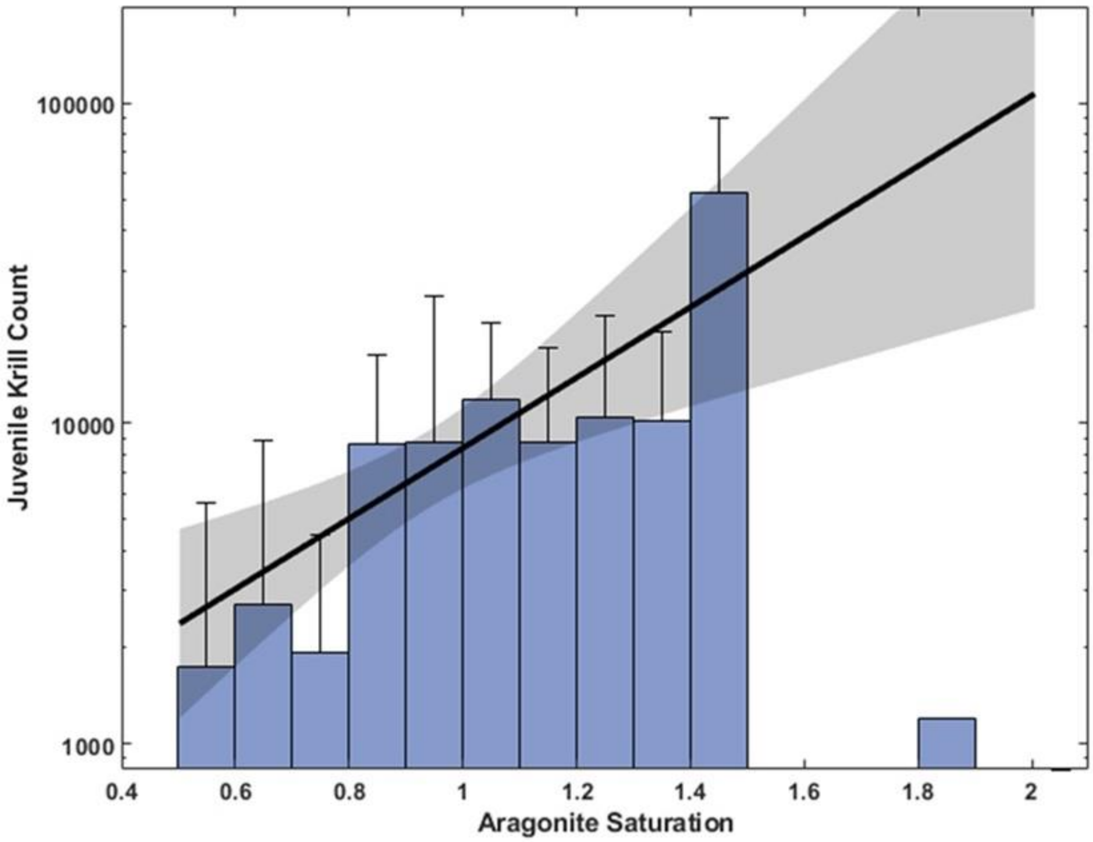


Figure App.E.8.14. Zero-inflated negative binomial model of juvenile krill counts (in the upper 50 m of the water column) in relation to aragonite saturation values at ACCESS stations (lines 2, 4, 6) for years 2010–2014. Bars are average counts with error bars representing one standard deviation above the mean. The black line is the count model and the gray shading is ±2 standard errors for the model. Source: ACCESS, 2021; Image: Ryan Anderson/San Francisco State University

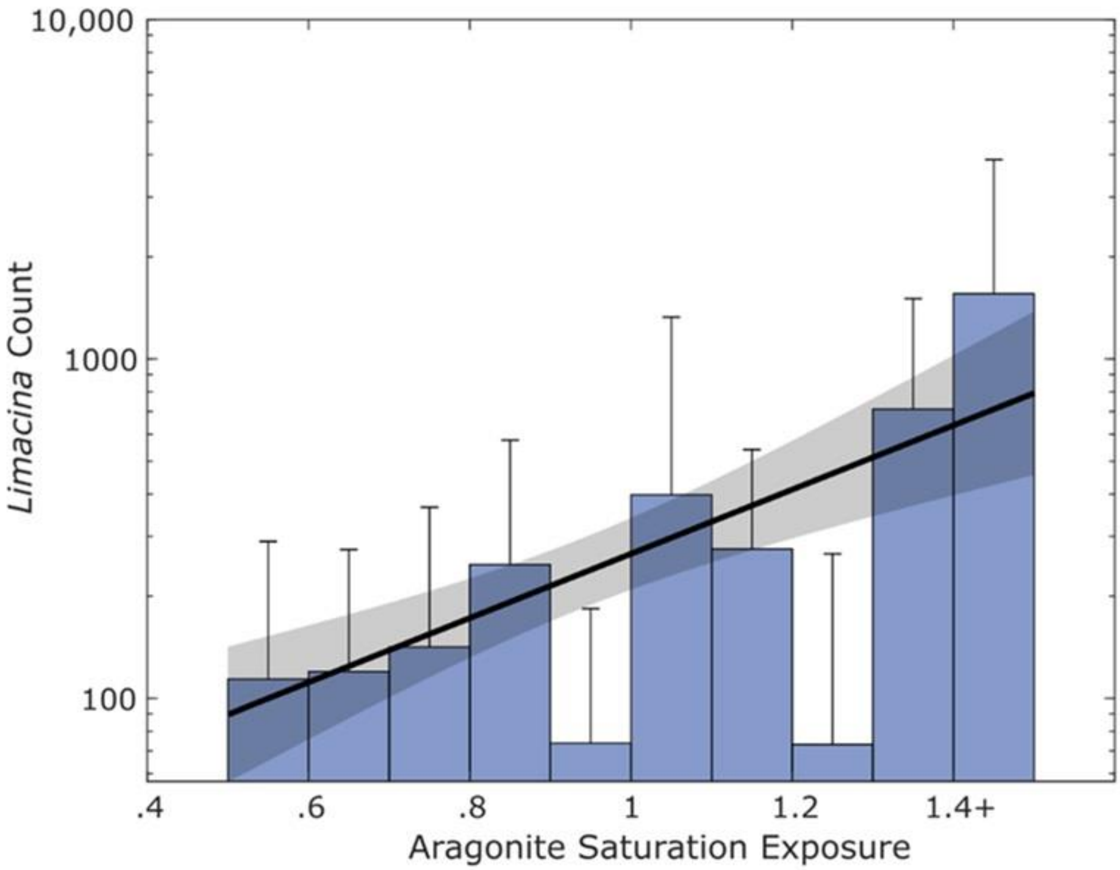


Figure App.E.8.15. Zero-inflated negative binomial model of *Limacina helicina* counts (in the upper 50 m of the water column) in relation to aragonite saturation values at ACCESS stations (lines 2, 4, 6) for years 2011–2014. Bars are average counts of each bin of aragonite saturation exposure with error bars representing one standard deviation above the mean. The black line is the count model and the gray shading is ±2 standard errors for the model. Source: ACCESS, 2021; Image: Ryan Anderson/San Francisco State University

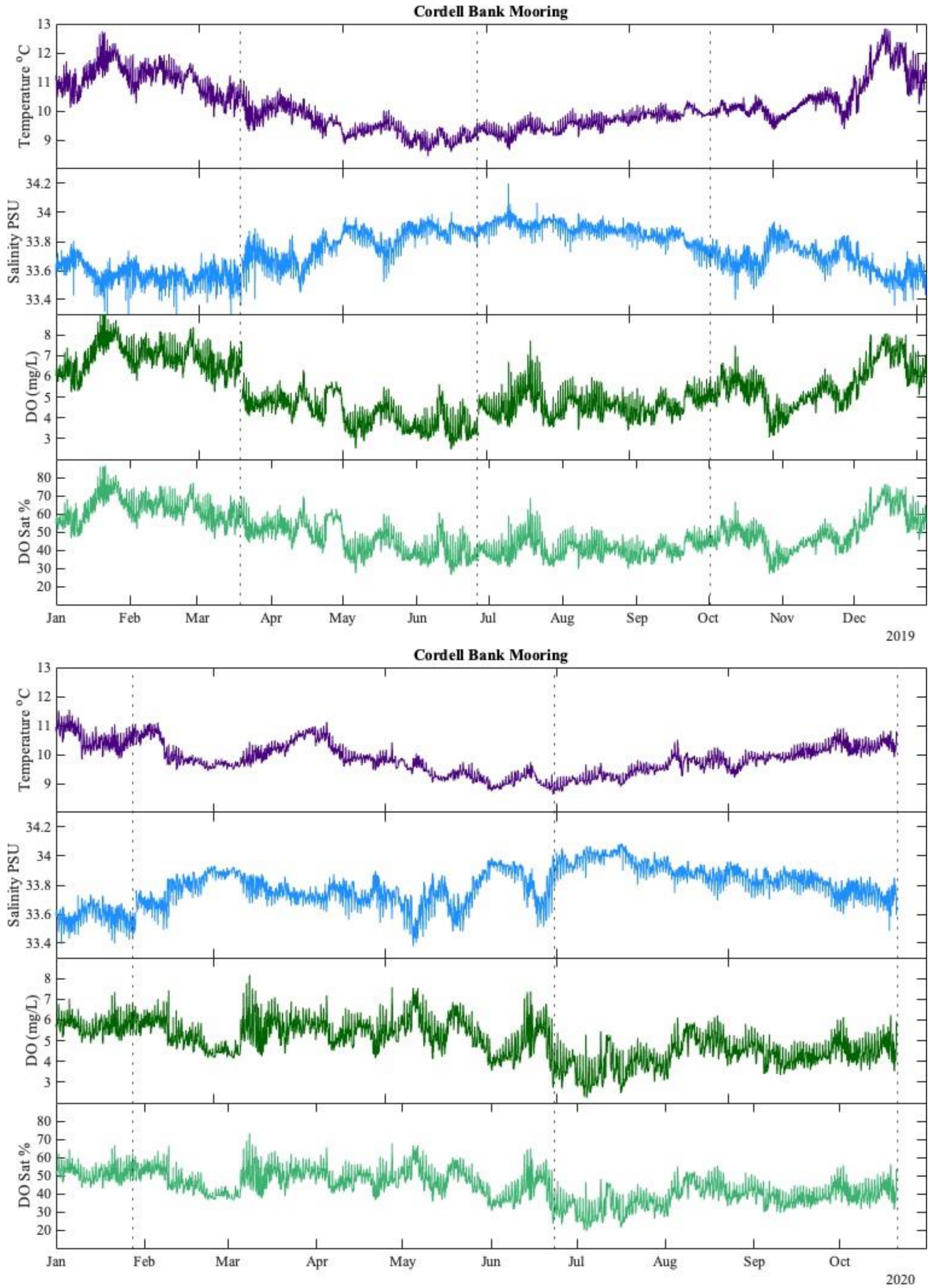
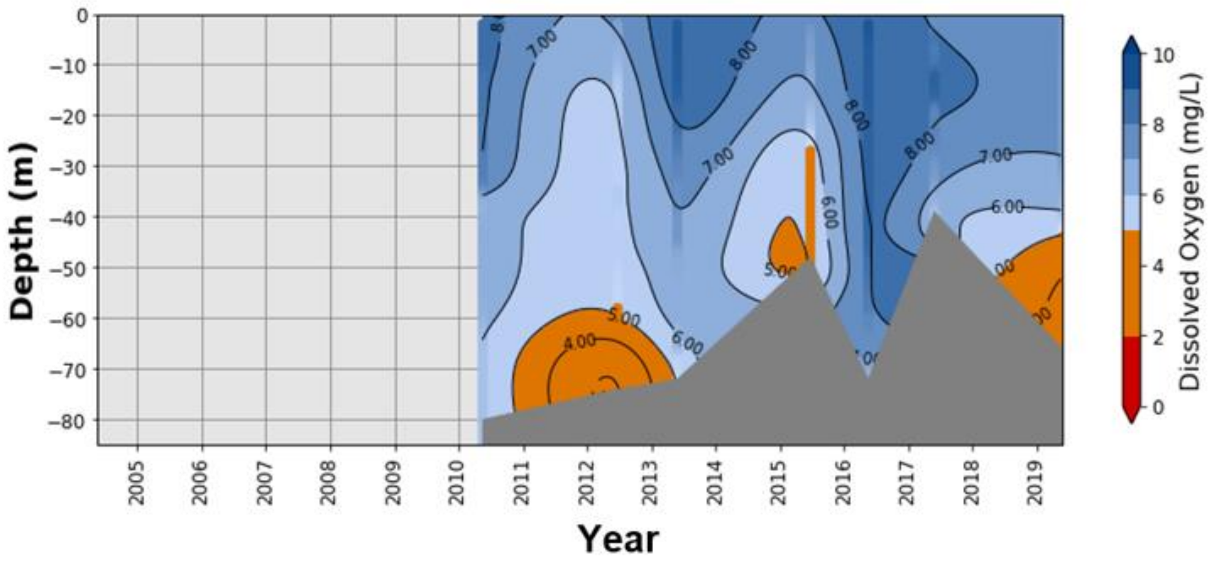
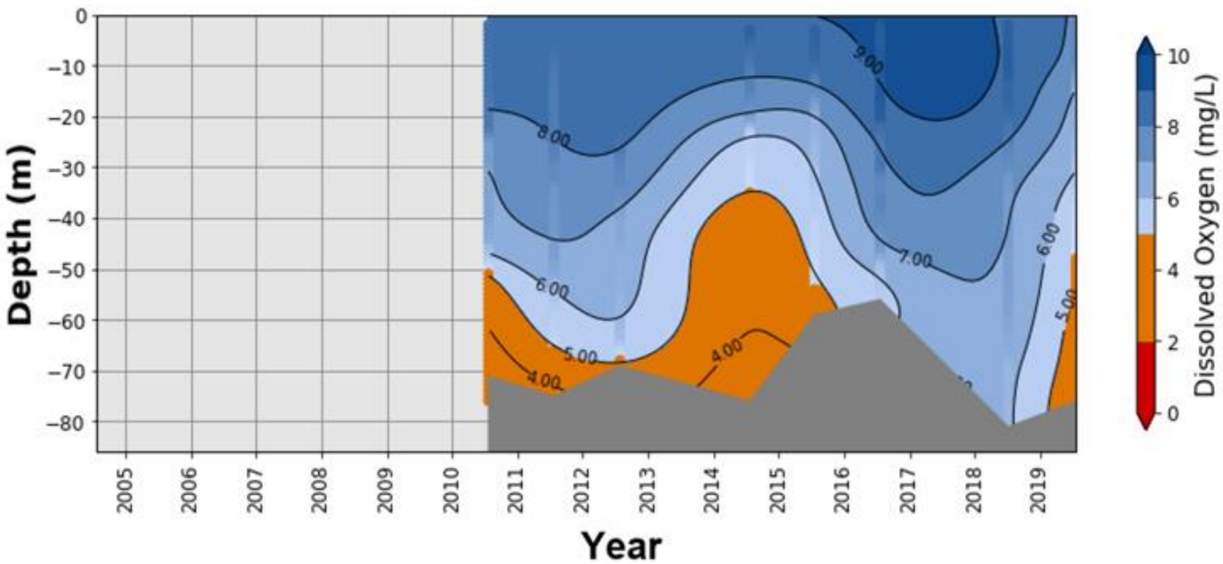


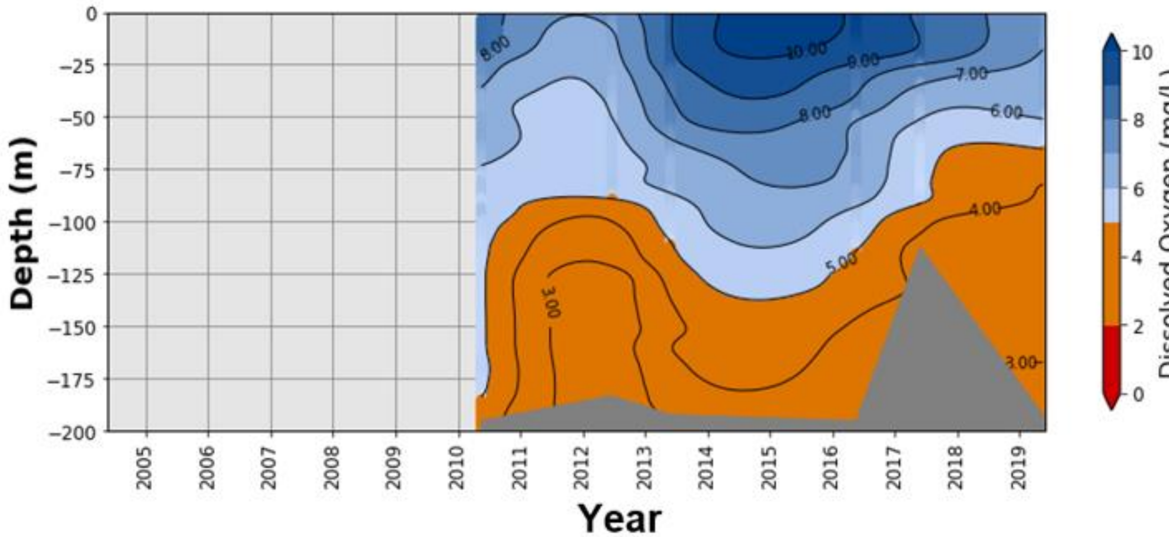
Figure App.E.8.16. Temperature, salinity, and dissolved oxygen (mg/L and % saturation) at 80 meters depth on the Cordell Bank mooring in (top) 2019 and (bottom) 2020. Source: University of California Davis Bodega Marine Laboratory & CBNMS, 2021; Image: University of California Davis Bodega Marine Laboratory a)


Depth (m)
Year
Dissolved Oxygen (mg/L)
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

b)


Depth (m)
Year
Dissolved Oxygen (mg/L)
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

c)



d)

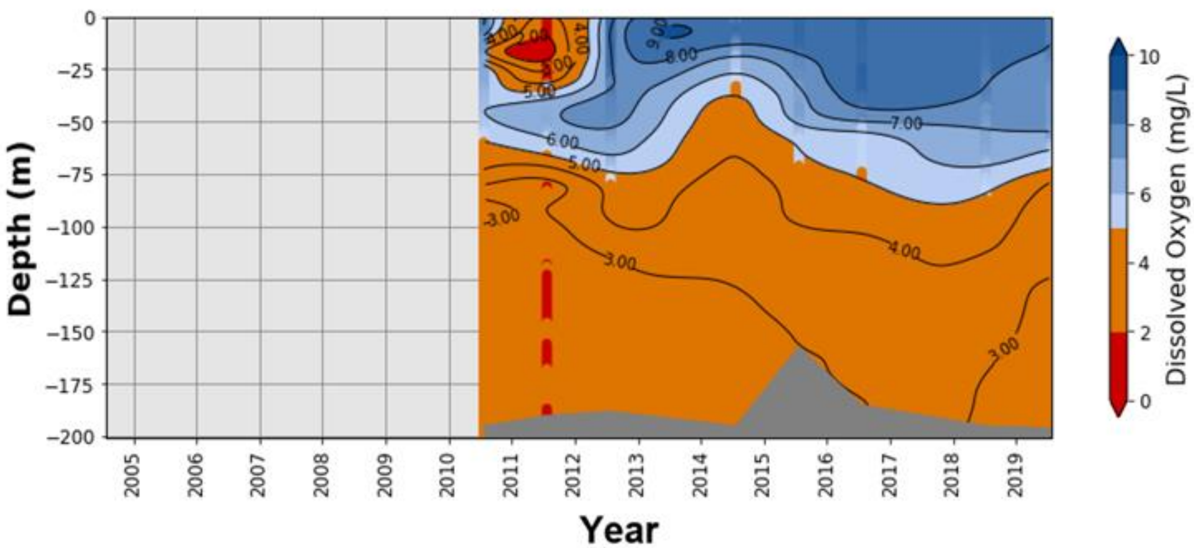


Figure App.E.8.17. Dissolved oxygen values with depth, a) station 2-M spring, b) station 2-M summer, c) station 2-W spring, and d) station 2-w summer, 2010–2019. Source: ACCESS, 2021; Image: Point Blue Conservation Science

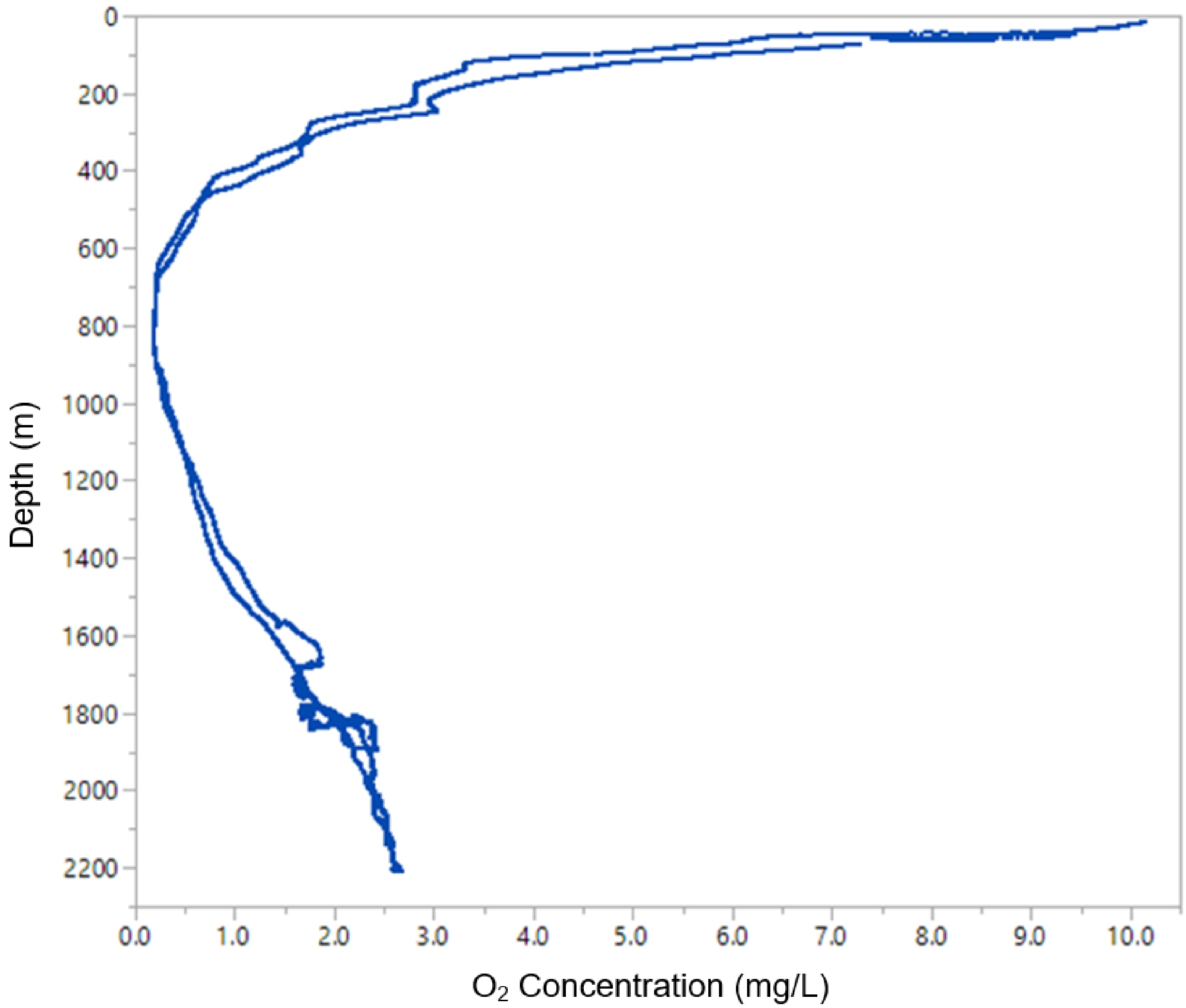


Figure App.E.8.18. Dissolved oxygen profile from ROV *Hercules* during a dive at Bodega Canyon, August 7, 2017. The Coastal Upwelling Transport Index on this day was -1.038, indicating downwelling, at 38 °N latitude near the location of the ROV dive. Source: Ocean Exploration Trust, Cordell Bank National Marine Sanctuary, 2017; Environmental Research Division, 2022

Question 9: Are other stressors, individually or in combination, affecting water quality, and how are they changing?

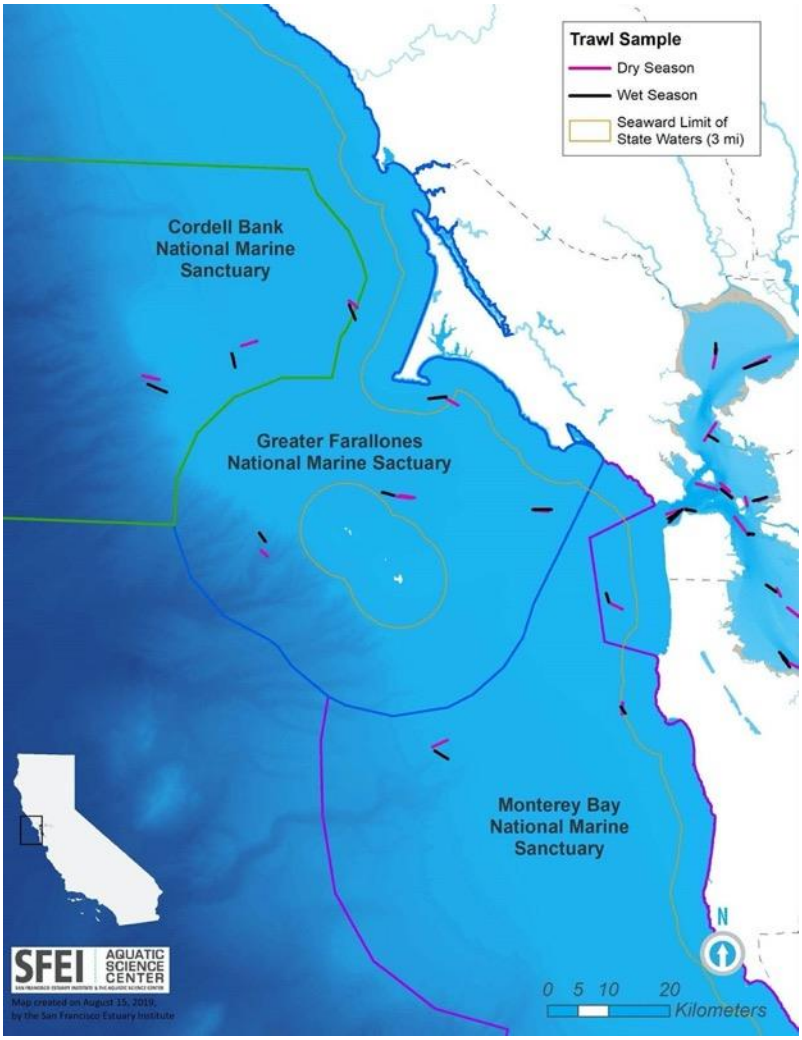


Figure App.E.9.1. Map of the San Francisco Estuary Institute microplastic study areas from 2017–2018. Surface water samples were collected using manta trawls during the dry and wet seasons. Image: Sutton et al., 2019

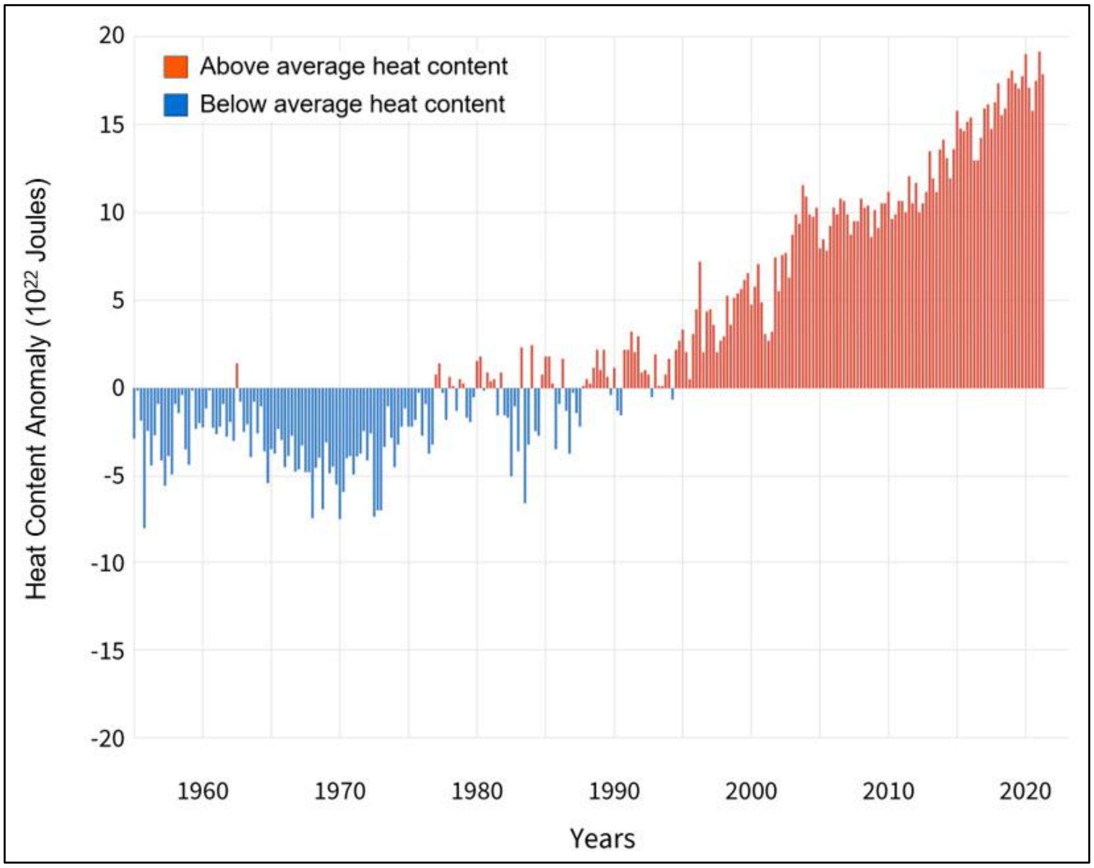


Figure App.E.9.2. Seasonal (3-month) heat energy in the top half-mile of the ocean compared to the 1955–2006 average. Heat content in the global ocean has been consistently above average (red bars) since the mid-1990s. More than 90% of the excess heat trapped in the Earth system due to human-caused global warming has been absorbed by the oceans. Source: NCEI, 2020c; Image: NOAA

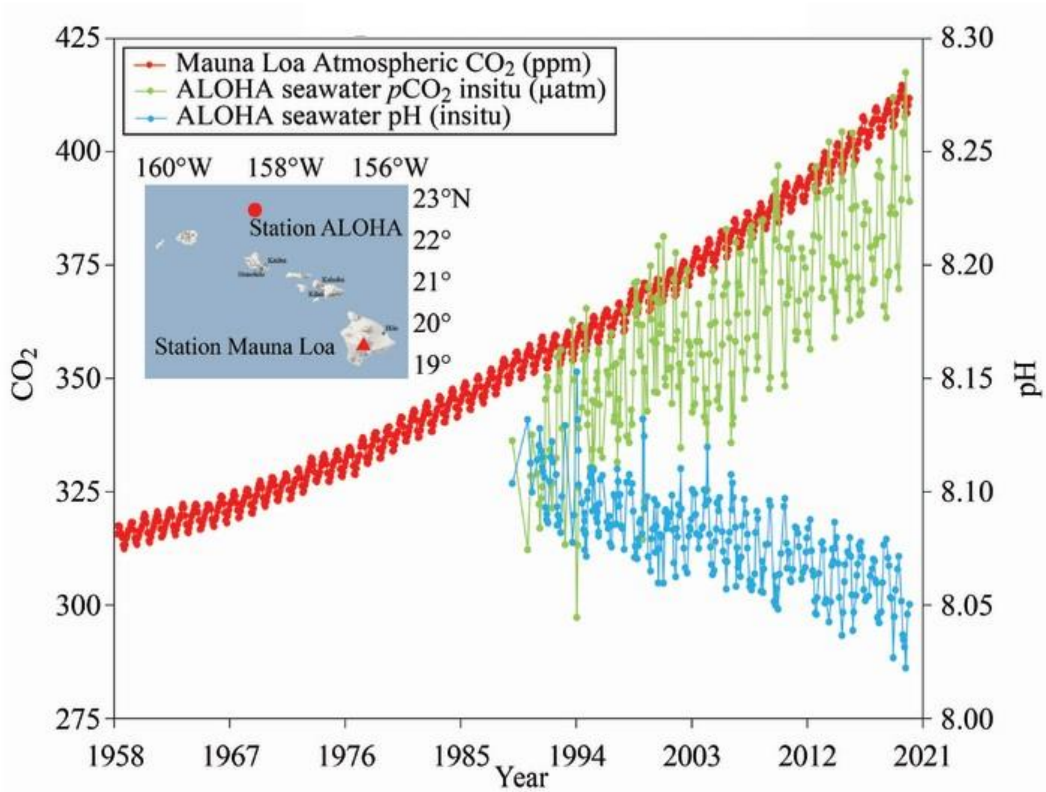


Figure App.E.9.3. Time series of atmospheric CO_2 at Mauna Loa (ppm) and surface ocean pH and pCO_2 (µatm) at Ocean Station ALOHA in the subtropical North Pacific Ocean. ALOHA pH and pCO_2 are calculated at in situ temperature from dissolved inorganic carbon and total alkalinity. Source: Tans & Keeling, 2021; Adapted from Dore et al., 2009; Image: NOAA

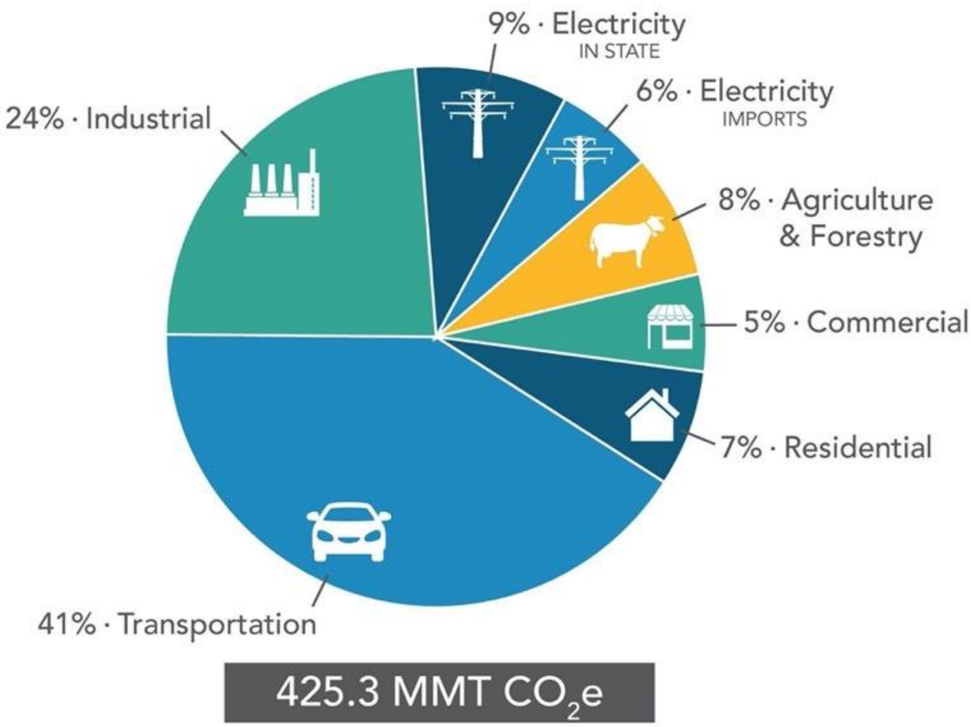


Figure App.E.9.4. Total greenhouse gas emissions in million metric tons in California in 2018. Image: California Air Resources Board, 2020

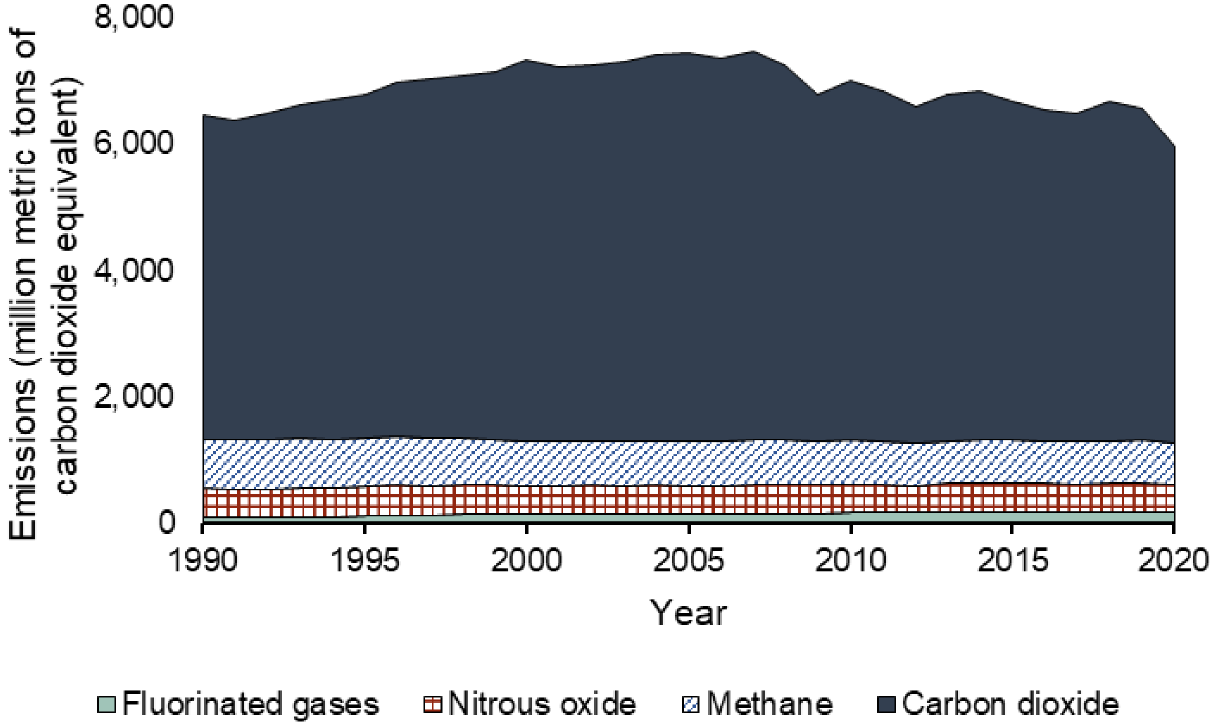
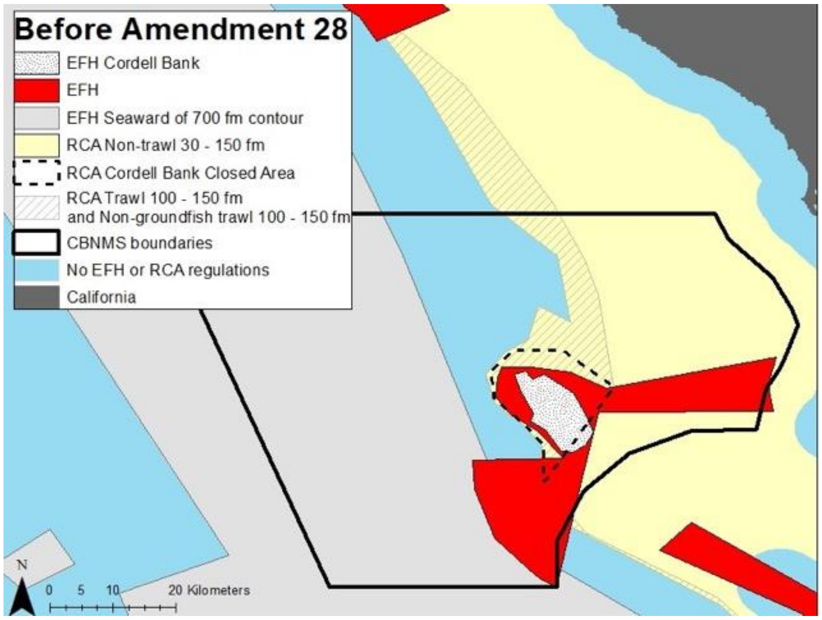


Figure App.E.9.5. Greenhouse gas emissions by gas in the United States from 1990–2018. Source: U.S. EPA, 2021; Image: NOAA

Additional Habitat Figures

Question 10: What is the integrity of major habitat types and how are they changing?

a)



b)

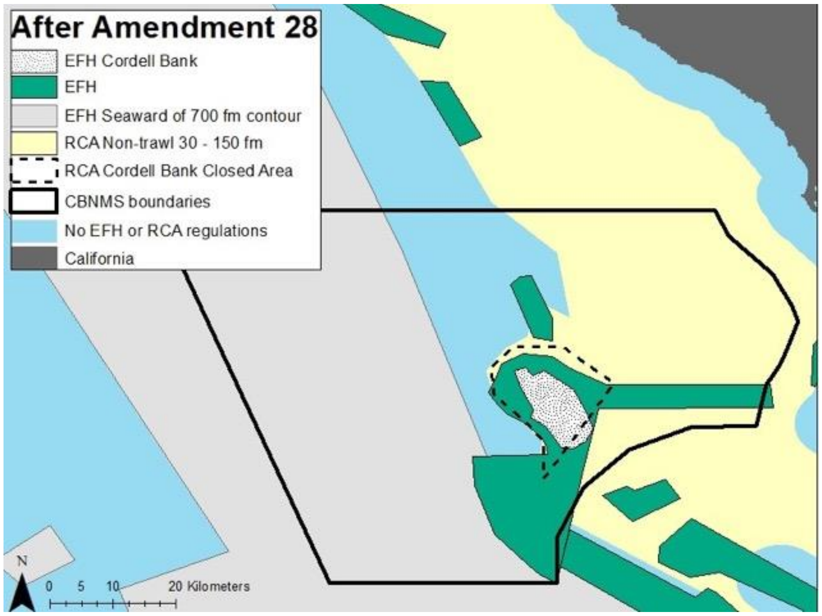


Figure App.E.10.1. Fisheries management areas (Essential Fish Habitat and Rockfish Conservation Areas) in CBNMS managed by the Pacific Fishery Management Council, (a) first implemented in 2005–2006 and (b) modified through Amendment 28 in January 1, 2020. Image: NOAA

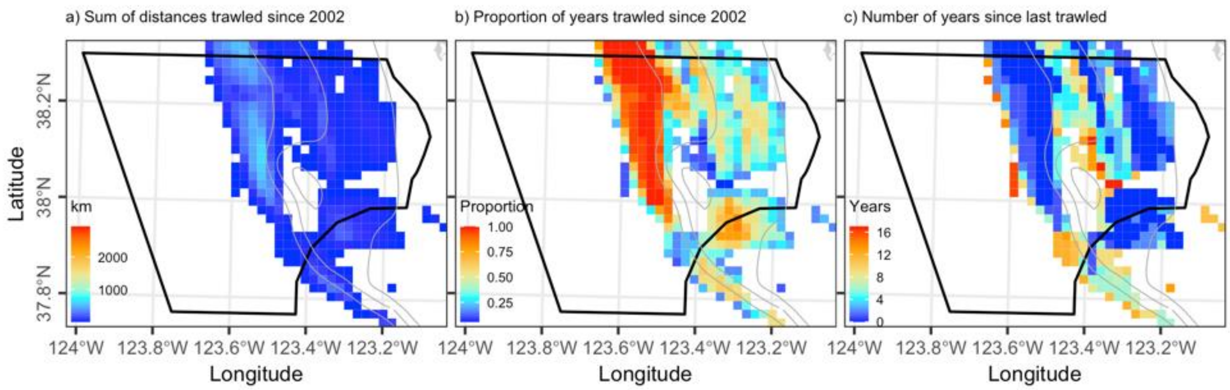


Figure App.E.10.2. Spatial representation of seafloor contact by bottom trawl gear from federal groundfish fisheries operating within CBNMS and nearby areas, calculated from annual distances trawled within each 2x2 km grid cell from 2002–2019. (a) Sum of distance trawled; legend is scaled to distances trawled across the entire U.S. West Coast. (b) Proportion of years with >0 distance trawled. (c) Number of years since last bottom trawl gear activity. Gray lines represent 100-, 200-, and 500-m depth contours. Grid cells with <3 vessels operating within the time period represented have been removed due to confidentiality. Source: NOAA Northwest Fisheries Observation Science Program, 2021; Image: CCIEA

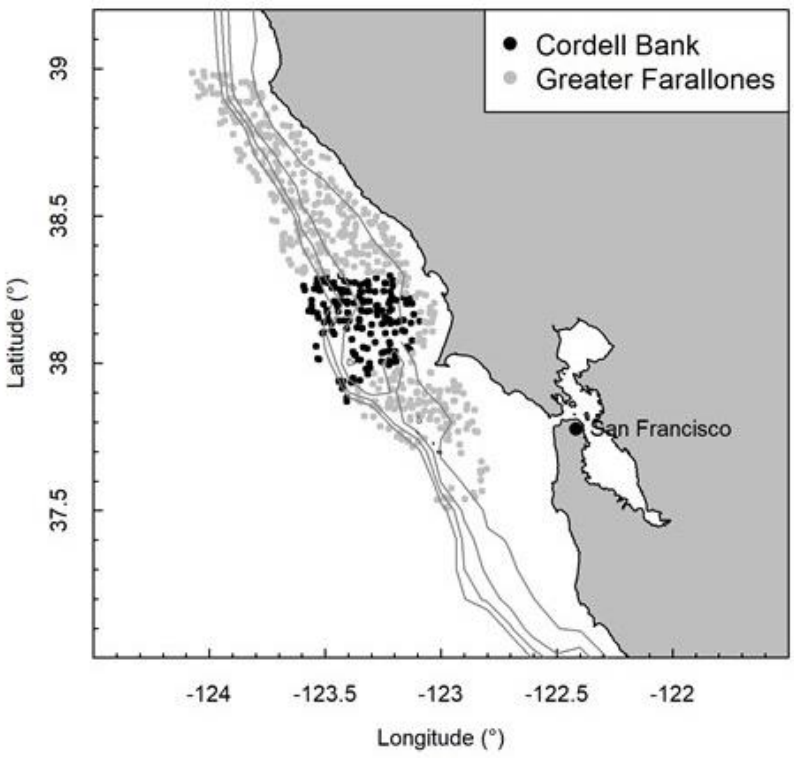


Figure App.E.10.3. Locations of permitted research trawls concluded by NOAA's Northwest Fisheries Science Center Groundfish Survey in CBNMS and GFNMS from 2003–2019. Research trawls occur from the sanctuary's eastern boundaries to about 400 m depth. Gray lines represent 100-, 200-, 300-, and 400-m depth contours. Source: WCGBTS, 2019; Image: CCIEA

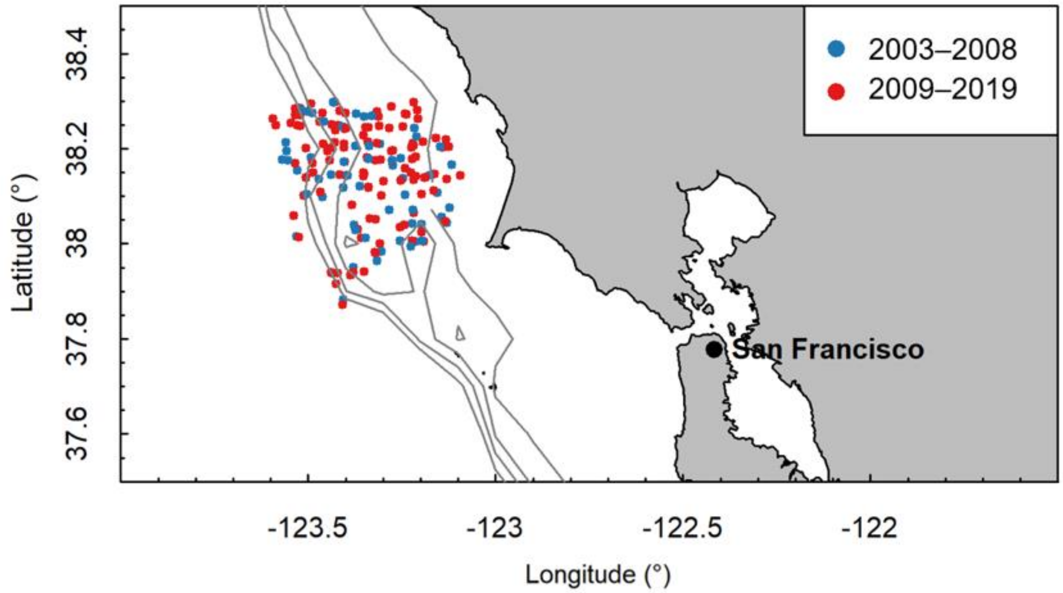


Figure App.E.10.4. Locations of permitted research trawls concluded by NOAA's Northwest Fisheries Science Center Groundfish Survey in CBNMS from 2003–2008 and 2009–2019. Research trawls occur from the sanctuary's eastern boundary to about 400 m depth. Gray lines represent 100-, 200-, 300-, and 400-m depth contours. Source: WCGBTS, 2019; Image: CCIEA

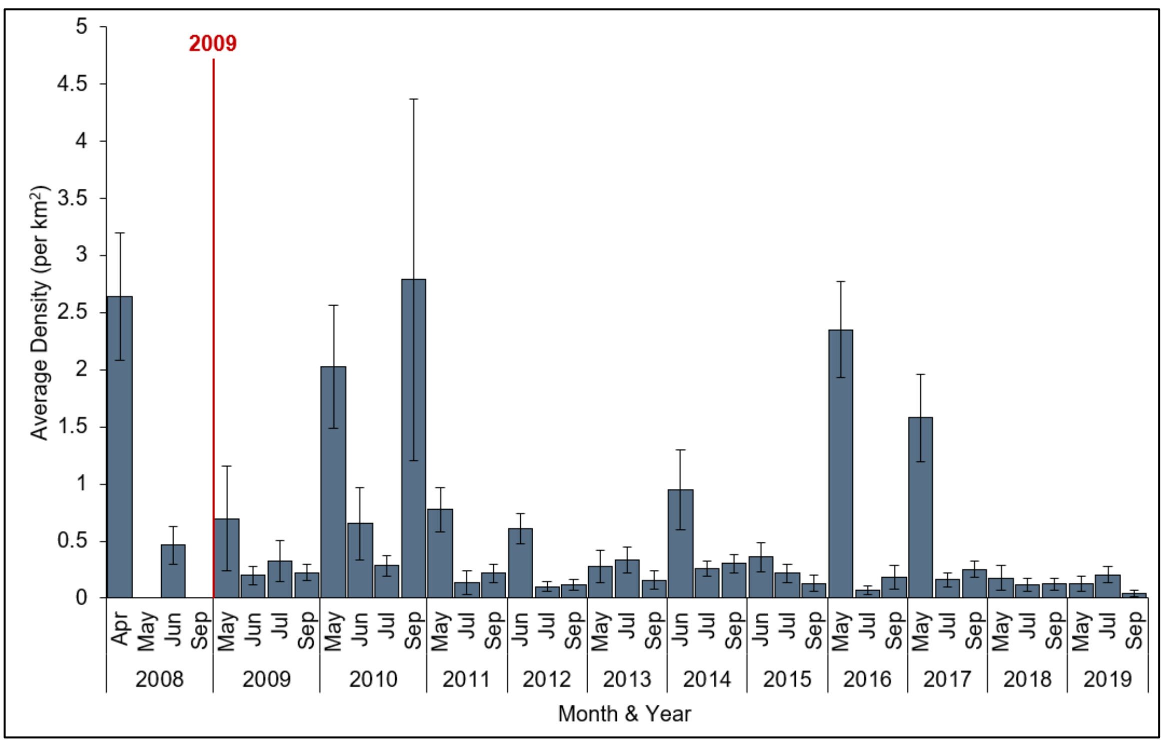


Figure App.E.10.5. Average density and standard error of marine debris (#/km^2) observed on ACCESS lines 1–7 in CBNMS and GFNMS from 2008–2019. Marine debris types include out-of-season crab pots, balloons, styrofoam, wood debris, and garbage, such as plastic bags, bottles, and floats. The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

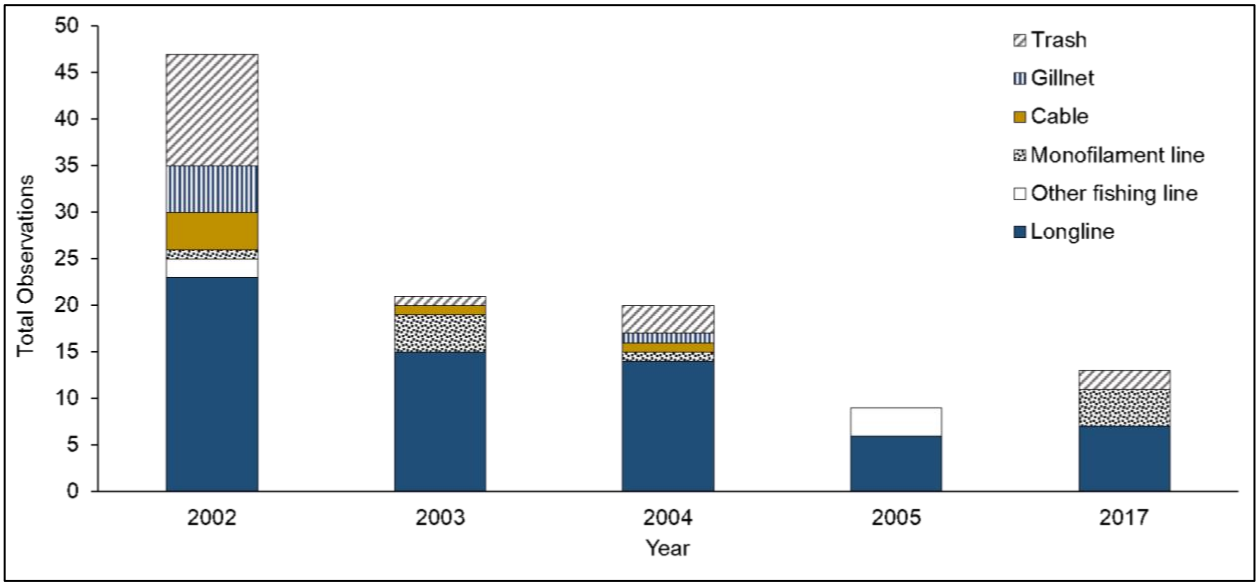


Figure App.E.10.6. Abundance (total observations, not standardized for effort) of benthic marine debris by type observed on Cordell Bank from submersible dives from 2002–2005 and ROV dive in 2017. Some marine debris was removed in 2008 during a dedicated marine debris removal ROV cruise. Source: CBNMS, 2020, 2021a; Image: NOAA

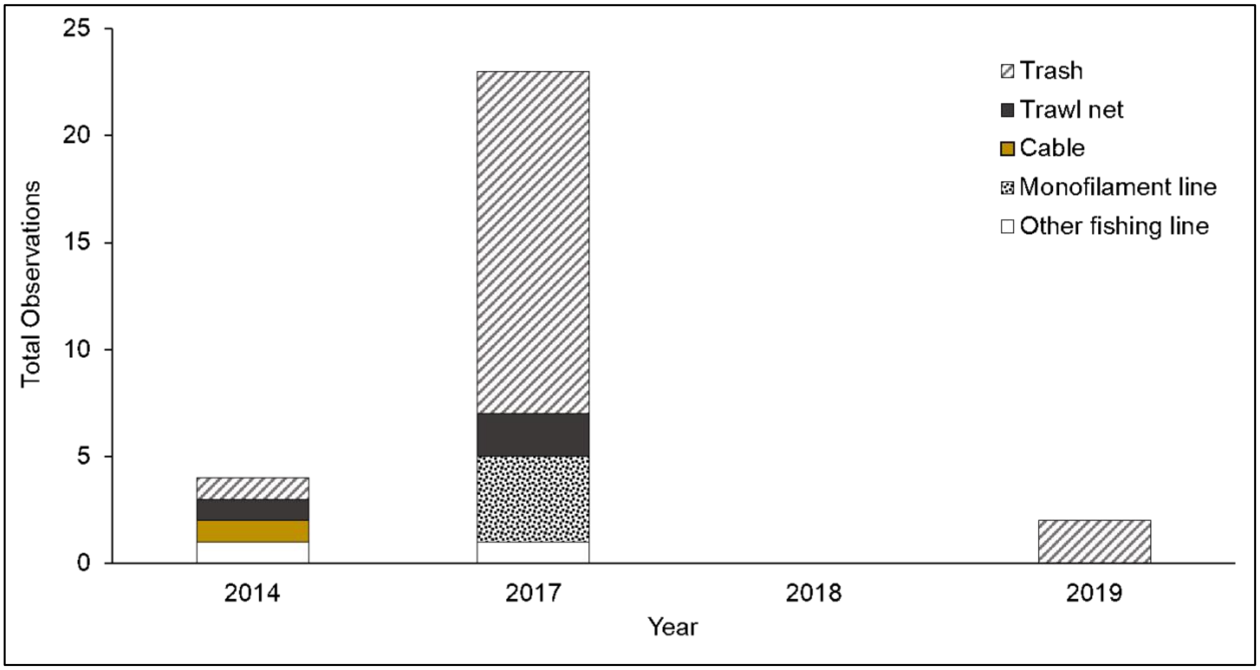


Figure App.E.10.7. Abundance (total observations, not standardized for effort) of benthic marine debris by type observed on CBNMS deep slope and canyons from ROV dives in 2014, 2017–2019. Source: CBNMS, 2020, 2021a; Image: NOAA

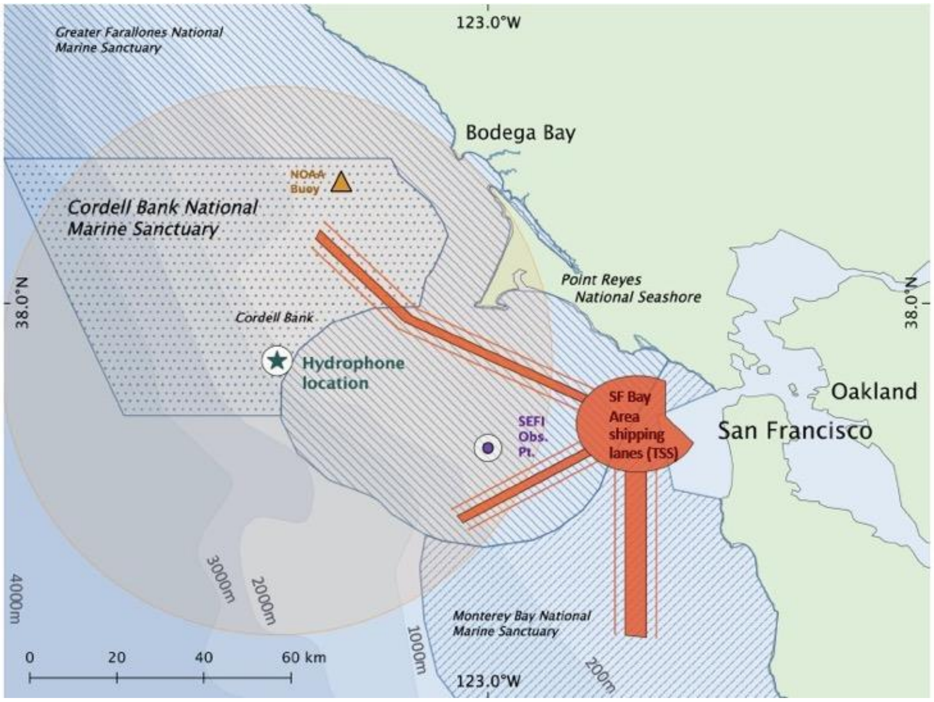


Figure App.E.10.8. Location of a stationary, bottom-mounted noise reference station hydrophone deployed in October 2015. The CBNMS noise reference station is located near the southern border of the sanctuary, approximately 30 kilometers offshore of the northern approach San Francisco Bay Area TSS shipping lane. Image: Haver et al., 2020

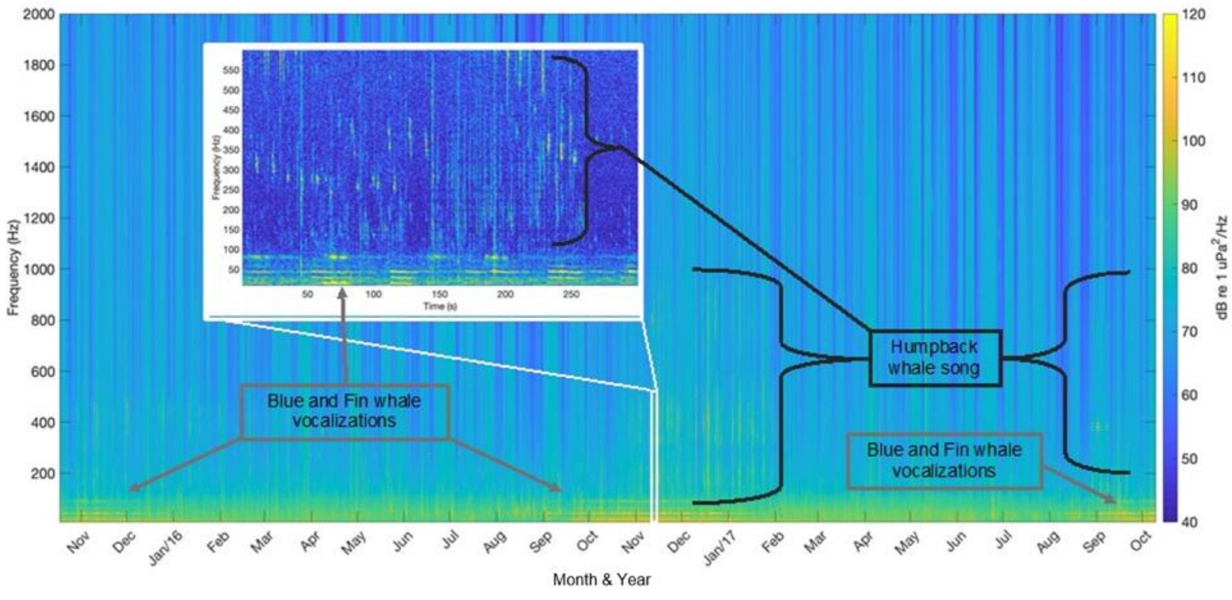


Figure App.E.10.9. Plot of CBNMS noise reference station data analyzed from Oct 2015–Oct 2017 across 10 Hz–2 kHz frequencies in 1 hr/1 Hz bins. The soundscape was dominated by ships and whales. Blue and fin whales were most audible in Fall (>100 Hz). Humpback whales were detected year-round but were most prominent in fall and winter. Vessels were detected year-round with minimal seasonal variation. Source: Pacific Marine Environmental Laboratory et al., 2014; Image: Haver et al., 2020

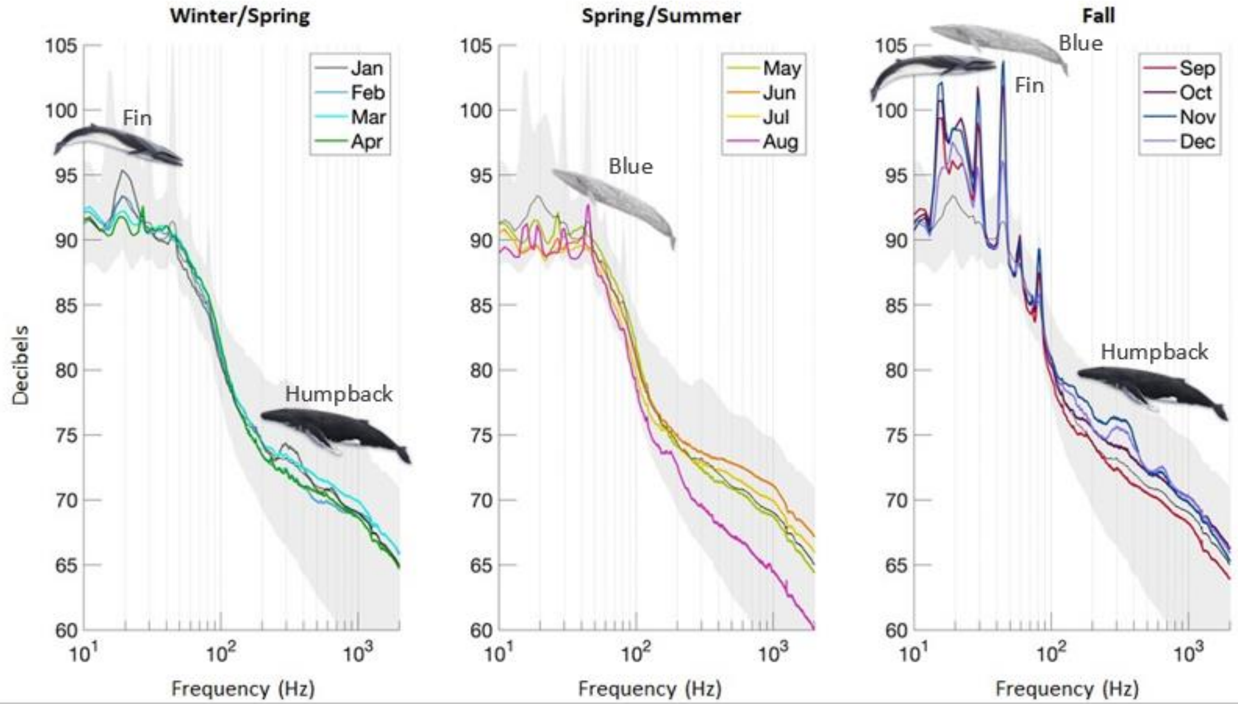


Figure App.E.10.10. Seasonal plots (winter/early spring, late spring/summer, and fall) when different whale species contribute to ambient sound levels. Data from the CBNMS noise reference station were analyzed as 10 Hz–2 kHz acoustic data average in 1 hr/1 Hz bins. Lines are 2-year average median sound levels at each frequency in each month of the year. The colored lines represent single months. The gray shading indicates the 10th–90th percentiles of sound levels (i.e., all sound except for the most extreme loud and quiet). Fin and humpback whales were heard in winter/spring, blue whales in spring/summer, and fin, humpback, and blue whales (peak activity) in fall. Source: Pacific Marine Environmental Laboratory et al., 2014; Image: Haver et al., 2020

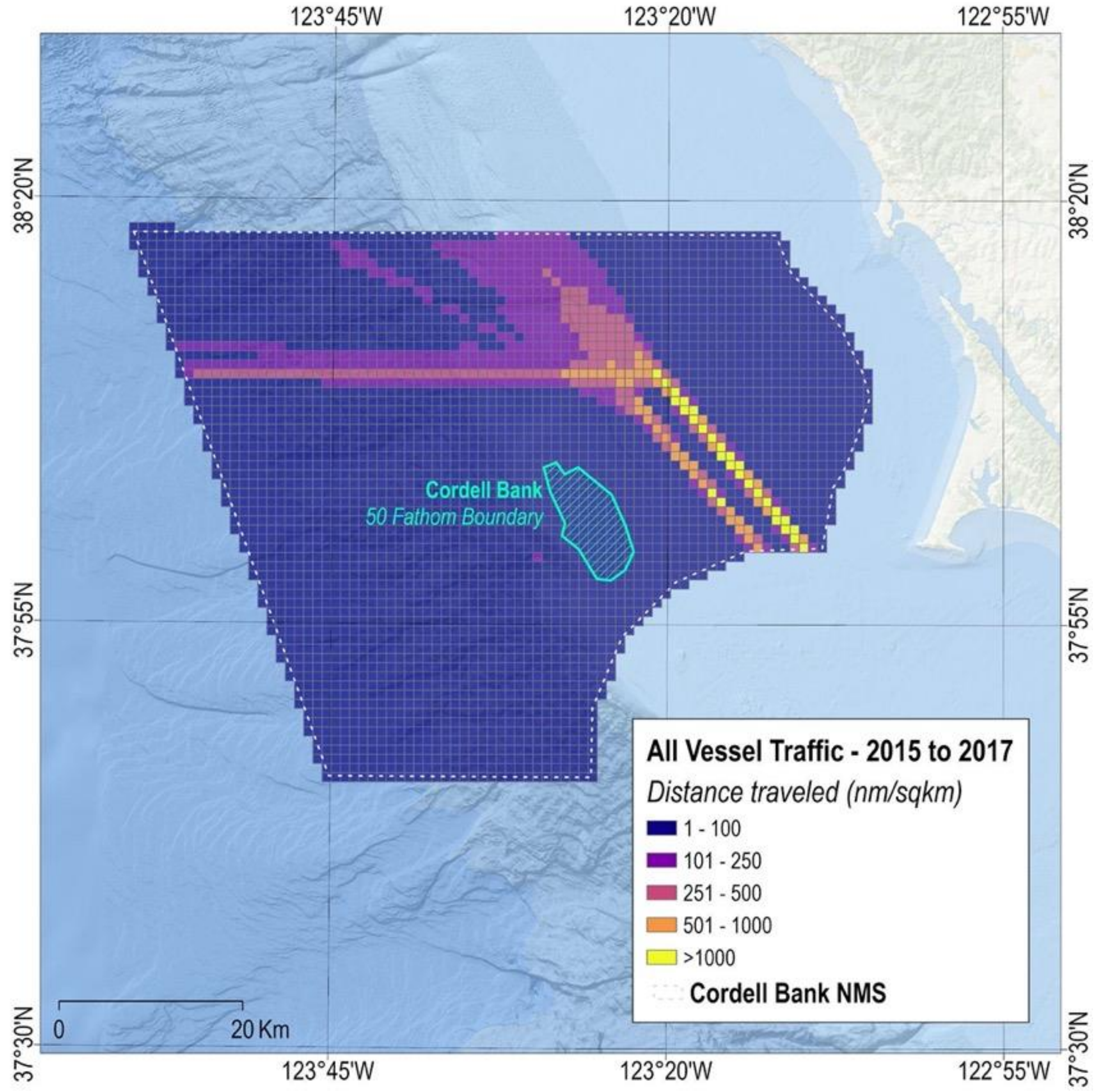


Figure App.E.10.11. Vessel traffic from 2015–2017 in CBNMS as distance traveled (nm/sq km). Source: USCG, 2021; Image: NCCOS

Table App.E.10.1. Marine debris counts and dive effort. Source: CBNMS, 2020, 2021a

Year	Marine Debris Count	Number of Dives	Dives with Debris (Percentage of Total)
2002	47	31	22 (71%)
2003	21	10	8 (80%)
2004	20	12	11 (92%)
2005	9	7	5 (71%)
2017	13	12	5 (42%)

Table App.E.10.2. Marine debris counts and dive effort. Source: CBNMS, 2020, 2021a

Year	Marine Debris Count	ROV Bottom Time (hours:minutes)	Depth Range (m)
2014	4	4:51	273–306
2017	23	76:29	740–2700
2018	0	2	415–626
2019	2	26:25	1784–3318

Question 11: What are contaminant concentrations in sanctuary habitats and how are they changing?

Table App.E.11.1. Contaminant levels measured in fish, in parts per billion wet weight. Sample locations range from South Sonoma Coast/North Sonoma Coast to San Mateo Coast. Sample types are either composites (C) or averages of individuals (A). Asterisks next to contaminant measurements indicate advisories have been issued based on assessment of human health risk by the Office of Environmental Health Hazard Assessment (Klasing & Brodberg, 2008): (*) indicates 2 servings/week, (**) indicates 1 serving/week, and (***) indicates no consumption. "ND" indicates that no data were available. Note that this table was not presented to experts during the status and trends workshop. Source: California Environmental Data Exchange Network, 2021; San Francisco Estuary Institute, 2021; Surface Water Ambient Monitoring Program, 2021

Location	Species	Year sampled	Sample type	Mercury	DDTs	PCBs	Selenium	Chlordanes	Dieldrin
South Sonoma Coast/North Sonoma Coast	Blue rockfish	2010	C	ND	ND	1.89	400	ND	ND
South Sonoma Coast/North Sonoma Coast	Blue rockfish	2010	A	70*	ND	ND	ND	ND	ND
South Sonoma Coast/North Sonoma Coast	Brown rockfish	2010	C	400**	1.89	1.33	270	ND	ND
South Sonoma Coast/North Sonoma Coast	Copper rockfish	2010	C	590***	2.46	1.04	300	ND	0.45
South Sonoma Coast/North Sonoma Coast	Olive rockfish	2010	C	ND	ND	ND	320	ND	ND
South Sonoma Coast/North Sonoma Coast	Olive rockfish	2010	A	110*	ND	ND	ND	ND	ND

Location	Species	Year sampled	Sample type	Mercury	DDTs	PCBs	Selenium	Chlordanes	Dieldrin
South Sonoma Coast/North Sonoma Coast	Vermilion rockfish	2010	C	330**	2.52	0.68	340	ND	0.57
Bodega Harbor	Leopard shark	2010	C	ND	1.29	1.17	180	ND	ND
Bodega Harbor	Leopard shark	2010	A	1370***	ND	ND	ND	ND	ND
Bodega Harbor	Rainbow surfperch	2010	C	ND	0.51	ND	80	ND	ND
Bodega Harbor	Rainbow surfperch	2010	A	60	ND	ND	ND	ND	ND
Northern Marin Coast	Blue rockfish	2009	C	ND	0.67	ND	450	ND	ND
Northern Marin Coast	Blue rockfish	2009	A	60	ND	ND	ND	ND	ND
Northern Marin Coast	Brown rockfish	2009	C	240**	2.21	1.65	280	ND	ND
Northern Marin Coast	Olive rockfish	2009	C	ND	0.7	ND	470	ND	ND
Northern Marin Coast	Olive rockfish	2009	A	40	ND	ND	ND	ND	ND
Southern Marin Coast	Barred surfperch	2009	C	200**	12.31	18.32	450	1.5	0.49
Southern Marin Coast	Barred surfperch	2009	A	140*	ND	ND	ND	ND	ND

Location	Species	Year sampled	Sample type	Mercury	DDTs	PCBs	Selenium	Chlordanes	Dieldrin
Southern Marin Coast	White croaker	2009	C	210**	1.3	1.96	290	ND	ND
Farallon Islands	Blue rockfish	2009	C	ND	1.71	ND	620	ND	ND
Farallon Islands	Blue rockfish	2009	A	40	ND	ND	ND	ND	ND
Farallon Islands	Gopher rockfish	2009	C	290**	2.28	0.29	330	ND	ND
Farallon Islands	Olive rockfish	2009	C	ND	3.03	0.21	540	ND	ND
Farallon Islands	Olive rockfish	2009	A	140*	ND	ND	ND	ND	ND
San Francisco	Barred surfperch	2009	C	110*	21.7	35.77*	210	3.07	0.6
San Francisco	Barred surfperch	2009	A	140*	ND	ND	ND	ND	ND
San Francisco	White croaker	2009	C	240**	3.24	4.98	310	ND	ND
Pacifica Coast	Blue rockfish	2009	C	ND	3.33	1.55	520	ND	ND
Pacifica Coast	Blue rockfish	2009	A	80*	ND	ND	ND	ND	ND
Pacifica Coast	Gopher rockfish	2009	C	340**	1.66	0.56	320	ND	ND
Pacifica Coast	Lingcod	2009	C	420**	9.98	8.11	250	0.35	ND
Half Moon Bay Coast	Barred surfperch	2009	C	ND	2.71	0.57	370	ND	ND

Location	Species	Year sampled	Sample type	Mercury	DDTs	PCBs	Selenium	Chlordanes	Dieldrin
Half Moon Bay Coast	Barred surfperch	2009	A	200**	ND	ND	ND	ND	ND
Half Moon Bay Coast	Blue rockfish	2009	C	ND	0.98	ND	410	ND	ND
Half Moon Bay Coast	Blue rockfish	2009	A	70*	ND	ND	ND	ND	ND
Half Moon Bay Coast	Blue rockfish	2010	A	70*	ND	ND	ND	ND	ND
Half Moon Bay Coast	Brown rockfish	2009	C	260**	1.97	3.22	290	ND	ND
Half Moon Bay Coast	Gopher rockfish	2009	C	260**	1.39	0.52	360	ND	ND
Half Moon Bay Coast	Lingcod	2009	C	270**	12.11	4.95	300	0.35	ND
Pillar Point Harbor	Black perch	2009	C	ND	1.69	0.63	180	0.3	ND
Pillar Point Harbor	Black perch	2009	A	60	ND	ND	ND	ND	ND
Pillar Point Harbor	Shiner surfperch	2009	C	60	12.99	12.72	230	2.56	ND
Pillar Point Harbor	Shiner surfperch	2009	A	60	ND	ND	ND	ND	ND
Pillar Point Harbor	Topsmelt	2009	C	90*	15.81	11.54	230	1.75	0.51
Pillar Point Harbor	White croaker	2009	C	100*	3.38	3.27	270	0.28	ND

Location	Species	Year sampled	Sample type	Mercury	DDTs	PCBs	Selenium	Chlordanes	Dieldrin
Pillar Point Harbor	White surfperch	2009	C	60	6.86	5.26	190	1.74	ND
Pillar Point Harbor	White surfperch	2009	A	70*	ND	ND	ND	ND	ND
San Mateo Coast	Black rockfish	2009	C	ND	2.65	0.29	380	ND	ND
San Mateo Coast	Black rockfish	2009	A	50	ND	ND	ND	ND	ND
San Mateo Coast	Blue rockfish	2009	C	ND	1.57	ND	360	ND	ND
San Mateo Coast	Blue rockfish	2009	A	50	ND	ND	ND	ND	ND
San Mateo Coast	Gopher rockfish	2009	C	430**	3.34	0.24	360	0.23	ND
San Mateo Coast	Olive rockfish	2009	C	ND	4.63	3.01	330	0.23	ND
San Mateo Coast	Olive rockfish	2009	A	150*	ND	ND	ND	ND	ND

Additional Living Resources Figures and Tables

Question 12: What is the status of keystone and foundation species and how is it changing?

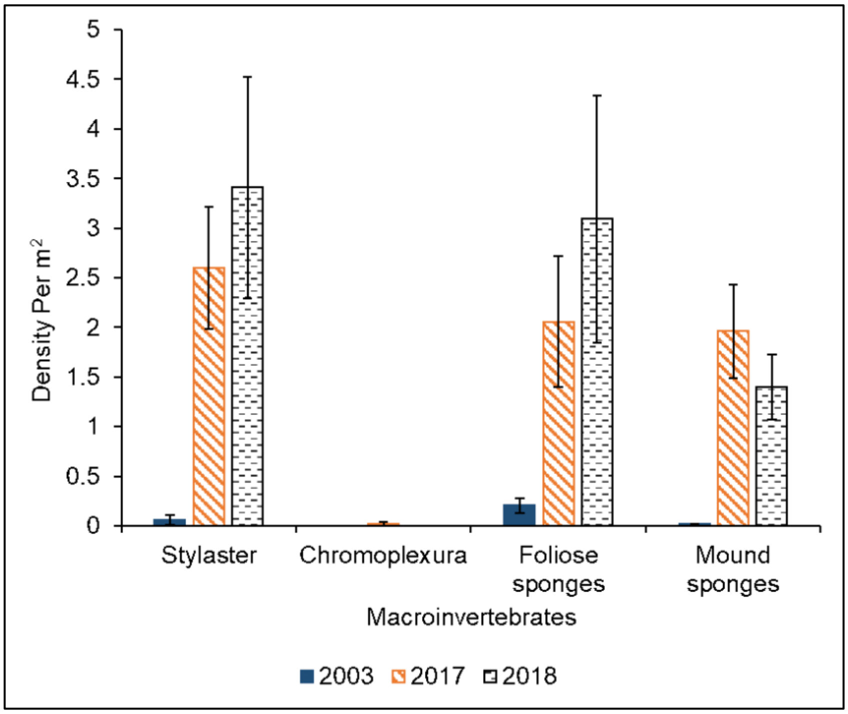


Figure App.E.12.1. Average densities (per m^2) and standard error of indicator macroinvertebrates enumerated from benthic surveys in 2003, 2017, and 2018 at a fixed sampling site named North Point on Cordell Bank at <80 m depth. Source: CBNMS, 2020; Image: NOAA

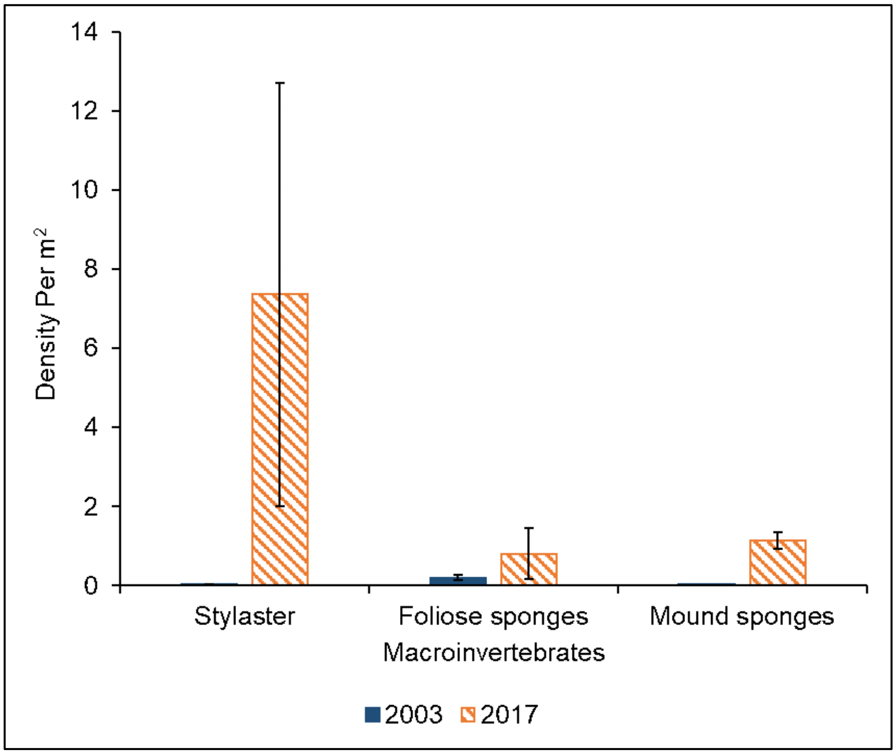


Figure App.E.12.2. Average densities (per m^2) and standard error of indicator macroinvertebrates enumerated from benthic surveys in 2003 and 2017 at a fixed sampling site named Northwest Ridge on Cordell Bank at <76 m depth. Source: CBNMS, 2020; Image: NOAA

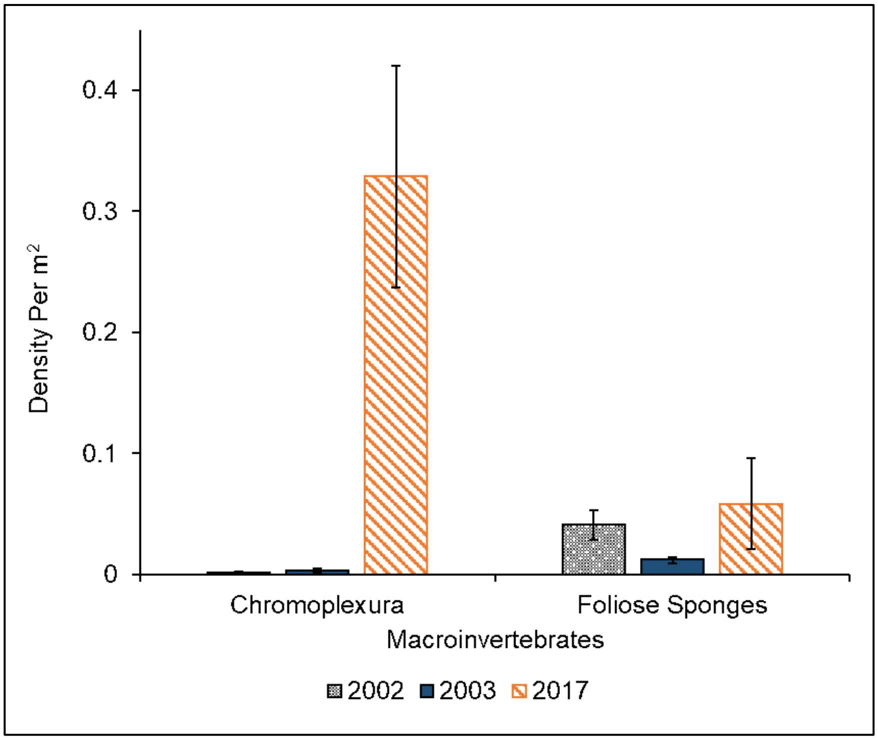


Figure App.E.12.3. Average densities (per m^2) and standard error of indicator macroinvertebrates enumerated from benthic surveys in 2002, 2003, and 2017 at mid-water (70–120m) rocky ridges on Cordell Bank. Source: CBNMS, 2020; Image: NOAA

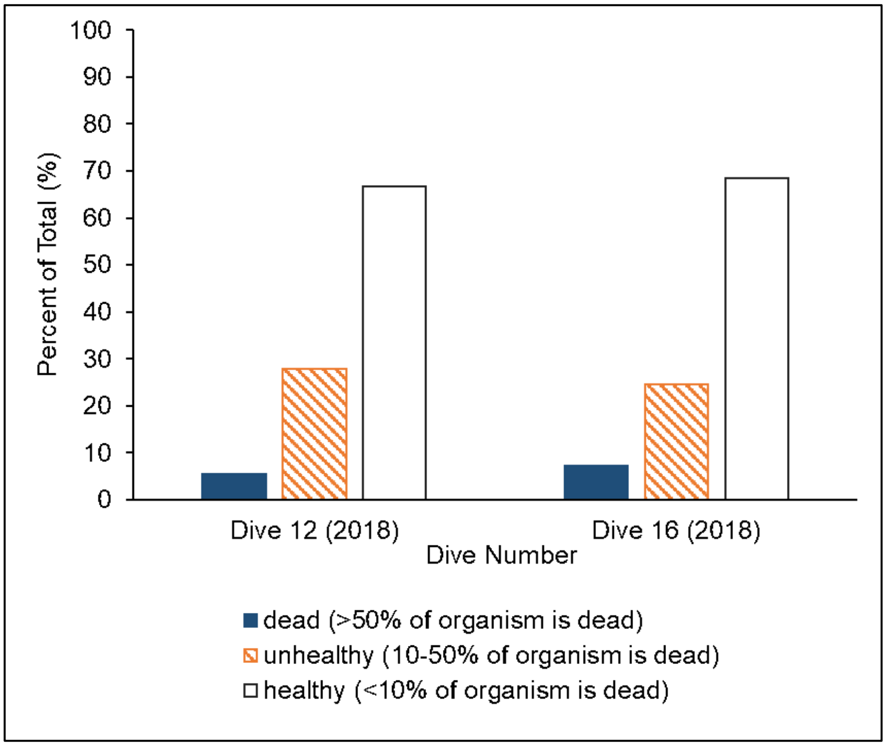


Figure App.E.12.4. Percent of total *Swifita* spp. gorgonians per condition category, healthy (<10% of organism is dead), unhealthy (10–50% is dead), or dead (>50% of organism dead), observed from ROV video collected in 2018 on the CBNMS slope (415–626 m depth). Source: Graiff and Lipski, 2020a; Image: NOAA

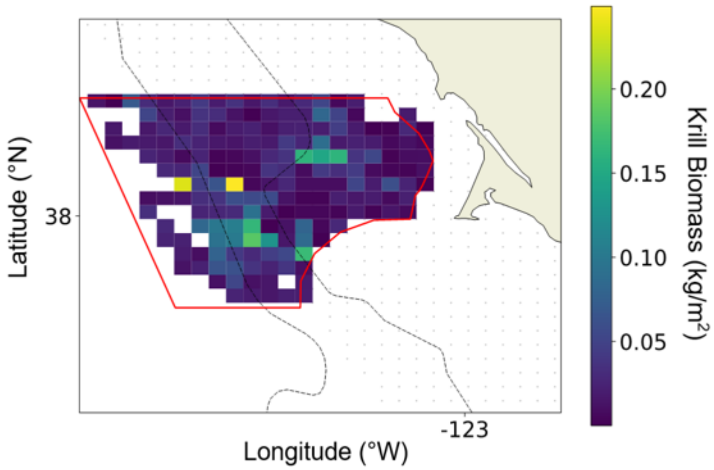
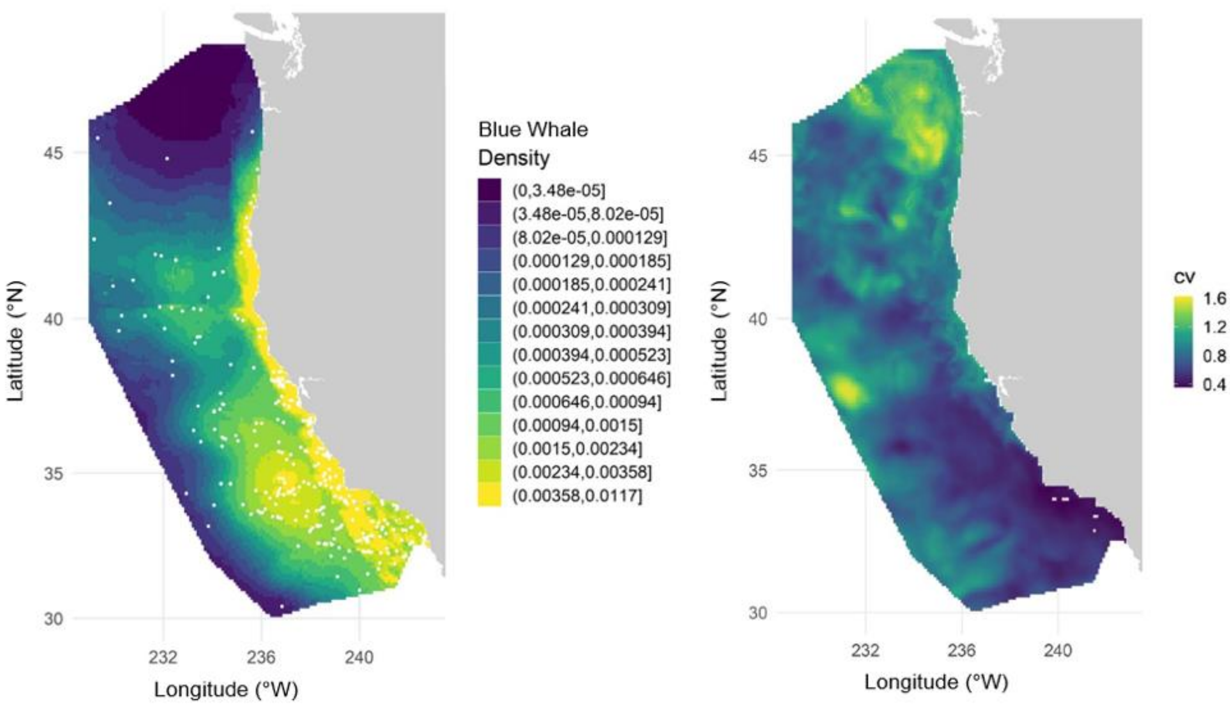


Figure App.E.12.5. Krill biomass (kg/m^2) from samples collected from the Point Reyes line in CBNMS from 2012–2018. Krill biomass measured in samples were scaled up for the CBNMS area. Source: Southwest Fisheries Science Center, 2021; Image: Farallon Institute

Table App.E.12.1. Krill biomass (mt) scaled up for the CBNMS area from 2012–2018. Source: NOAA/Farallon Institute

Year	Biomass (mt)	% Coverage	Scaled Up Biomass (mt)
2012	13,100	24.8	52,900
2013	47,900	23.4	205,100
2014	134,700	54.2	248,700
2015	51,800	39.7	130,300
2016	34,800	25.2	137,700
2017	43,700	31.8	137,400
2018	33,900	30.9	109,800

Question 13: What is the status of other focal species and how is it changing?



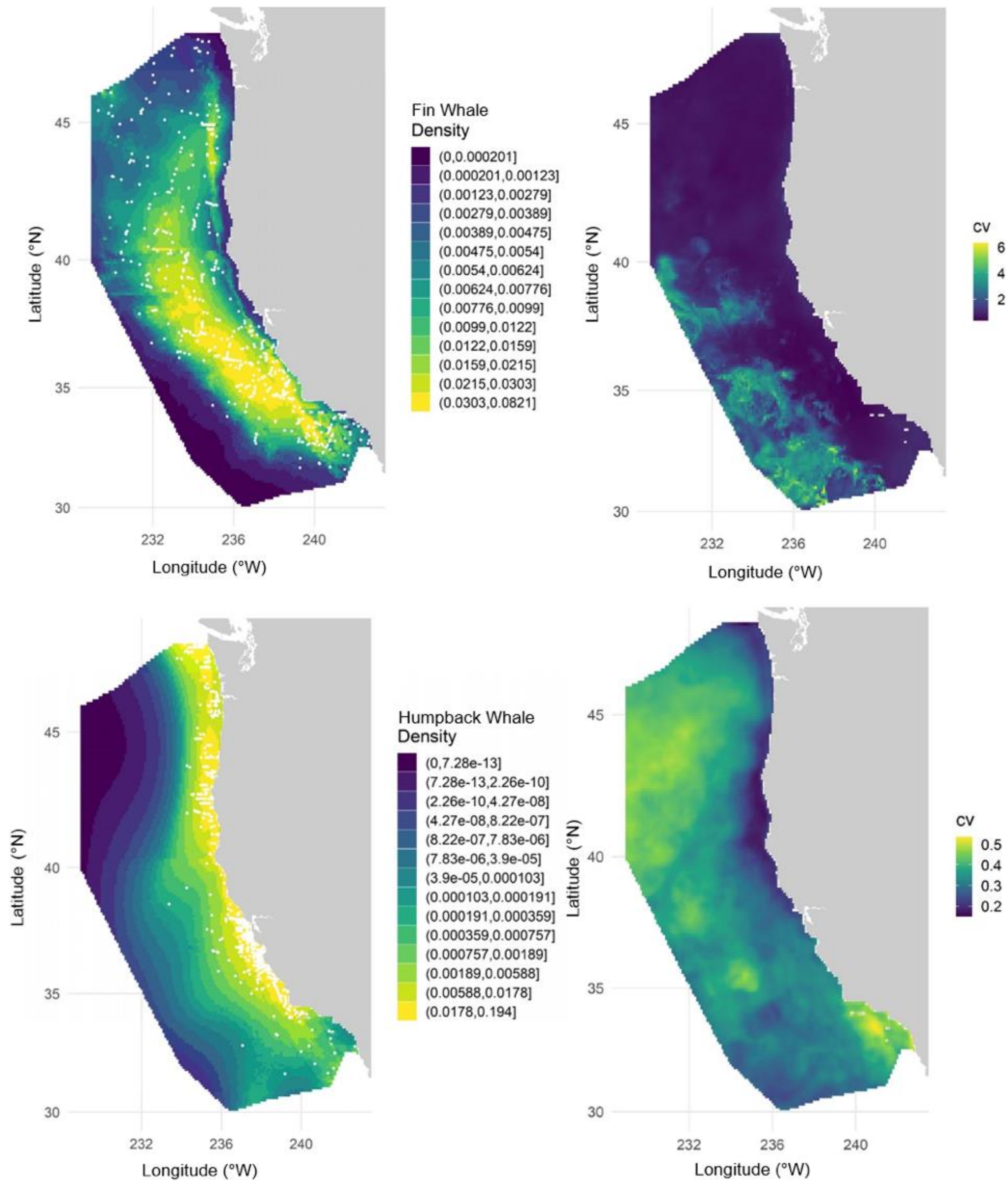


Figure App.E.13.1. Predicted mean density (animals per km²) and associated coefficients of variation from the 1991–2018 habitat-based density models for blue whale (top), fin whale (middle), and humpback whale (bottom). Panels show the multi-year average density based on predicted daily cetacean species densities covering the 1996–2018 survey periods (summer/fall). Predictions are shown for the study area (1,141,800 km²). White dots in the average plots show actual sighting locations from the Southwest Fisheries Science Center 1996–2018 summer/fall ship surveys for the respective species. Source: Becker et al., 2020

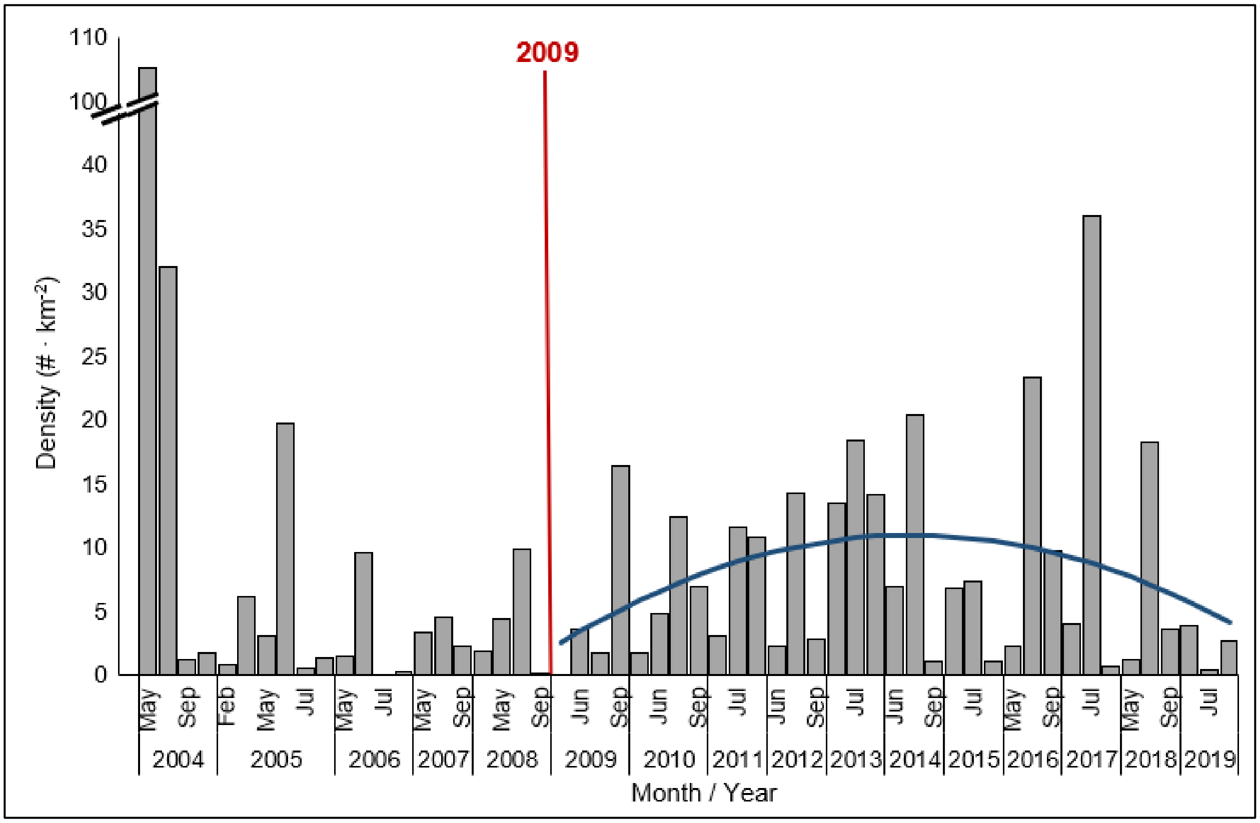


Figure App.E.13.2. Cassin's auklet densities observed on ACCESS transect lines 1–7, years 2004–2019. Line shows polynomial trend for 2009–2019. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

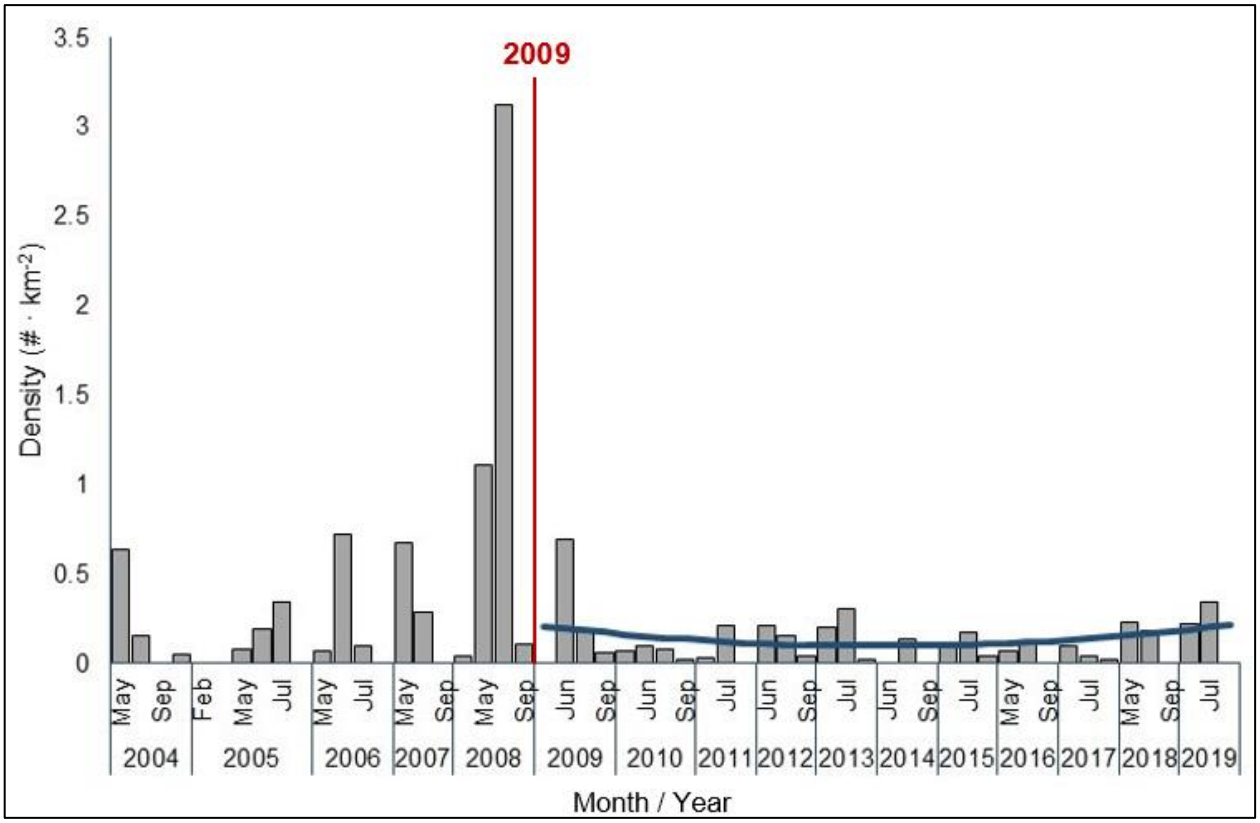


Figure App.E.13.3. Black-footed albatross densities observed on ACCESS transect lines 1–7, years 2004–2019. Line shows polynomial trend for 2009–2019. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source ACCESS, 2021; Image: Point Blue Conservation Science

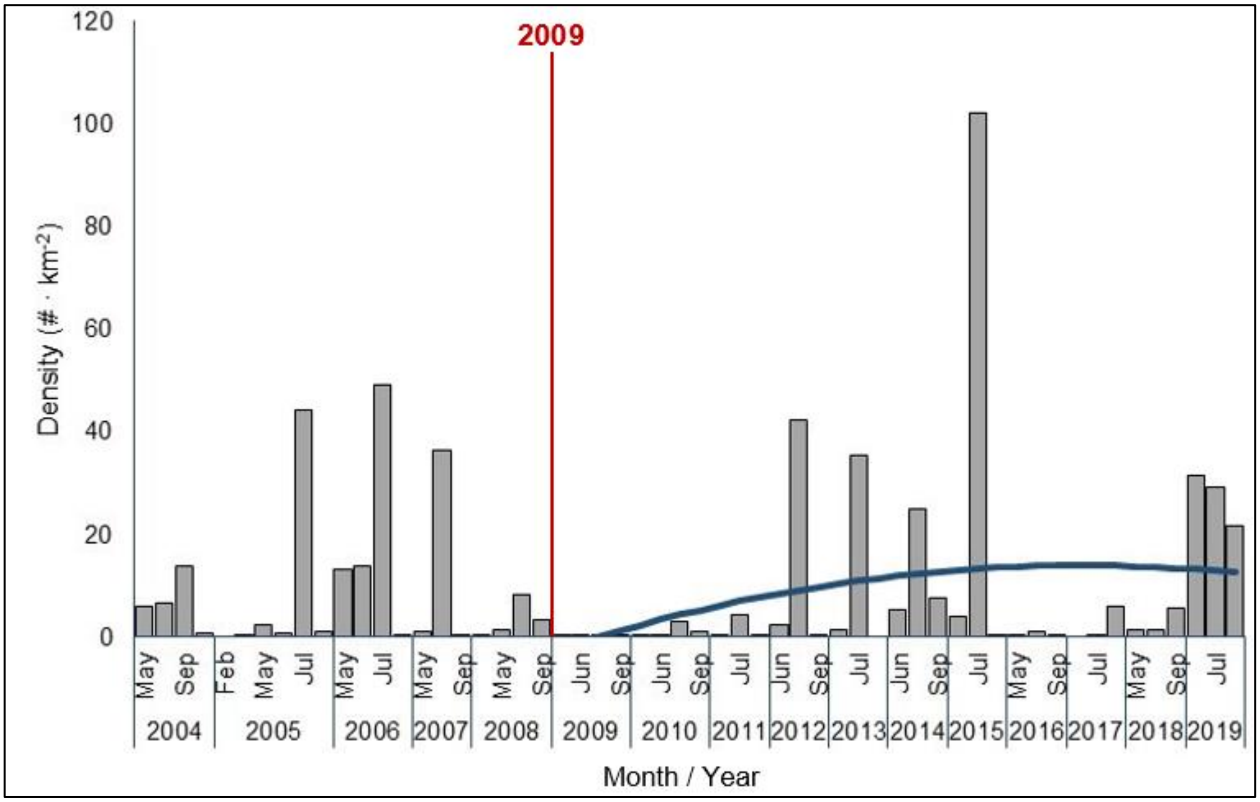


Figure App.E.13.4. Sooty shearwater densities observed on ACCESS transect lines 1–7, years 2004–2019. Line shows polynomial trend for 2009–2019. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source: ACCESS, 2021; Image: Point Blue Conservation Science

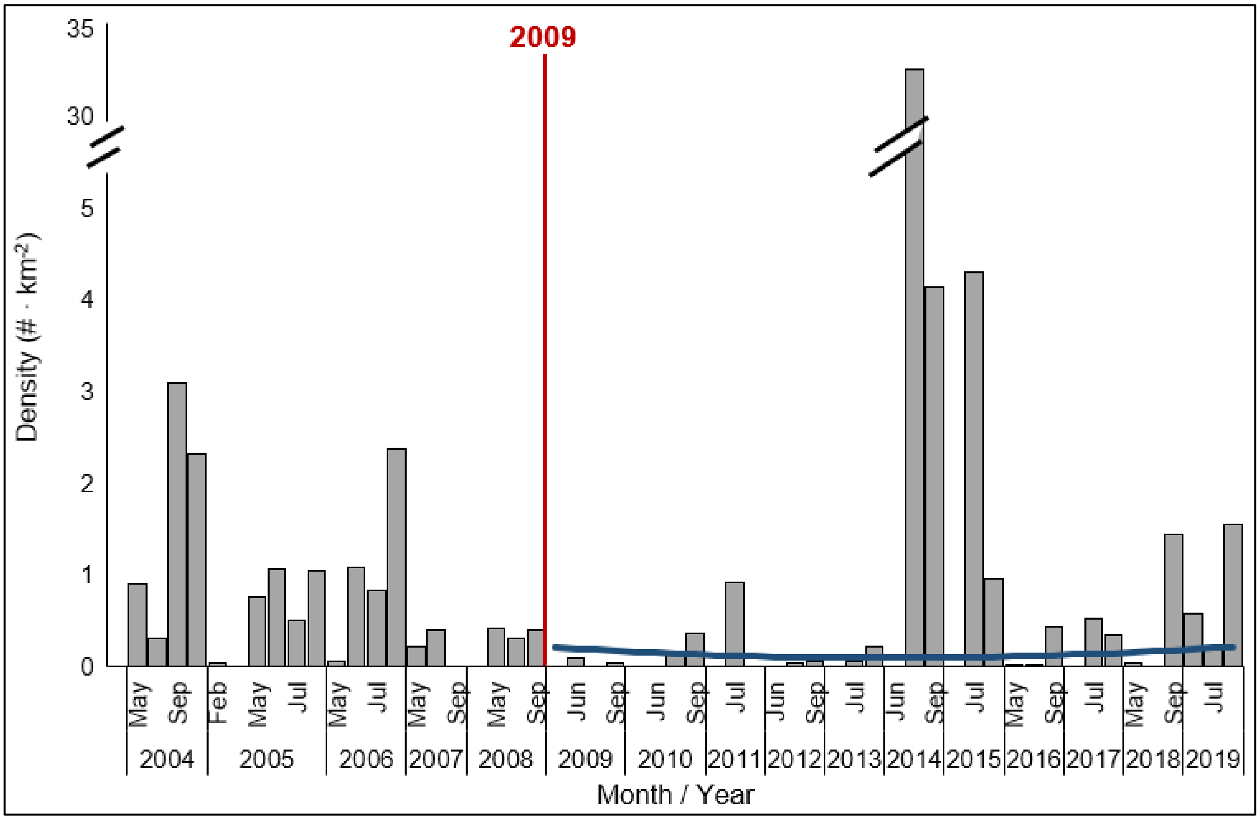


Figure App.E.13.5. Pink-footed shearwater densities observed on ACCESS transect lines 1–7, years 2004–2019. Line shows polynomial trend for 2009–2019. Each bar represents the summed total observations for the area surveyed per cruise. The vertical red line indicates the year of the last condition report (2009). Source ACCESS, 2021; Image: Point Blue Conservation Science

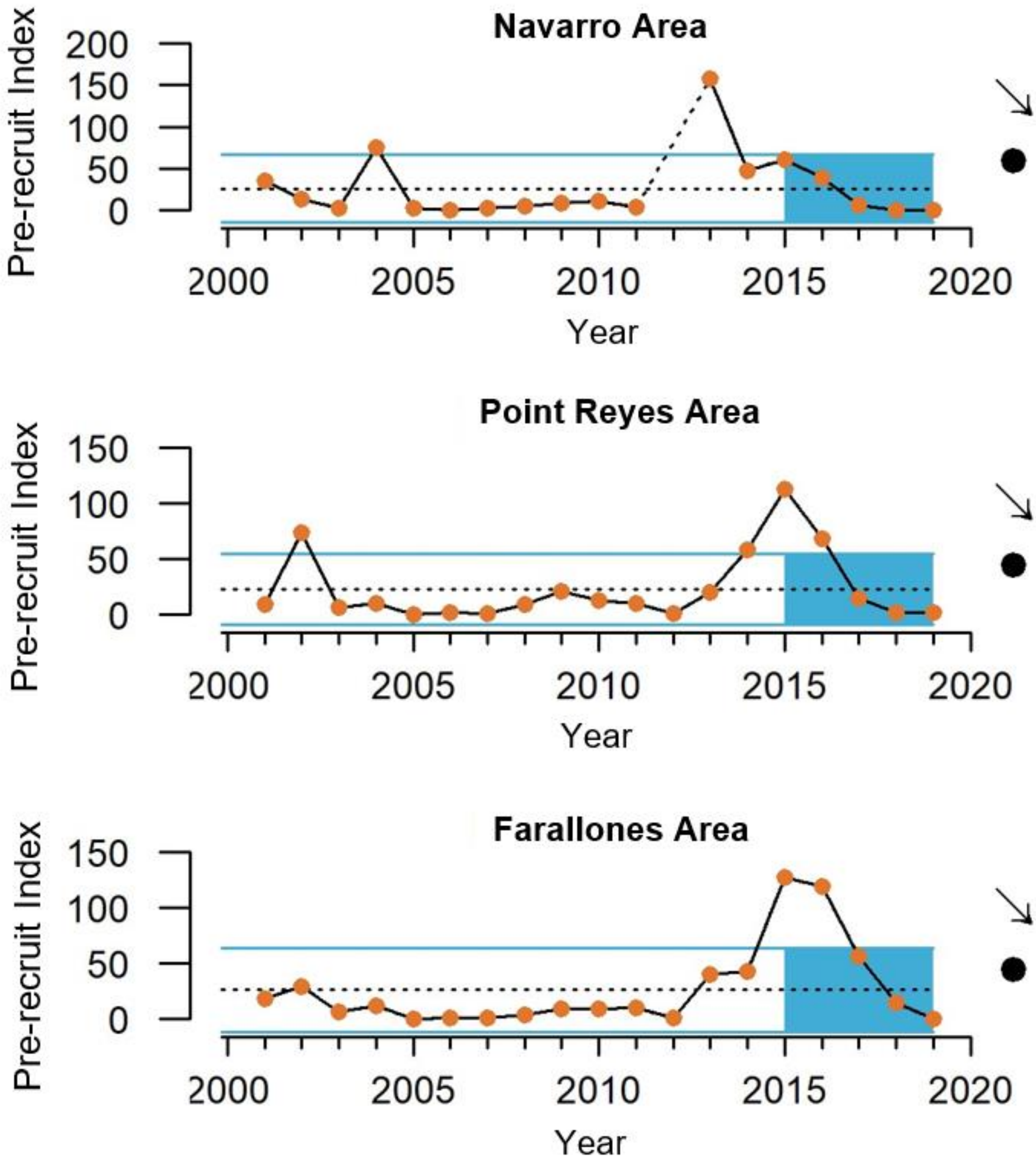


Figure App.E.13.6. Index of abundance for rockfish pre-recruits for 2001–2019. The black dots indicate the recent mean (2015–2019) is within 1.0 standard deviation of the long-term mean (2003–2019) and the arrow indicates the trend from 2015–2019 decreased more than 1.0 standard deviation compared to the full time series. CBNMS is within the Point Reyes sampling area. Source: WCGBTS, 2019; Image: CCIEA

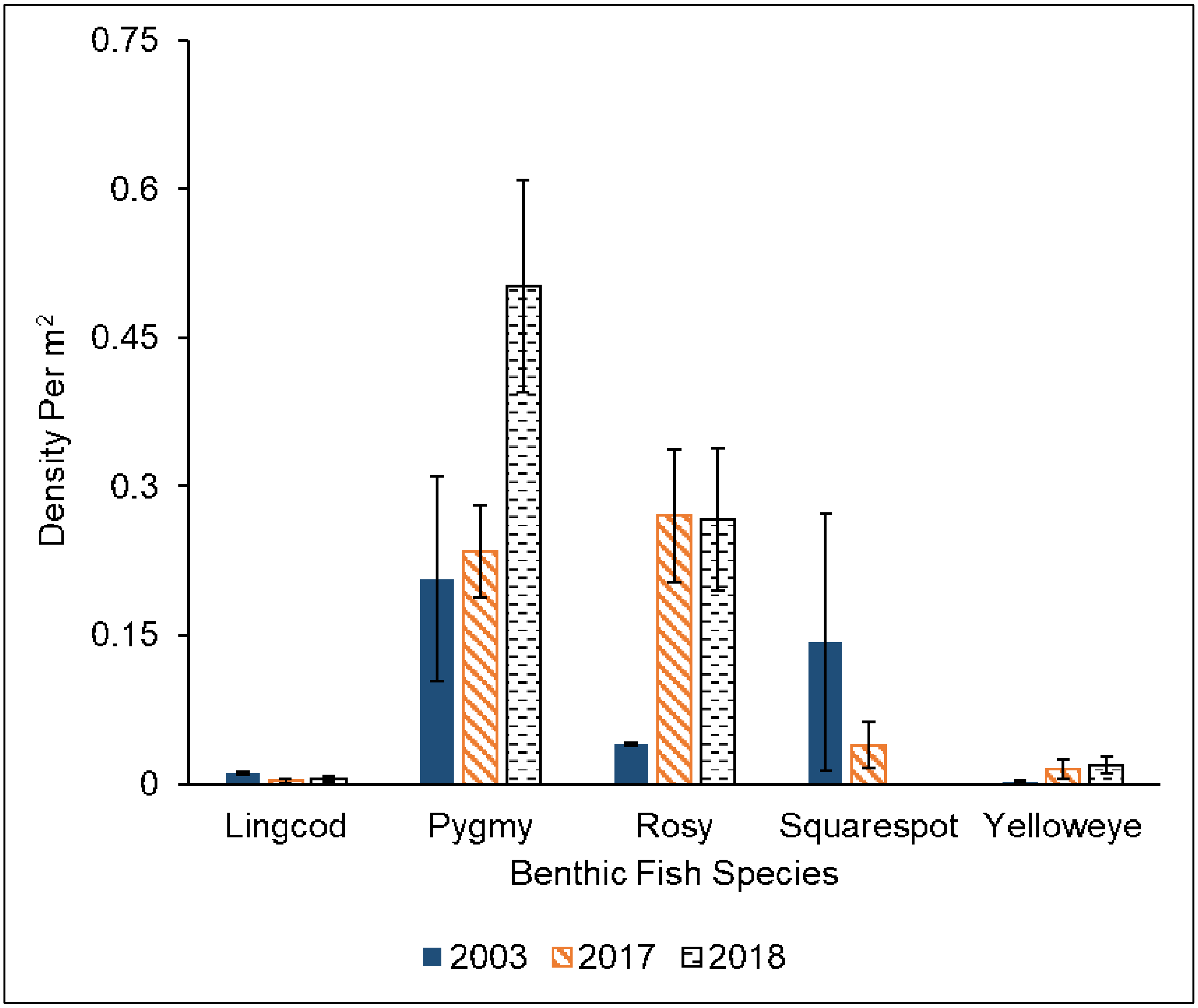


Figure App.E.13.7. Average fish densities (per m^2) and standard error from North Point on Cordell Bank. Source: CBNMS, 2020; Image: NOAA

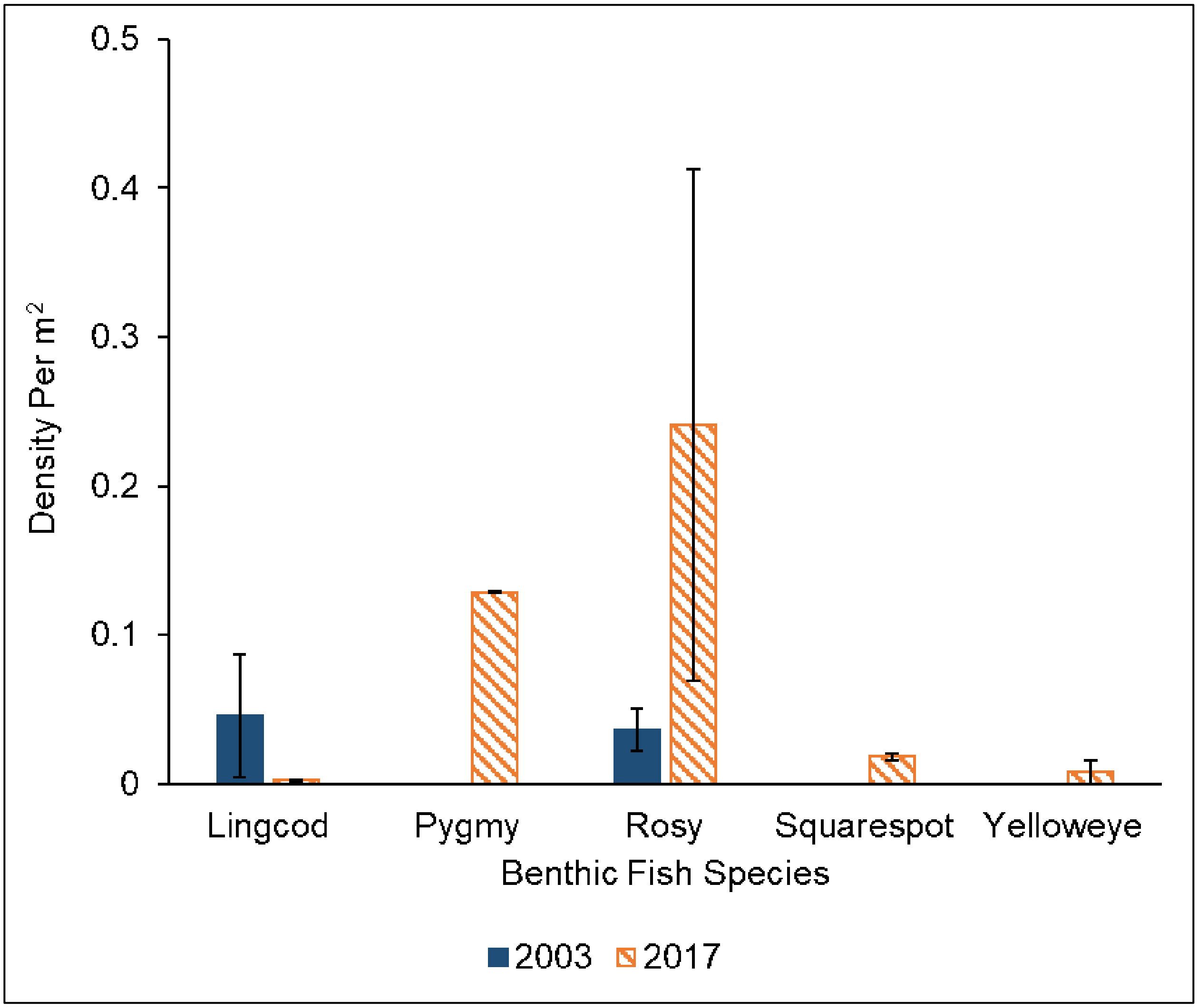


Figure App.E.13.8. Average fish densities (per m^2) and standard error from Northwest Ridge on Cordell Bank. Source: CBNMS, 2020; Image: NOAA

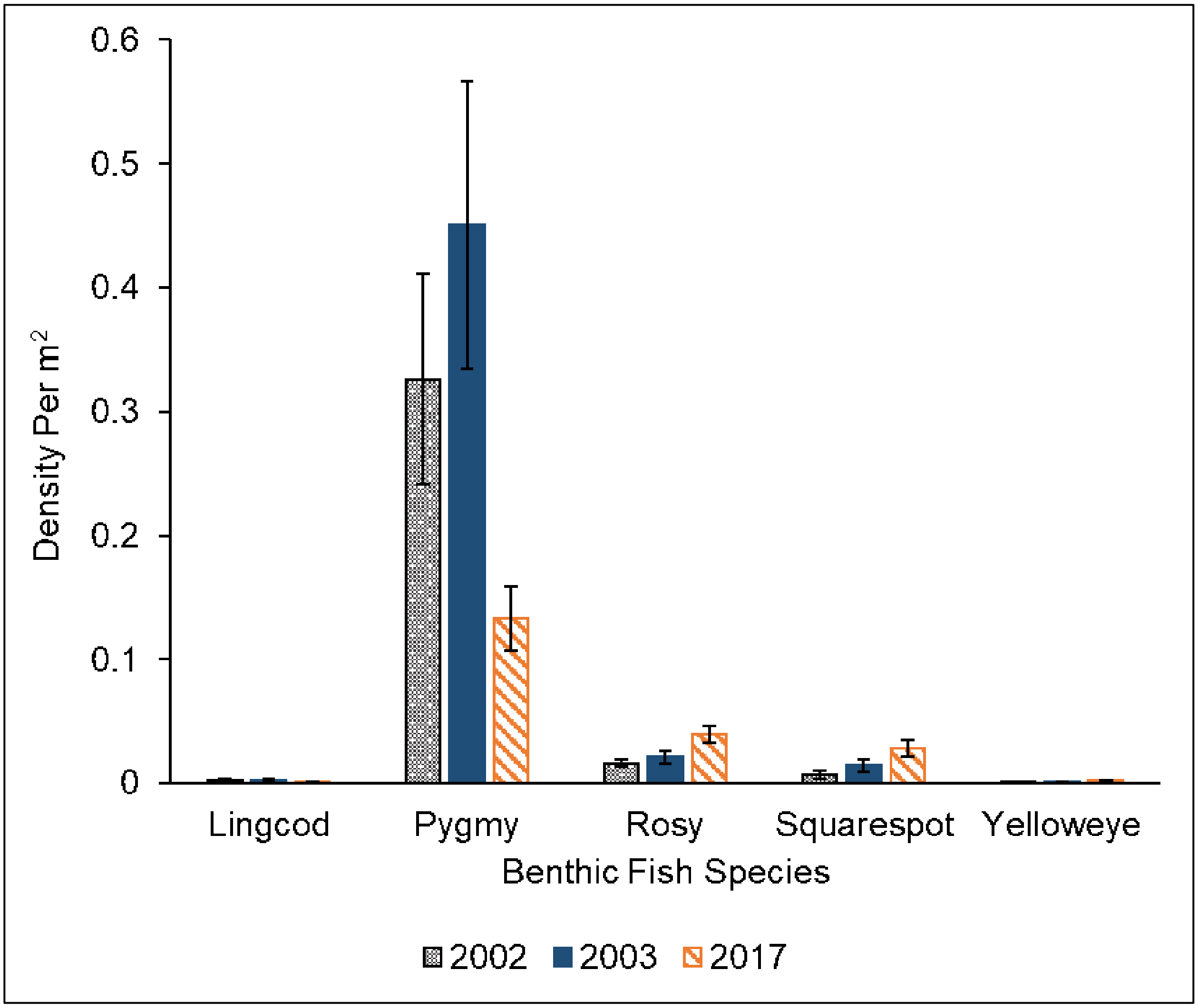


Figure App.E.13.9. Average fish densities (per m^2) and standard error from depths 70–120 meters on Cordell Bank. Source: CBNMS, 2020; Image: NOAA

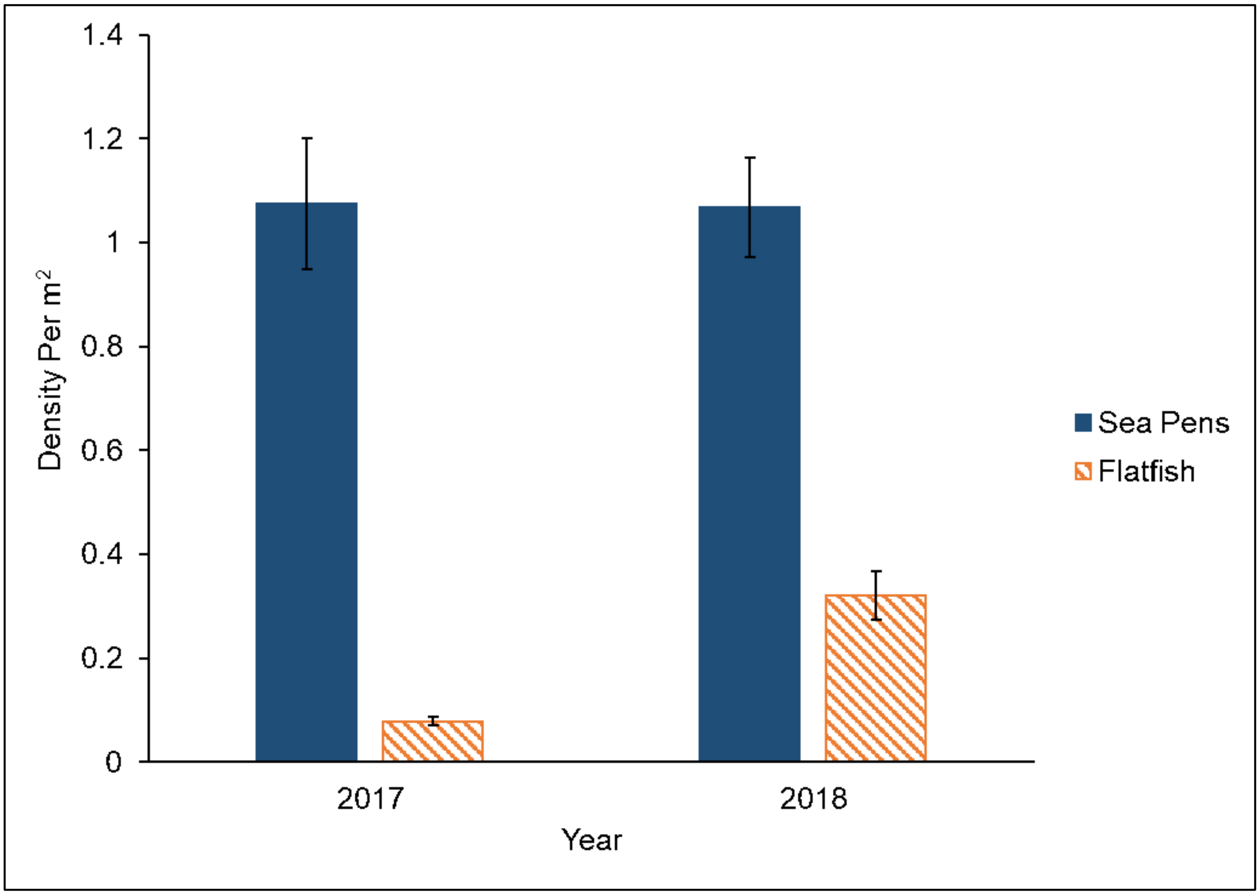


Figure App.E.13.10. Average sea pen and flatfish densities (per m^2) and standard error on continental shelf soft sediment habitat. Source: CBNMS, 2020; Image: NOAA

Question 15: What is the status of biodiversity and how is it changing?

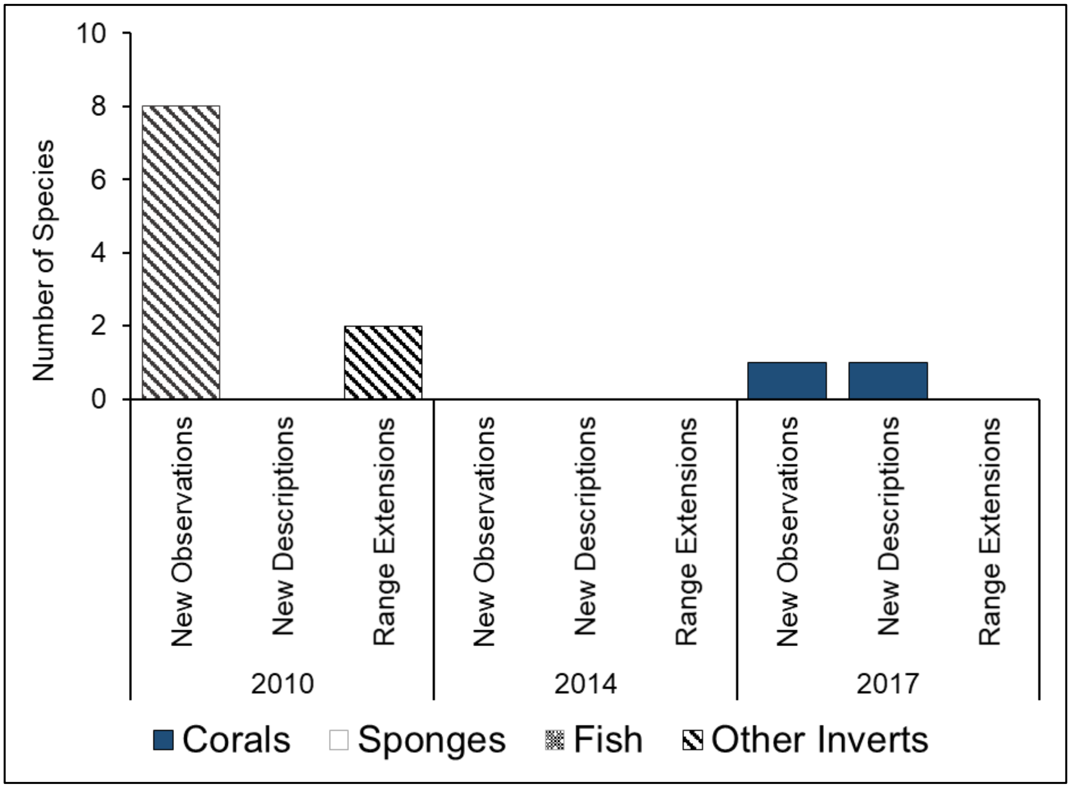


Figure App.E.15.1. Total number of new macroinvertebrate and fish species observations, descriptions and range extensions from benthic surveys on Cordell Bank. Collections were made by scuba in 2010 (37–59 m) and by ROV in 2014 and 2017 (46–119 m). Source: CBNMS, 2020, 20201a; Image: NOAA

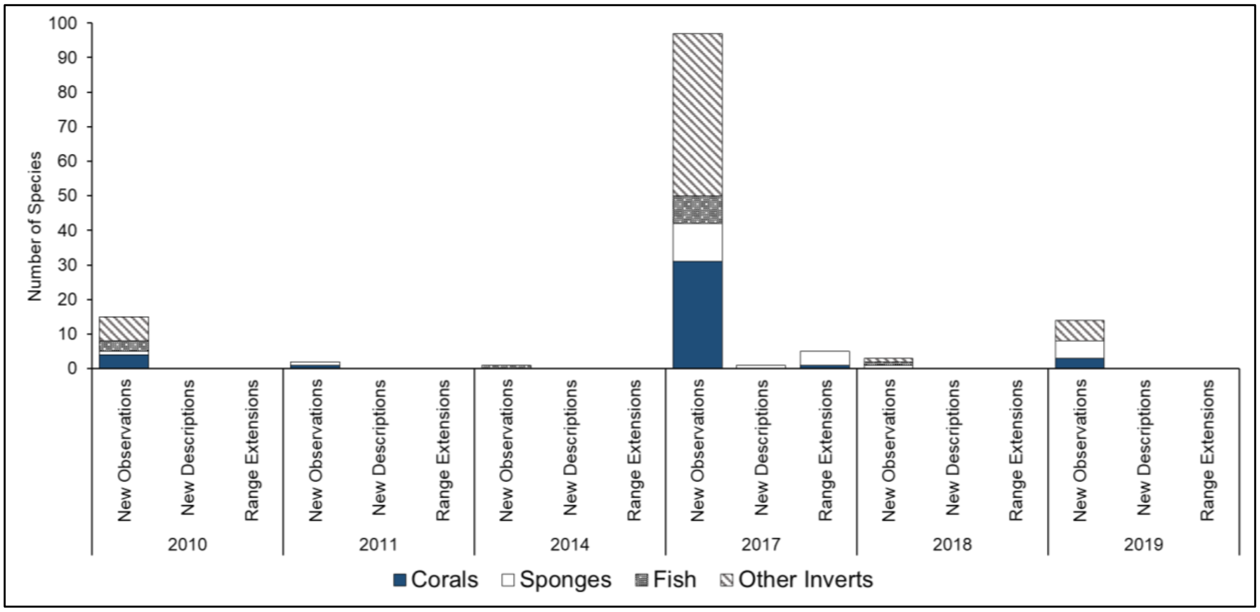
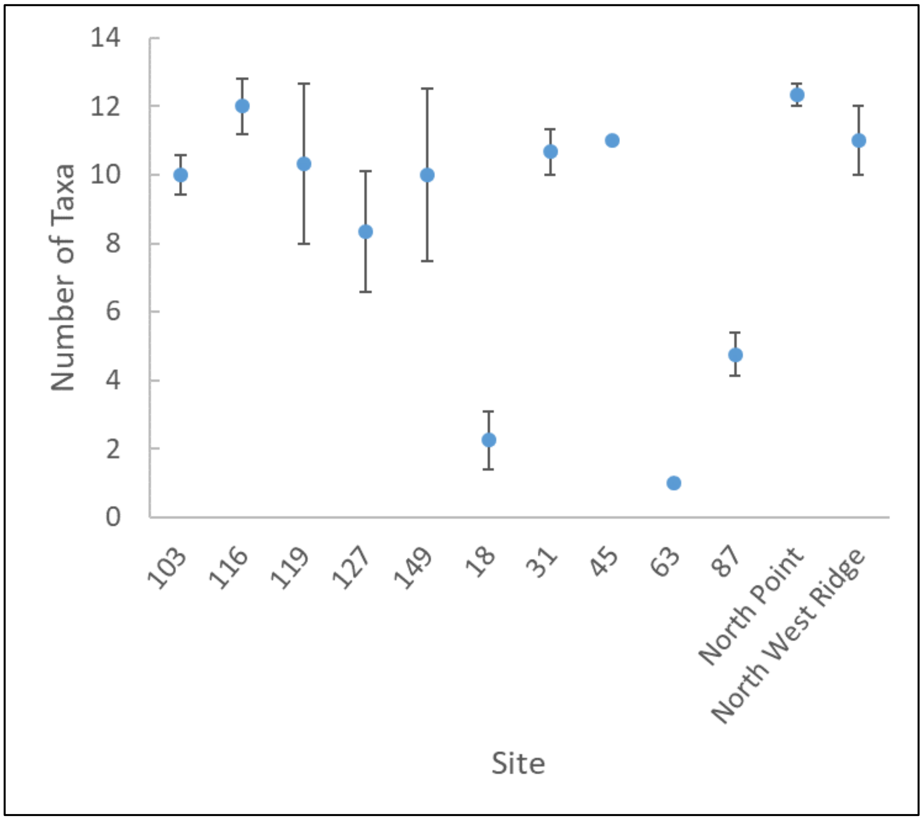
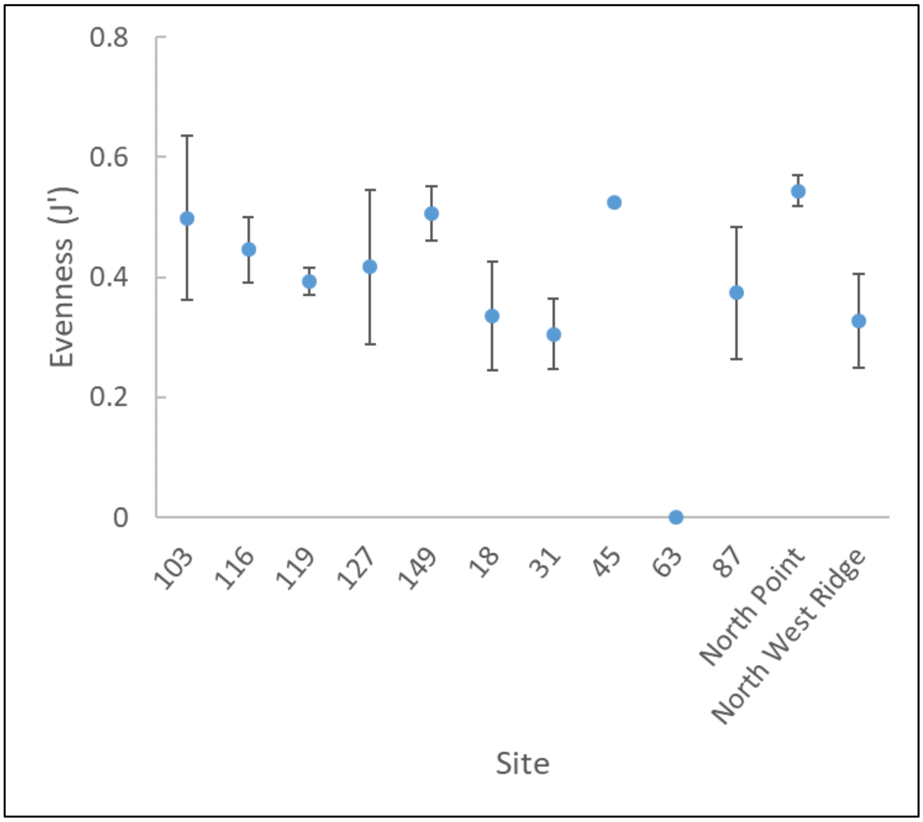


Figure App.E.15.2. Total number of new macroinvertebrate and fish species observations, descriptions, and range extensions from benthic surveys on the shelf, slope, and canyons in CBNMS (167–3,318 m depth). Surveys in 2010 and 2014–2019 used an ROV and the 2011 survey used an AUV. More survey time and focused effort on species identification has led to new observations and range extensions as seen in the 2017 survey that had a total ROV dive time of 76 hours among five sites. Source: CBNMS, 2020, 2021a; Image: NOAA





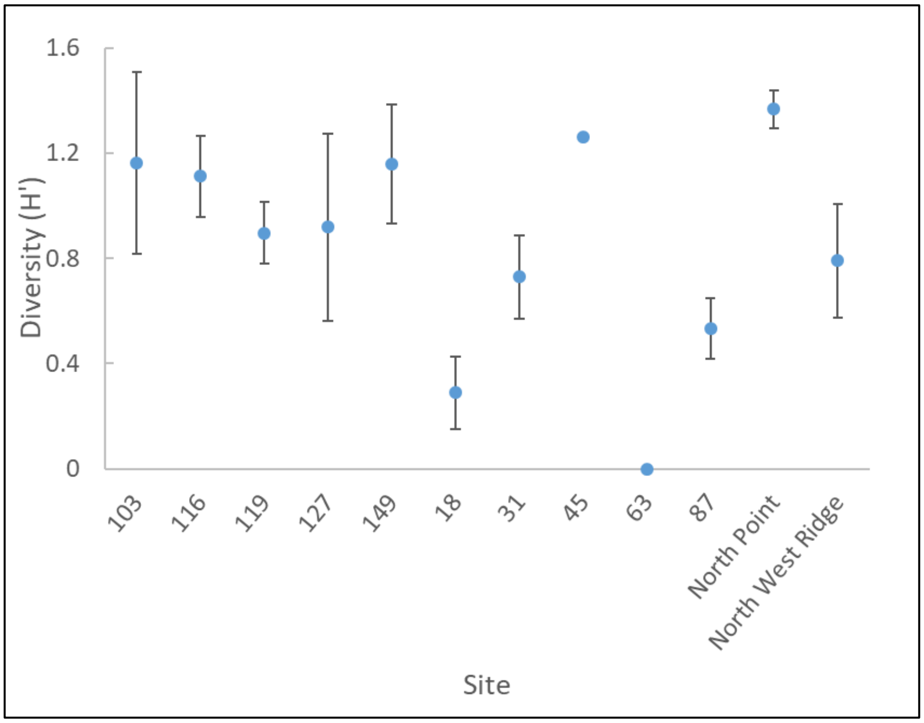
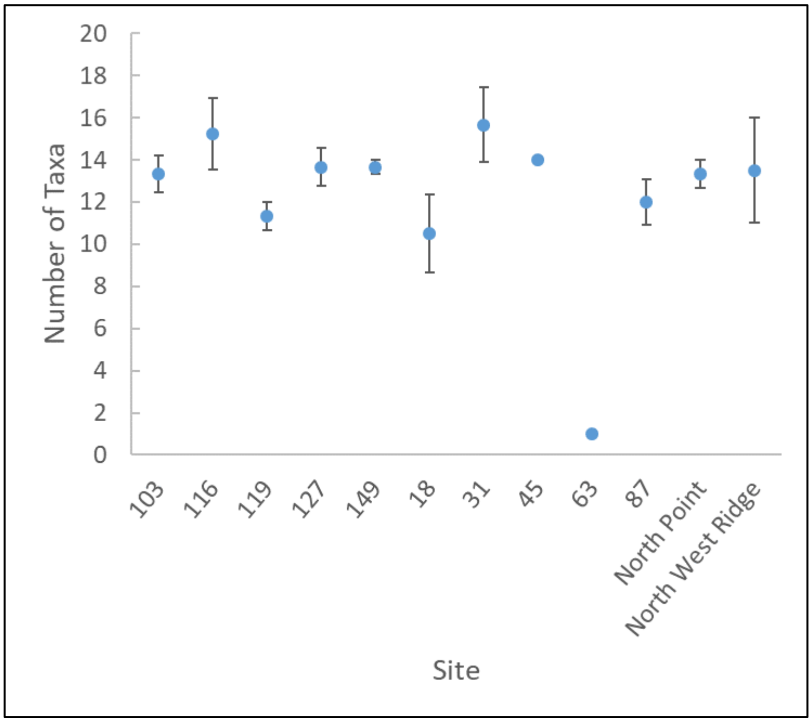
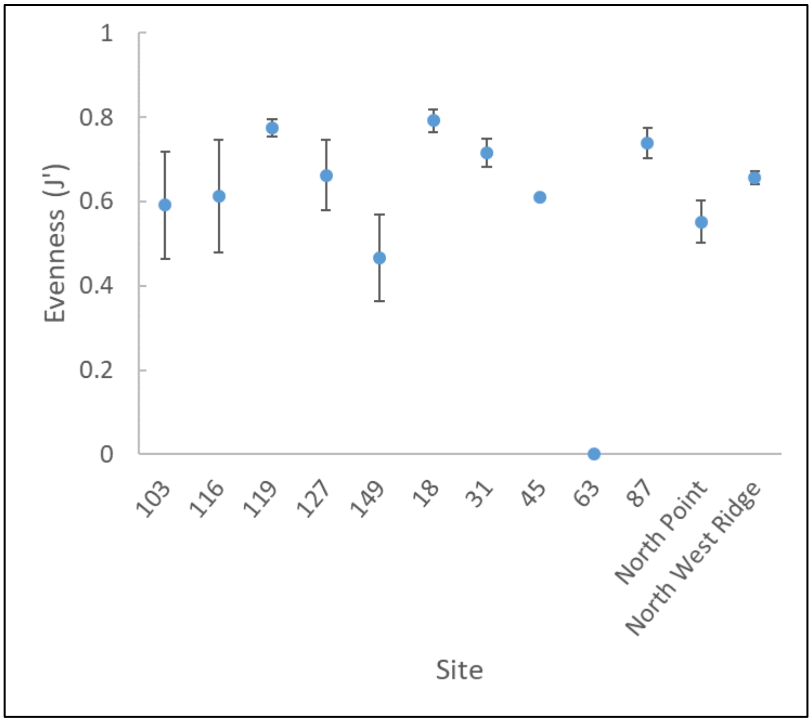


Figure App.E.15.3. Diversity metrics (mean ± standard error): number of taxa, evenness (J'), and diversity (H') of corals and sponges observed by ROV from sites (70–120 m depth) on Cordell Bank in 2017. Source: Graiff et al., 2019; Image: NOAA


Number of Taxa
20
18
16
14
12
10
8
6
4
2
0
103
116
119
127
149
18
31
45
63
87
North Point
North West Ridge
Site


Evenness (J')
1
0.8
0.6
0.4
0.2
0
103
116
119
127
149
18
31
45
63
87
North Point
North West Ridge
Site

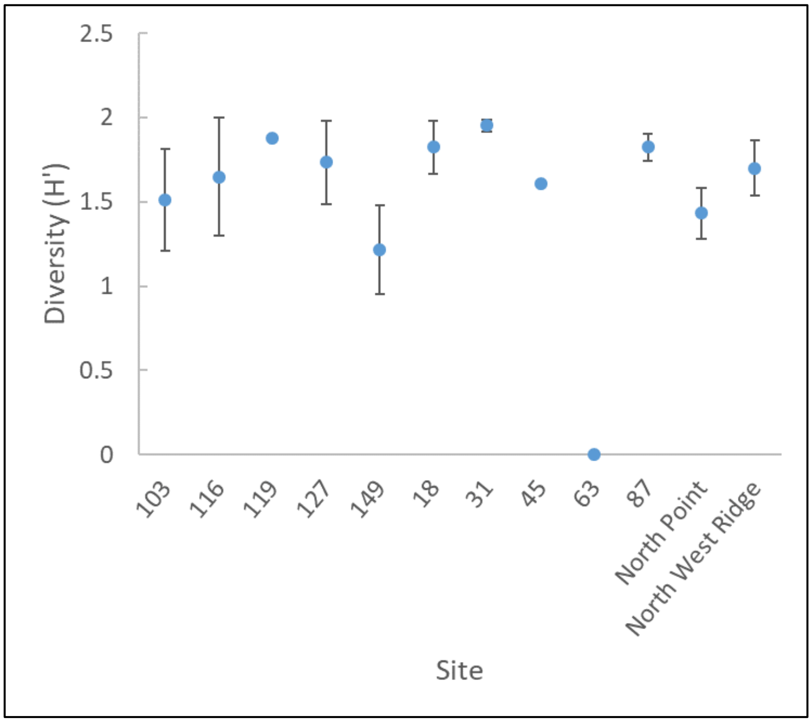
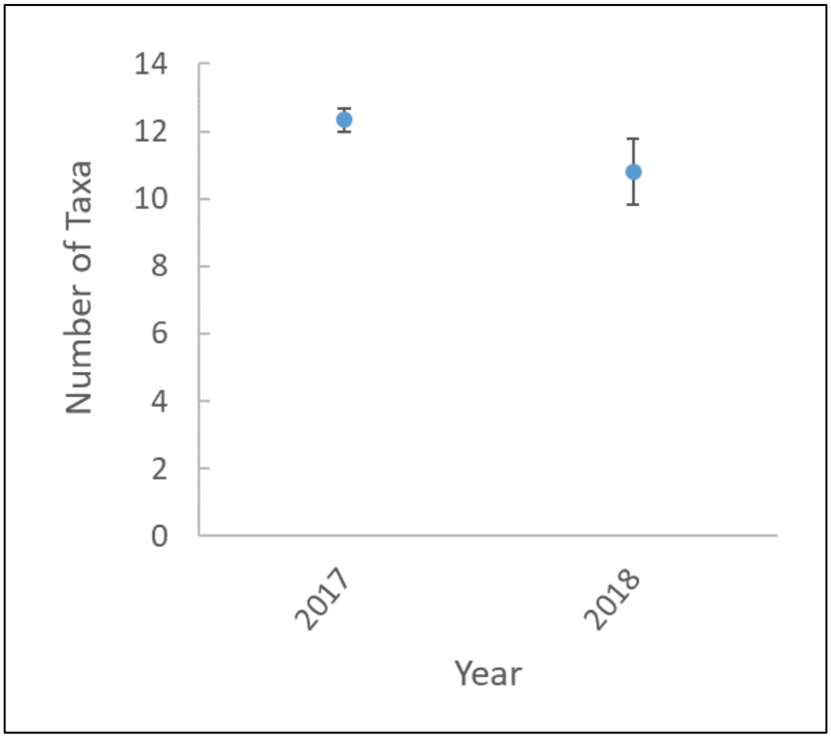
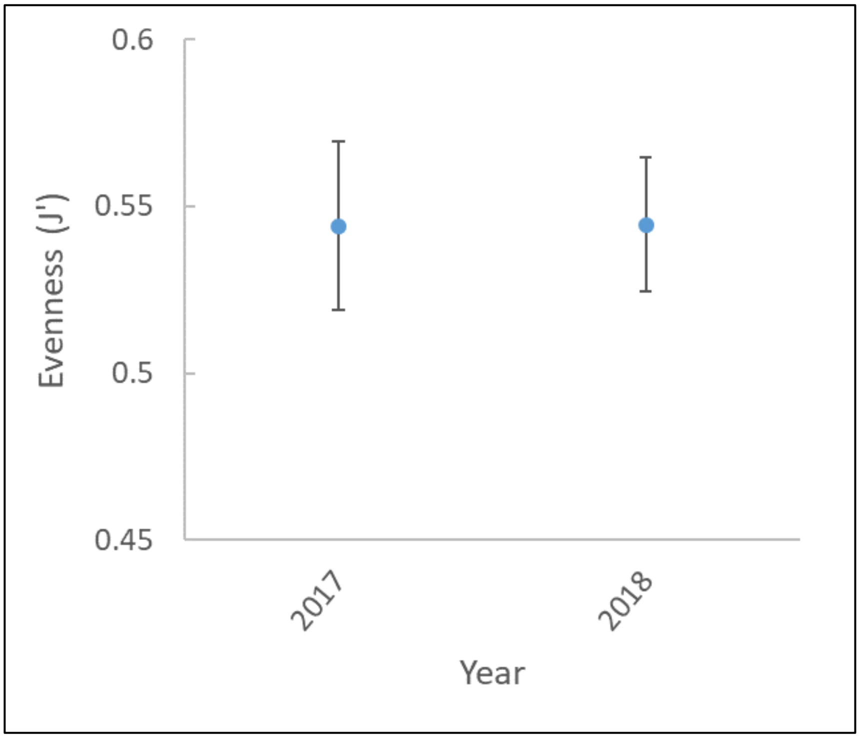


Figure App.E.15.4. Diversity metrics (mean ± standard error): number of taxa, evenness (J'), and diversity (H') of fish observed by ROV from sites (70–120 m depth) on Cordell Bank in 2017. Source: Graiff et al., 2019; Image: NOAA





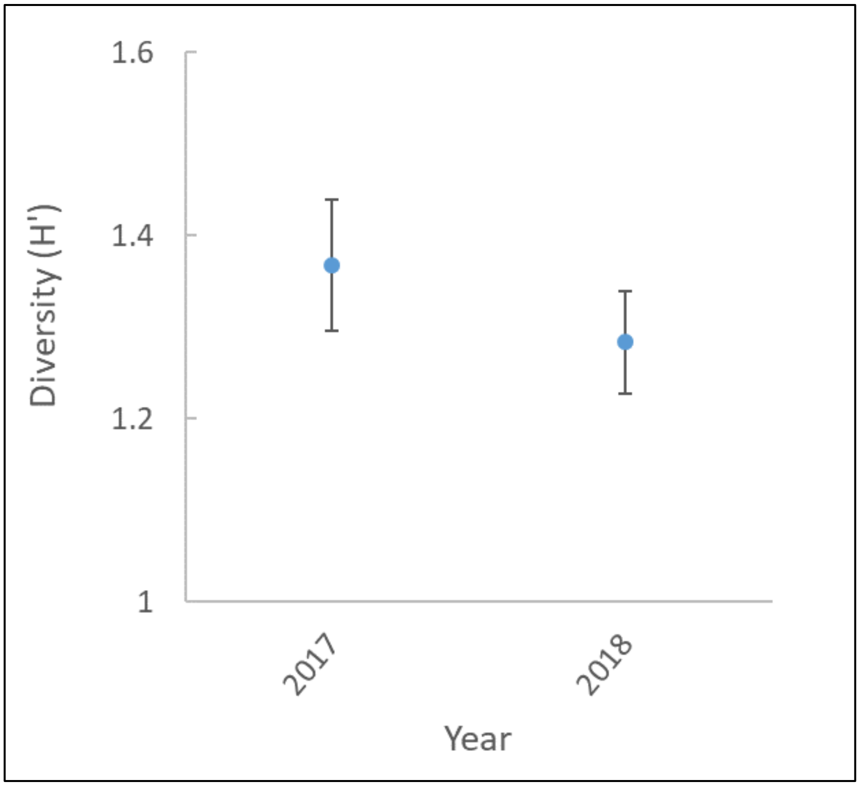
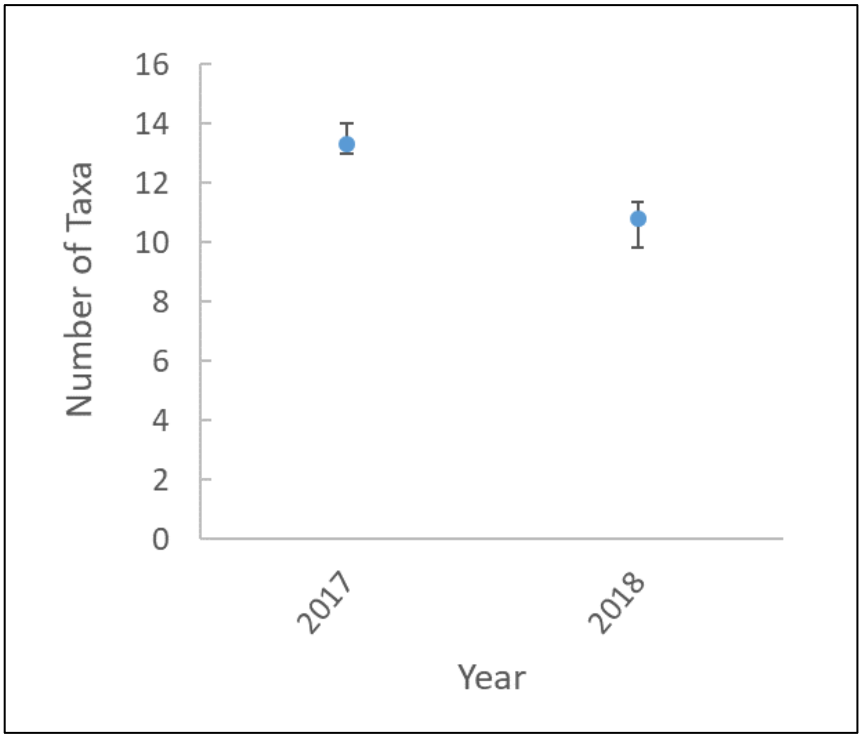
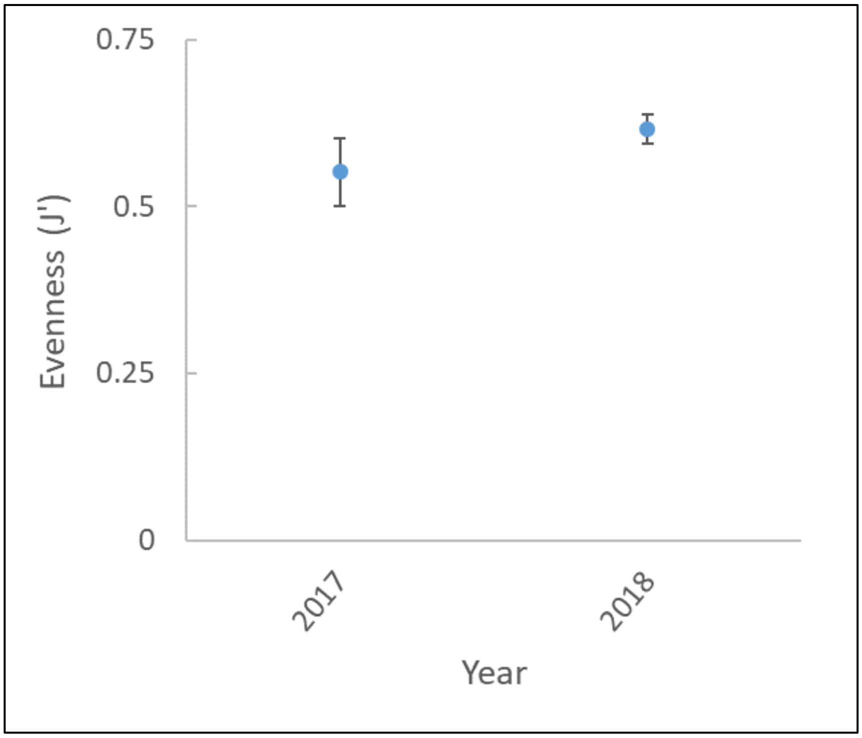


Figure App.E.15.5. Temporal comparison of diversity metrics (mean ± standard error): number of taxa, evenness (J'), and diversity (H') of corals and sponges from the fixed site North Point surveyed by ROV in 2017 and 2018. Source: Graiff et al., 2019; Graiff and Lipski, 2020a; Image: NOAA


Number of Taxa
16
14
12
10
8
6
4
2
0
2017
2018
Year


Evenness (J')
0.75
0.5
0.25
0
2017
2018
Year

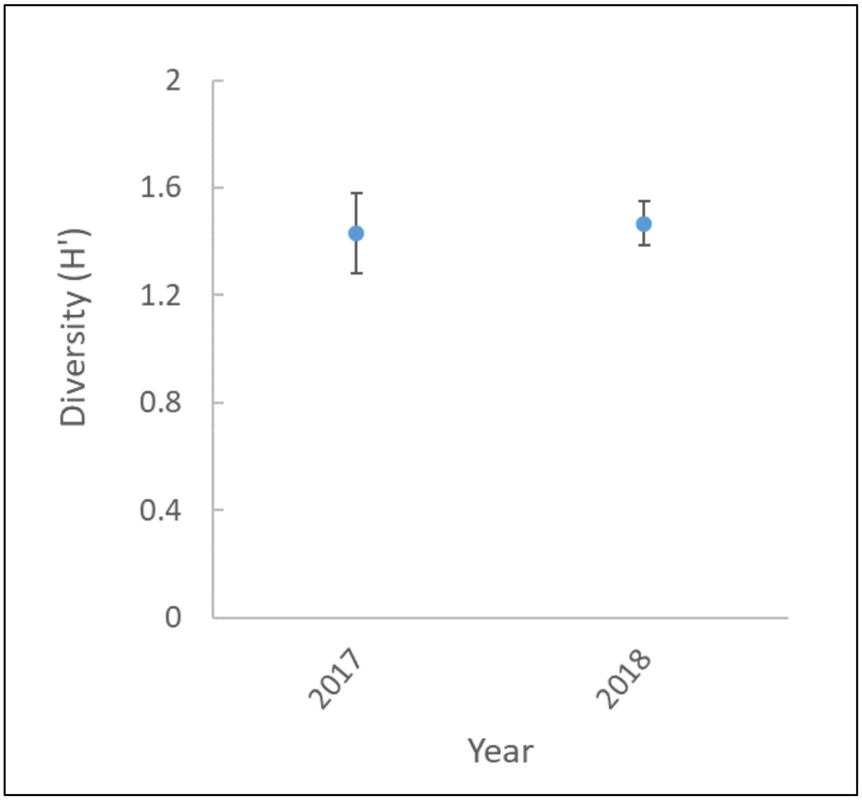
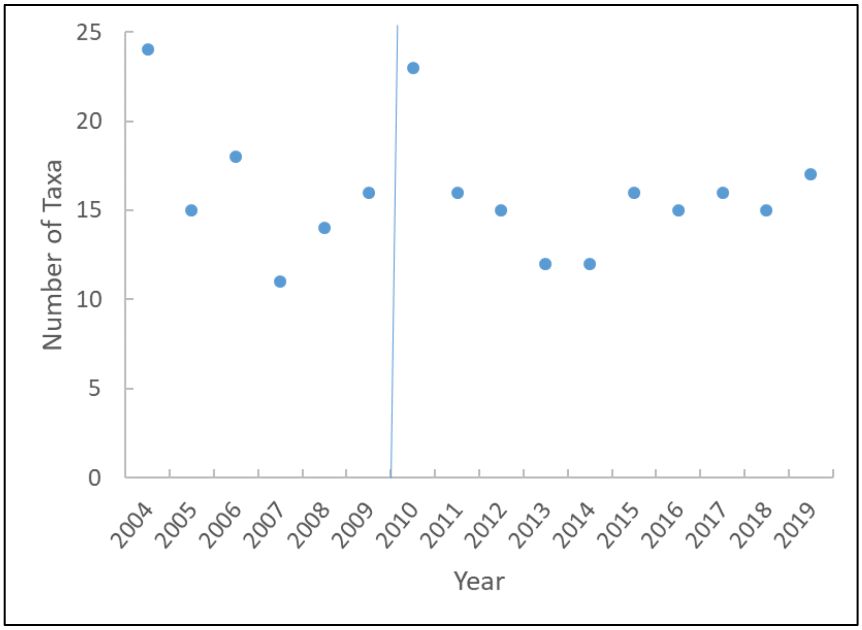
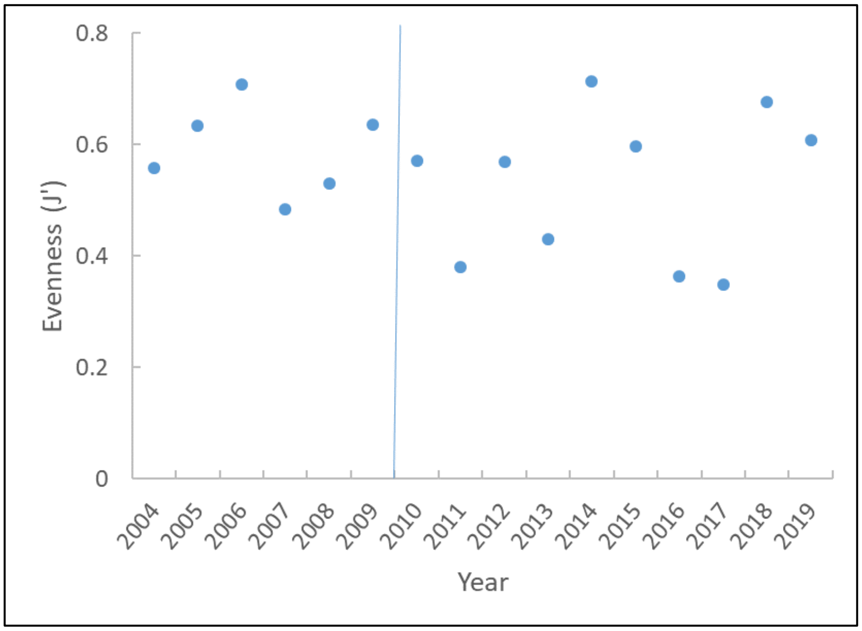


Figure App.E.15.6. Temporal comparison of diversity metrics (mean ± standard error): number of taxa, evenness (J'), and diversity (H') of fish from the fixed site North Point surveyed by ROV in 2017 and 2018. Source: Graiff et al., 2019; Graiff and Lipski, 2020a; Image: NOAA





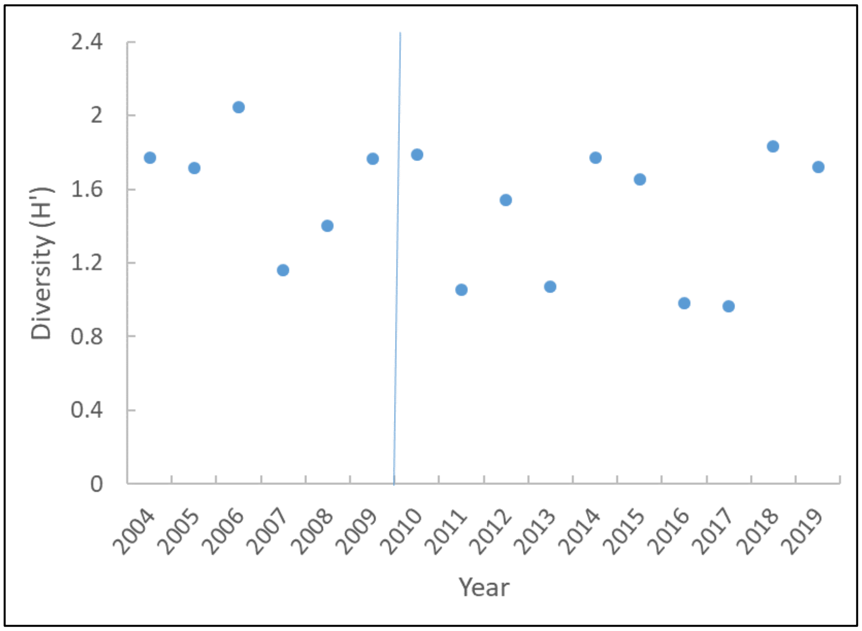


Figure App.E.15.7. Diversity metrics (mean ± standard error): number of taxa, evenness (J'), and diversity (H') of seabirds observed on ACCESS survey lines (1–10) in CBNMS and GFNMS from fall (Sept–Oct) surveys. Source: ACCESS, 2021; Image: NOAA

Appendix F:
Additional Ecosystem Services Tables

Additional Provisioning Figures

Commercial Harvest

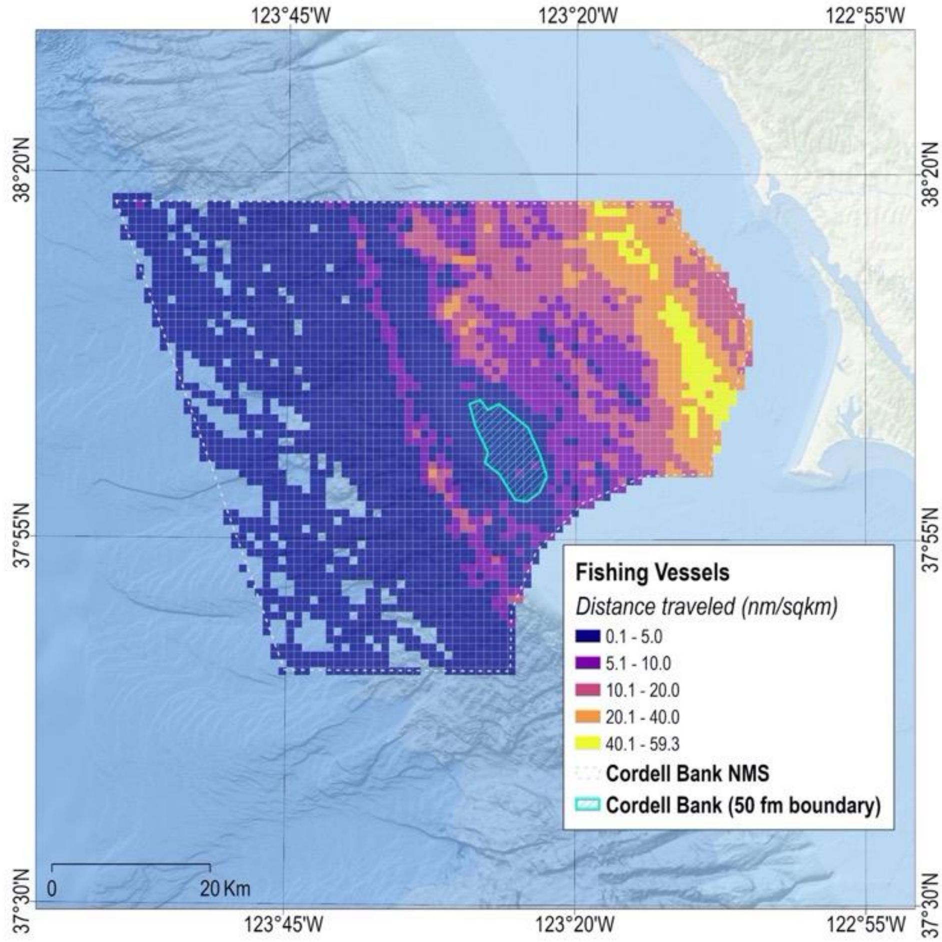


Figure App.F.CH.1. Distance traveled per grid cell (nm/km2) by all fishing vessels from 2009–2020. Note that there was no way to separate commercial fishing vessels from recreational fishing vessels for AIS data across all years. Source: United States Coast Guard, 2021; Image: NCCOS

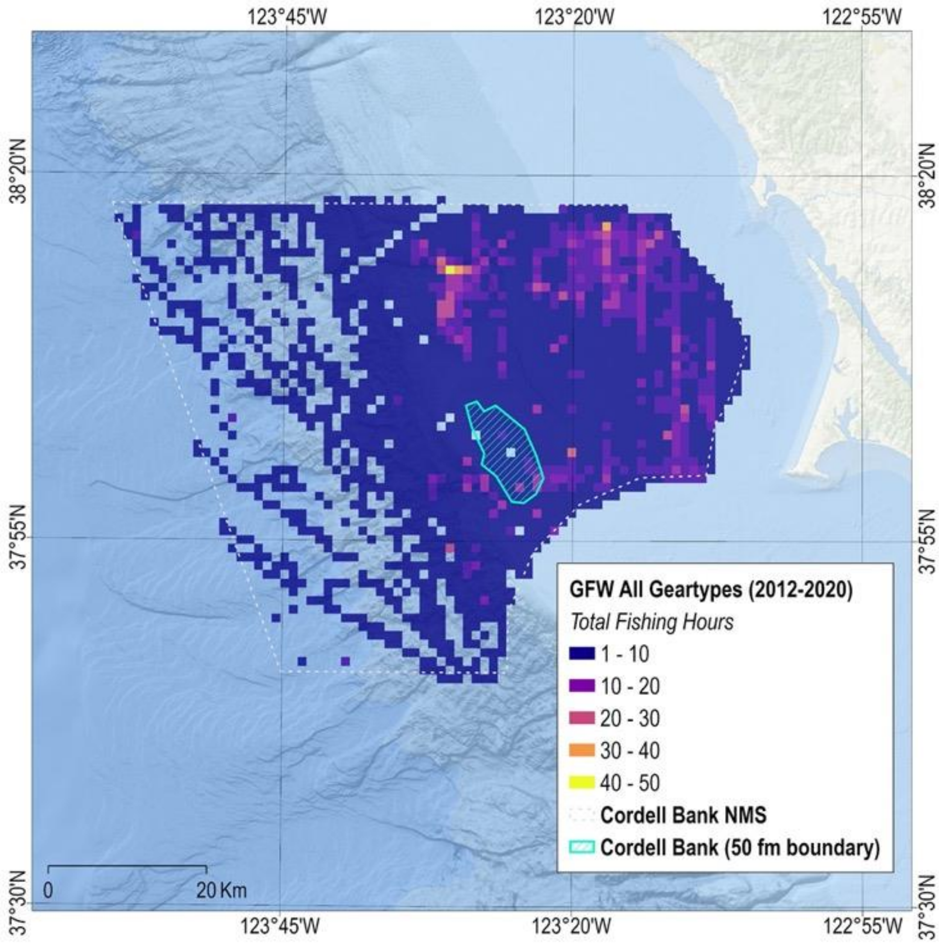


Figure App.F.CH.2. Total fishing hours for all gear types, 2012–2020. Source: Global Fishing Watch,[33] 2021; Image: NCCOS

[33] Global Fishing Watch has made every attempt to ensure the completeness, accuracy and reliability of the information provided on this Site. However, due to the nature and inherent limitations in source materials for information provided, Global Fishing Watch qualifies all designations of vessel fishing activity, including synonyms of the term "fishing activity," such as "fishing" or "fishing effort," as "apparent," rather than certain. And accordingly, the information is provided "as is" without warranty of any kind.

Consumptive Recreation

Table App.F.CR.1. Economic contribution of CPFVs from 2013–2018. Economic contributions in 2016 were low compared to other years. Source: CDFW, 2020a

Year	Employment	Income	Output
2013	0.25	$15,249	$31,670
2014	0.46	$28,249	$58,668
2015	0.29	$17,749	$36,862
2016	0.15	$9,250	$19,210
2017	0.44	$26,999	$56,072
2018	0.43	$26,499	$55,034
Total	2	$123,995	$257,516

Non-Consumptive Recreation

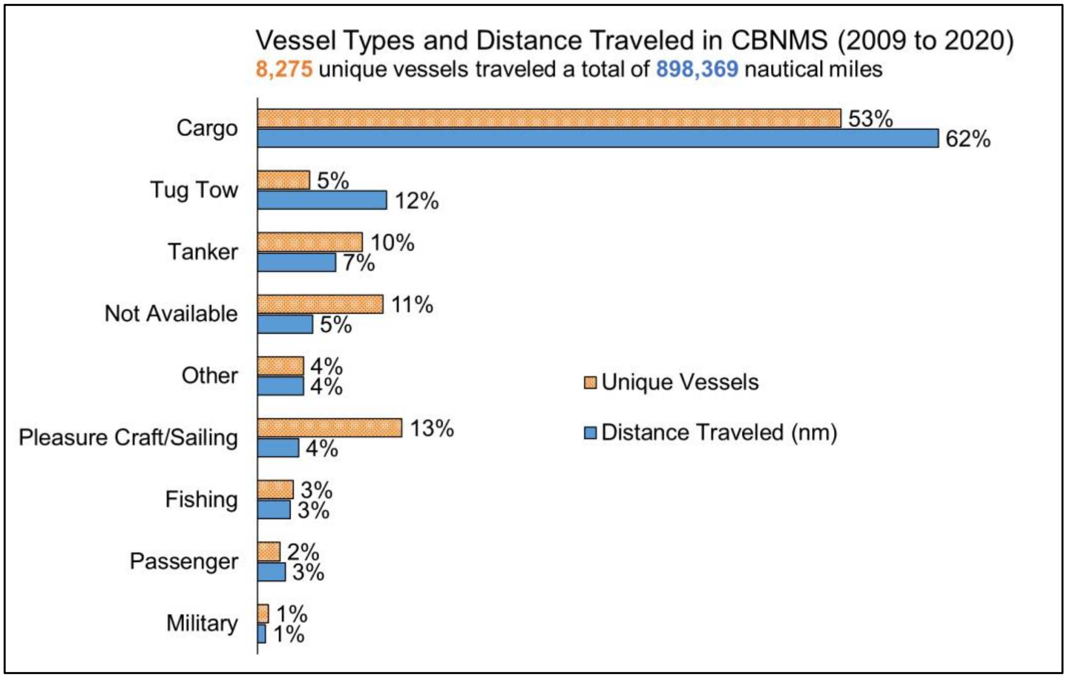


Figure App.F.NCR.1. Unique vessels and distance traveled by all vessels in CBNMS, 2009–2020. Source: United States Coast Guard, 2021; Image: NCCOS

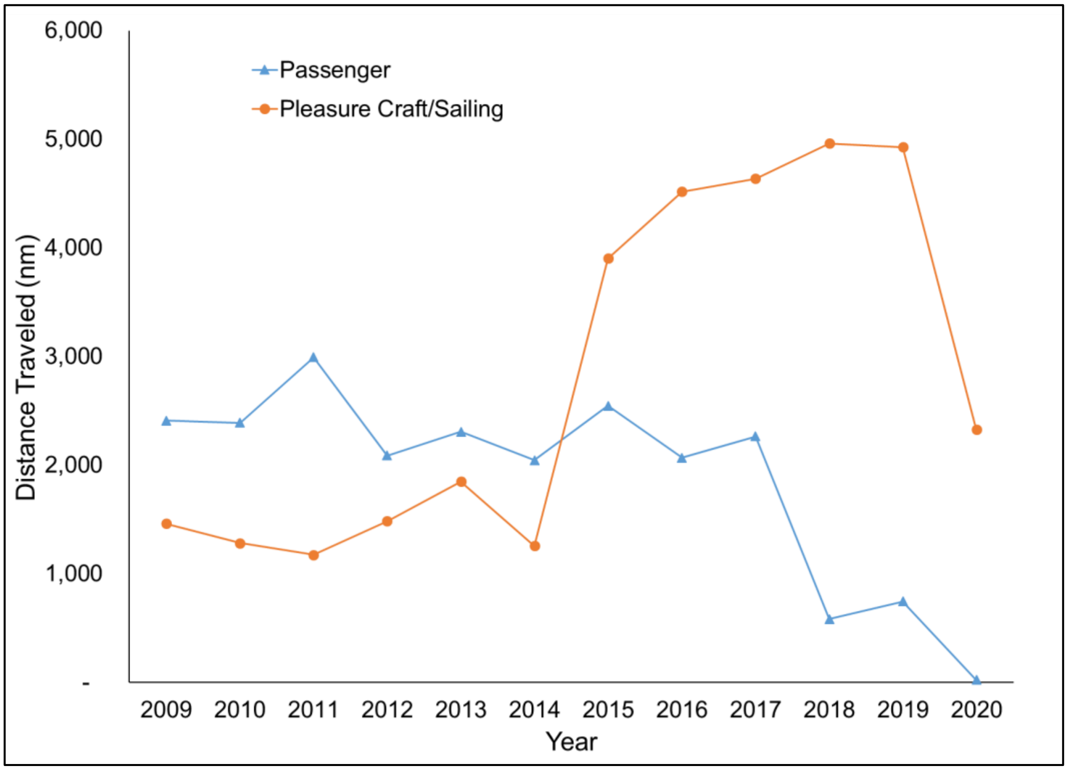


Figure App.F.NCR.2. Trends in distance traveled of AIS-carrying vessels in CBNMS, 2009–2020. Distance traveled by passenger vessels declined over the time period. The distance traveled by pleasure craft and sailing vessels increased to a decadal high of nearly 5,000 nm in 2018 and 2019, then declined dramatically in 2020. Source: United States Coast Guard, 2021; Image: NCCOS

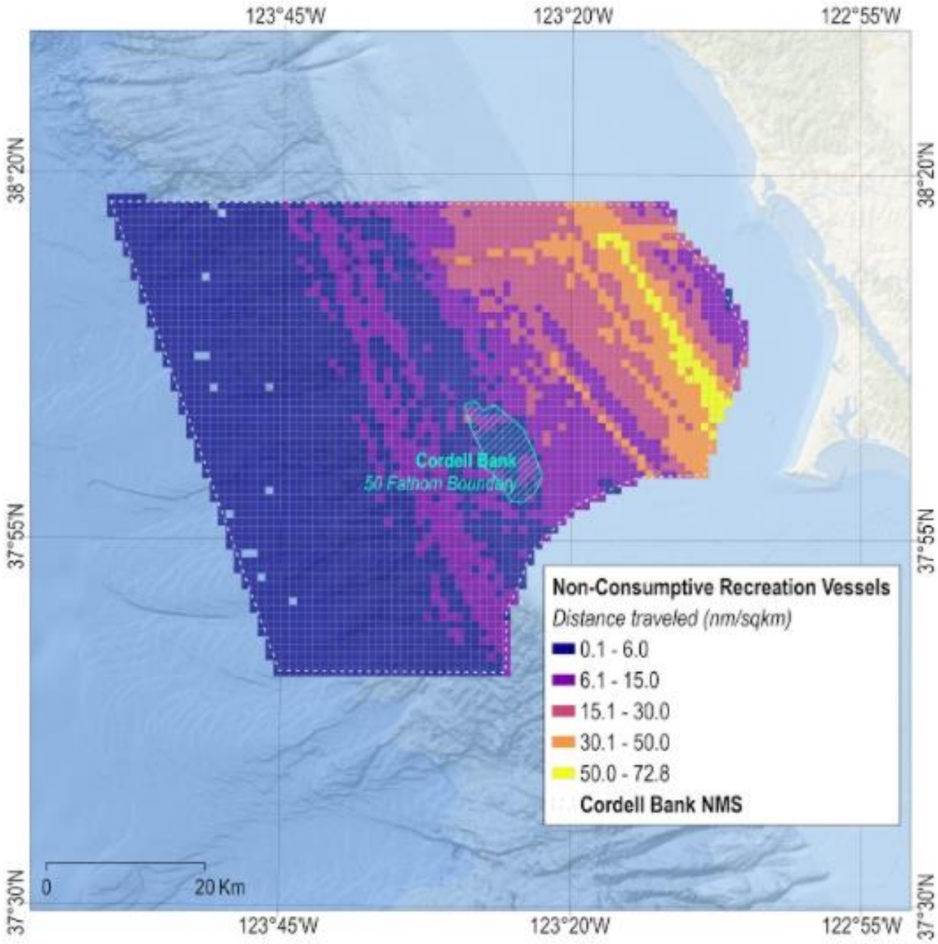


Figure App.F.NCR.3. Non-consumptive recreation vessel presence, 2009–2020. Much of the vessel traffic was concentrated in the eastern portion of the sanctuary, closer to the coast. Each grid cell represents 1 km2, with the cell color corresponding to the distance traveled through that cell over the time period. Source: United States Coast Guard, 2021; Image: NCCOS

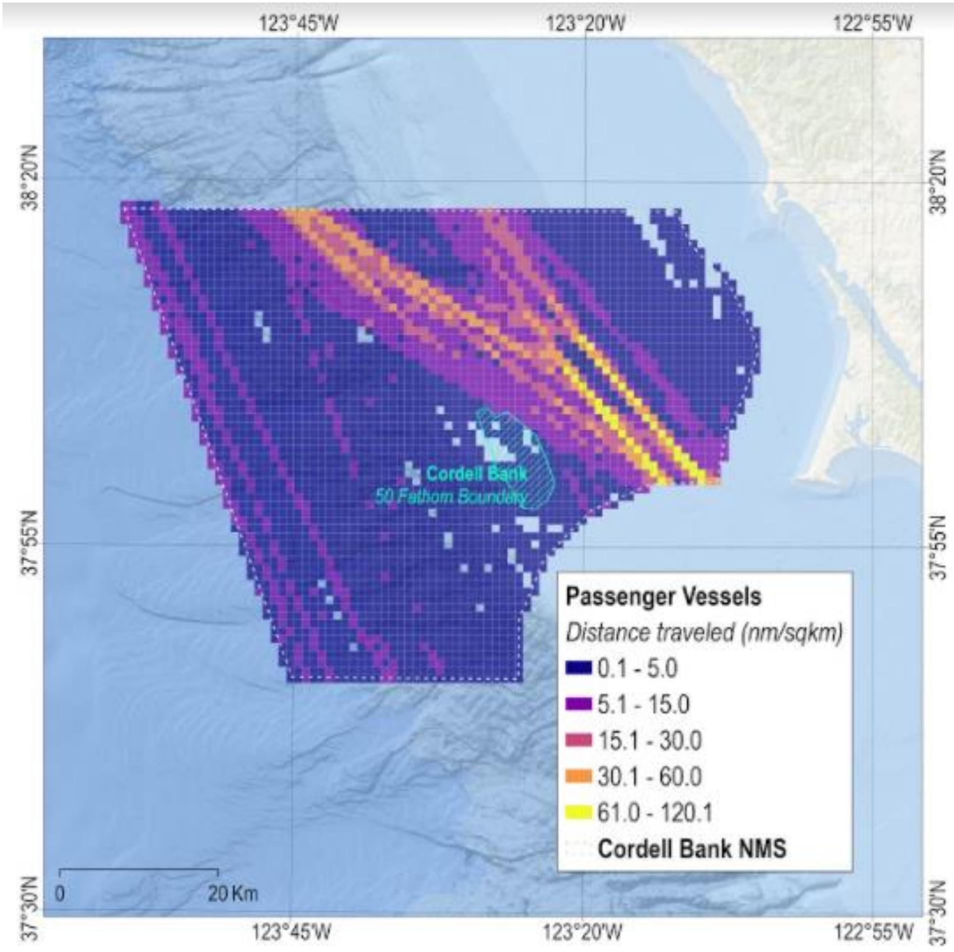


Figure App.F.NCR.4. Passenger vessel presence, 2009–2020. Passenger vessel traffic was concentrated in distinct lanes of travel. Source: United States Coast Guard, 2021; Image: NCCOS

Appendix G: List of Acronyms

ACCESS	Applied California Current Ecosystem Studies
AIS	automatic identification system
CARB	California Air Resources Board
CBNMS	Cordell Bank National Marine Sanctuary
CCIEA	California Current Integrated Ecosystem Assessment
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CPFV	commercial passenger fishing vessel
CPUE	catch per unit effort
CTD	conductivity, temperature, and depth
DA	domoic acid
DDT	dichlorodiphenyltrichloroethane
DPSER	Driving forces (Drivers)-Pressure-State-Ecosystem Services-Response
ECA	Emission Control Areas
EEZ	Exclusive Economic Zone
EU	European Union
GFNMS	Greater Farallones National Marine Sanctuary
HAB	harmful algal bloom
IMO	International Maritime Organization
MBNMS	Monterey Bay National Marine Sanctuary
MTL	mean trophic level
NIS	non-indigenous species
NMFS	National Marine Fisheries Service
NOAA	National Ocean and Atmospheric Administration
NPP	net primary productivity
ONMS	Office of National Marine Sanctuaries
PCB	polychlorinated biphenyl
pDA	particulate domoic acid
ROV	remotely operated vehicle
SST	sea surface temperature
TSS	Traffic Separation Scheme
USCG	U.S. Coast Guard
VMS	vessel monitoring system

NATIONAL MARINE
SANCTUARIES

AMERICA'S UNDERWATER TREASURES

https://sanctuaries.noaa.gov