Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

GREATER FARALLONES & CORDELL BANK NATIONAL MARINE SANCTUARIES

CONDITION REPORT

2010–2022

GREATER FARALLONES

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Cover photo: Many species use the rich and productive waters of Greater Farallones National Marine Sanctuary for feeding, including iconic humpback whales and a variety of seabirds. Photo: Douglas Croft

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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 national marine sanctuaries and 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.

Greater Farallones National Marine Sanctuary

Just beyond San Francisco's Golden Gate lies a globally significant ecosystem. Few ocean regions in the world host the diversity and abundance of marine life found in Greater Farallones National Marine Sanctuary (GFNMS). The unique combination of seafloor contours, ocean currents, and wind patterns, along with energy from the sun, triggers an explosion of life in these waters. Huge blooms of microscopic phytoplankton are consumed by zooplankton, which in turn provide a feast for fishes, seabirds, seals, whales, sharks, and humans. GFNMS protects this rich marine ecosystem through research, education, conservation, and stewardship programs.

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 national marine sanctuaries and 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. The evolution of the condition report process is described in greater detail 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. Earlier condition reports were structured around a Pressures-State-Response framework; however, this approach was expanded to better understand the drivers that influence pressures as well as resulting changes in ecosystem service benefits and how these might influence management actions (ONMS, 2018a). 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).

[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.

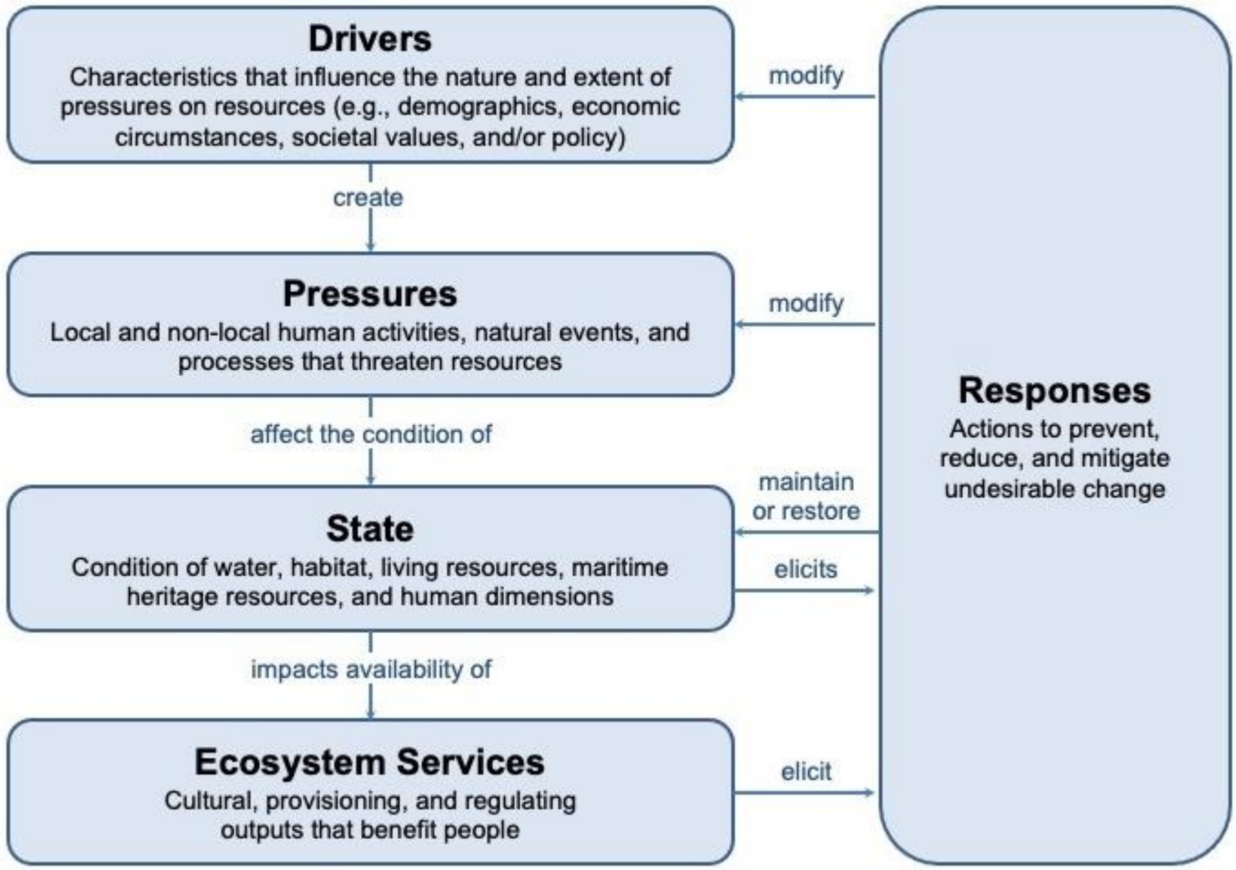


Figure FCR.1. This diagram of the DPSER framework illustrates the functional connections between components and the targets of management responses designed to modify driving forces, pressures, and resource conditions. Image: NOAA

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 GFNMS was released in 2010 (ONMS, 2010); ratings from that report are provided in Appendix E. Two notable management changes have occurred since the last condition report. In 2015, the sanctuary expanded and changed its name from Gulf of the Farallones National Marine Sanctuary to Greater Farallones National Marine Sanctuary. In 2021, the staff merged with Cordell Bank National Marine Sanctuary to form one joint management unit to administer the two sanctuaries (however, this condition report focuses solely on GFNMS). This updated condition report marks a second comprehensive description of the status and trends of sanctuary resources and ecosystem services. Because of the considerable differences between the sanctuary's coastal and offshore region and estuarine and lagoon region, these two environment types were assessed separately. The findings in this condition report document status and trends in water quality, habitat, living resources, maritime heritage resources, and ecosystem services from 2010–2022, 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 GFNMS management plan. The management plan helps guide future work and resource allocation decisions at GFNMS by describing strategies and activities designed to address priority issues and advance core sanctuary programs. The next update to the sanctuary management plan will build on the 2014 management plan, which details a number of actions to address issues and concerns (ONMS, 2014a). Updating the management plan 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 2010–2022, unless otherwise noted. The State of Ecosystem Services section includes an assessment of human benefits derived from science, education, heritage, sense of place, consumptive recreation, non-consumptive recreation, commercial harvest, and coastal protection 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.

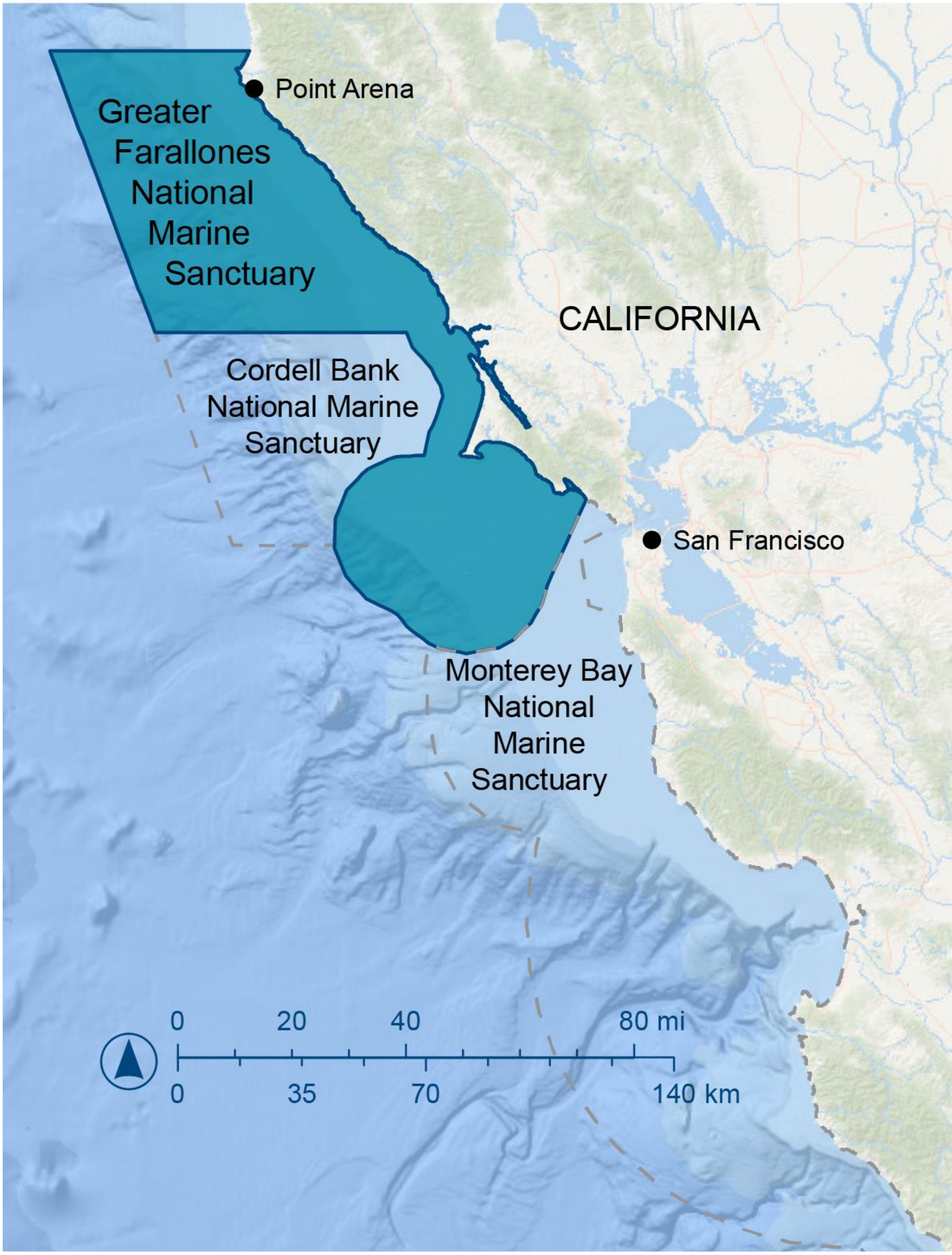
Two other important changes to the condition report process since 2010 should be noted. First, in response to feedback provided to ONMS, the process used to generate the current condition report is more quantitatively robust and repeatable. This was achieved by using the NOAA Integrated Ecosystem Assessment framework (NOAA, 2020), which takes a data-driven 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

Greater Farallones National Marine Sanctuary (GFNMS) was designated in 1981 and expanded to its current size of 3,295 square miles in 2015. GFNMS is located off the California coast, extending west of southern Mendocino, Sonoma, Marin, San Francisco, and San Mateo counties. The sanctuary extends from the mean high tide line, with exceptions, to the continental margin at or about the 10,000-foot depth contour. The sanctuary is adjacent to Cordell Bank National Marine Sanctuary (CBNMS), sharing CBNMS's northern and eastern boundaries, and Monterey Bay National Marine Sanctuary (MBNMS), sharing MBNMS's northern boundary. GFNMS includes Estero Americano, Estero de San Antonio, Tomales Bay, and Bolinas Lagoon, as well as the waters surrounding the Farallon Islands.



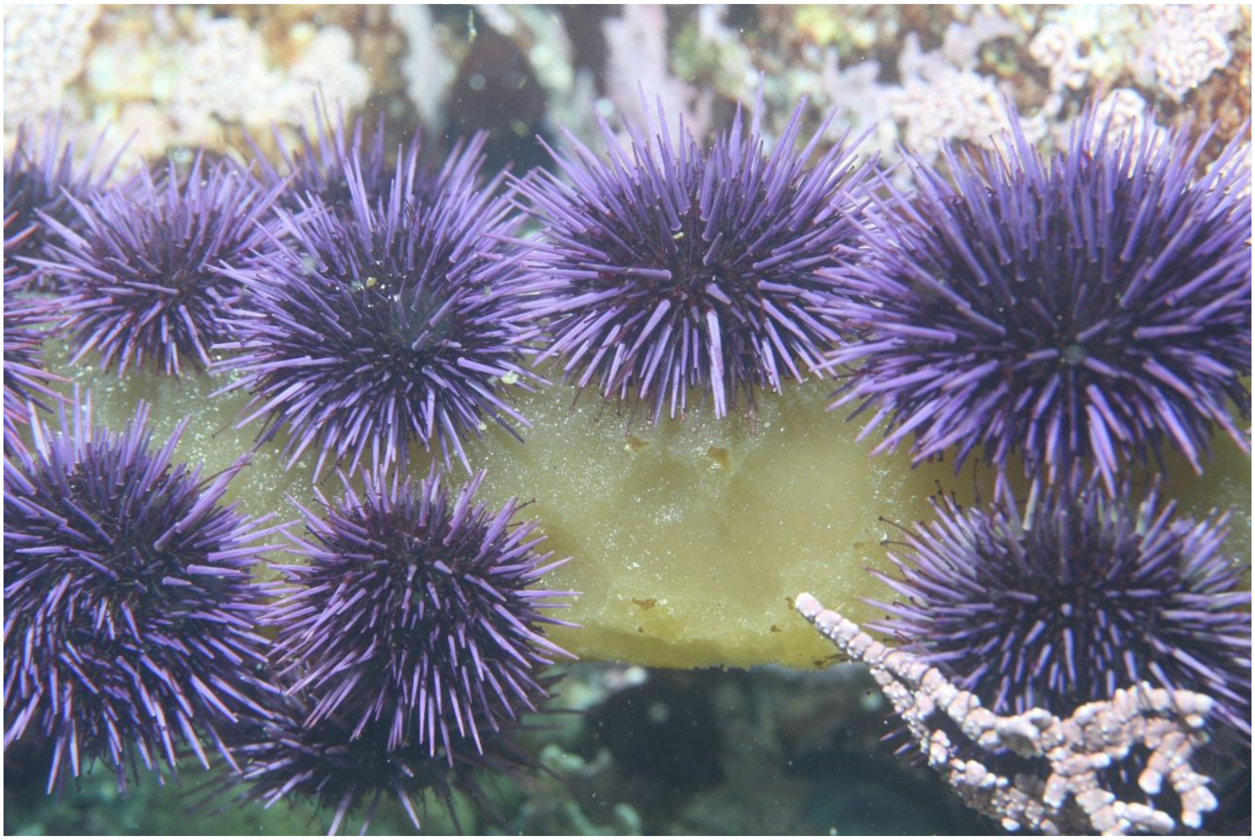
GFNMS encompasses 3,295 square miles, and is located off the northern and central California coast. Image: Dayna McLaughlin/NOAA

This condition report uses the best available information to assess the status and trends of the sanctuary's resources and ecosystem services from 2010 to 2022. The report, structured around a Drivers-Pressures-State-Ecosystem Services-Response model, covers water quality, habitat, living resources, and maritime heritage resources, and 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.

Pressures on the Sanctuary

The primary pressures identified for GFNMS were climate change, land use, marine harvest activities, vessel activity, marine debris, wildlife disturbance, and non-indigenous species. Below is a summary of the primary pressures and the status of these pressures in the sanctuary.

Climate change affects 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 rising ocean temperatures, marine heatwaves, habitat compression, and ocean acidification, as well as sea level rise and changes in storm frequency and intensity, which can cause secondary pressures such as changes to shorelines and sediment transport. The marine heatwave in 2014–2016 was a significant event that resulted in unprecedented ecological and economic impacts in the region.

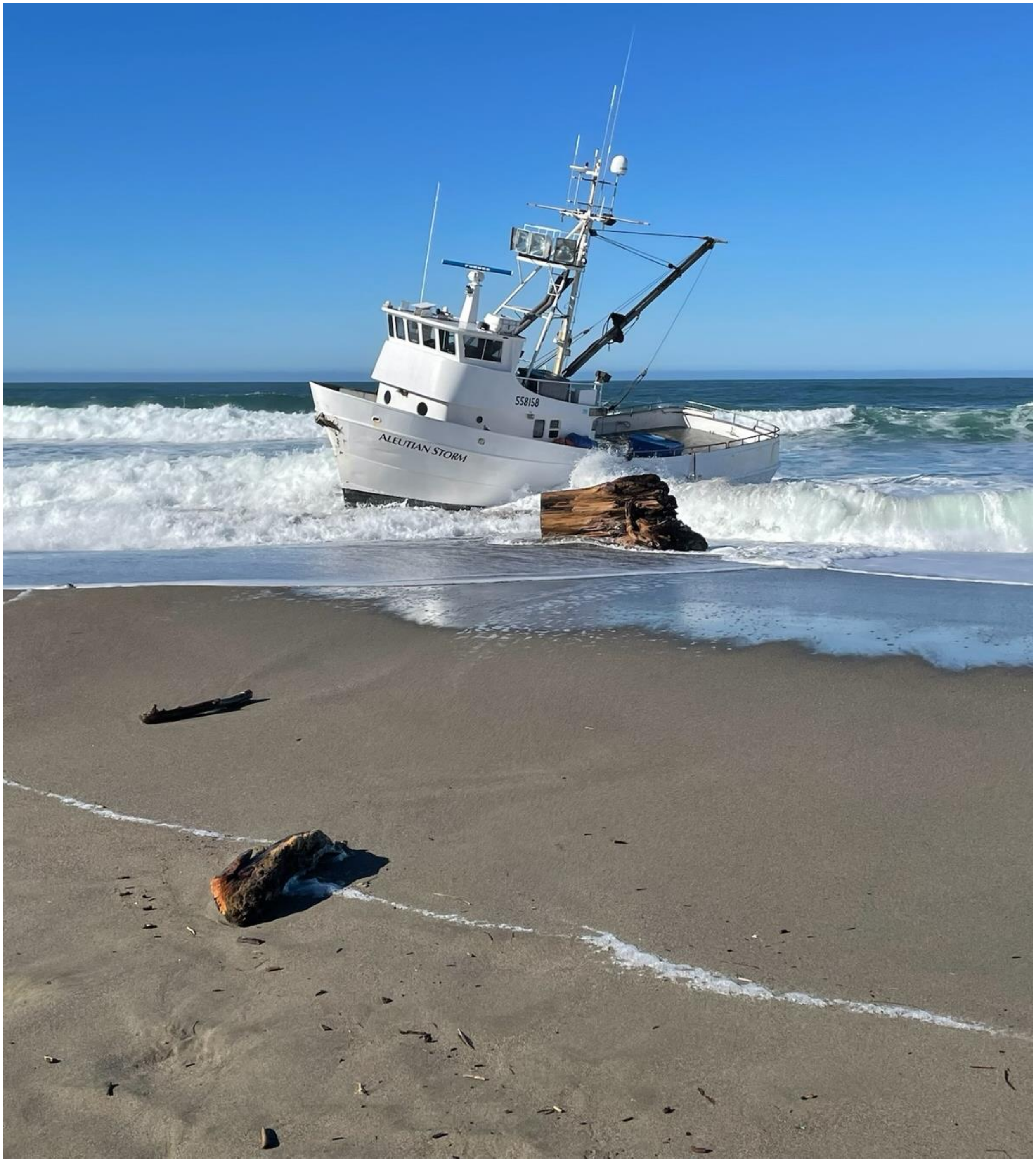


Greater Farallones National Marine Sanctuary has seen a series of compounding stressors that have led to extensive kelp declines in recent years, starting in 2014 (up to 95% in some regions) and loss of critical ecosystem function. Photo: Steve Lonhart/NOAA

Land use activities adjacent to the sanctuary, such as agriculture, transportation, urbanization, and construction create pollutants, including sediments, plastics, and chemicals that impact water quality, marine species, and habitats. In addition, artificial structures that harden or stabilize shorelines in and around Bolinas Lagoon and Tomales Bay (such as seawalls, rip rap, roadways, etc.) can reduce habitat quality and availability, as well as reduce natural buffering capacity, but are fairly minimal in the sanctuary. Historic mercury mining led to the impairment of Tomales Bay and connected watersheds.

Commercial and recreational fishing in GFNMS contribute to the local economy and culture, support jobs, and provide food, but also impact sanctuary habitats and species through harvest, bycatch, seafloor impacts, lost gear, and wildlife entanglement. Entanglement of humpback whales in Dungeness crab gear, as well as other types of debris, is a concern in GFNMS. Aquaculture operations in Tomales Bay produce marine debris and alter habitat through infrastructure installations on the seafloor.

Vessel impacts include damage to seafloor habitat from anchoring or grounded or sunken vessels; discharge of oil and sewage and debris in the water; air and water pollution via exhaust gas emissions; and noise pollution. Although no major vessel oil spill events occurred in the sanctuary during the study period, small oil discharges did occur, and cruise ships discharged large amounts of untreated blackwater and graywater, membrane bioreactor sludge, exhaust gas cleaning system effluent, and food waste. Unpermitted vessel moorings have been removed from Tomales Bay, which appears to have allowed eelgrass beds to recover. In addition to impacts on habitat, vessels may also directly affect living resources; vessel strikes to whales can lead to injury or death of the whale and are a concern in GFNMS.



Abandoned, derelict, or grounded vessels can damage sanctuary ecosystems by scouring or crushing sensitive marine habitats or by discharging oil and/or hazardous substances into the ocean. Photo: U.S. Coast Guard

Marine debris enters the sanctuary from both water and land-based activities, accumulates in the water column and benthic habitats, and also poses a risk of ingestion by wildlife. Marine debris of many varieties has been observed in all habitats in the sanctuary, and has entangled wildlife and damaged sensitive habitats and species. Lost fishing gear is the most common type of debris observed in benthic habitat.

When larger marine debris enters the sanctuary and sinks, it disturbs the seafloor environment, potentially crushing sensitive habitats and/or species. Photo: Ocean Exploration Trust/NOAA

Wildlife disturbance includes trampling sensitive intertidal species and close approaches from humans, dogs, boats, aircraft, and uncrewed aerial systems, which disturb seabirds and marine mammals. Birds were disturbed primarily by low-flying aircraft, and harbor seals were disturbed by humans, motorboats, and other sources; however, these disturbances did not appear to impact population sizes of harbor seals or seabirds or their use of the sanctuary. Overall levels of wildlife disturbance in recent years were lower compared to the previous decade.

Non-indigenous species in the marine and estuarine environment can alter species composition, threaten the abundance and diversity of native marine species, interfere with ecosystem function and disrupt fisheries. Non-indigenous species are present in GFNMS coastal and offshore and estuarine and lagoon habitats.

Status and Trends of Sanctuary Resources

In addition to describing pressures on the sanctuary, the condition report rates the status and trends of water quality, habitat, living resources, maritime heritage resources, and ecosystem services in GFNMS. Coastal and offshore environments were evaluated separately from estuarine and lagoon environments in the report. Representative data indicators were selected for each section that would be informative of the status and trend of conditions in the sanctuary. Criteria for data indicator selection included: 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 section below summarizes the most noteworthy results.

Water Quality

Climate change has affected water quality in the coastal and offshore environment of GFNMS. In the offshore environment, marine heatwaves in 2014–2016 and 2019 were correlated with harmful algal blooms and habitat compression. There were also more instances of unusually high sea surface temperature during the study period, and ocean acidification was evident at deeper offshore depths. Eutrophication (excessive algae growth resulting from increased nutrient input) was not present in the offshore environment.

Algal blooms affect the food web in the offshore environment and can result from warm water conditions. Photo: Dru Devlin/NOAA

Water quality in the estuarine and lagoon environment was impacted by climate stressors such as increased sea surface temperatures, as well as a decline in precipitation and associated increase in salinity. In Tomales Bay, there was an overall decrease in corrosive conditions for shell forming species over the study period, but corrosive conditions were present during the winters.

Water quality issues also posed a risk to human health in both the coastal and offshore and estuarine and lagoon environments. In coastal and offshore environments, levels of toxins exceeding regulatory thresholds were present. The biotoxin saxitoxin, which causes paralytic shellfish poisoning, exceeded regulatory thresholds in offshore shellfish samples in most years. The Dungeness crab fishery experienced temporary closures due to domoic acid in 2015–2018. Beach advisories for water contact due to elevated pathogenic bacteria were issued for some beaches in Sonoma and Marin counties.

Dungeness crab is a valuable fishery on the west coast and is vulnerable to closures due to levels of toxins exceeding regulatory thresholds. Photo: Austin Trigg/NOAA

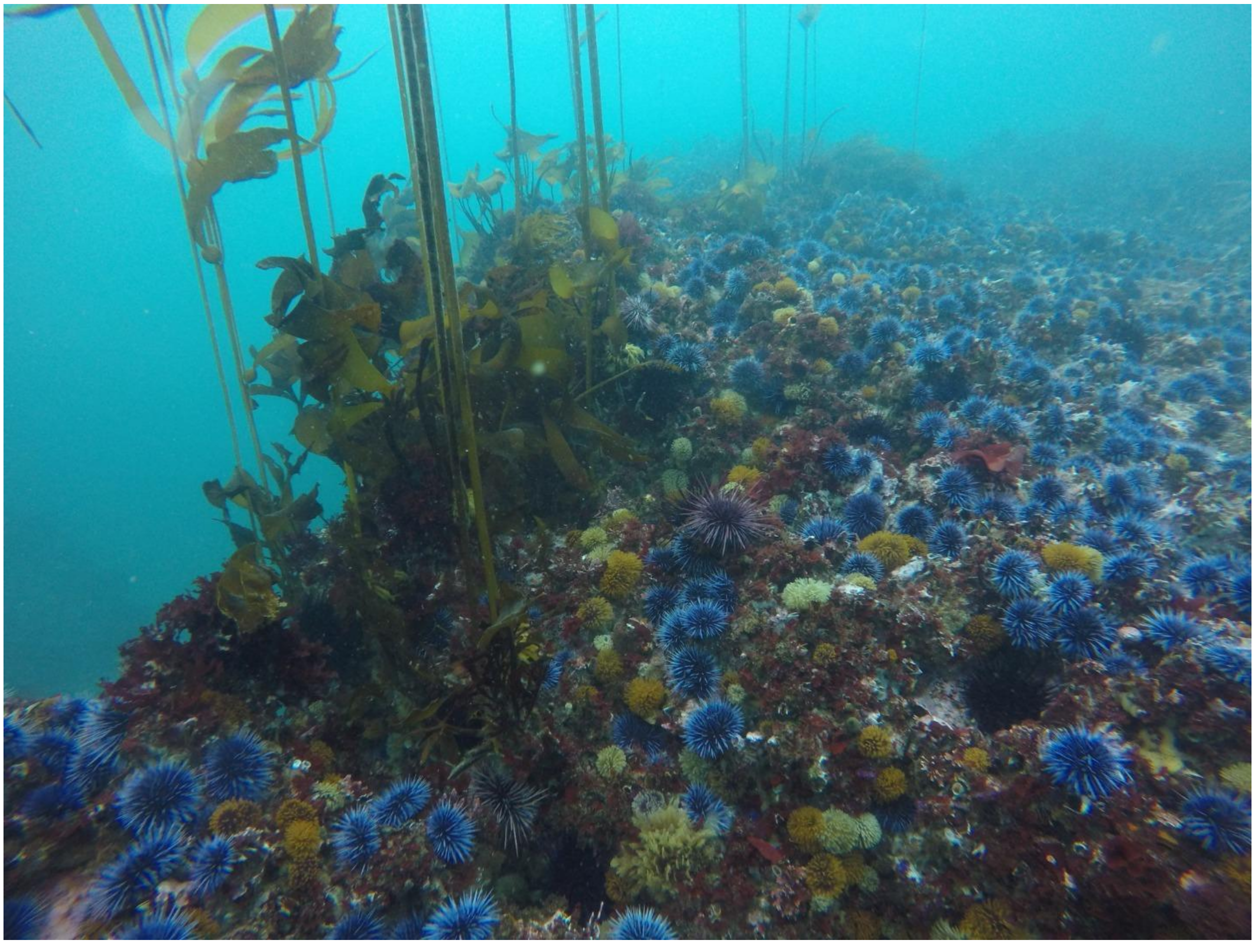
In estuaries, advisories were in place to limit consumption of some fish species from Tomales Bay due to mercury contamination, saxitoxin concentrations exceeded the regulatory threshold in 2013, 2014, 2017, 2018, and 2019, and shellfishery closures occurred every year due to rainfall, saxitoxin, *Vibrio*, or norovirus. Tomales Bay was listed as an impaired body under Section 303(d) of the Clean Water Act due to sedimentation/siltation, nutrients, mercury, and pathogens, while Estero Americano and Estero de San Antonio were listed as impaired due to nutrients and sedimentation. Beaches in Tomales Bay had beach advisories due to elevated levels of fecal coliform bacteria on 131 occasions from 2010–2021. Other water quality concerns in the sanctuary included microplastic pollution and vessel discharges, however there were limited data available to evaluate the status and trends and assess the impacts to the sanctuary from these stressors. Most water quality parameters are measured by partners.

Habitat

In the coastal and offshore environment, kelp habitat decreased by over 90% since 2014 and has not recovered. Rocky intertidal habitat was stable based on the percent cover or abundance of key habitat-forming species. Levels of shoreline armoring remained low at 2% of shoreline armored, with no new armoring added during the study period. The majority of beaches in GFNMS are experiencing erosion that threatens beach and dune ecosystems, but more information is needed to assess the trends in sediment dynamics. In deep-sea habitats that were explored in GFNMS, diverse communities of corals, sponges, other invertebrates, and fish were observed. However, only a small portion of this habitat has been explored, and more information is needed to be able to fully characterize this habitat and track trends. There is concern about impacts to benthic habitat from active and lost fishing gear and derelict or sunken vessels, but more information is needed to fully characterize the impacts.

King tide events, when extra-high tides occur, show what the future holds for coastal beaches; beaches are expected to become narrower, reducing habitat for species that use them. Photo: Wendy Kordesch

In the estuarine and lagoon environment, there were no losses to marsh and mudflat habitat during the study period, although the amount of this habitat had been reduced from historic levels. Restoration projects have improved water quality and circulation and allowed native vegetation to increase, but more data are needed to determine the trend. The extent of eelgrass habitat in Tomales Bay appears to be increasing as a result of removing unpermitted moorings from eelgrass beds, but continued monitoring is needed to fully understand the trend, and additional measurements are needed to better understand the health and ecosystem function of the eelgrass beds.



GFNMS has experienced a 90% loss of bull kelp with minimal natural recovery in the sanctuary as a result of a series of compounding stressors resulting from climate change. Photo: Steve Lonhart/NOAA

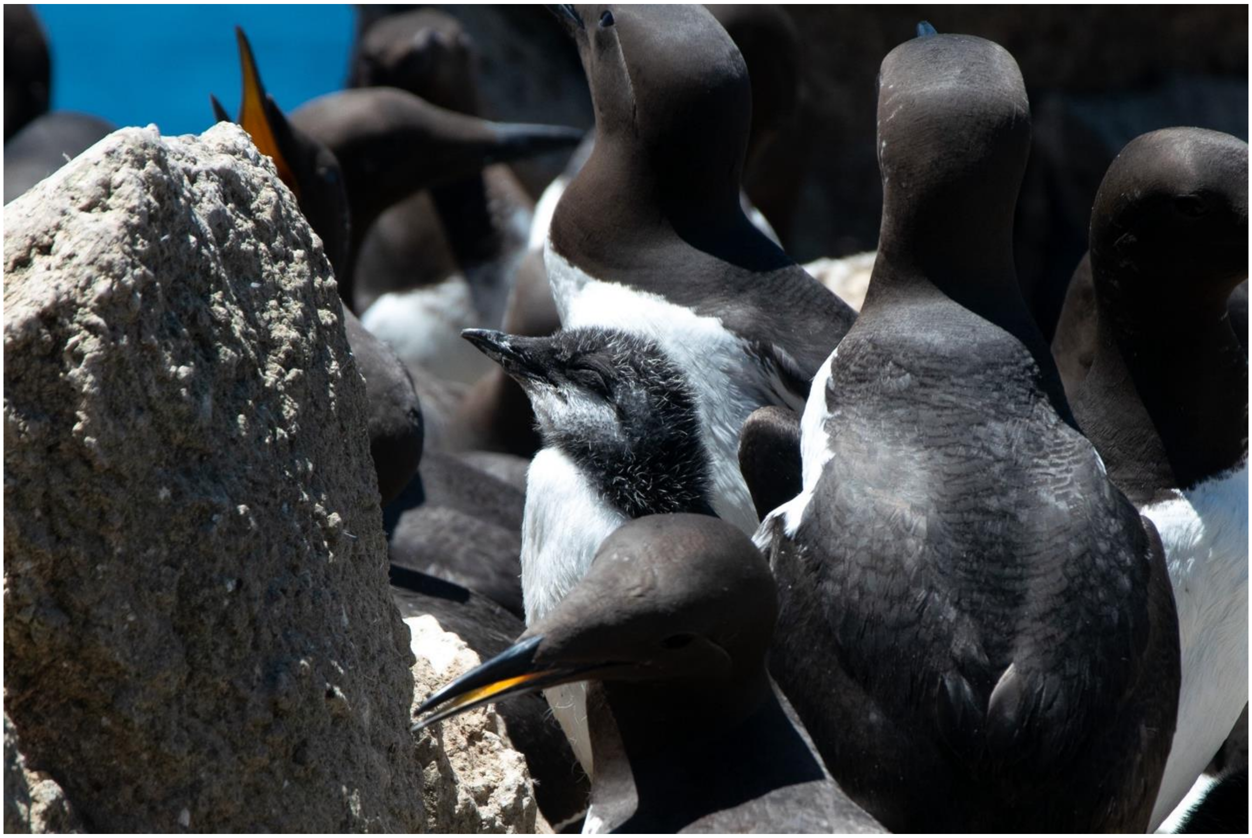
Contaminants were documented in sanctuary habitats. In the offshore environment, mercury was present in sediment samples collected offshore from Stinson Beach, and levels significantly increased over time during the study period, but remained below the threshold for negative effects to marine organisms. Multiple contaminants in Dungeness crab were below regulatory thresholds, except for mercury in 2010 and PCBs in 2015. Tarballs were present on coastal beaches; although not definitive, tests showed that these tarballs likely came from natural seeps. There were no major oil spills during the study period. Mercury is present in Tomales Bay due to historic mining. After remediation in 1999–2000, mercury was still present, but had decreased in the bay's sediment.

Living Resources

In the coastal and offshore environment, sea stars were decimated by sea star wasting disease. This resulted in an increase in their prey, purple urchins, which extensively fed on kelp and contributed to bull kelp loss and lack of recovery. Although the abundance of prey species naturally fluctuates, in recent years, there was a notable increase in anchovy and decline in krill, and, following peaks in abundance, decreases in juvenile rockfish in the offshore environment. White sharks were abundant and were estimated to be increasing.

Densities of humpback whales increased in the sanctuary during the study period, but the status of humpback whales is a concern because they face several threats in and around GFNMS, including ship strikes, entanglements, and climate-related changes in forage species and habitat compression. Habitat compression, when cool, upwelled water is restricted to the coast instead of across the continental shelf, 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.

Seabird abundances at the South Farallon Islands remained stable or increased over the past couple of decades, while shorebird presence along the mainland remained stable or decreased.



Common murres breed on the Farallon Islands and depend on the productive food available in the sanctuary nearby for reproductive success. Photo: Danielle Devincenzi

Rocky intertidal species showed variability over time, but overall species abundances or percent cover remained stable or increased once the 2014–2016 marine heatwave subsided, with the exception of northern rockweed, which decreased.

In the estuarine and lagoon environment, native Olympia oysters are present. Although their population size was unknown for this study period, it was thought to be low. Shorebird encounter rates declined in the sanctuary, consistent with declines in global populations of shorebirds. The encounter rates of brant, a small sea goose, were variable in the past several decades and were at the low end of the range in recent years.

Eighty-four non-indigenous species have been documented in the sanctuary. The most notable species are the European green crab and the Japanese mud snail; both species can have measurable impacts but are currently restricted to specific locations in estuarine and lagoon habitat.

Overall, biodiversity in the sanctuary was within the expected range of long-term natural variability, although data in the estuarine and lagoon environment was insufficient to assess this component. Shifts in species distribution resulting from the 2014–2016 marine heatwave may have affected the biodiversity of the sanctuary in both positive and negative ways.

Maritime Heritage Resources

Shipwrecks and doghole ports are the primary documented tangible maritime heritage resources in the coastal and offshore environment of GFNMS. Of the records of hundreds of possible shipwrecks in the sanctuary, only a small fraction have been confirmed and documented, and 14 of the 24 doghole ports have been documented. Although these sites are not monitored, human impacts to resources were thought to be minimal, with natural degradation as the primary threat. Further exploration and assessment could reveal additional historical resources in GFNMS.

Status and Trends of Ecosystem Services

Ecosystem services evaluated in the report included science, education, heritage, sense of place, consumptive recreation, non-consumptive recreation, commercial harvest, and coastal protection.

GFNMS has several long-term monitoring projects that have provided critical scientific information to inform the sanctuary and guide management actions. Through work on these projects, staff have developed partnerships with many agency, non-profit, and academic scientists, and the science findings have been shared through presentations, reports, and articles. However, research and monitoring is minimal in some habitats, such as estuarine and lagoon and deep-sea habitats, and there are significant challenges to accessing some portions of the sanctuary due to weather, hazardous diving conditions, and limited vessel capabilities, which limited the capacity to conduct research in these areas.

GFNMS has been monitoring the offshore environment through the collaborative Applied California Current Ecosystem Studies monitoring program with Point Blue Conservation Science. Photo: Sophie Webb/NOAA and Point Blue Conservation Science

The education program of GFNMS has a diverse repertoire of offerings to reach students and teachers in formal classroom settings, as well as informal education and outreach to general audiences. The demand for sanctuary school education programs exceeded the capacity of GFNMS staff, facilities, and funding, limiting the ability to reach new audiences and engage the diverse communities of the San Francisco Bay Area in sanctuary education.

Hundreds to thousands of years of maritime and coastal history contribute to the rich heritage of the GFNMS region, and the sanctuary supports the heritage ecosystem service through protection of historic shipwrecks and places, interpretation through exhibits and programs, and partnerships with regional museums and organizations. As a result of the sanctuary expansion north along Sonoma County and into Mendocino County and increased recognition of the important maritime heritage resources in the expanded boundaries, the ability to support this service has improved, but more information, collaboration, and partnership is needed. There is a need to identify and characterize iconic heritage locations and locate and assess shipwrecks so that the sanctuary can protect these special places.

The sanctuary's long shoreline and proximity to a major metropolitan area provides access points to connect many communities in north-central California to the sanctuary. GFNMS cultivates this community connection and sense of place through media (film, video, and photograph), field trips, and volunteer opportunities.

Sanctuary habitats provide opportunities for non-consumptive recreation, including wildlife viewing, board sports, kayaking, diving, beachgoing, and tidepooling. The productive ocean ecosystem in GFNMS has supported wildlife viewing businesses, with some increase in demand observed. Engagement in recreational activities like surfing, stand-up paddle boarding, and wildlife watching from shore and from vessels appear to have increased in GFNMS.

The waters of the sanctuary provide the ecosystem service of commercial and recreational consumptive harvest. Fisheries in the region are considered abundant and diverse, with Dungeness crab, salmon, and groundfish commonly targeted for both commercial and recreational fisheries, along with other species. Recent changes in ocean temperature and extensive harmful algal blooms have impacted fisheries, causing crab fishery opening delays and closures to mitigate harmful algal bloom exposure and fishing gear entanglement risk to whales, and contributed to the loss of kelp, resulting in the collapse of the red abalone sport fishery.

GFNMS provides a fantastic wildlife viewing experience for recreational kayakers. Photo: Sara Heintzelman/NOAA

Climate-change-related impacts, such as extreme storm events, rising sea levels, marine heatwaves, ocean acidification, and increased erosion, negatively impact livelihoods dependent on a healthy ocean environment, such as commercial fishing, recreational operations, and tourism economies. Additionally, these impacts can affect shoreline stability and access for coastal communities and participation in recreational activities such as diving, beach combing, and tidepooling, compromising the sanctuary’s capacity to provide these ecosystem services.

Response to Pressures

Since the last condition report, the sanctuary has responded to pressures by developing more robust, new, and extensive monitoring projects to better understand impacts and measure management effectiveness. Since 2015, shoreline monitoring has been extended north into Mendocino County to understand human uses, wildlife presence, and identify potential threats to the sanctuary. Offshore monitoring has been opportunistically extended north off of Sonoma County when NOAA ships are available to monitor vessel traffic, wildlife, water quality, and threats. The data collected from sanctuary and partner monitoring projects have been used by GFNMS's Seabird Protection Network project to address seabird disturbance from vessels. As a result, a decrease in vessel disturbance has been observed at breeding seabird colonies. After GFNMS clarified NOAA low overflight zone regulations and initiated a pilot engagement project, recorded disturbance to seabirds from low-flying aircraft decreased. Since 2010, GFNMS has been working to reduce ship strikes to whales in the sanctuary. After implementing seasonal voluntary vessel speed reduction throughout the sanctuary and sending letters to the shipping industry, GFNMS observed 61% of all the vessels 300 gross tons or larger traveling at speeds of 10 knots or less in 2022 resulting in an approximate 25% reduction in risk in lethal ship strikes to endangered blue whales and endangered and threatened humpback whales, compared to 2015 transits, in the sanctuary. The sanctuary has observed eelgrass returning to sites where unpermitted moorings were removed in Tomales Bay. Data collected by the sanctuary to characterize deep sea coral and sponge habitat has been provided to the Pacific Fisheries Management Council and used by the council to develop fisheries policies that reduce impacts to sanctuary benthic habitat.

The co-occurrence of whales and ships in space and time creates an elevated risk of fatal vessel strikes on endangered whales. Photo: Adam Ernster/NOAA

Recognizing that climate change had the potential to be the biggest threat to the health of the sanctuary, the sanctuary developed a systematic approach to understanding and addressing climate impacts. A climate impact report was developed with the guidance of the Sanctuary Advisory Council to document observed and predicted climate impacts to the sanctuary. The advisory council used the climate impacts report to advise the sanctuary on biological and physical climate change indicators to monitor. Building off the two reports, the sanctuary conducted an expert-guided climate vulnerability assessment to identify the most vulnerable species, habitats, and ecosystem services in the sanctuary. The climate vulnerability assessment was used by the advisory council to provide a suite of recommended actions to GFNMS, which were then used as a foundation for the sanctuary's climate adaptation plan, which describes strategies and actions to address the greatest climate threats in the sanctuary. GFNMS has been implementing the strategies in the adaptation plan, including prioritizing whale and deep-sea coral protection, restoring coastal habitats that sequester carbon, investigating offshore habitats that sequester carbon, and working with Bay Area agencies to develop coastal resilience strategies.

To ensure the current and next generation of ocean stewards are aware of the sanctuary, understand its ecological importance and importance to a healthy Bay Area community, and engage in active participation with the sanctuary, GFNMS delivered targeted education projects that have supported a sense of place and engagement in conservation. Education and outreach efforts included formal (e.g., teacher workshops and student field trips) and informal (e.g., exhibits and lectures) efforts. Efforts to share the heritage of the sanctuary were done through sharing information about historic places and ships in the sanctuary, participating in heritage-related community events, and partnering with museums and parks on exhibits.

Conclusion

In summary, from 2010–2022, GFNMS has focused on reducing human-caused pressures that have threatened sanctuary resources. GFNMS has made significant contributions that are responsive to known or emerging pressures, including direct interventions by sanctuary managers or actions resulting from GFNMS-led partnerships. Recommendations for future actions are not included in the condition report; however, information is provided on potential future needs to address pressures that need attention and responses that may need to continue. This condition report will support the development of a new management plan, and its findings will serve as an important foundation to help GFNMS set future priorities based on known needs and ensure current management and regulatory responses are adequate. GFNMS staff will be fully evaluating the data gaps and information needs highlighted in this report to ensure the next management plan addresses the highest priority topics and management actions.

Deep-sea corals and sponges provide shelter, especially for larval and juvenile fish and invertebrates; areas for breeding and brooding; and food for many species of fishes and invertebrates. Photo: Ocean Exploration Trust/NOAA

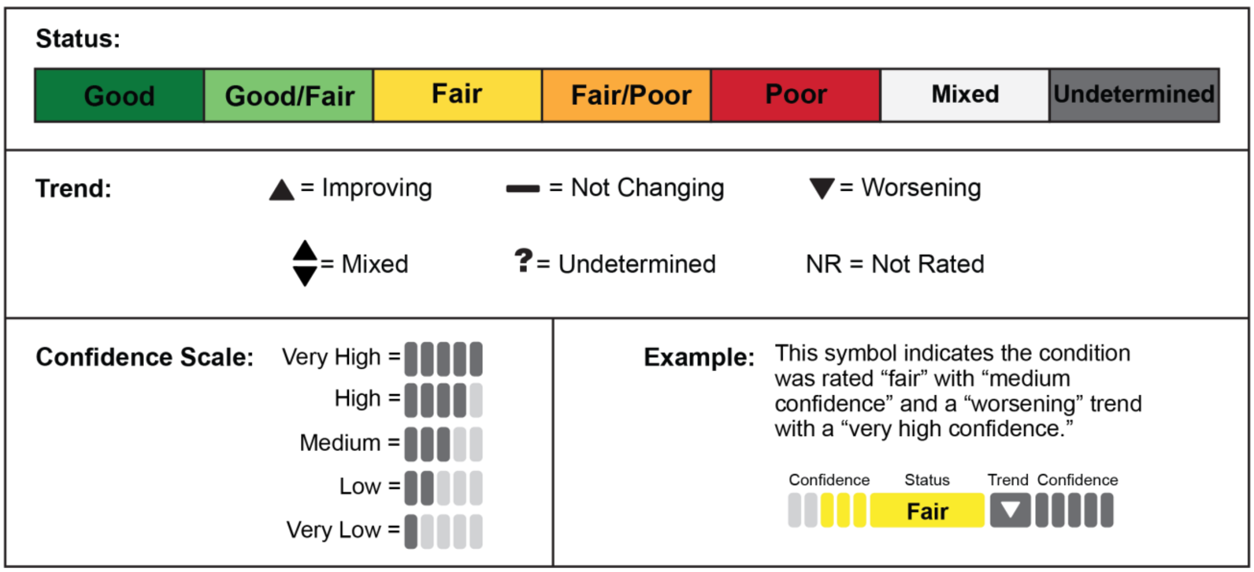
Greater Farallones National Marine Sanctuary
Summary of Resource Conditions

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, 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 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 GFNMS staff decided not to rate the status and trend of influential human drivers at GFNMS. 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?

Coastal and Offshore Region

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

Rationale: Consideration of both land- and sea-based activities that pose threats to water quality indicated a mix of improving and worsening threats. While the number of transits by large commercial shipping vessels remained consistent throughout the study period, the distance transited through the sanctuary decreased. Cruise ships reported illegal discharges in the sanctuary during the study period. However, there was a decrease in the number of discharge incidents and volume discharged from barges transporting dredged materials, as well as a decrease in the number of large oil spills. Lastly, there was a minor increase in land use along the coast in recent years.

Estuarine and Lagoon Region

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

Rationale: There is a limited amount of quantitative data on human activities that may affect water quality in GFNMS estuarine and lagoon habitats. Although remediation has occurred at the inactive Gambonini Mine, mercury remains elevated in Walker Creek and the Walker Creek Delta. Vessel activities, which elevate the risk for petroleum product releases and potentially human waste discharge, remain popular in Tomales Bay. There was a minor increase in developed high-intensity land use, but the associated impacts to water quality in sanctuary estuaries are unknown. Oil releases from vessels and vehicles occurred, but the volumes and impacts are generally unknown.

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

Coastal and Offshore Region

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

Rationale: Marine debris was documented on beaches regionally and on the surface and the seafloor in GFNMS. The most commonly found type of debris on the seafloor was commercial fishing gear. Trawling and crab fishing activities occur each year through large areas of the sanctuary. In 2020, more areas were opened to trawling in GFNMS. Easy access to some rocky reefs in the sanctuary, such as Duxbury Reef, resulted in comparatively high human visitation. The lack of baseline data for these indicators prevented the determination of a trend.[2]

Estuarine and Lagoon Region

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

Rationale: There is limited information on specific human activities that may adversely impact estuarine and lagoon habitat in GFNMS, and ratings were based on a limited number of relevant indicators for which information was available in Tomales Bay. Removal of moorings from eelgrass beds since 2016 reduced the potential for damage to eelgrass habitat. Marine debris was consistently present in Tomales Bay despite some removal efforts. Clamming activities continued to occur, and activity was likely lower compared to historic levels, though data were limited. Little to no data were available for all indicators for Bolinas Lagoon, Estero Americano, and Estero de San Antonio.

[2] At the 2022 status and trends workshop, experts assigned a status rating of fair/poor with a high confidence score. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and determined that a status rating of fair with low confidence was more appropriate, as the data did not sufficiently show that impacts were severe during the study period. See Appendix C for more information regarding these changes.

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

Coastal and Offshore Region

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

Rationale: Vessel activities and trap fisheries affected living resources through ship strikes and entanglement, potentially affecting the recovery of threatened and endangered species. Although these activities do not appear to have substantially changed during the study period, changes in whale distribution increased the risk of ship strikes and entanglements. Pinnipeds and seabirds were also observed entangled in trash and fishing gear during the study period; entanglement trends for these species were variable, and there were no apparent effects on abundance of these species in the sanctuary. Although there were some exceptions, human activities that disturb seabirds and harbor seals generally remained stable or decreased, and did not appear to affect wildlife abundance or use of the sanctuary. There were no substantial oil spills in the sanctuary during the study period, and tar ball deposition was infrequent (and likely resulted from natural seeps).

Estuarine and Lagoon Region

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

Rationale: Disturbances to wildlife were documented, but these did not appear to hinder use of the sanctuary by wildlife. Human activities in GFNMS estuarine habitats were stable from 2010–2019, but increased in 2020–2021. Oil pollution from vessels and vehicles was observed but not quantified in Bolinas Lagoon and Tomales Bay.

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

Coastal and Offshore Region

Status Description: Some potentially damaging activities exist, but they have not been shown to degrade maritime heritage resource condition.

Rationale: The levels of human activities that may adversely affect maritime heritage resources are not thought to have caused widespread impacts during the study period; for some indicators, no adverse impacts are known. Potentially damaging human activities in the coastal and offshore region of the sanctuary have occurred, including scuba diving and commercial fishing, but these are not thought to have caused widespread impacts during the study period. Anecdotal information from divers indicated a decrease in looting at maritime heritage sites since sanctuary designation, and no looting was documented during the study period. Additionally, there was no new nearshore or offshore development in the coastal and offshore region of GFNMS. A few adverse impacts were observed; for example, commercial fishing gear was documented on two shipwrecks, the SS *Selja* and the TV *Puerto Rican*. Climate impacts are likely occurring and are of concern, but difficult to measure without comprehensive site baseline data or regular monitoring. The lack of systematic monitoring of all GFNMS maritime heritage sites limited this assessment.

Estuarine and Lagoon Region

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

Rationale: There is one known historic maritime heritage resource in the estuaries of GFNMS, the shipwreck *Oxford*. The remains of the wreck are submerged and buried under sediment, which provides a measure of protection from human activities. During the study period, only one research activity allowing contact with the submerged lands at the shipwreck site was permitted, to confirm the wreck's presence. This research activity likely had negligible adverse impacts on the wreck. The site has not been revisited for further research. *Oxford* is not located where vessels are known to anchor. Commercial herring fishing was low during the study period compared to historic levels and has not resulted in known adverse impacts on the wreck. There are data gaps for all indicators, particularly related to climate change, and there is a need to determine if there are other maritime heritage resources in the GFNMS estuarine and lagoon region.

Water Quality

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

Coastal and Offshore Region

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

Rationale: Eutrophication was not detected in the coastal and offshore region of GFNMS based on nutrient concentration, phytoplankton community composition, chlorophyll *a* concentration, and net primary productivity. There was no evidence to suggest that there have been major influxes of nutrients into these areas of the sanctuary. A lack of year-round data for most indicators limited the assessment of trends during the study period.

Estuarine and Lagoon Region

Status Description: Eutrophication is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.

Rationale: Data documenting eutrophication were limited. While spikes in chlorophyll *a* and dinoflagellate/diatom relative abundance index and low dissolved oxygen occurred in some years, this was generally sporadic and did not suggest widespread eutrophication throughout the study period, and no signs of negative effects on ecological integrity were detected. However, Tomales Bay, Estero Americano, and Estero de San Antonio have been listed as impaired water bodies due to high levels of nutrients.

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

Coastal and Offshore Region

Status Description: Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.

Rationale: The presence of biotoxins posed a threat to human health and resulted in fishery closures during the study period. In addition, swimming advisories were issued for some beaches adjacent to the sanctuary due to elevated levels of pathogenic bacteria; however, no beaches were listed as impaired water under the standards of the Clean Water Act. Mercury and PCBs were below regulatory thresholds during the study period except in 2010 and 2015, respectively. Although there were some improvements in beach water quality, worsening levels of biotoxins and fishery closures were of concern.

Estuarine and Lagoon Region

Status Description: Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.

Rationale: Saxitoxin exceeded thresholds in some years in Tomales Bay, but domoic acid was consistently below the detection limit. Shellfishery closures occurred regularly in Tomales Bay, primarily due to rainfall, but also as a result of norovirus, Vibrio, or saxitoxin. A norovirus outbreak linked to oysters cultured in Tomales Bay sickened 44 people in 2018–2019. Tomales Bay, Estero Americano, and Estero de San Antonio were listed as impaired bodies of water, and beach advisories were issued for Tomales Bay throughout the study period without a clear trend. Mercury contaminant levels were high for some species in Tomales Bay, and recommendations to limit consumption were issued. Data were generally unavailable for human health indicators in Estero Americano, Estero de San Antonio, and Bolinas Lagoon.

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

Coastal and Offshore Region

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

Rationale: Increased positive sea surface temperature anomalies were associated with two marine heatwave events during the study period. The marine heatwave in 2014–2016 resulted in unprecedented ecological and economic impacts. Habitat compression was high during the 2014–2016 and 2019 marine heatwaves, but there was no change in the habitat compression index during the study period. Low dissolved oxygen was observed at multiple sampling depths in multiple years, and hypoxic events were observed, typically in deeper water. Low aragonite saturation corresponding to corrosive conditions was observed, especially at deeper locations.

Estuarine and Lagoon Region

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

Rationale: Data were only available for Tomales Bay, limiting the ability to assess this question. Sea surface temperature increased significantly during the study period, and positive anomalies were associated with marine heatwaves in 2014–2016 and 2019. Aragonite saturation increased during the study period, but was seasonally low enough to result in corrosive conditions. Stream flow into Tomales Bay decreased over time, and was lower than historical median discharge values in some years; salinity increased during the study period.[3]

[3] Status and trend ratings and associated confidence scores were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status and trend ratings and associated confidence scores.

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

Coastal and Offshore Region

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

Rationale: Microplastics were present in the sanctuary, but in lower abundance compared to more heavily developed coastal areas. Although discharges from U.S. Coast Guard vessels remained low, numerous illegal discharges into the sanctuary from cruise ships were documented during the study period. However, the volume of dredged material illegally discharged into the sanctuary decreased significantly. Vessel discharges and small oil spills were observed, but their impacts were not assessed or documented; no large spills occurred during the study period. Atmospheric emissions and illegal exhaust gas cleaning system discharges from vessels may result in harmful water quality impacts, but these have generally not been quantified in the sanctuary. It is unknown whether disruptions to natural sediment movement have affected turbidity.[4]

Estuarine and Lagoon Region

Status Description: Selected stressors have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Pathogens from human and animal waste were prevalent in Tomales Bay; however, management actions have been taken to address this issue. Microplastics were detected in Tomales Bay sediments and biota, suggesting they were also present in the water column. There have been measurable improvements in sediment transport and tidal prism in Bolinas Lagoon due to restoration activities. Trend data were unavailable for most indicators, and no data for Estero Americano or Estero de San Antonio were available.

[4] A status rating and associated confidence score were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

Habitat

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

Coastal and Offshore Region

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

Rationale: There has been a significant loss of kelp canopy cover, stipe density, and understory algae and a proliferation of urchin barrens during the assessment period, resulting in a decline in habitat integrity. Sediment imbalances occurred along sandy beach habitat; however, shoreline armoring was stable during the study period. Structure-forming species within the rocky intertidal habitat were apparently stable in general. Healthy deep-sea coral and sponge habitats were documented in the sanctuary; however, sunken marine debris was also found at these sites.

Estuarine and Lagoon Region

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

Rationale: Estuarine and lagoon habitats in GFNMS remained significantly degraded compared to historic levels. There was no evidence that marsh or mudflat habitat has worsened since the last assessment, and some restoration projects have been undertaken to improve the integrity of these habitats. Anecdotal evidence suggested that Olympia oysters were low compared to historic levels. Eelgrass extent varied with no clear trend in Estero Americano and Estero de San Antonio, but may have increased at Tomales Bay (although differences in methodology preclude the full assessment of a trend); eelgrass was not present in Bolinas Lagoon, consistent with earlier surveys. More data are needed to better understand any specific quantitative changes in mudflat, marsh, and eelgrass over time and to assess the status and trends of Olympia oyster populations in all estuaries, especially Tomales Bay.

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

Coastal and Offshore Region

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

Rationale: Mercury was present in sediments and levels increased. Levels of PAHs and DDT (and its derivatives) in Dungeness crab samples were below regulatory thresholds during the study period. Mercury in Dungeness crab exceeded the state limit in 2010 and PCBs in Dungeness crab exceeded the FDA limit in 2015, but both contaminants were low throughout the remainder of the study period. Mercury, PAH, PCB, and DDT levels in Dungeness crab were stable during the study period. Tarball pollution decreased, except for one isolated event in the winter of 2015–2016.

Estuarine and Lagoon Region

Status Description: Selected contaminants have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: There is ongoing mercury contamination in sediments and biota in the Walker Creek Delta in Tomales Bay as a result of historic mining activities in the Walker Creek watershed. Mercury levels in sediment decreased following cleanup of a key mine site, but total maximum daily load was exceeded in Walker Creek in multiple years since the cleanup. Vessel and car sinkings have occurred in the sanctuary's estuaries, resulting in the release of fuel into sanctuary habitats, but the volume of contaminants released during these incidents is unknown. Tarballs, tar patties, and oiled wildlife were not observed on beaches in Tomales Bay or Bolinas Lagoon during the study period. There were little to no data on contaminants in Estero Americano, Estero de San Antonio, or Bolinas Lagoon.

Living Resources

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

Coastal and Offshore Region

Status Description: The status of keystone and foundation species suggests severe degradation in some but not all attributes of ecological integrity.

Rationale: Bull kelp declined significantly in the sanctuary due to a series of events, including the 2014–2016 marine heatwave and a historic imbalance within the kelp forest ecosystem. Sea star wasting syndrome led to the loss of the predators of purple urchins, e.g., sunflower and giant sea stars, allowing the purple urchin population to increase dramatically. Purple urchins thus overgrazed kelp beds, resulting in a persistent loss of bull kelp. During the 2014–2016 marine heatwave, habitat compression also occurred, resulting in a redistribution of forage species from further offshore to closer inshore. During cooler water conditions and stronger upwelling periods, the proportion of krill to less nutritious gelatinous zooplankton was high. During warmer water conditions, the proportion of krill to gelatinous zooplankton was low.

Estuarine and Lagoon Region

Status Description: The status of keystone or foundation species suggests measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Eelgrass was documented in Tomales Bay, Estero Americano, and Estero de San Antonio. Anecdotal observations noted the absence of eelgrass in Bolinas Lagoon prior to and during the study period. There were dense eelgrass beds in Tomales Bay, which generally appeared to be healthy, although time series data were limited. Eelgrass wasting disease was present in Tomales Bay; its extent and impacts are unknown, but its presence is of concern.[5]

[5] A status rating and associated confidence score was not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

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

Coastal and Offshore Region

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

Rationale: The 2014–2016 marine heatwave greatly impacted the abundance and distribution of numerous species that are neither keystone nor foundation species, but are considered important to sanctuary management for other reasons (i.e., other focal species). However, some focal species remained stable or increased during the study period. Although the relative abundance of young-of-the-year rockfish was relatively high from 2013–2016, it declined overall in the Gulf of the Farallones and Monterey Bay region during the study period. The regional abundance of white sharks increased in Central California. Humpback whale populations increased gradually on the West Coast, and their densities in GFNMS varied with krill densities. Since the 2014–2016 marine heatwave, densities of whales and krill increased slightly. In some years, habitat compression was a key driver of the distribution of forage species; this shifted the distribution of some focal species from the shelf break to the shelf, closer to shore, including humpback whales and Cassin's auklets. Breeding populations of Brandt's cormorant, Cassin's auklet, and common murre increased during the study period. Encounter rates for shorebirds in the sanctuary were lower during the study period compared to historic values; encounter rates decreased for willets, although worldwide populations remained stable or increased, and encounter rates increased slightly for snowy plover. Sea palm and abalone densities declined during the 2014–2016 marine heatwave; sea palm showed signs of recovery, but abalone abundances remained very low.

Estuarine and Lagoon Region

Status Description: Selected focal species are at substantially reduced levels, and prospects for recovery are uncertain.

Rationale: Anecdotal observations suggest that Olympia oysters, a native species, were present in Tomales Bay and Bolinas Lagoon, but no information on their abundance was available. Brant are thought to be declining throughout their range, but encounter rates for brant in the sanctuary fluctuated without a clear trend during the study period. Shorebird encounter rates during the study period were lower than in previous decades, but it is unknown whether this reflects the global decline in shorebird abundance or a range shift out of the sanctuary.

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

Coastal and Offshore Region

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: Non-indigenous species were present within the coastal and offshore region of GFNMS, and the number of non-indigenous species detected increased during the study period. However, available evidence suggests that the impacts of these species have been limited. Status and trend data, including abundance, density, and spatial distribution, were limited for most non-indigenous species of concern, and more long-term monitoring and systematic surveys are needed.

Estuarine and Lagoon Region

Status Description: Non-indigenous species have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Non-indigenous species remained present within the estuarine and lagoon region of GFNMS and caused measurable degradation at the local level. In particular, European green crabs in Tomales Bay and Bolinas Lagoon and non-native snails in Tomales Bay have had negative impacts on native species. The number of non-indigenous species in the sanctuary increased, but the rate of increase slowed during the study period compared to the last century. Some species, such as non-indigenous *Spartina* spp., declined, while others remained stable (European green crabs) or had variable or undetermined trends (snails). Data for most non-indigenous species were limited, and more long-term monitoring and systematic surveys are needed.

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

Coastal and Offshore Region

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: Biodiversity was altered compared to near-pristine conditions, but was within the expected range of long-term natural variability. This is with the possible exception of range shifts and changes in species composition caused by the 2014–2016 marine heatwave, which, exacerbated by climate change, may have exceeded natural levels of variation. Benthic infauna species richness was high compared to areas near San Francisco Bay outflow areas. Rocky shore community stability was high. Kelp community indicators (fish, invertebrates, and understory species richness) varied. Forage fish species richness was high and remained stable over time. Groundfish species density was consistent with long-term means and was stable during the study period.

Estuarine and Lagoon Region

Status Description: N/A

Rationale: At the time of the assessment, there were no known comprehensive surveys of biodiversity in GFNMS estuaries. There was no apparent change in shorebird and marine mammal species richness during the study period, but these data were not sufficient to assess biodiversity for the entirety of the estuarine and lagoon region of the sanctuary.

Maritime Heritage Resources

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

Coastal and Offshore Region

Status Description: 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.

Rationale: Historic sites, properties, and artifacts associated with shipwrecks and doghole ports are known to exist within GFNMS boundaries. The 2015 expansion of the sanctuary increased the number of maritime heritage resources within its boundaries. Summary findings of condition could be made for 13 of the 33 known shipwrecks; all 13 showed structural degradation. Some impacts to condition were due to physical processes, while others related to human interactions, although the latter did not appear to be significant. Two shipwrecks showed signs of fishing gear entanglement; however, neither trawling nor looting was known to have impacted any shipwrecks during the rating period. Twenty-four historic doghole port sites have been documented in or adjacent to GFNMS. No other maritime heritage properties were documented within sanctuary boundaries, though more are likely present. Expert confidence in the trend assessment was low because of limited evidence due to a lack of systematic site assessment and monitoring data.

Estuarine and Lagoon Region

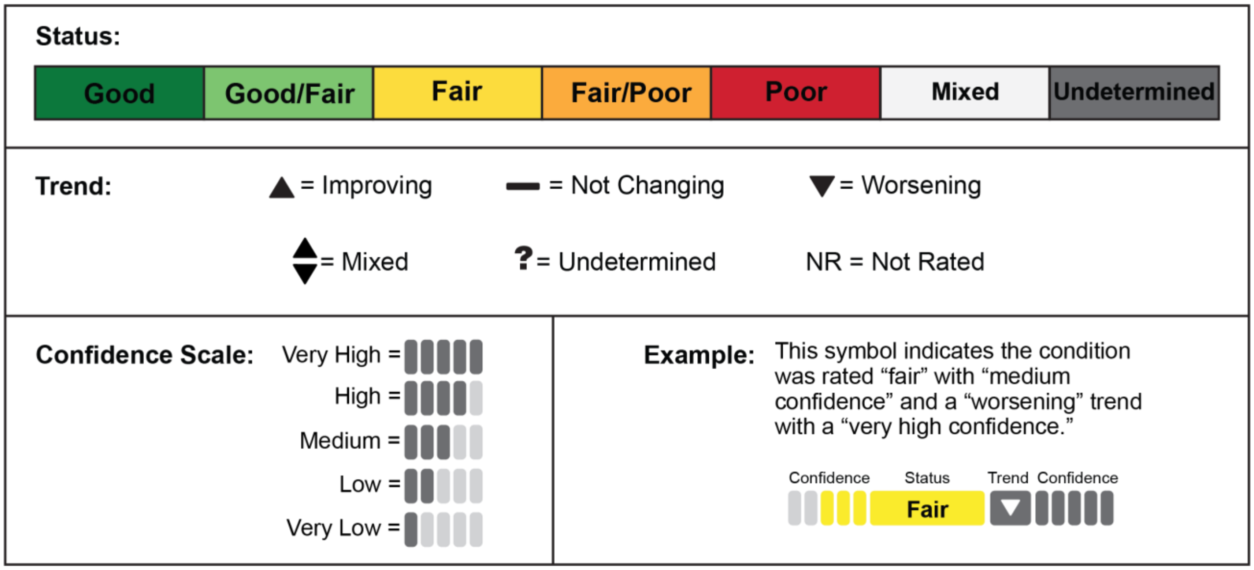
Status Description: Known maritime heritage resources appear to reflect little or no unexpected natural or human disturbance.

Rationale: The one known resource, the shipwreck *Oxford*, located in Tomales Bay, is buried by mud, which makes both natural and anthropogenic deterioration less likely. Expert confidence was low in determining a trend because the assessment was based on one site and a single survey. Aircraft, doghole ports, and other maritime heritage resources were investigated as data indicators but no known resources were identified.

Greater Farallones 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.



Cultural Services (Non-material Benefits)

Science — The capacity to acquire and contribute information and knowledge

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

Rationale: Long-term scientific data on resources in the sanctuary have been collected for over 30 years, and some projects have grown over time. Data on the sanctuary have been disseminated through online data portals, publications, reports, and GFNMS-supported symposia. However, staffing and funding levels have not been adequate to fully support science activities and data collection in all areas of the sanctuary. Accessing some areas of the sanctuary was also challenging due to weather, the presence of white sharks (which limits diving operations), and limited vessel capabilities.

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: The quality, diversity, and reach of education programs provided or supported by GFNMS were considered excellent by experts. Programs reached a wide range of socioeconomic status levels, geographies, and ages. Educational partnerships were strong and could be expanded to reach more target audiences with additional financial support. The diversity of programs offered and the number of participants and collaborators were robust. The number of people served by various education programs was stable or increased during the study period. The lack of increased participation for some programs was determined to reflect limited staff capacity rather than reduced ecosystem function or a lack of desire for programs among the community. Staff capacity did not meet the community demand for intellectual enrichment during the study period.

Heritage — Recognition of historical and heritage legacy and cultural practices

Status Description: The capacity to provide the ecosystem service has remained unaffected or has been restored.

Rationale: There has been a gradually increasing amount of recognition of the importance of heritage by GFNMS staff, community members, and some government agencies. The expansion of the sanctuary in 2015 approximately doubled its size, thus associating with it a broader set of communities and additional aspects of maritime heritage (inclusive of historical and heritage legacy and cultural practices). The ecosystem service of heritage was already well supported prior to 2010 through events, stories, and management of historic places by various agencies. New partnerships, events, and exhibits on heritage were initiated by various groups and agencies, including GFNMS staff. With the 2015 expansion of the sanctuary, new connections have been made with communities adjacent to the northern area of the sanctuary, including coastal Indigenous communities. There is a need to include more experts, particularly from Indigenous communities, in future assessments of this ecosystem service.

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: Many communities have deep connections to the sanctuary and recognize its unique power as a place that sustains, nurtures, and inspires. These connections to the sanctuary have been reflected in a variety of exhibits, film, photography, books, and businesses, as well as in long-term commitments to supporting sanctuary conservation. Experts stated that although environmental conditions were highly variable and increasingly unpredictable due to climate change, the aesthetic attraction of the sanctuary remained uncompromised, and it continued to offer inspiration for individuals and communities. Additionally, experts noted an increase in coastal recreation activities during the COVID-19 pandemic, as well as an increase in community awareness of the sanctuary since its expansion in 2015.

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

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

Rationale: Though data were limited, there is evidence that commercial passenger fishing vessel fishing activity and shoreline angling have increased over the past decade. The number of recreationally harvested rockfish (unspecified species) and Dungeness crab also increased, while other species varied without a clear trend. Although the Chinook salmon ocean fishery was reopened following statewide closures just prior to the study period, some stocks that inhabit the sanctuary were listed as endangered or threatened, and progress toward recovery has been mixed. Additionally, the sport abalone fishery has been compromised by multiple stressors and has been closed since 2017.

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: Many types of recreational activities take place in the sanctuary, and its capacity to provide non-consumptive recreation opportunities appeared to be robust. Common activities included wildlife viewing, surfing, and other board sports, which increased during the study period, as well as kayaking, tidepooling, and beachgoing, which varied without trend. The decline of kelp likely contributed to a decrease in scuba diving in the northern portion of the sanctuary, although more information is needed to fully assess patterns in this activity. Data on recreational boating in the sanctuary were limited, and available data did not suggest a clear pattern during the study period. Effects of the COVID-19 pandemic were apparent for multiple indicators.

Provisioning Services (Material Benefits)

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

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

Rationale: Although certain high-value fisheries, including Dungeness crab and Chinook salmon, have been impacted by management interventions and environmental pressures, stock assessments and catch trends indicated satisfactory performance across most key fisheries in the sanctuary. Despite some challenges, there appeared to be continued participation across a variety of fisheries. Shellfish aquaculture in Tomales Bay also contributed to commercial harvest in the sanctuary.

Regulating Services (Buffers to Change)

Coastal Protection—Flow regulation that protects habitats, property, coastlines, and other features

Status Description: The capacity to provide the ecosystem service is compromised, and substantial new or enhanced management is required to restore it.

Rationale: Significant external (e.g., dams and culverts) and some internal built infrastructure (shoreline armoring) has disrupted the supply of sediment in numerous areas along the already naturally eroding coastline of GFNMS. The effects have likely been far ranging, and are being exacerbated by changes in climate that directly affect sediment delivery to coastal ecosystems. The extent of these influences is not fully understood, but it is clear that substantial management would be needed to restore natural control of sediment delivery and movement, as the entirety of the GFNMS coast is actively erosive. There was a lack of information on changes in shoreline hardening and habitat condition during the study period.

Sanctuary Setting

Overview

GFNMS is part of the National Marine Sanctuary System—a network of underwater parks administered by NOAA that encompasses more than 620,000 square miles (1.6 million square kilometers) of marine and Great Lakes waters. It is located off the California coast, extending west of southern Mendocino, Sonoma, Marin, San Francisco, and San Mateo counties (Figure SS.1). From east to west, the sanctuary extends from the mean high tide line, with exceptions, to the continental margin at or about the 10,000-foot (3,000-meter) depth contour. The sanctuary is adjacent to Cordell Bank National Marine Sanctuary (CBNMS), sharing CBNMS's northern and eastern boundaries, and Monterey Bay National Marine Sanctuary (MBNMS), sharing MBNMS's northern boundary. GFNMS includes Estero Americano, Estero de San Antonio, Tomales Bay, and Bolinas Lagoon. The sanctuary also includes the waters surrounding the Farallon Islands.

GFNMS was established in 1981 to protect the largest assemblage of breeding seabirds in the contiguous United States, as well as large concentra-tions of marine mammals that use these productive waters. Recognizing GFNMS as one of the most biologically important ecosystems in the world, the federal gov-ernment expanded the sanctuary in 2015 to encom-pass the nutrient-rich upwelling zone off of Point Arena. Originally named Point Reyes-Farallon Islands National Marine Sanctuary and renamed Gulf of the Farallones National Marine Sanctuary in 1987, the sanctuary was renamed Greater Farallones National Marine Sanctuary in 2015 and now encompasses 3,295 square miles (8,534 square kilometers). GFNMS has been vested with the authority, in accordance with the National Marine Sanctuaries Act (1972), to pro-vide comprehensive and coordinated conservation and management of the nearshore and offshore wa-ters within its boundaries. In addition, ONMS has directed GFNMS staff to manage the portion of MBNMS north of the Santa Cruz/San Mateo county line, which encompasses 1,374 square miles (3,559 square kilometers; however, that portion of MBNMS is not assessed within this condition report).

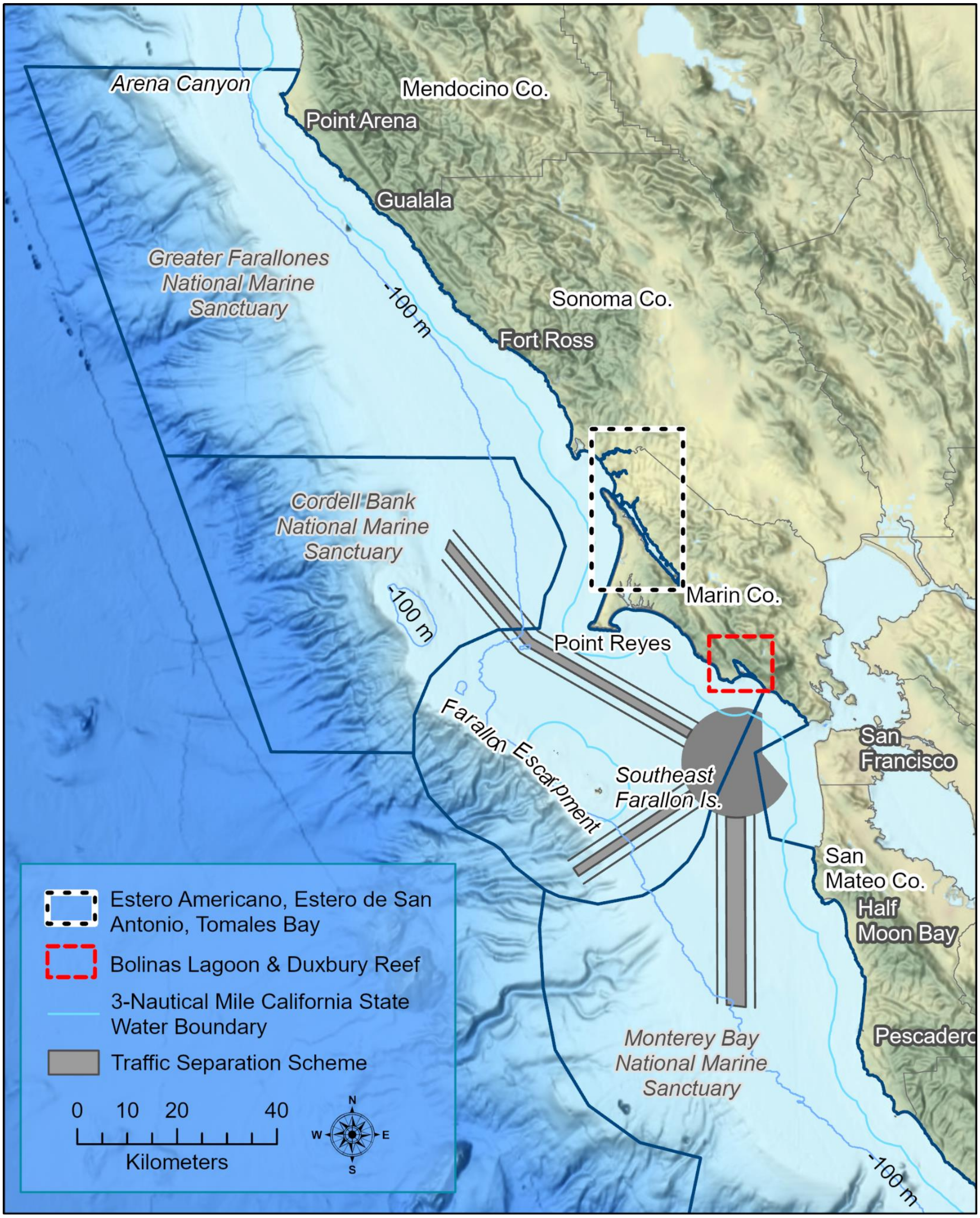


Figure SS.1. Map of GFNMS, and the adjacent CBNMS and MBNMS. Image: NOAA; Source: Esri, 2020

GFNMS protects a complex array of habitats, from exposed rocky head-lands to protected sandy beaches; open bays to calm estuaries; rocky intertidal habitats to mudflats; offshore islands to submerged seamounts and kelp forests; and the continental slope, dissected by numerous submarine canyons, to the deep sea.

Figure SS.2. The Farallon Islands National Wildlife Refuge, surrounded by GFNMS waters and administered by the U.S. Fish and Wildlife Service, provides habitat for nesting seabirds, as well as resting and breeding pinnipeds. Photo: J. Roletto/NOAA

Some of the largest and most diverse eastern Pacific assemblages of seabirds and pinnipeds (seals and sea lions) south of Alaska occur in GFNMS. Large flocks of Cassin's auklets, common murres, western gulls, and brown pelicans feed on the small fish and crustaceans that are abundant in the surface waters of the sanctuary. This food source also supports California's largest breeding population of harbor seals. Large numbers of whales and dolphins, including California gray whales, humpback whales, and blue whales, are found in the area. Around the Farallon Islands is one of the world's largest seasonal congregations of adult white sharks. Twenty-seven endangered or threatened species breed and/or feed in the sanctuary.

Regional Cultural History

Figure SS.3. The Point Arena Lighthouse, which overlooks GFNMS, was first built in 1870, then rebuilt in 1908 after the original was destroyed in the 1906 San Francisco earthquake. Photo: Michael Beattie

The history of California's North Central Coast is predominantly a maritime one. From the arrival of the early Indigenous peoples 11,000 or more years ago, through the exploration and settlement of California from the mid-16th century onwards by the English, Spanish, Mexicans, Russians, Chinese, Italians, and others, coastal waterways have been a main route of travel and source of subsistence, trade, and supply. Ocean-based commerce and industries, such as fisheries, hunting for blubber and fur, logging, shipping, military, recreation, tourism, extractive industries, exploration, and research, are all parts of the maritime history, modern economy, and social character of this region. Groups that continue to make their homes in the region include descendants of the original inhabitants. Locations of Pleistocene/Early Holocene habitation or archaeological sites may possibly be parts of the ancient paleo shoreline, now submerged by the modern ocean stand (ICF International et al., 2013). Ever-changing human uses of the region's ocean and coasts are defining features of its maritime heritage.

Indigenous peoples on the west coast of North America had and continue to have many connections to coastal and ocean resources. Today, there are three federally recognized tribes along the coastline of GFNMS: the Kashia Band of Pomo Indians, the Manchester Band of Pomo Indians, and the Federated Indians of Graton Rancheria (GFNMS, 2022a).

San Francisco Bay ports, one of the largest and busiest commercial port complexes in the country, were developed through fishing, shipping, and economic exchange and are now major urban areas. Regional economies and populations notably increased as a result of the California Gold Rush, which started in 1848, turning remote and sparsely populated Yerba Buena into the multi-cultured, cosmopolitan San Francisco. Coastal harbor communities like Bodega Bay, Point Arena, and other small ports formed at locations along the coastline where goods were loaded and unloaded on ships and passengers embarked or disembarked. Cities inland from the GFNMS coastline, such as Santa Rosa, also became urbanized, bringing millions of residents and visitors in proximity to GFNMS. In addition to maritime commerce, recreational activities, including surfing, boating, diving, and fishing, connect people to GFNMS.

Physical Setting

Oceanography

The unique combination of oceanographic conditions and undersea topography create conditions that support a rich and diverse assemblage of marine species. GFNMS is located in one of the world’s four major coastal upwelling systems. There are three oceanographic seasons in this region: 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; García-Reyes & Largier, 2012).

During the upwelling season, strong northwest winds and the southward flowing California Current system combine with the earth’s rotation to drive surface waters away from the shore. These surface waters are replaced by an upwelling of nutrient-rich deeper water from offshore, which spurs phytoplankton growth and in turn supports zooplankton and fuels 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 in the sanctuary and is responsible for the incredible productivity of the ocean in this region. The upwelling-driven productivity influences many aspects of the sanctuary’s ecosystem, from the timing and success of seabird nesting (Jahncke et al., 2008; Piatt et al., 2020) to the presence of migratory species. Species such as blue and humpback whales travel from Mexico and Central America to feed in the sanctuary, while seabirds arrive from as far as New Zealand (Shaffer et al., 2006) and South America (Felis et al., 2019) to take advantage of upwelling-driven blooms of prey. Species diversity is directly related to the diversity of habitats and oceanic conditions, and its location within a broad biogeographic transition zone (Point Arena to Año Nuevo). This transition zone provides a complex gradient of changing environments in which the relative proportions of species changes from north to south.

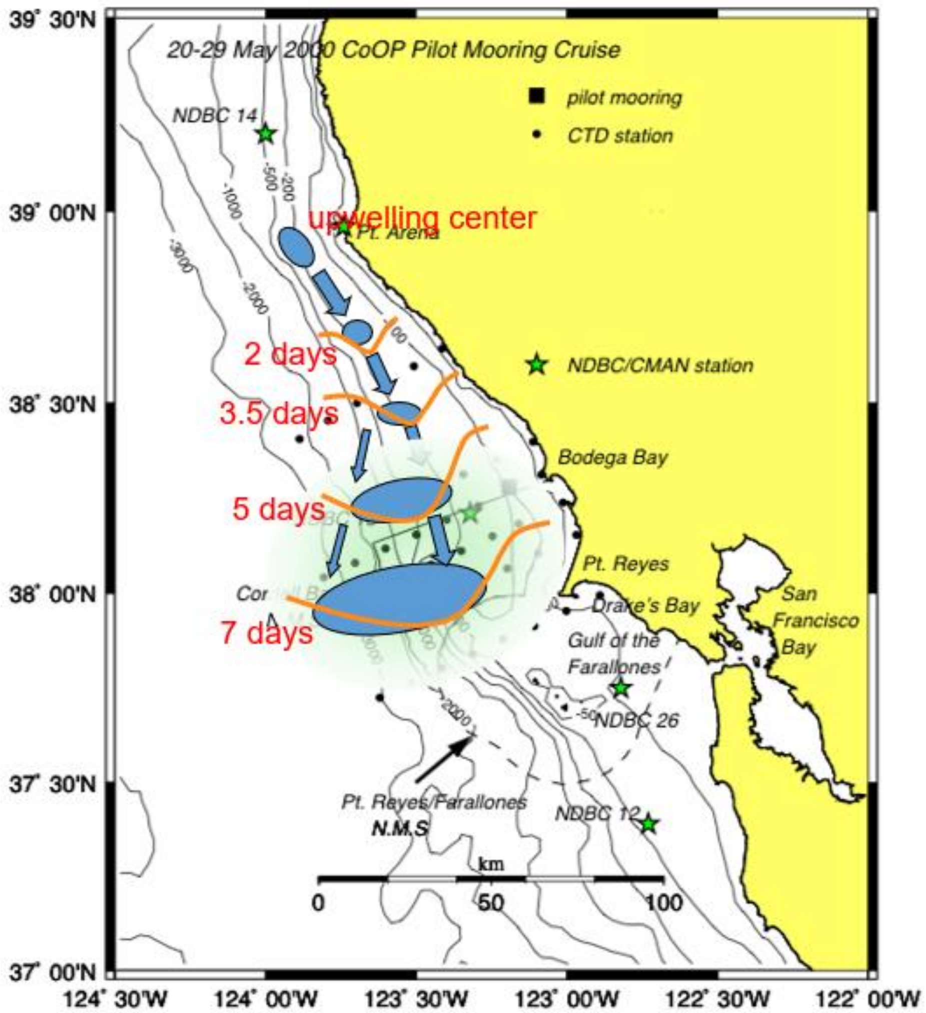


Figure SS.4. Point Arena upwelling center with a plankton bloom growing and moving within the California Current to GFNMS. Image: J. Largier/University of California, Davis

The portion of GFNMS that is offshore of San Francisco is characterized by the widest continental shelf on the west coast of the contiguous United States. The Gulf of the Farallones region lies mostly within GFNMS, extending westward from the opening of San Francisco Bay and Drakes Bay to the Farallon Islands, with the northward extent offshore of Point Reyes and the southern extent offshore of Point Año Nuevo. The continental shelf reaches a width of about 36 miles (58 km) in the Gulf of the Farallones region and narrows to a width of about 17 miles (27 km) in the Point Arena region. Shoreward of the shelf break and Farallon Islands, the continental shelf is sandy and contains large underwater sand dunes. The shelf slopes gently to the west and north from the mainland shoreline and provides an especially large and relatively shallow (about 394 feet [120 meters]) foraging and habitat area for coastal and oceanic seabirds, marine mammals, and fish.

Biological Setting

Rocky Shore

The intertidal habitat between the low and high tides is biologically rich, supporting diverse assemblages of algae, plants, and animals. There are approximately 79 miles (127 kilometers) of rocky shoreline in GFNMS, which hosts foundation species, such as mussels, and endangered species, such as black abalone. Rocky shores are characterized by extreme conditions caused by wind, waves, and the fluctuation of tides. Organisms living in the intertidal face many challenges that are unique to living at the edge of the ocean, including threat of desiccation, physical wave action, and competition for limited space. Rocky shores are found throughout GFNMS, but particularly at Duxbury Reef, Farallon Islands, Bodega Head, Sea Ranch, Salt Point, and Point Arena.

Figure SS.5. Duxbury Reef is one of the largest shale reefs in North America. It is home to a large diversity of marine invertebrates, such as sea snails, sea stars, anemones, crabs, and octopuses. Photo: T. Mears/NOAA

Sandy Shore

North Central California beaches exhibit classic structures like cliffs or dunes that demarcate the upper boundary of the beach; berms at mean high tide lines; and beach flats, troughs, or sandbars that form the seaward side of beaches. The total length of sandy beach habitat within GFNMS boundaries is approximately 55.43 miles. This habitat type includes fine- to medium-grained sand beaches, coarse-grained sand beaches, and mixed sand and gravel beaches (Office of Response and Restoration, 2006, 2008; Vos et al., 2019). Exposed sand beaches are harsh environments subjected to high wave action, wide temperature ranges, and periodic tidal exposure. Beaches of estuaries and bays are calmer environments subjected to less wave action.

Figure SS.6. Bowling Ball Beach, south of Point Arena, features unique concretions where the surrounding rock has eroded away, leaving bowling-ball-shaped formations at the shoreline. Photo: Matt McIntosh/NOAA

Species distributions on exposed sand beaches are strongly influenced by physical factors, whereas species distributions on protected beaches of estuaries and bays are more influenced by biological factors (e.g., competition and predation). Exposed beaches of northern California show distinct patterns of biological zonation defined by the amount of tidal inundation to each region.

Estuaries

Estuaries, including bays, mudflats, and marshes, are productive natural systems. Their physical, chemical, and biological characteristics are critically important to sustaining living resources (Mann, 1982; Weinstein, 1979). The four main estuaries within GFNMS are Estero Americano, Estero de San Antonio, Tomales Bay, and Bolinas Lagoon. Bays and estuaries are important nursery areas that provide food, refuge from predation, and a variety of habitats. Eelgrass beds occur along the subtidal margin of Tomales Bay and within the esteros. Eelgrass supports a unique and diverse assemblage of birds, fishes, and invertebrates, including snails, shrimp, nudibranchs, and sea hares. The structure of eelgrass beds provides protection from predation, especially for juvenile invertebrates and fishes. The two esteros are typically closed to the ocean during summer and fall by seasonally formed sand bars, while both Tomales Bay and Bolinas Lagoon remain open to the ocean year-round. The open bays are sheltered from prevailing southerly currents by headlands and points projecting westward and are important nutrient and plankton retention areas.

Figure SS.7. Bolinas Lagoon is a 1,100-acre tidal estuary that was designated as a Ramsar Site (a wetland of international importance) by UNESCO in 1998. Photo: B. Wilson & LightHawk

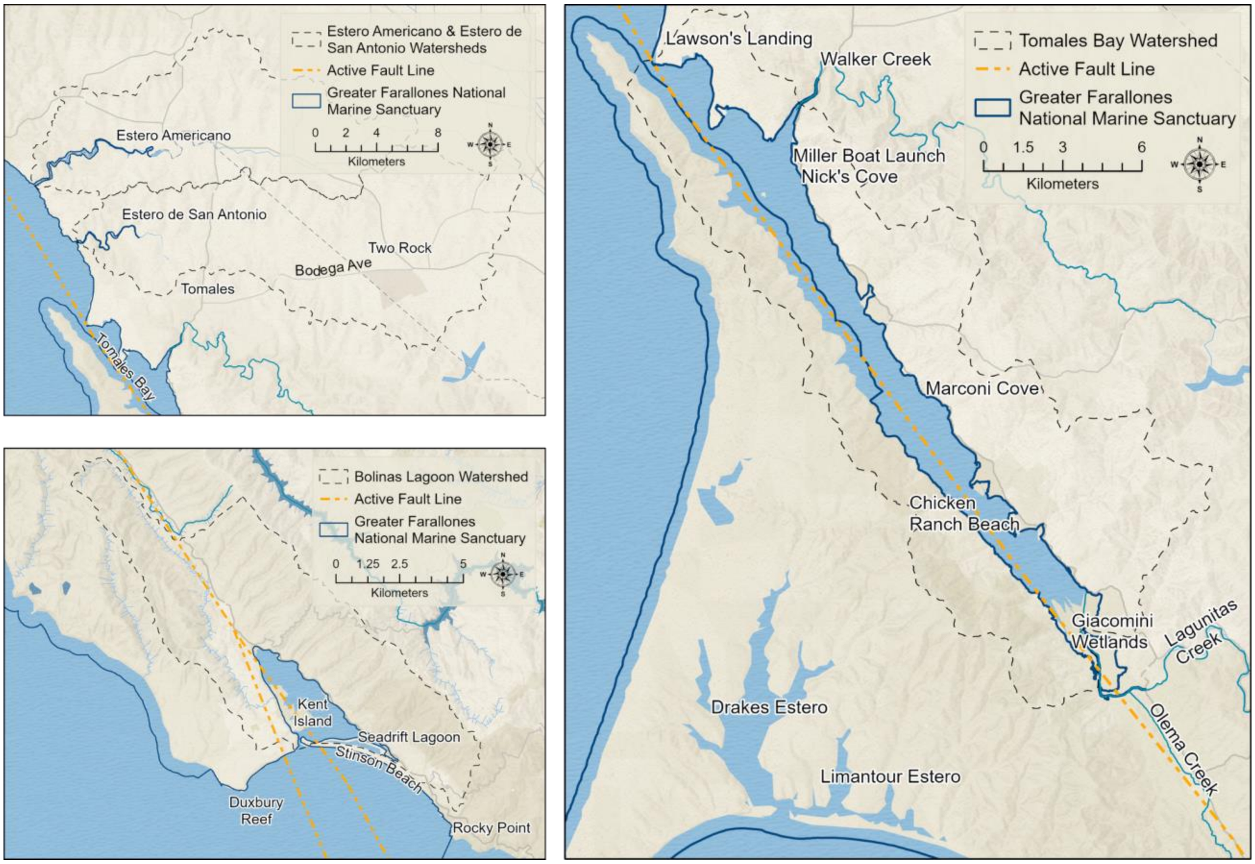


Figure SS.8. The estuaries of GFNMS include Estero Americano and Estero de San Antonio (upper left); Bolinas Lagoon (lower left); and Tomales Bay (right). The Lagunitas Creek and Walker Creek subwatersheds are not outlined on the map, as they lie mainly outside of the map boundaries due to scale. Also shown on each map are active fault lines. Image: NOAA; Source: Esri, 2016

Tomales Bay

Tomales Bay is one of the top five coastal estuaries for eelgrass abundance along the U.S. west coast (Sherman & DeBruyckere, 2018), and eelgrass meadows occur primarily in shallow areas of the bay (Merkel & Associates, Inc., 2022). Tomales Bay is a fault-controlled valley along the San Andreas Fault. Lagunitas Creek, one of two major subwatersheds that drain into Tomales Bay, supports a run of approximately 10% of California's coho salmon population. Pacific herring use the eelgrass beds for spawning. Tomales Bay also supports seasonal populations of salmon, steelhead, sardines, and lingcod. The shallow bay's sandy bottom attracts a variety of bottom-dwelling fish, including sole, halibut, skates, and rays, in addition to red rock crab and Dungeness crab. Leopard sharks are common in Tomales Bay, and blue sharks are sighted occasionally. White sharks, although not usually found in enclosed bays or estuaries, do hunt for seals and sea lions that frequent the bays to haul out on the sandy beaches and rocks near the mouths of Tomales Bay and Bolinas Lagoon. Over 20,000 shorebirds and seabirds, including loons, grebes, geese, cormorants, and ducks, spend the winter in Tomales Bay. In 2002, Tomales Bay was designated as a wetland of international importance by UNESCO under the Ramsar Convention. Tomales Bay and its main tributaries, Lagunitas, Walker, and Olema creeks, are impaired by human and animal waste pathogens (California State Water Resources Control Board [CSWRCB], 2022a; San Francisco Bay Regional Water Quality Control Board, 2023).

Estero Americano and Estero de San Antonio

Estero Americano and Estero de San Antonio are coastal, river-like estuaries located on Bodega Bay. Estero Americano drains into Bodega Bay at the Sonoma-Marin county line. South of Estero Americano, small springs converge with Stemple Creek and become the Estero de San Antonio, draining into Bodega Bay. Many different habitat types are found in the esteros, including mudflats, marshes, and rocky shore. With their variety of habitats, the esteros support many species of plants, invertebrates, fishes, birds, and mammals. They provide essential feeding and resting areas for shorebirds and seabirds. Some common fish species found in the esteros include Pacific herring, staghorn sculpins, and starry flounder. The endangered tidewater goby breeds in the shallow waters of Estero de San Antonio (ONMS, 2014b).

Bolinas Lagoon

The 1,100-acre Bolinas Lagoon supports a rich diversity of shorebirds and waterfowl, fish, invertebrates, and marine mammals, including threatened and special status species. Located on the Pacific Flyway, Bolinas Lagoon's diverse open water, mudflat, and marsh habitats provide a major stopover and wintering area for 50,000 migratory birds and over 245 bird species year-round. The lagoon's tidal flats and protected sandbars also provide year-round haul-out sites for harbor seals, as well as seasonal pupping grounds. The lagoon was designated as a Ramsar Site (a wetland of international importance) by UNESCO and an Important Bird Area by Audubon.

Kelp Forest

Kelp forests are recognized as highly dynamic ecosystems that support dense populations of fishes, invertebrates, and other algal species. Bull kelp is the dominant canopy-forming species in GFNMS and is most abundant in the nearshore sanctuary waters along Sonoma and Mendocino counties, where it grows at depths from six feet (1.8 meters) to just over 60 feet (18.3 meters) and attaches to bedrock reefs and boulder fields.

Figure SS.9. Bull kelp grows offshore in GFNMS. Photo: S. Lonhart/NOAA

Kelp provides habitat and food for threatened and endangered species, like abalone, and increases local biodiversity. Kelp beds form habitats for juvenile fishes, which hide among kelp stalks, canopies, and floating kelp. When kelp detaches and washes ashore, it becomes a food source for kelp flies, beach hoppers, and various insects. Birds such as snowy plovers, whimbrels, and black-bellied plovers feast on the organisms that live in the beach wrack. Similar to terrestrial rainforests, bull kelp contributes to climate resilience by capturing carbon from the atmosphere and exporting it to deep-sea environments for long-term storage (Hutto et al., 2021).

Open Ocean

The pelagic (open ocean) habitat covers the largest area within GFNMS. This habitat includes the euphotic zone where sunlight penetrates and photosynthesis occurs, forming the base of the productive food web, as well as the mesopelagic and bathypelagic zones at deeper depths. Zooplankton, including larval fish, krill, copepods, crab larvae, and other species, are an important component of the food web in this habitat. Distribution and abundance of zooplankton are related to the physical dynamics of the California Current system (Huntley et al.,1995; Parrish et al., 1981; Reid et al., 1958) and species composition responds to seasonal shifts and climate variability (Hooff & Peterson, 2006; Lilly & Ohman, 2021; Peterson & Keister, 2003). The euphotic zone supplies food for deep-sea organisms, such as deep-sea corals and sponges, within the continental shelf, continental slope, and submarine canyons and seamounts, as food sources rain down in marine snow.

Figure SS.10. Krill form the foundation of the food web in GFNMS; they are critical prey for many species of seabirds, whales, and fish. Photo: S. Haddock

Continental Shelf Communities

The continental shelf is located at depths ranging from zero to 650 feet (0–200 meters). Off central and northern California, the shelf generally slopes gradually to the shelf break, and the bottom substrate is a combination of varying amounts of sand, silt, and clay. Much of the mud and sand on the continental shelf was deposited by rivers that formed during the melting of the glaciers approximately 18,000 years ago (Eittreim et al., 2000).

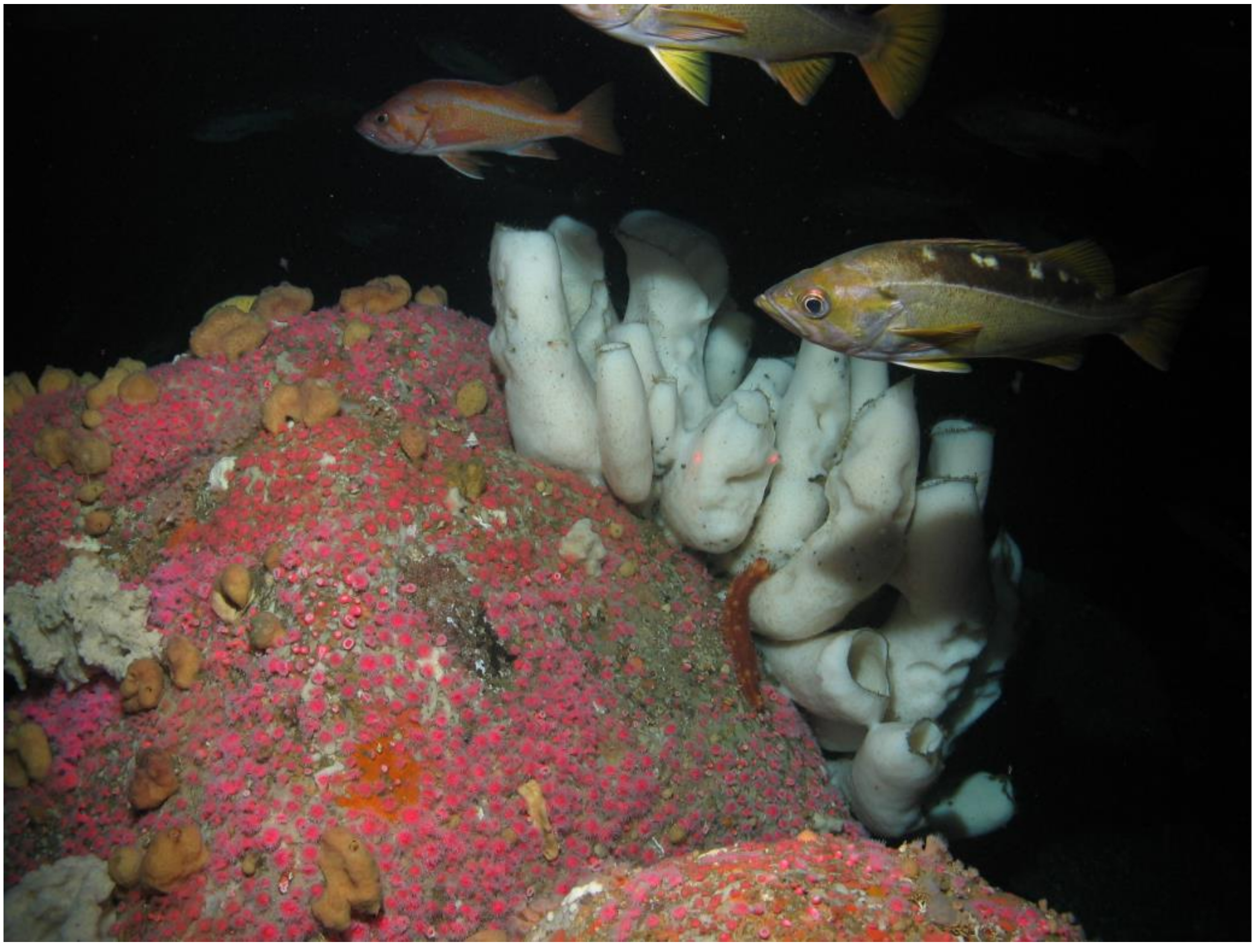


Figure SS.11. Strawberry anemones, corals, sponges, and other invertebrates cover Rittenburg Bank in GFNMS. Photo: Marine Applied Research and Exploration & NOAA

Submarine banks and shoals are found near the shelf break along a submarine ridge that extends for approximately 30 nautical miles (56 kilometers) between the Farallon Islands and Cordell Bank. A few of these vertical structures, including Fanny Shoal, Rittenburg Bank, Cochrane Bank, and the submerged rocky outcrops surrounding the Farallon Islands, provide rich habitat for diverse rocky reef communities. There are other known rocky banks and rock outcrops in GFNMS on the continental shelf, including “The Football,” an elevated feature on the continental shelf north of Bodega Canyon and 65 km northwest of Point Reyes.

Continental Slope Communities

The continental slope in GFNMS drops steeply from an area known as the shelf break, at a depth of around 650 feet (200 meters), to the deep ocean seafloor (around 10,000 feet [3,000 meters]). The deep waters of the continental slope are characterized by extremely low light conditions, nearly freezing temperatures, and very high pressures (Laidig, 2002). Species that live here, such as deep-sea corals and sponges, are adapted to dark, cold, conditions with sparse food resources; tend to be slow growing and long-lived; and can take many years to reach sexual maturity and reproduce.

Submarine Canyons and Seamounts

Submarine canyons traverse the continental slope and beyond to depths of over 10,000 feet (3,000 meters). Submarine canyons, gullies, and rocky ridges indent the steep continental slope and include the Farallon Escarpment, Arena Canyon, and an unnamed canyon west of the South Arena Biogenic Area. Deep-sea corals and sponges, as well as rockfish, can be found in these submarine canyons and seamounts. Submarine canyons are hotspots for krill and other epipelagic forage species, and consequently are also foraging areas for seabirds, marine mammals, and other predators (Santora et al., 2018).

Living Resources

Marine and Coastal Birds

One of the most spectacular components of the sanctuary's abundant and diverse marine life is its nesting and migratory seabirds and shorebirds. Over 420,000 seabirds and shorebirds breed on islands, rocks, and cliffs adjacent to the sanctuary, plus millions of birds migrate to the sanctuary to forage on the abundant prey species (McChesney et al., 2013). The most common species observed in GFNMS are sooty shearwater, common murre, and western gull.

Over 400,000 birds breed in the Farallon Islands National Wildlife Refuge (McChesney et al., 2013), including 12 species of seabirds, plus one shorebird and one landbird species. Eleven of the 16 species of seabirds known to breed along the U.S. Pacific coast have breeding colonies on the Farallon Islands. Breeding colonies include ashy and Leach's storm-petrels; Brandt's, pelagic, and double-crested cormorants; California and western gulls; common murres; pigeon guillemots; tufted puffins; and Cassin's and rhinoceros auklets. The black oystercatcher, a moderate-sized shorebird, also nests on the Farallon Islands.

Figure SS.12. Nearly half the world's ashy storm-petrels feed and nest in island burrows adjacent to the sanctuary on the Farallon Islands. These petrels feed on krill, larval fish, and squid. Photo: National Park Service (NPS)

The sanctuary also protects foraging habitat for aquatic birds such as waterfowl, shorebirds, pelicans, loons, and grebes, plus millions of migrating and wintering birds. More than 170 species of birds use the sanctuary for shelter, food, or as a migration corridor. Of these, over 55 species of birds are known to use the sanctuary during their breeding season. Four marine and coastal bird species that are federally listed as threatened or endangered can be observed in the sanctuary on rare occasions (U.S. Fish and Wildlife Service, 2022). These include the marbled murrelet, western snowy plover, short-tailed albatross, and dark-rumped petrel.

Marine Mammals

At least 37 species of marine mammals have been observed in GFNMS, including blue, gray, and humpback whales; harbor and elephant seals; Pacific white-sided dolphins; and one of the southernmost U.S. breeding colonies of the once-threatened Steller sea lion. Specifically, there are six species of pinnipeds (seals and sea lions), 29 species of cetaceans (whales, dolphins, and porpoises), and two species of otters (southern sea otter and river otter). Pinnipeds and cetaceans occur in large concentrations and are dependent on the productive and secluded habitats for breeding, pupping, hauling out, feeding, and/or resting during migration. The Farallon Islands provide habitat for breeding populations of five species of pinnipeds. The sanctuary and adjacent haul-outs support at least 20% of the harbor seal population within California (Carretta et al., 2022).

Figure SS.13. Humpback whale breaching. Photo: R. Schwemmer/NOAA

Turtles

Figure SS.14. Leatherback turtles transit through GFNMS in late summer and fall. Photo: Douglas Croft

All sea turtles in the sanctuary are federally listed as endangered or threatened. The largest of these, weighing up to 1,500 pounds, is the leatherback sea turtle. This species is observed annually in GFNMS, which is part of its critical feeding habitat. Threats to leatherback sea turtles include habitat loss at their nesting areas in Indonesia, where egg harvesting and entanglement in nets and trawls from commercial and artisanal fisheries also greatly impact their survival. In addition to leatherbacks, three other sea turtle species have been observed in the sanctuary: green, olive Ridley, and loggerhead sea turtles.

Fish

More than 400 species of fish use sanctuary habitats for shelter, food, reproduction, and/or as a migration corridor. Because of the comparatively wide continental shelf and the configuration of the coastline, the sanctuary is vital to the health and existence of salmon (Chinook and coho), northern anchovy, rockfish, sardines, and flatfish. Sanctuary waters offshore of the Farallon Islands act as habitat for shallow and intertidal fishes, which further enhance finfish stocks.

Figure SS.15. Rockfish are among the most diverse fish species in nearshore and deep habitats within GFNMS. Photo: NOAA/MARE

Bays and estuaries are especially important as feeding, spawning, and nursery areas for a wide variety of finfish. Common fish species of the major bays and estuaries include Pacific herring, smelts, starry flounder, surfperch, sharks and rays, and coho salmon. The rocky intertidal zone supports a specialized group of fish adapted for life in tidepools, including monkeyface prickleback, rock eels, dwarf surfperch, juvenile cabezon, sculpins, and blennies. Subtidal habitats, such as kelp forests and eelgrass beds, support large populations of juvenile finfish (e.g., flatfish, rockfish). Nearshore pelagic environments are habitat for large predatory finfish, such as sharks and tuna. Northern anchovies, Pacific mackerel, Pacific sardines, and market squid are abundant coastal pelagic forage species that are also commercially important. Groundfish, such as bocaccio, chilipepper rockfish, widow rockfish, and Pacific hake are found in a variety of habitats and depth ranges.

Benthic Fauna

Benthic faunal communities refer to organisms living directly on or in the seafloor. Benthic faunal communities differ according to habitat type and exist in all habitats of the sanctuary (bays and estuaries, intertidal zones, nearshore, and offshore). Generally, each habitat area supports differing benthic species assemblages (e.g., corals, sponges, worms, clams, crabs). The most conspicuous species nearshore include abalone, crabs, and sea urchins. Hundreds of other species (including sea stars, clams, amphipods, and shrimp) are part of the food webs of fish, birds, and mammals.

Over 1,900 square miles (4,963 square kilometers) of the sanctuary's deep seafloor regions have been mapped on the continental shelf and slope, and some of this area includes rocky and mixed substrate that supports deep-sea corals and sponges, as well as a diversity of fishes. Cochrane Bank, Rittenburg Bank, The Football, and Point Arena Biogenic Area South are documented to support biologically rich rocky seafloor habitats (see Figure S.H.10.3).

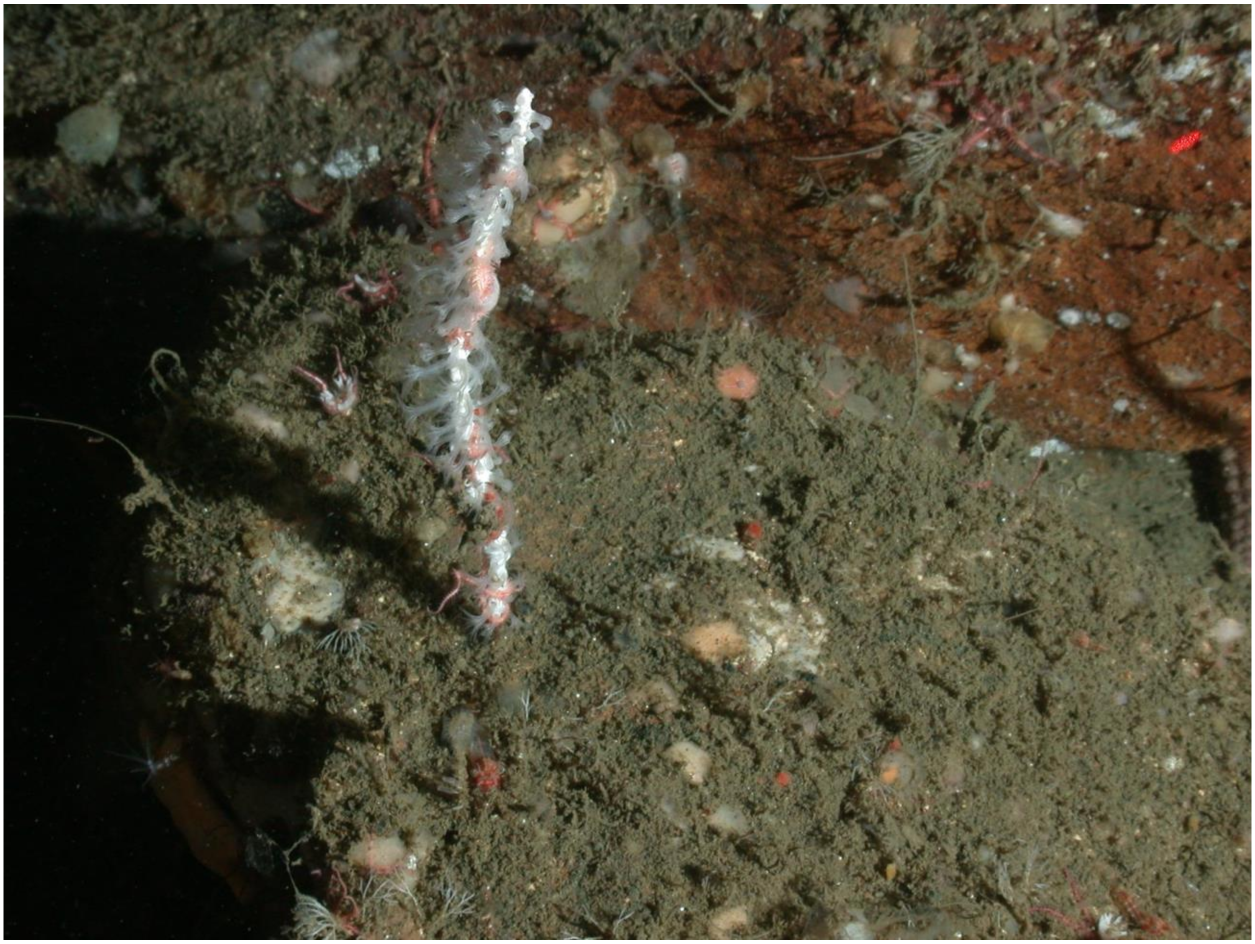


Figure SS.16. Named after GFNMS, *Swiftia farallonesica* is a coral species that was discovered in 2014 at The Football. Photo: NOAA

Marine Flora

Algal and plant communities within the sanctuary include kelp forests and other algae, salt marshes, and eelgrass beds. Plants, algae, and microscopic phytoplankton provide food, nurseries, and protected habitat for many coastal species. In addition to providing habitat and food for wildlife, salt marshes and eelgrass beds improve water quality along the coast by trapping sediments and reducing excess nutrients and pollutants in the water column. In some cases, eelgrass beds and salt marshes also help prevent coastal erosion by buffering the impacts of wave energy and storms, and can ameliorate impacts from excess carbon, thus reducing impacts from ocean acidification and release of carbon dioxide into the air. There are 3.17 square miles (8.21 square kilometers) of eelgrass and 1.37 square miles (3.55 square kilometers) of marsh habitat within the GFNMS boundary.

Figure SS.17. Eelgrass beds trap sediments and reduce excess nutrients and pollutants in the water column. They also serve as buffer zones, protecting the coast from erosion. Photo: C. King/NOAA

Maritime Heritage Resources

The National Marine Sanctuaries Act of 1972 authorized the Secretary of Commerce to "designate and protect areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archeological, educational or esthetic qualities as national marine sanctuaries" (16 U.S.C. §§ 1431 *et seq*.). The term "maritime heritage" encompasses historical, cultural, and archaeological resources, and these can take a wide variety of forms.[6] Archaeological and historical resources are material evidence of past human activities and may include vessels, aircraft, structures, habitation sites, and objects created or modified by humans. Cultural resources and locations or other forms of intangible cultural heritage often contribute to community identity in terms of traditional religion, beliefs, customs, and practices. Cultural resources may include certain culturally significant resources, locations, and viewsheds (Appendix A).

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[6] ONMS (2021) defines maritime heritage resources as "the wide variety of tangible and intangible elements (historic, cultural, and archaeological resources) [that] represent our human connections to our Great Lakes and ocean areas."

GFNMS is rich in historical resources and sites. Thirty-four wrecks of ships used for trade, transportation, and military purposes are documented at locations throughout the sanctuary. Based on historical loss records, remnants of many more ships and sunken aircraft, beyond those documented to exist now, and other historic or prehistoric maritime heritage resources may also be present within GFNMS. These are covered by water, sand, or mud, particularly in precontact or historic areas of human activity. There are also 24 documented doghole port sites in GFNMS. Doghole port sites, historically used for shipping lumber in Sonoma and Mendocino counties in the mid-19th and early 20th centuries, were so named because they were so small and exposed that mariners joked they were barely large enough for a dog to turn around (GFNMS, 2022b; ONMS & California State Parks, 2021). Learning more about the sanctuary's maritime heritage resources and tribal and other aspects of the sanctuary's cultural landscape[7] are areas for future investigation.

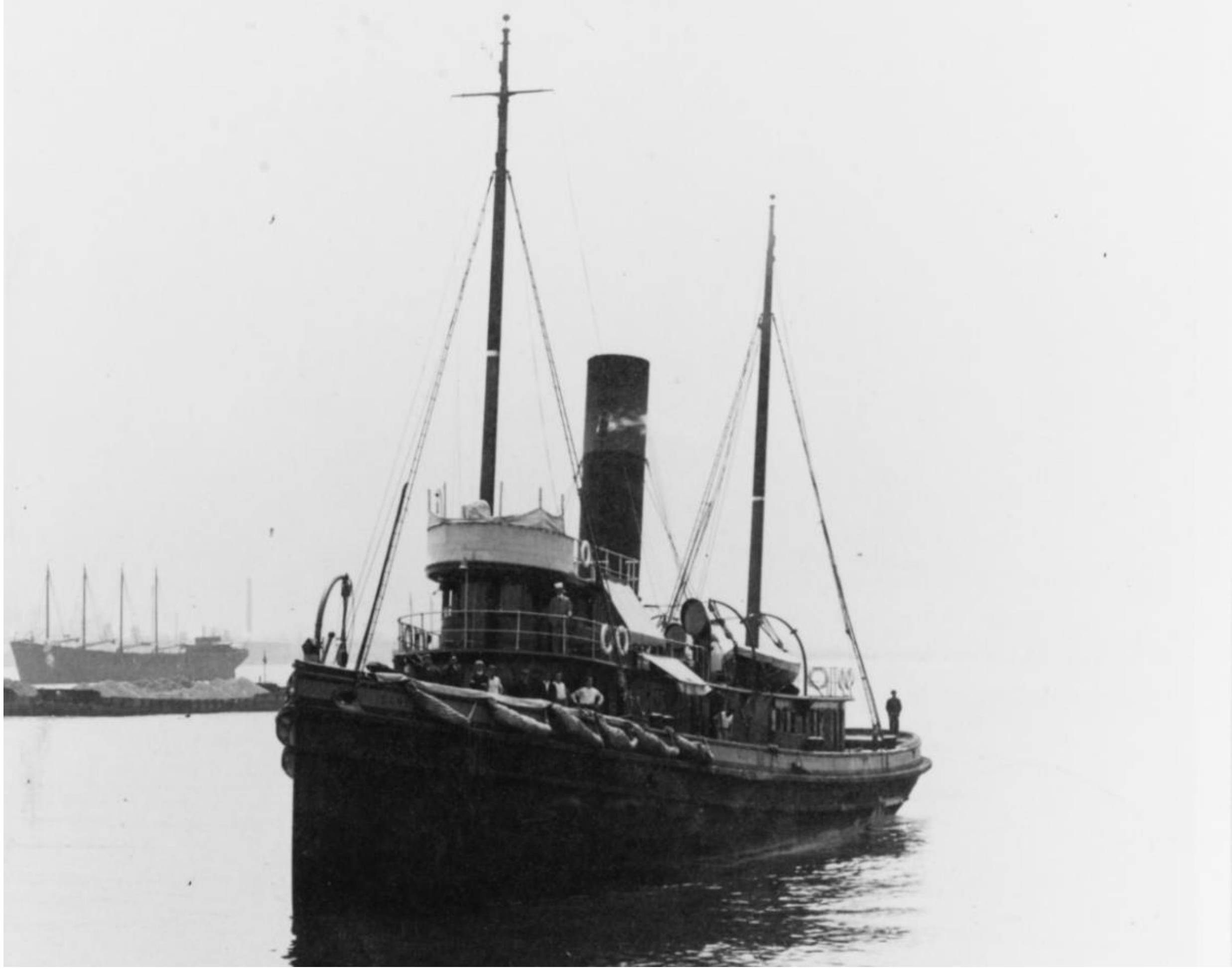

Figure SS.18. The USS *Conestoga* was lost at sea in 1921 and now lies within GFNMS. Image: Naval Heritage and History Command

[7] NPS (2022a) defines a cultural landscape as "a geographic area, including both cultural and natural resources and the wildlife or domestic animals therein, associated with a historic event, activity, or person, or exhibiting other cultural or aesthetic values."

Drivers and Pressures 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) on 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 for anticipating, evaluating, and reacting to changes in the condition of resources and ecosystem services.

Drivers on the Sanctuary

Whereas pressures on sanctuary resources occur locally, 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 and vessel traffic. Drivers and pressures may vary from sanctuary to sanctuary. Relevant drivers and associated pressures were identified in consultation with GFNMS staff and based on past experience identifying drivers and pressures at other sanctuary sites. Table D.1 summarizes the drivers that influence pressures at GFNMS and the scale at which they occur.

Drivers affect pressures by influencing demand for marine-based goods and services like food, energy, recreational opportunities, and transportation. Drivers that influence demand in GFNMS include population, per capita income, trade policy, and societal values and conservation ethic. Other factors that influence demand may include consumer tastes and preferences. As demand for marine resources increases, higher prices and/or quantity demanded 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. 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 GFNMS 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. 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.

Table D.1. Drivers and their relationship to pressures that affect GFNMS resources. Each row begins with a pressure that is known to act at GFNMS, and bullets across the row indicate each driver that affects that pressure. Each column begins with a driver, and the bullets indicate the range of pressures upon which that driver acts. The letter(s) following each driver indicate the geographic scale(s) at which that driver originates to affect pressure (G = global, N = national, R = regional, L = local). The following narrative describes each driver and pressure in detail.

Drivers (→) **Pressures (↓)**	**Population** (G, N, R, L)	**Per-capita Income** (G, N, R, L)	**Gross Domestic Product** (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)	**Trade Policy** (N, R, L)	**Ocean Policy** (N, R, L)	**Environmental Activism** (R, L)	**Technological Advancement** (G, N, R, L)	**Demand for Energy** (G, N, R, L)	**U.S. National Security** (N)
Climate change: Changing ocean conditions	•	•	•	•	•		•		•	•		•	
Land use: Coastal development and nearshore construction	•	•	•			•	•		•	•	•	•	•
Land use: Nonpoint source pollution	•	•			•		•		•	•	•		
Land use: Point source pollution	•	•	•		•		•		•	•	•		
Marine harvest activities: Aquaculture	•	•	•		•		•		•	•	•		
Marine harvest activities: Fishing	•	•	•	•	•		•	•	•	•	•		
Vessel activity: Ship strikes	•	•	•		•			•	•	•	•	•	•
Vessel activity: Anchoring	•	•	•	•	•			•	•	•	•	•	
Vessel activity: Petroleum and other chemical spills	•	•	•						•	•	•	•	
Vessel activity: Vessel discharges	•	•	•	•	•	•		•	•	•			•

Drivers (→) **Pressures (↓)**	**Population** (G, N, R, L)	**Per-capita Income** (G, N, R, L)	**Gross Domestic Product** (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)	**Trade Policy** (N, R, L)	**Ocean Policy** (N, R, L)	**Environmental Activism** (R, L)	**Technological Advancement** (G, N, R, L)	**Demand for Energy** (G, N, R, L)	**U.S. National Security** (N)
Vessel activity: Exhaust gas cleaning discharges	•	•	•						•	•	•		
Vessel activity: Dredging	•	•	•				•		•	•			•
Vessel activity: Vessel groundings	•	•	•	•	•			•			•		
Vessel activity: Noise	•	•	•	•	•	•		•	•	•	•	•	•
Marine debris	•	•	•	•	•		•		•	•	•		
Wildlife disturbance: Visitation	•	•	•	•	•		•	•	•	•			•
Wildlife disturbance: Vessel and aircraft disturbance	•	•	•	•		•	•	•	•	•	•		•
Non-indigenous species	•	•	•		•		•		•	•	•		

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. Demand is a ubiquitous, primary driver of pressures on sanctuary resources. The data provided in this section are from the U.S. Census Bureau (2022) and U.S. Bureau of Economic Analysis (2022). The GFNMS study area for assessing population and per capita income was identified following the methods of Leeworthy & Schwarzmann (2015). First, the counties directly bordering GFNMS were selected; these include Mendocino, Sonoma, and Marin counties. Next, employment in neighboring counties was assessed using data from the American Community Survey (U.S. Census Bureau, 2020). Non-adjacent counties were included in the study area if >1% of workers in that county were employed in one of the counties that directly border the sanctuary; non-adjacent counties that met these criteria were San Francisco, Contra Costa, and Solano counties. Although only these six counties met the criteria for inclusion in the economic study area for the sanctuary, other neighboring counties, such as Alameda and San Mateo, are also considered to be sanctuary stakeholders, and GFNMS works closely with these counties on various conservation and management initiatives.

Table D.2. Population and mean per capita income in a six-county study area associated with GFNMS. The counties included in the study area were Contra Costa, Solano, Marin, Mendocino, San Francisco, and Sonoma. Monetary values are inflation-adjusted to 2021 dollars. Source: U.S. Bureau of Economic Analysis, 2022; Federal Reserve Bank of Minneapolis, 2022

Year	Mean Per Capita Income	Population	Per Capita Income (% Change)	Population (% Change)
2010	$71,497	3,098,058	—	—
2011	$73,327	3,130,790	2.56%	1.06%
2012	$76,895	3,165,515	4.87%	1.11%
2013	$76,470	3,205,170	-0.55%	1.25%
2014	$80,335	3,246,707	5.05%	1.30%
2015	$86,267	3,284,673	7.38%	1.17%
2016	$89,501	3,316,226	3.75%	0.96%
2017	$92,111	3,337,924	2.92%	0.65%
2018	$95,605	3,345,816	3.79%	0.24%
2019	$97,493	3,344,982	1.97%	-0.02%
2020	$104,547	3,330,325	7.23%	-0.44%
2021	$111,194	3,265,728	6.36%	-1.94%

From 2010 to 2021, the population in the GFNMS study area grew by roughly 5.4%, which is less than the rate of population increase for the United States (7.3%) and slightly greater than that of California (5.1%). As of 2021, roughly 8.3% 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 2019, 2020, and 2021, population-driven pressures do not seem to be of immediate concern to GFNMS on a regional level, although localized population pressures may persist.

From 2010 to 2021, real per capita income in the GFNMS study area increased by around 56%, outpacing income growth in the state of California and the United States (roughly 43% and 27%, 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 GFNMS, created by higher demand for products and services. Demand may increase for activities including fishing, transportation, visitation, and construction and land development, among others.

Gross Domestic Product

Another high-level driver is the gross domestic product (GDP) of trade partners. The top importers of U.S. seafood and other fishery products from 2013 to 2022 were the European Union, Canada, China, Japan, and South Korea (Foreign Agricultural Service, 2023). Changes in GDP in these countries directly affect demand for all goods. Furthermore, seafood is bought and sold in a global market such that changes to demand directly affect prices of species caught in GFNMS and, thus, affect fishing behavior in and around the sanctuary itself. From 2010 to 2022, most countries experienced positive GDP growth, with a lower rate of growth during the later half of the study period and several countries experiencing negative growth rates in 2020 (International Monetary Fund, 2023). The slow growth rates and disruption to economic growth caused by the COVID-19 pandemic likely reduced pressure for seafood imports during 2020.

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). In turn, those decisions determine the intensity of pressures, such as vessel traffic, discharges, noise, and resource extraction. 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, 2014). The price of retail gasoline and diesel in California varied without trend from 2010 to 2022 (Energy Information Administration, 2022; Figure D.1).

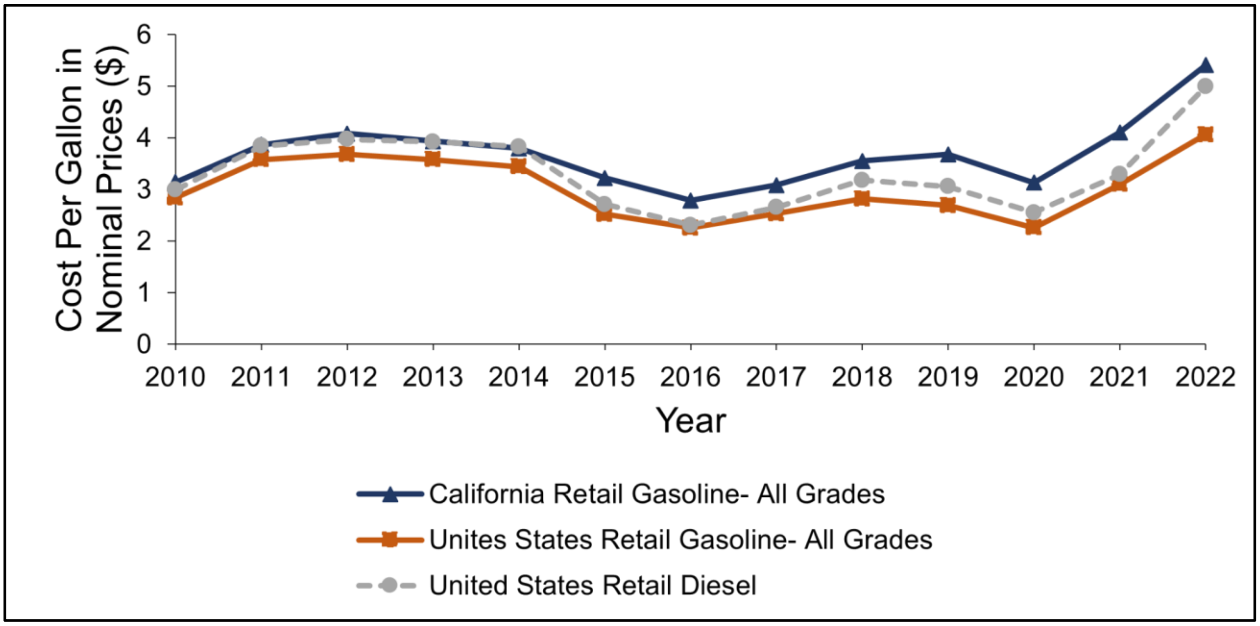

Figure D.1. Nominal prices for California retail gasoline (all grades), U.S. retail gasoline (all grades), and U.S. retail diesel from 2010–2022. Source: Energy Information Administration, 2022

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., 2021). Global seafood consumption increased by an estimated average annual rate of 3.1% from 1961 to 2017 (Food and Agriculture Organization of the United Nations, 2020). Although aquaculture already accounts for over half of seafood produced for human consumption globally, farmed seafood makes up only 8% of domestic production in the U.S. (Food and Agriculture Organization of the United Nations, 2020; Froehlich et al., 2021). Offshore farming has been identified as a strategy to increase U.S. seafood production and reduce reliance on imports (e.g., Executive Order No. 13921), 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 GFNMS except Mendocino, totaled roughly 55.5 million pounds (25.2 million kilograms; Office of Science and Technology, 2022). Over the same period, an average of over 132 million pounds (nearly 60 million kilograms) of seafood products were imported through the district (Office of Science and Technology, 2022). Of the top species harvested in GFNMS, market squid has the highest volume of exports from San Francisco area ports, with an average of 26.7 million pounds (12.1 million kilograms) exported from 2015–2019 (Office of Science and Technology, 2022). For other commercially important species, the five-year (2015–2019) average exports from San Francisco area ports were approximately 601,000 pounds (272,609 kilograms) of sablefish, 364,000 pounds (165,108 kilograms) of Dungeness crab, 193,000 pounds (87,543 kilograms) of unspecified groundfish, and 170,000 pounds (77,111 kilograms) of salmon.

The U.S. seafood industry was heavily impacted by the COVID-19 pandemic and response. Restaurants and other "away from home" venues accounted 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; Froehlich 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 were 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 and a desire for sustainable products (Lem et al., 2014). These shifts in attitudes toward and perceptions of food will place pressures on marine resources worldwide, including those in GFNMS.

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. These regulatory exemptions could affect the sanctuary through water quality degradation, injury to sanctuary resources or habitats, or other impacts. As outlined in sanctuary regulations (15 C.F.R. § 922), all activities carried out by the Department of Defense at the time of designation that are necessary for national defense are exempt from prohibition. Exemption of additional Department of Defense activities is subject to consultation with ONMS. 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.

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 provided point estimates of Californians' attitudes and perceptions toward the environment (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. 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. Finally, about three in four respondents were either very or somewhat concerned about the impact of sea level rise on flooding and beach erosion.

A separate survey of Monterey Bay area residents provided insight into 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.” 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. 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.

Trade Policy

As with many industries, U.S. seafood harvesters and producers are impacted by foreign trade policies, such as import bans and tariffs on U.S. goods by foreign countries, which reduce demand for U.S. exports, and bans on importing foreign goods into the U.S., which could increase demand for domestic goods. 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 at home (Asche et al., 2022). In 2019, the seafood industry faced a major disruption due to the trade war with China (Froehlich et al., 2021). In addition, as of spring 2023, the industry continues to be impacted by a Russian ban on all food imports from the U.S. that began in 2014. On March 11, 2022, President Biden issued Executive Order 14068, which prohibits the importation of seafood originating in Russia.

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 U.S. is party to numerous agreements that establish international entities composed of member governments that focus on various topics, ranging from managing shipping (International Maritime Organization), global whale stocks (International Whaling Commission), fisheries (International Pacific Halibut Commission, Pacific Salmon Commission, etc.), and oil spill response (CANUSPAC). These international agreements affect local processes.

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. 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 (PFMC) is another partnership that manages federal fisheries for around 119 species in the Exclusive Economic Zone of the U.S. West Coast. The council collaborates with states, tribes, and international forums to develop management measures for recommendation to NOAA Fisheries (PFMC, 2020a). PFMC-managed fisheries include salmon, groundfish, coastal pelagic species, and highly migratory species; PFMC also collaborates with the International Pacific Halibut Commission on Pacific halibut fisheries and administers a Fishery Ecosystem Plan that helps the PFMC incorporate ecosystem science into its fishery management decisions (PFMC, 2023). The California Department of Fish and Wildlife (CDFW) manages fisheries in state waters (1–3 miles offshore) and certain fisheries that occur in federal waters, like Dungeness crab, California halibut, and pink shrimp (CDFW, 2020a).

Environmental Activism

Environmental activism refers to activity by community members to address or raise awareness of environmental issues. As stewardship 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. The GFNMS community has engaged in activism to support ocean protection in the region. For example, members of the public initially proposed expansion of the sanctuary in 2001, which led NOAA to initiate a public process to evaluate and assess a proposed expansion beginning in 2012. Leading up to the 2015 expansion of the sanctuary, members of the public expressed support by providing public comments and attending public meetings.

Technological Advancement

Technology can influence pressures on marine resources in several ways. 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 have increased 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, manufacturers and fishers are in the early stages of testing 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).

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 oil and gas resources is prohibited in GFNMS. However, 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 the first quarter of 2023, the Transmountain Pipeline expansion in Canada would increase the volume of tar sands being shipped to refineries in the bay (Center for

Biological Diversity, 2019). Along with infrastructure changes affecting supply, changes in the U.S. and global demand for energy products can impact levels of vessel traffic and associated impacts on sanctuary resources.

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 Coast Guard is responsible for enforcing federal laws in U.S. waters, including 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 (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 the sanctuary (ONMS, 2014b). The Navy maintains two special-use airspaces in and around the boundaries of GFNMS and CBNMS, and naval submarines and surface ships routinely transit the area (ONMS, 2014b).

Pressures on the Sanctuary

Human activities and natural processes affect the condition of natural, cultural, and maritime heritage resources in national marine sanctuaries. This section describes the general nature and extent of known human-caused pressures with documented effects on GFNMS resources, including climate change, land use, marine harvest activity, vessel activities, marine debris, wildlife disturbance, and non-indigenous species. The list of pressures in this section is not exhaustive and does not discuss the potential full range of additional pressures that can cause impacts to sanctuary resources. Other pressures considered included radioactive waste and military activity, but these are not discussed as they did not rise to the level of a documented, existing threat with known impacts.

Climate Change

Climate change resulting from human activities has profoundly impacted coastal and marine ecosystems on a global scale, with projected worsening effects on sea level rise, ocean temperatures, ocean chemistry, storm intensity, and ocean current patterns. The impacts of climate change are intensifying both globally and locally, threatening America’s physical, social, economic, and environmental wellbeing (U.S. Global Change Research Program, 2018).

Anthropogenic climate change is accelerated primarily by greenhouse gas emissions (e.g., carbon dioxide, methane), which trap heat in the atmosphere and lead to higher air and water temperatures. Since pre-industrial times, global air temperature has increased on average by 1 °C, and in the last 50 years, this increase was driven nearly entirely by anthropogenic greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2019). GFNMS is affected by global greenhouse gases and local emissions from vessel and aircraft engines, shipboard incinerators (ONMS, 2014b), and other motorized equipment that produces exhaust. As global temperatures rise, the ocean has absorbed over 90% of the excess heat, causing the average ocean temperature to increase worldwide (Intergovernmental Panel on Climate Change, 2019).

Rising Ocean Temperatures, El Niño-Southern Oscillation, and Marine Heatwaves

From 1980 to 2019, annual sea surface temperatures were consistently above average globally, and increased over time (National Centers for Environmental Information, 2023a). Water temperatures in the GFNMS region have risen slightly over the past century (Johnstone & Mantua, 2014; ONMS, 2020a).

Rising ocean temperatures are also linked to oceanographic phenomena: the El Niño-Southern Oscillation (ENSO) and marine heat waves. El Niño is the warm phase of the ENSO cycle and is characterized by above-average sea surface temperature (SST) in the central and eastern tropical Pacific Ocean (L'Heureux, 2014). Although conditions may vary, El Niño can result in warmer SSTs in GFNMS that last for months to years. During the past 30 years, the California Current Ecosystem has experienced an intensification of El Niño events (McGowan et al., 1998; Fiedler, 2002). In contrast, marine heatwaves (MHWs) occur when ocean temperatures are extremely warm for an extended period of time, generally from weeks to months and occasionally longer (e.g., the 2014–2016 MHW). MHWs are defined as SSTs that exceed the 90th percentile of the baseline climatology (i.e., the previous three decades of temperatures) for at least five consecutive days (Hobday et al., 2016).

The timing and magnitude of upwelling has become much more variable over the last six centuries (Sydeman et al., 2014; García-Reyes et al., 2023), and upwelling intensity is expected to increase (Xiu et al., 2018). However, warm water events like El Niño and MHWs can alter the timing, intensity, and location of upwelling events, often by creating stratification or forcing nutrient-rich water closer to shore, away from the majority of the sanctuary (Jacox et al., 2016; Santora et al., 2020). When this occurs, coastal waters receive fewer 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 plankton, 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). During past El Niño events and MHWs in the California Current Ecosystem, zooplankton communities shifted to smaller, less nutritious copepod species from the south (Fisher et al., 2015; Leising et al., 2015, Elliott et al., 2022a), plankton biomass declined, and functional groups shifted (McGowan et al., 1998).

Higher water temperatures and reduced food availability may affect species abundance and distribution by encouraging species to move to cooler northern or deeper waters (Poloczanska et al., 2013) and altering migration patterns (Gulland et al., 2022). Some species that are unable to acclimate or adapt over time could decline in abundance (Hobday et al., 2016). Warmer water holds less oxygen and could fall below the range of natural variability by 2030 (Long et al., 2016), reducing habitat for species like rockfish (Koslow et al., 2011; Hamilton et al., 2017). Higher temperatures can also increase the occurrence of disease outbreaks such as sea star wasting syndrome (Bates et al., 2009; Eisenlord et al., 2016), and lead to more frequent and more intense harmful algal blooms (HABs; Cavole et al., 2016; Gobler, 2020). HABs can produce toxins that can harm wildlife, causing mass mortalities of sea lions, whales, seabirds, and other animals (McCabe et al., 2016; Griffith & Gobler, 2019; Sanford et al., 2019; Gulland et al., 2022).

Warmer water temperatures, especially those resulting from MHWs, can be a catalyst for habitat compression in the offshore environment. The recent 2014–2016 MHW, for example, caused by a persistent high-pressure system in the eastern North Pacific (Bond et al., 2015), raised water temperatures in the sanctuary by 7.2°F (3.6°C) above normal (Gentemann et al., 2017; Sanford et al., 2019), causing many southern species to move northward (Hobday et al., 2016). During this period, offshore upwelling was reduced, and the cooler upwelling habitat for forage species in the central California Current Ecosystem, such as anchovy and krill, was also compressed eastward toward the mainland; this resulted in habitat compression for some predator species, such as whales and seabirds (Santora et al., 2020). For whales, foraging closer to shore as a result of habitat compression can increase the risk of ship strikes and entanglement in crab pots. MHWs are expected to increase in frequency and intensity (Frölicher et al., 2018), and these phenomena may be a predictor of future ecological conditions in the offshore environment (Cavole et al., 2016).

Ocean Acidification

Ocean acidification occurs when increased levels of carbon dioxide (CO_2) in the atmosphere dissolve in seawater, reducing the pH value and making the ocean more acidic (ONMS, 2020b). The ocean absorbs around 30% of CO_2 emissions (National Centers for Environmental Information, 2023a), and global average surface ocean pH has decreased by 0.1 units since pre-industrial times (Doney et al., 2009), which corresponds to a 30% increase in acidity. Aragonite, a form of calcium carbonate, is considered a key indicator of ocean acidification, as its availability in seawater is affected by increasing CO_2. The saturation state of aragonite is projected to drop rapidly in the California Current Ecosystem within the next 30 years, with much of the nearshore region developing summertime undersaturation in the top 200 feet (60 meters; Gruber et al., 2012; Anderson et al., 2022).

Ocean acidification slows the growth of calcium carbonate structures and can dissolve these structures faster than they form, impacting shelled organisms in the California Current Ecosystem (Hales et al., 2005). Corrosive conditions can occur for many species, like oysters, crabs, and pteropods, when aragonite saturation is <1.0 (Barton et al., 2012; Bednaršek et al., 2014; Marshall et al., 2017; Hodgson et al., 2018). Ocean acidification can also impact larval and juvenile fish through changes in behavior, physiology, and patterns of gene expression (Munday et al., 2009; Hamilton et al., 2017). Acidification in the sanctuary is accelerated by upwelling, because cool, upwelled waters are more acidic than surface waters (García-Reyes & Largier, 2010). As a result, California waters have increased in acidity by up to 60% since 1895 and could increase to 40% above 1995 levels by 2050 (Gruber et al., 2012; Osborne et al., 2020). Portions of the sanctuary's nearshore region are already acidic enough to impair the growth of shell-forming animals (Davis et al., 2017; Chan et al., 2017), including species with commercial or recreational value, such as Dungeness Crab (Bednaršek et al., 2020), oysters, clams, and mussels. Increasingly acidic waters make it difficult for organisms like coral to make and maintain their shells and stony skeletons. Deep-sea corals are particularly susceptible, as the deep waters where they live are naturally more acidic than the surface (Gómez et al., 2018). Pteropods, important prey for fish, are particularly susceptible to increasingly acidic waters (Bednaršek et al., 2017), and krill, prey for salmon, seabirds and whales, may experience reduced larval survival as acidity increases (McLaskey et al., 2016). The effects of ocean acidification could thus have consequences for the entire food web (Bednaršek et al., 2017; Hodgson et al., 2018; Gentemann et al., 2017; ONMS 2020a).

Ocean acidification, in combination with other local conditions, may also affect historic resources. Historic shipwrecks could be threatened by an increasingly acidic ocean, which has the potential to change the corrosion rate of metal ship parts and artifacts (Rockman et al., 2016).

Sea Level Rise, Increased Storms and Wave Activity, and Precipitation Variability

Sea level rise impacts beaches and dunes, marshes, and rocky intertidal habitats through increased coastal erosion and damage from increased storm surges, which can lead to drowning and/or erosion of coastal habitats. Numerous factors contribute to global sea level rise, including melting glaciers and thermal expansion of seawater. Factors such as currents and changing land height cause sea level rise to occur at different rates in different locations (Slangen et al., 2014). In the sanctuary, sea level has risen approximately 9 inches (23 centimeters) since 1854 (NOAA, 2022a), and the most recent NOAA sea level rise projections predict an increase of another 9–11 inches (23–28 centimeters) by 2050 and up to 78 inches (198 centimeters; high scenario) by 2100 (Sweet et al., 2022). In GFNMS, sea level rise is impacting critical pupping and haul-out habitat for marine mammals such as harbor seals and Steller sea lions, as well as nesting areas for birds like the threatened western snowy plover (Largier et al., 2010; Funayama et al., 2013).

Winter storms have increased in frequency and intensity in the North Pacific, including in the sanctuary, since 1950 as a result of climate change (Largier et al., 2010; Graham & Diaz, 2001) and strong waves driven by these storms are exacerbating sea level rise impacts, like erosion (Largier et al., 2010; Dettinger, 2011; Erikson et al., 2015). Overall, increased erosion and runoff are likely to occur in association with winter storms that bring large waves and heavy precipitation to the region (Largier et al., 2010). Projected increases in the intensity of storms and waves (Dettinger, 2011; Erickson et al., 2015) could also reduce the ability of encrusting organisms to stay attached to substrate in the intertidal zone.

As with ocean acidification, sea level rise and increased wave activity and erosion negatively impact nearshore maritime heritage properties and coastal cultural sites in many locations (Roth, 2021). The Society for California Archaeology launched a Climate Change and California

Archaeology study in 2011, and current research includes coastal regions adjacent to GFNMS (Newland, 2014).

Climate change is also altering precipitation. Snowpack in the Sierra Nevada mountains has declined in recent decades (Sun et al., 2019; Pederson et al., 2011). The shift from snowpack to rain-dominated runoff, along with increases in extreme wet and dry events, could alter the timing and intensity of runoff and sediment input into the sanctuary, impacting organisms that depend on streamflow, such as salmon.

Shoreline Change and Sediment Transport

Sea level rise, increased frequency and intensity of storms, and changes in precipitation can alter sedimentation patterns along the sanctuary's coast through increased flooding of low-lying areas and increased erosion of cliffs, bluffs, and dunes (Limber & Barnard, 2018), which can lead to disappearing beaches and coastal wetlands with significant ecological implications.

Tidal marshes depend on a steady sediment supply and factors such as altered precipitation patterns and land use may prevent marshes from keeping pace with the expected rate of sea level rise (Thorne et al., 2018; Weston, 2014). In some cases, overaccumulation of sediment can occur, damaging habitats, interfering with the food chain, obstructing channels, and increasing turbidity.

Warmer water events can exacerbate shoreline change as well. California shorelines retreated beyond previously measured landward extremes in 2015–2016 as a result of one of the strongest El Niño events in the last 145 years (Barnard et al., 2017).

Land Use

Land use activities adjacent to marine and estuarine waters, such as agriculture, forestry, transportation, urbanization, and construction, can create pollutants, including sediments, plastics, and chemicals, that can impact water quality, marine species, and habitats.

High pollution loads can lead to eutrophication—an overload of nutrients such as nitrogen and phosphorus. The excess nutrients can cause algal blooms, which can lead to depleted oxygen levels and subsequent harmful effects on marine life. These pollutants are often introduced via runoff from land activities, such as agriculture, and can enter the sanctuary through rivers, estuaries, and other pathways, adversely impacting water quality.

Artificial structures that stabilize shorelines (such as seawalls, rip rap, roadways, etc.) can result in narrower coastal habitats and reduced space for habitat migration as sea level rises and storm surge intensity increases.

Marine Harvest Activities

Fishing offers many benefits to society, including the economic, nutritional, and employment benefits of commercial fisheries (Kelleher et al., 2012) and the economic, social, physiological, educational, and economic benefits of recreational fishing (Leeworthy & Schwarzmann, 2015; Arlinghaus et al., 2019). However, fishing can also negatively impact sanctuary resources, including habitat, living resources, and maritime heritage resources. The extraction of certain fish species can alter ecosystem function, especially when one part of the food web or a predator and prey population is reduced or removed from the food chain (Hammerschlag et al., 2019). The removal of targeted fish species, along with mortality through bycatch, can also result in changes in biodiversity. Catch-and-release recreational fishing (and the release of incidentally caught species) can also result in mortality through barotrauma, increased depredation, hook wounds, and other pathways, as well as sublethal effects like behavioral impairment and decreased feeding success (Davis, 2002; Campbell et al., 2010). The mortality rate of catch-and-release fishing has a large range (0–95%, median = 11%, mean = 18%) and is dependent on factors such as hooking location, type of hook used, type of bait used, depth of capture, temperature, and hooking and handling times (Bartholomew & Bohnsack, 2005).

The use of mobile commercial fishing gear, such as bottom trawls, is 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; Kaiser et al., 2006).

Impacts to deep-sea communities from these activities may be long lasting. Corals and sponges on hard substrate are vulnerable to damage and removal from bottom trawling (Althaus et al., 2009), as are the biota of soft-sediment habitats, such as sea pens (Hall-Spencer et al., 2002; Heifetz et al., 2009). Deep-sea corals and sponges are slow growing and may have long recovery times following disturbance (Prouty et al., 2016). Slow-growing, large-biomass biota such as sponges and soft corals take much longer to recover (up to 8 years) than biota with shorter life spans, such as polychaetes (<1 year; Kaiser et al., 2006).

Additional impacts can occur from other commercial fishing gear, such as bottom longlines and vertical hook and line, which can cause damage to sensitive habitats and species, such as deep-sea corals (Stone, 2006; Stone et al., 2015). Derelict (lost or discarded) fishing gear is also a concern, as these items can continue to trap and kill marine life for many years (NOAA Marine Debris Program, 2015). However, some types of gear, such as Dungeness crab traps, are required to have a disabling mechanism via a biodegradable release, which can have varying degrees of success based on design and crab health (Antonelis et al., 2023). Active, lost, or discarded gear can lead to marine mammal and seabird entanglement and strandings (Moore et al., 2009, Donnelly-Greenan et al., 2019, NOAA Fisheries, 2020a). Commercial fishing, particularly bottom trawling, can also result in mechanical damage to and entanglement of maritime heritage resources (Meyer-Kaiser et al., 2022; Brennan et al., 2016).

Aquaculture operations can impact ecosystems by altering the deposition of organic material; altering sedimentation processes due to the anchoring, harvesting, and maintenance of moored oyster bags and floats, which can affect biogeochemical and biological processes in sediments (McKindsey et al., 2006; Dumbauld et al., 2009); removing benthic species; causing changes to resource or habitat availability (Dumbauld et al., 2009); and influencing the number and intensity of phytoplankton blooms directly through grazing and indirectly by modifying nutrient fluxes. Shellfish aquaculture operations occur in Tomales Bay, which has the greatest number of state bottom water leases in California (CDFW, 2020b).

A variety of fishing gear types are used in the offshore region, including pots/traps, troll gear, trawls, seines, longlines, and hook and line (CDFW, 2020a). The most commonly used types of commercial bottom contact fishing gear (in terms of harvest revenue and pounds landed) throughout GFNMS that can alter seafloor habitat are traps and trawls (CDFW, 2020a; ONMS, 2023a). Commercial and recreational fishing of invertebrates also occurs in some intertidal areas through direct collection (harvesting). Fishing activities in GFNMS estuaries include the harvest of crab, herring, halibut, surf perch, striped bass, salmon, leopard shark, and bat rays, primarily via traps and hook and line. Most fishing activity is by recreational anglers; however, commercial fishing is allowed in GFNMS estuaries and may occur for certain species.

GFNMS does not have the authority to manage fisheries. Instead, commercial and recreational fisheries in GFNMS, including species managed through the Groundfish Fishery Management Plan, Highly Migratory Species Management Plan, Coastal Pelagic Species Management Plan, and Salmon Management Plan, are managed by PFMC and NOAA's National Marine Fisheries Service. State fisheries (e.g., Dungeness crab, market squid, herring, and nearshore finfish) are managed by CDFW.

Vessel Activity

Private, commercial, and military vessels may impact the sanctuary and sanctuary users in several ways, including:

- Ship strikes on whales and other species;
- Anchor damage to seafloor habitats and/or maritime heritage resources;
- Discharge of oil, sewage, chemicals, and non-biodegradable materials;
- Seafloor damage from vessel groundings and sinkings; and
- Elevated noise levels.

Pressures from vessel traffic through the sanctuary vary depending on vessel size, transit frequency, route, and type of vessel. Numerous types of domestic and foreign-flagged commercial vessels (some of which carry hazardous materials), including large vessels (greater than 300 gross tons) such as container ships, tankers, car carriers, bulk cargo carriers, and cruise ships, transit through GFNMS. Smaller commercial and recreational vessels are also present in the sanctuary, including in Tomales Bay and Bolinas Lagoon. Thousands of commercial, recreational, fishing, military, and research vessels berth in harbors near the sanctuary.

Pressures are likely to continue in the region from small boat and large vessel traffic, given forecasted trends and the increase in size of commercial ships over the last several decades.

Ship Strikes

Vessels can injure or kill animals. Slow-moving whales rely on the highly productive waters of the sanctuary as a destination feeding ground or part of their migratory routes, and are particularly vulnerable to ship strikes. Ship strike risk for whales is highest in shipping lanes and at the western ends of shipping lanes over the shelf break (Rockwood et al., 2020a), a whale foraging area (Rockwood et al., 2020b).

Levels and location of shipping traffic, vessel speeds, whale abundance, and whale behavior are factors affecting ship strike risk to whales (Laist et al., 2001; Dransfield et al., 2014; McKenna et al., 2015; Rockwood et al., 2017). Ship strikes, along with entanglements, are the primary sources of anthropogenic mortality to threatened and endangered whales listed under the Endangered Species Act along the West Coast (Carretta et al., 2021), with a model-estimate of approximately 80 threatened and endangered whales hit and killed each year (Rockwood et al., 2017). 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 endangered blue whales is of concern, given their low population estimate (1,050 in California, Oregon, and Washington; Carretta et al., 2021). Humpback and fin whales are also at risk; humpback whales traveling to GFNMS are listed as threatened for the Mexico Distinct Population Segment and endangered for the Central America Distinct Population Segment (Carretta et al., 2021), and fin whales are listed as threatened.

Anchoring

Anchoring by vessels of all sizes can damage sensitive benthic habitats and protected maritime heritage resources, particularly shipwrecks found in anchor-depth waters. Further, improper anchoring can result in anchor dragging and potentially grounding of vessels. Grounded vessels may later break apart, discharging debris and pollutants. Anchoring in eelgrass beds can scour the seafloor and uproot eelgrass, causing fragmentation of the beds, reductions in habitat integrity, and changes in eelgrass community structure (Kelly et al., 2019).

Petroleum and Other Chemical Spills

Oil pollution can come from vessel collisions, sinkings, groundings, discharges, and historic sunken wrecks. Cargo ships and oil tankers transit the sanctuary and are of particular concern for spills and discharges. Large cargo ships can carry up to 4 million gallons (15 million liters) of fuel oil (Office of Response and Restoration, 2016). Oil tanker size varies, and these ships can carry 9–150 million gallons (34–568 million liters) of oil (Kummerlowe et al., 1996). Supertankers can carry over 80 million gallons (303 million liters) of oil. Vessels can introduce pollution into the marine environment from spills; blowing or drifting trash (e.g., oil containers and portable gas tanks); faulty equipment; and other mishaps or poor waste control practices.

Oil pollution in any form has adverse impacts on sanctuary 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. Past spills, such as the 2007 motor vessel (MV) *Cosco Busan* spill, which killed over 6,800 birds both inside and outside the sanctuary (Cosco Busan Oil Spill Trustees, 2012), have impacted seabird populations and future spills could impact multiple species on a local or regional scale. Oil spills can have lethal and long-term, sub-lethal effects on fish (e.g., behavioral changes, reproductive abnormalities) and can also contaminate fish targeted for human consumption. Some fishing industry sectors could be shut down for years by an oil spill.

Due to its proximity to San Francisco and its surrounding metropolitan area, shipping ports, and petroleum refineries, GFNMS has a history of large spills and has been impacted by six major vessel-based oil spills since designation in 1982: steamship (SS) *Jacob Luckenbach* (which sank in 1953 and had ongoing releases until oil was lightered in 2002), tank vessel

Puerto Rican (1984), tank barge *Apex Houston* (1986), SS *Cape Mohican (*1996), tank vessel *Command* (1998), and MV *Cosco Busan* (2007). Vessels that sink with product on board can continue to release oil as currents and large swell events move the vessel. For example, SS *Jacob Luckenbach* released an estimated 300,000 gallons of bunker fuel oil over more than 48 years, killing at least eight sea otters and over 51,000 birds (Luckenbach Trustee Council, 2006). Small oil releases caused by small to medium sized boat groundings and sinkings (i.e., recreational and commercial fishing vessels) also occur every year in estuarine, coastal, and offshore sanctuary waters.

Due to the sanctuary's proximity to San Francisco Bay and its tributaries, land-based spills and discharges also pose threats. Naturally occurring oil seeps also cause periodic tarball pollution events along the GFNMS coastline.

Offshore Discharges

While GFNMS regulations prohibit most discharges in the sanctuary, illegal discharges have occurred, including the dumping of sewage and other hazardous liquid substances, as well as solid materials like shipping containers and other marine debris, which can impact water quality, seafloor habitat, and wildlife.

Cruise ships 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. Cruise ships regularly transit the sanctuary and passengers embark at the cruise ship terminal in San Francisco Bay. Cruise ship discharges are prohibited within the sanctuary except for clean vessel engine cooling water, clean vessel generator cooling water, vessel engine or generator exhaust, clean bilge water, and anchor wash. Volumes of sewage generated by a typical cruise ship have been estimated at 8.4 gallons (31.8 liters) per person per day or 147,000 gallons (>556,000 liters) per week (MBNMS, 2023), with an additional 85 gallons of graywater per person per day (Herz & Davis, 2002). Known pollutants generated by cruise ships include food waste; processed permeate; treated and untreated graywater (wastewater from sinks and showers) and blackwater (sewage); membrane bioreactor sludge; advanced wastewater treatment permeate; exhaust gas cleaning system (EGCS or scrubber[8]) washwater; oily bilge water; hazardous wastes; and trash. Scrubber washwater is of particular concern, because it may contain concentrations of metals and pollutants that could result in increased acidification, eutrophication, and accumulation of polycyclic hydrocarbons in the marine environment (U.S. Environmental Protection Agency [EPA], 2011; Endres et al., 2018). Illegal cruise ship discharges of a number of substances have been documented over the last decade in GFNMS. Nutrients and compounds can remain in waste streams after treatment (EPA, 2008). These discharges are known to have effects on water quality and sea life through the potential introduction of harmful components such as bacteria, heavy metals, pharmaceuticals, pathogens, and viruses (EPA, 2008). Feeding in polluted waters has been known to negatively

[8] EGCS or scrubbers are devices used on large vessels to remove sulfur dioxide from the exhaust of marine engines to reduce air emissions. The extracted sulfur is removed using either seawater or freshwater wash and is prohibited from being discharged into the sanctuary.

affect the health of marine mammals, including dolphins, sea otters, seals, and sea lions (Bossart, 2011).

The accidental or intentional discharge of dredged material can affect water clarity by blocking sunlight, restricting the growth of plankton, and disrupting the foraging of fish, birds, and marine mammals. It can also change the character of seafloor habitat and smother bottom-dwelling organisms, such as corals and sponges, and potentially bury or damage submerged maritime heritage resources. Material dredged from marinas and navigation channels in nearby harbors and ports (mainly Bodega Harbor and San Francisco Bay) is periodically towed through the sanctuary via barge and scow for legal disposal at the San Francisco Deep Ocean Disposal Site (SF-DODS), located approximately 59 miles (95 km) from the Golden Gate Bridge and 9 miles (14 km) west of the closest point of the sanctuary boundary. While material is tested for suitability for ocean disposal and is relatively clean, accidental releases have been known to occur in the sanctuary in the last 10 years.

Grounded and Sunken Vessels

Grounded and sunken vessels can cause physical adverse effects to seafloor habitat and maritime heritage resources, release fuel and other chemicals, and generate marine debris. Groundings and sinkings are a regular but unpredictable occurrence in the sanctuary and cause a range of impacts, including short- and long-term habitat loss from vessel recovery or complete habitat loss with ongoing risk of debris and pollutants. Vessels grounded or sunk fewer than 50 years ago are not considered potential heritage or historic properties by GFNMS.

Noise

Many marine organisms, including marine mammals, turtles, fish, and invertebrates, rely on sound for their survival and the degree to which biota are impacted depends on the interaction of noise intensity, duration, timing, and frequency, among other factors. Exposure to high-decibel noise, especially in close proximity, can cause acute impacts like tissue damage, hearing impairment or loss (either temporary or permanent), and death (Gedamke et al., 2016). Elevated underwater noise levels can mask biologically important acoustic signals (e.g., those used for echolocation, interspecies communication, mother/calf contact, predator-prey cues, and navigation) and cause behavioral alterations (such as changes in migration patterns or abandonment of important habitats; National Research Council, 2003; Erbe et al., 2018). Many marine mammals respond to noise by altering their breathing rate, increasing or reducing their time underwater, changing the depth or speed of their dives, changing their song duration, and swimming away from the affected area (National Research Council, 2003; Goldbogen et al., 2013; Southall et al., 2007). Higher stress loads have been documented in whale populations exposed to chronically louder conditions (Gedamke et al., 2016). These effects can negatively impact animals' energy and physiology, which in turn can reduce their ability to survive and reproduce (reviewed in Francis & Barber, 2013).

The level of noise pollution in the oceans has increased dramatically during the last 50 years, mainly from commercial shipping in coastal environments (National Research Council, 2003; Frisk, 2012; Southall et al., 2018). 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;

Southall et al., 2018). Studies have also shown that slower and smaller ships produce less noise (McKenna et al., 2013).

Noise was not selected as an indicator for this condition report as limited data were available. Analysis of acoustic data, vessel traffic patterns, and related noise inputs to GFNMS is required to assess status and trend in the future.

Marine Debris

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 (Office of Response and Restoration, 2023). Marine debris enters the sanctuary from both water- and land-based activities, and it has accumulated in the water column and benthic habitats. Land-based sources include stormwater runoff, landfills, and recreational and commercial activities. Marine-based sources include commercial and recreational fishing and aquaculture; military activities (Keller et al., 2010); and cargo containers falling off ships in high seas (Frey & DeVogelaere, 2014). Marine debris is also generated by some research activities. A wide variety of objects can become marine debris, including lost fishing gear; passenger and commercial shipboard waste; lost vessel cargo; metal military debris; abandoned or lost moorings and buoys; abandoned, grounded, and/or sunken vessels; and a variety of household goods. The most prevalent type of marine debris found in the ocean, including the sanctuary, is plastic.

Marine mammals and seabirds are known to be affected by marine debris (Gall & Thompson, 2015; NOAA Marine Debris Program, 2014). Marine mammals can become entangled in fishing gear; on the U.S. West Coast, including GFNMS, this is particularly a problem for large whales. Derelict (lost or discarded) fishing gear can trap, injure, or kill marine life, sometimes impacting wildlife for years. The timing of the arrival of humpback whales in the Gulf of the Farallones region has shifted earlier since the mid-1990s, which has increased co-occurrence of whales with the historic timing of commercial fishing activities, thus increasing the risk of entanglement, particularly in the lines and surface buoys of Dungeness crab traps (Figure S.P.4.4).

Other sanctuary wildlife, such as pinnipeds and seabirds, can also become entangled in fishing gear and debris. 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, 2014). Plastics in the marine environment never fully degrade, and organisms consume plastic at all levels of the marine food web (Tuuri & Leterme, 2023). In general, given the quantities of plastic debris floating in the ocean, the potential for wildlife to ingest plastic is high. The ability for plastics to attract and transport contaminants into the marine food web has been documented (Arthur et al., 2009), and research suggests microplastics (i.e., plastic pieces less than five millimeters in length) can accumulate in seafood (Mercogliano et al., 2020). Common surface-feeding seabirds in GFNMS, including albatross, shearwaters, fulmars, and storm-petrels, are highly susceptible to plastic ingestion (Nevins et al., 2005).

Sunken vessels, shipping containers, and other large debris may crush, smother, or displace corals, sponges, and other benthic invertebrates in offshore and/or nearshore environments.

Heavier objects can cause the permanent loss and/or scarring and damage to rocky reef habitat, which reduces the value of substrate to support coral/sponge colonies, algal assemblages, and other encrusting and habitat-forming organisms.

Wildlife Disturbance

Wildlife in GFNMS is diverse and includes iconic species such as whales, pinnipeds, white sharks, and birds, in addition to fish and invertebrates. GFNMS directly monitors and tracks partner reports of human disturbance to wildlife at seabird colonies and pinniped haul-outs within the sanctuary, including popular areas for visitation such as Bolinas Lagoon, Tomales Bay, and Duxbury Reef (GFNMS, 2022c; Codde, 2020). Disturbances that have been studied (Reyna et al., 2021) include:

- Close-approaching water-based activities (e.g., kayaking, stand up paddleboarding, jet skiing) and boating tourism/recreation (e.g., wildlife watching, diving);
- Low-flying planes, helicopters, uncrewed aerial systems (i.e., drones);
- Increased visitation impacts, including rocky intertidal trampling and harvesting of flora and fauna; and
- Close-approaching land-based activities like human foot traffic and dog interactions with birds and marine mammals on beaches.

For seabirds, frequent disturbance or a single severe event can disrupt nest site prospecting, courtship, resting, and feeding of young. It can lead to increased predation, increased stress levels, and higher energy costs, the net effect of which reduces breeding success, results in fewer young, and can cause colony abandonment over time (Rojek et al., 2007). Marine mammal disturbance can cause stress, displacement, and physical injury (NOAA Fisheries, 2023a).

Visitors at rocky reefs have been documented trampling and collecting intertidal invertebrate species (Lindquist & Roletto, 2022a; Patton et al., 2021). These activities can cause long-term negative impacts to habitats and species through altered abundances and community interactions.

Non-Indigenous Species

Non-indigenous species are organisms living outside their native distributional range, having arrived there by human activity, either deliberate or accidental, and are also called alien, exotic, non-native, or introduced species. Non-indigenous species that have damaging effects on ecosystems are called invasive species. Invasive species are one of the greatest threats to rare, threatened, or endangered species in the U.S., thought to be second only to habitat destruction (Dueñas et al., 2018). In general, non-indigenous species in the marine and estuarine environment can alter species composition, threaten the abundance and diversity of native marine species, interfere with ecosystem function, and disrupt fisheries (Bax et al., 2003; (Grosholz, 2002). Invasive marine species can result in declines, extirpations, or extinctions of native plants and marine life, reduce biodiversity by competing with native organisms for limited resources, limit resiliency of wildlife and habitats to recover from anthropogenic impacts, limit effectiveness of restoration actions, alter habitats, and compound the impacts from climate change.

Marine non-indigenous species may enter the sanctuary by traveling on the hulls of ocean-going ships and on the hulls, propellers, or trailers of small private and commercial boats, including from San Francisco Bay, which is considered the most invaded aquatic ecosystem in the world, with over 230 non-indigenous species (Cohen & Carlton, 1998). In addition, non-indigenous species may be released in or near the sanctuary in ballast water. Other potential vectors for the spreading of non-indigenous species in the sanctuary include recreational and research equipment, marine debris, and buoys. Organisms used for live bait and aquaculture also have the potential for accidental or intentional release into the marine/estuarine environment.

European green crabs are highly adaptable predators originating from Western Europe and Africa that first appeared along the western U.S. in 1989. This species, likely transported in the ballast water of cargo ships and boats, became established in shallow intertidal and subtidal habitats. The highest density of European green crabs along the entire West Coast is in Seadrift Lagoon, a human-made lagoon connected to Bolinas Lagoon by a managed intake near the northwestern end and an outfall on the southeastern end. European green crabs are also established in Bolinas Lagoon and Tomales Bay with interannual variability in abundance.

Status and Trends of Drivers and Pressures

This section answers questions related specifically to the drivers and pressures discussed in the previous chapter. Drivers, or driving forces, are the socioeconomic and sociocultural forces driving human activities, which increase or mitigate pressures on the environment. Pressures are the stresses that human activities place on the environment. The effect of pressures on the status and trends of sanctuary resources are addressed in the following section.

Two virtual expert workshops were convened on May 17 and July 11, 2022 to discuss and determine status and trend ratings in response to a series of standard condition report questions related to human activities occurring in the sanctuary (see Appendix A and Appendix C). It is important to note that, in general, the assessments of the status and trends of key indicators in GFNMS are for the period from 2010–2022. During the virtual workshops, indicators for each topic were presented, accompanied by data sets ONMS had collected prior to the meeting. Attendees were then asked to review the indicators and data sets, identify data gaps or misrepresentations, and suggest any additional data sets that may be relevant. Once all data sets 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 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 May or July 2022). However, in some instances, staff later reevaluated and/or incorporated newly available data 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 Drivers (Question 1)

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

Not Rated

Rationale: ONMS and GFNMS staff decided not to rate the status and trend of influential human drivers at GFNMS. 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 GFNMS resources are 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, but drivers are not typically manageable by GFNMS. 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 and stewardship 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. Pressures are typically manageable by GFNMS, thus status and trend ratings for pressures (i.e., human activities) and their potential effects on sanctuary resources were 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 transits and use of the sanctuary, including cruise ship transits, dredge material barge transits, and oil release incidents associated with vessels; coastal development; and agriculture and other types of land use.

Question 3 covers human activities that may adversely influence habitats. Some human activities may have structural and non-structural impacts to habitats. For example, commercial 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 (e.g., those that produce greenhouse gases) are not discussed in this report. National marine sanctuary managers are not charged with controlling this and other issues (e.g., plastic pollution) at such large scales, 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 contribute to climate change (e.g., vessel traffic).

Because of the considerable differences in environmental pressures and responses between the coastal and offshore region and the estuarine and lagoon region of GFNMS, each question was assessed twice in order to represent these two environment types separately.

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

Coastal and Offshore Region

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

Rationale: Consideration of both land- and sea-based activities that pose threats to water quality indicated a mix of improving and worsening threats. While the number of transits by large commercial shipping vessels remained consistent throughout the study period, the distance transited through the sanctuary decreased. Cruise ships reported illegal discharges in the sanctuary during the study period. However, there was a decrease in the number of discharge incidents and volume discharged from barges transporting dredged materials, as well as a decrease in the number of large oil spills. Lastly, there was a minor increase in land use along the coast in recent years.

Findings from the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good/fair and the trend was not changing. Ratings were based on observations of few harmful algal blooms, continued nonpoint source discharges from San Francisco Bay and the Russian River, new coastal Clean Water Act 303(d) listings for various pollutants, decreased oil pollution, and decreased sediment spills from barges.

New Information in the 2010–2022 Condition Report

Human activities used to evaluate this question included vessel traffic, known discharges from cruise ships and dredge barges, oil spills, and changes in land use. Because discharges from vessels impact water quality but are likely underreported and challenging to track, vessel traffic data from the automatic identification system (AIS) since 2016 were used as a proxy for the potential for discharges (Table S.P.2.1).

Table S.P.2.1. Summaries for the key indicators related to human activities that impact water quality in the coastal and offshore region of GFNMS that were discussed during the July 11, 2022 virtual status and trends workshop.

Indicator	**Source**	**Data Summary**	**Figures**
Vessel traffic	Bureau of Ocean Energy Management (BOEM) & NOAA, 2022	Status: Cargo vessels had the highest documented distance traveled, percent of vessels, and number of transits compared to other vessel types. Trend: Globally, cargo vessels increased in size over the study period. Distances traveled within the sanctuary decreased during the study period.	S.P.2.1
Cruise ship discharges	Blank Rome LLP, 2017	Status: During the study period, 100 cruise ships entered the sanctuary annually, except during the COVID-19 pandemic. From 2015–2017, 190 incidents resulted in the discharge of 8,502,138 gallons (>32,000,000 L) of prohibited materials in the region, 95% of which occurred within GFNMS. Trend: Since 2017, there have been no reports of cruise ship discharges.	N/A
Dredge material discharges	Etrac, 2022	Status: A small number of dredged material leaks occurred from barges transiting through the sanctuary since 2010. From 2017–2021, 15 leaks occurred. Trend: Since 2010, there was a significant decrease in both the number of discharge incidents and total volume of discharge.	N/A
Oil release events	GFNMS, 2022d; U.S. Coast Guard (USCG), 2022	Status: Oil spills from smaller vessels (20–100 feet [6–30 m]) were a chronic issue in GFNMS, with an average of 6.8 incidents per year. Trend: No spills from large ships (>300 gross tons [305 metric tons]) occurred since the 2010 condition report.	S.P.2.2
Agriculture and developed land use	Dewitz & U.S. Geological Survey, 2021	Status: Land use in the areas surrounding GFNMS included development and agriculture. Trend: Since 2016, there has been a 1.2% increase in developed and agricultural land within 10 miles (16 km) of GFNMS.	N/A
Data gaps	Numbers of large vessels by type need to be better documented on an annual basis. The amounts of sulfur oxide emissions entering the sanctuary are not known. Runoff from developed land use into the sanctuary has not been quantified. More information on the quantified impacts from vessel sizes, distance traveled, and speeds (e.g., sulfur oxide emissions), as well as small fuel spills would better inform this question. Better understanding of the reasons why transit distances in the sanctuary have decreased while vessel numbers have remained fairly consistent from year to year is needed.		

Vessel Traffic

Vessel traffic is a human activity of interest for water quality because of the risk of oil spills, illegal discharges of exhaust gases and ballast water, air pollution (which can affect water quality, for example, through ocean acidification), container losses, and biological invasions (Hassellöv et al., 2013; Jägerbrand et al., 2019; Ruiz et al., 2000). GFNMS has regulations that prohibit discharge of material within sanctuary boundaries, with few exceptions. Other discharge regulations within the boundary of GFNMS include multiple state regulations prohibiting the discharge of pollutants and waste, U.S. Coast Guard (USCG) regulations on trash disposal, and the International Maritime Organization Ballast Water Management Convention, which aims to limit the introduction of non-indigenous species via discharged ballast water.

Yanzhu et al. (2022) noted that there is an increased risk of oil pollution with increased shipping. Transit of cargo ships and oil tankers through the sanctuary is of interest, because of the capacity of these vessels to carry large volumes of fuel and other materials and the potential for spills and discharges. Because there are limited data on how most oil pollution incidents have affected water quality in the sanctuary, vessel traffic data were used as a proxy for oil spills and other discharge risks.

Given the large volume of commercial traffic that transits the sanctuary, there is a heightened risk for spills and discharges. Most large commercial ships use the San Francisco Traffic Separation Scheme (TSS; Figure SS.1), which merges three shipping lanes into one precautionary circle near the entrance to San Francisco Bay. During the study period, the size of commercial ships increased, but the number of ships using the three lanes of the TSS remained constant at about 8,000 transits (both inbound and outbound) per year, with the exception of cargo vessels, which increased in size but decreased in numbers (Jensen et al., 2015; NOAA Office for Coastal Management, 2022a).

An estimated 1,383,729 miles (1,202,428 nm; 2,226,896 km) of vessel transits through GFNMS occurred from 2016 to 2020 (BOEM & NOAA, 2022), excluding vessels that are not required to carry AIS or vessel monitoring system (VMS) beacons[9] (Figure S.P.2.1). The distances cargo vessels transited through the sanctuary decreased during the study period (Figure S.P.4.1; Jensen et al., 2015; BOEM & NOAA, 2022). We speculate that more vessels are using the western TSS lanes, which are shorter in distance across the sanctuary. Further analysis is warranted.

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[9] 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 feet (20 meters) or greater in length. Previously, only vessels 300 gross tons and larger were required to carry and transmit AIS (33 C.F.R. § 164). VMS is required by NOAA's National Marine Fisheries Service on any vessel registered to a limited entry groundfish permit (NOAA Fisheries, 2022a; 50 C.F.R. § 660.14). VMS beacons do not reflect all fishing vessel activity in GFNMS. Therefore, VMS records only represent a subset of the fishing vessels that use the sanctuary. Spatial data for vessels not equipped with VMS or AIS beacons were not available.

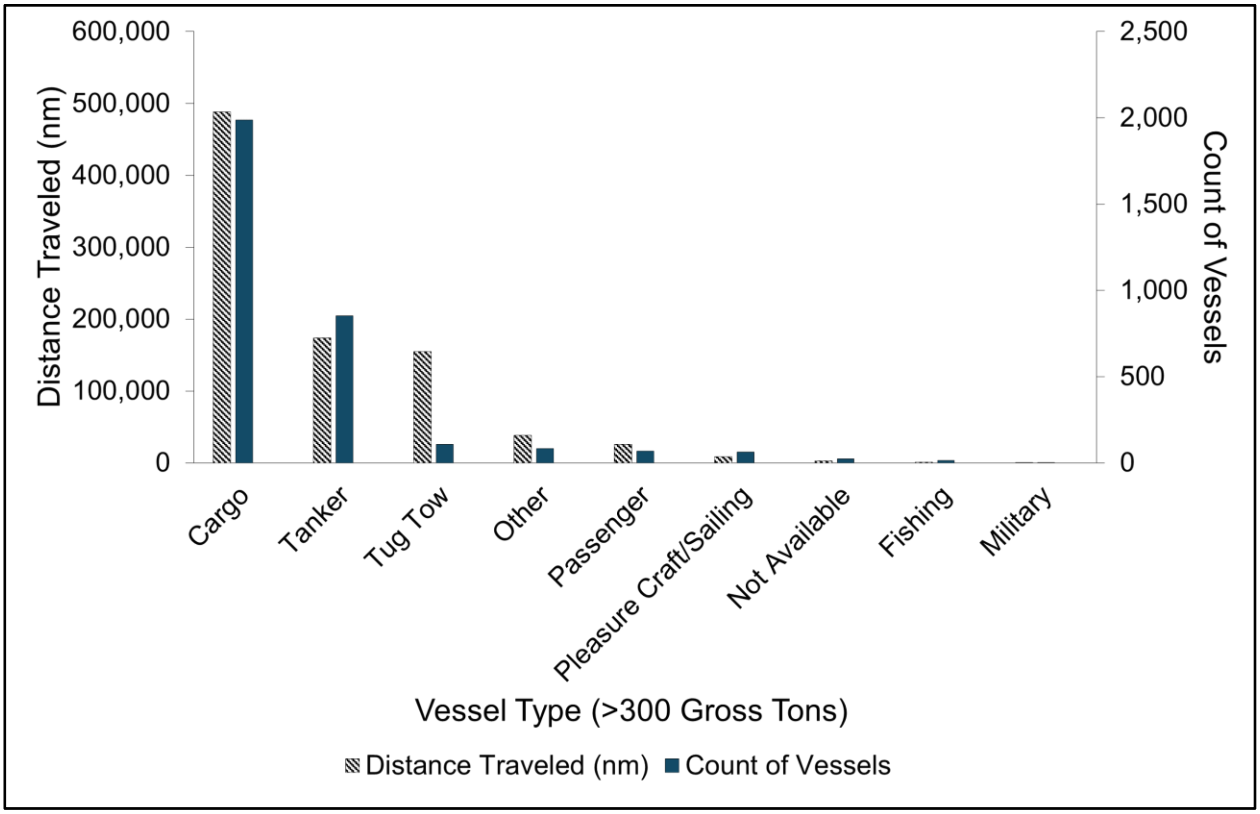


Figure S.P.2.1. Number of vessels, categorized by vessel type, and nautical miles traveled within GFNMS, 2016–2020. Note that the "Passenger" vessel type is inclusive of cruise ships. Source: BOEM & NOAA, 2022

The number and speed of vessels influences the amount of sulfur and other pollutants released into air and ocean. High-sulfur fuel used in commercial shipping for much of the 20th century emitted significant amounts of pollution. Formerly, pollutants from lower cost, high-sulfur fuel were redirected through EGCS (scrubbers), which reduce emissions but generate effluents and residues. In 2009, the California Air Resources Board mandated the use of low-sulfur fuels and restricted the use of EGCS to comply with these standards within California Emission Control Areas, which extended 24 nautical miles off the California shoreline. The first-phase fuel sulfur standard began in 2012, and the second phase began in 2015, which changed low-sulfur fuel requirements throughout the entire U.S. Exclusive Economic Zone. EGCS are not expressly prohibited in this expanded area, but the net effect of these regulations was a reduction in emissions from ships over the study period; however, some cruise ships used EGCS illegally in GFNMS from 2015–2017 (Blank Rome LLP, 2017), and there is uncertainty as to the scale of EGCS effluent that entered GFNMS. The effects of these emissions on water quality are considered in Question 9.

Cruise Ship Discharges

Cruise ships are a vessel type of particular concern in the sanctuary because of the amount of sewage and garbage they generate and their potential for illegal use of EGCS. During the study period, 100 cruise ships entered the sanctuary annually, except during the COVID-19 pandemic (2020–2021). Since the opening of a new cruise ship terminal in 2014, the Port of San Francisco has hosted more than 400,000 passengers every year (Port of San Francisco, 2023). From 2015–2017, there were 190 illegal discharges from cruise ships in GFNMS and CBNMS (Blank Rome LLP, 2017). A combined total 8,000,000 gallons (30,000,000 L) of untreated blackwater and graywater, membrane bioreactor sludge, EGCS effluent, and food waste were illegally discharged in both sanctuaries (Office of General Counsel, 2021). Approximately 95% of these discharges occurred within GFNMS, and over half were from EGCS. Because illegal vessel discharges are self-reported, it is likely that these are underreported.

Dredge Material Barge Transits

San Francisco Bay's 85 miles (137 km) of navigable waterways require annual maintenance dredging (Chin & Ota, 2001). The accidental discharge of dredge material from barges can affect water clarity by blocking sunlight, restricting the growth of plankton, and disrupting foraging by fish, birds, and marine mammals. It can also change the character of the seafloor habitat and smother bottom-dwelling organisms. SF-DODS was designated to dispose of dredged sediment that does not contain any significant toxic level of chemicals (U.S. Army Corps of Engineers, 1998). SF-DODS is located further offshore and in deeper water than any other ocean disposal site in the U.S. (Chin & Ota, 2001).

The San Francisco Bay Long-term Management Strategy for port maintenance dictates that barges transporting dredged material through sanctuary waters to SF-DODS must have an on-board, computerized recording system that notes the location of accidental spillage or premature dumping (U.S. Army Corps of Engineers, 1998). This system notifies GFNMS when barges leak or dump sediment outside of SF-DODS. From 1999–2003, there were 178 separate occasions on which barges leaked significant amounts of dredge materials in GFNMS (*U.S. Environmental Protection Agency & National Oceanic and Atmospheric Administration v. Dutra Dredging Company*, 2006). The amounts released varied, but the total volume was estimated to be 91,158 cubic yards (69,695 m^3). Incidents decreased following an enforcement case (*U.S. Environmental Protection Agency & National Oceanic and Atmospheric Administration v. Dutra Dredging Company*, 2006) and implementation of real-time reporting in 2010. Between 2011 and 2016, there were no incidents of leaks and spills within GFNMS. Between 2017 and 2021, 15 barge leaks were reported within GFNMS; these resulted in the release of approximately 21.5 cubic yards (16.4 m^3) of dredge materials (Etrac, 2022). This represents a substantial decrease in both the number of incidents and the amount of material discharged.

Oil Release Events

No major oil spills occurred during the current assessment period. Compared to the 2010 condition report, spill volumes declined substantially throughout GFNMS, even after sanctuary expansion. Between 2010 and 2021, there were 35 incidents (average of 6.4 incidents per year) of discharges from vessels and objects (e.g., airplanes), groundings, and sinkings within the GFNMS coastal and offshore region (GFNMS, 2022d; USCG, 2022). The majority resulted in small fuel spills. There was no discernible trend, and rough weather was a significant factor in vessel groundings and sinkings.

The total reported amount of fuel spilled between 2010 and 2021 was less than 10,000 gallons (~38,000 L). Spill size estimates were provided by emergency response partners and responsible parties (USCG, 2022) and are considered to be rough estimates due to uncertainty regarding exact quantities of fuel aboard a particular vessel at the time of an incident. Multiple reported spills did not have any estimated fuel quantities, and it is likely that small fuel spills are underreported because of the numbers of small recreational vessels operating throughout the sanctuary. Additionally, fuel type was not reported for a number of incidents. However, most known discharges from vessel incidents during this time period were diesel, which is lighter and evaporates more quickly but is more acutely toxic than crude oil (Kummerlowe et al., 1996; USCG, 2022). These types of incidents can have localized effects on water quality and wildlife (see Question 9).

Commercial fishing vessels were responsible for the largest number of small incidents. In 2021, the grounded vessel FV *American Challenger* was responsible for the largest release of fuel, estimated to have been between 6,000 and 9,000 gallons of diesel (USCG, 2022). As of April 2023, the vessel was still aground in the sanctuary and may still contain diesel fuel, hydraulic oil, and lube oil, as well as other materials that are known to be toxic.

Rates of tar ball deposition on beaches decreased since the lightering of SS *Jacob Luckenbach* in 2002 (ONMS, 2010). There was a spike in reported tarballs in 2016, attributable to a high number of tarballs (>10,000) reported on Limantour Beach during one survey (Figure S.P.2.2). The source of the majority of these tarballs is unknown due to lack of testing, but no oiled wildlife were recorded during the 2016 event (Lindquist & Roletto, 2022a). Of the few representative tarballs that were analyzed (n = 6) by the Petroleum Chemistry Laboratory at CDFW's Office of Spill Prevention and Response (2021), all were determined to be from the Monterey Formation, a natural, oil-rich geologic feature in coastal California. These tarballs likely come from natural seeps in the formation, although they could have been generated as a result of fuel extraction (Henkel et al., 2014). Tar ball deposition peaked seasonally in the fall and winter months. It is suspected that tarballs from natural seeps in the southern-central California region are transported to northern California beaches via the Davidson Current, which prevails along the coast from November through February (García-Reyes & Largier, 2012). Oil pollution in the sanctuary has decreased since 2010, and only a few oiled birds (less than 1% of dead birds observed during annual Beach Watch surveys [see Box 2], n = 30) were documented from 2010–2021 (Lindquist & Roletto, 2022a).

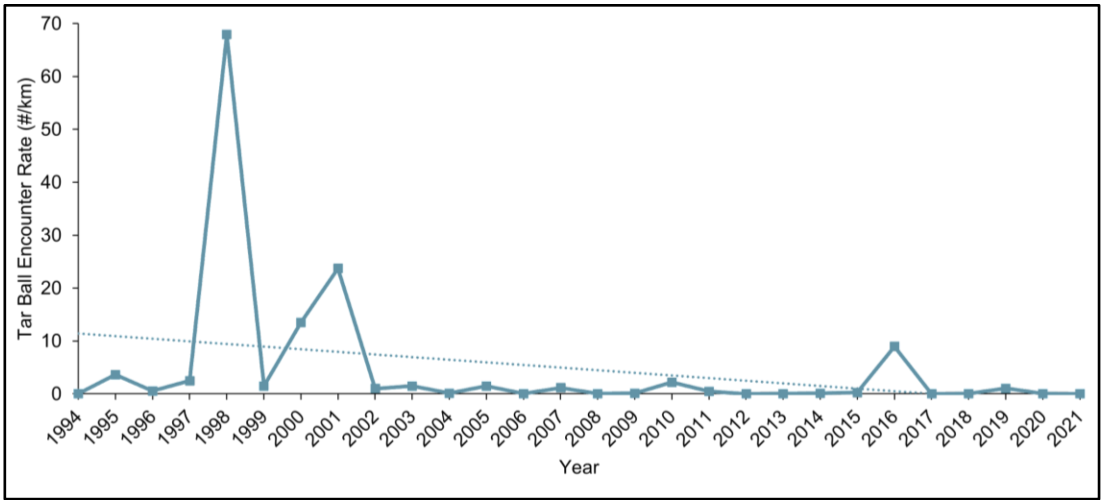


Figure S.P.2.2. Tar ball encounter rates on GFNMS beaches from 1994–2021. The peak in 2016 was due to a high number of tarballs (>10,000) on Limantour Beach during one survey, most likely attributed to a natural seep. Source: Lindquist & Roletto, 2022a

Agriculture and Developed Land Use

GFNMS regulations prohibit the construction of any structure within the sanctuary, but land development in the watersheds of the sanctuary can impact water quality through increased sedimentation and runoff. We reviewed the level of land use, agriculture, and construction within the watersheds of the sanctuary as a proxy for sedimentation and runoff. The U.S. Geological Survey's National Land Cover Database provides information on land surface characteristics (e.g., cover of urban areas, agricultural areas, forest, impervious surfaces, tree canopy; Homer et al., 2012). The database was used to evaluate all land use within 10 miles (16 km) of the GFNMS boundary from 2008–2019. From 2008–2015, there was no change in development, but from 2016–2019, there was approximately a 1.2% increase in high-, medium-, and low-intensity developed land (Dewitz & U.S. Geological Survey, 2021). Cultivated crop cover increased by three square miles [8 km^2] since 2009. During the same time period, shrub/scrub and grassland cover decreased (by 11 mi^2 [28 km^2] and 3.5 mi^2 [9 km^2], respectively). These decreases may be due to the conversion of these lands into agricultural lands (Dewitz & U.S. Geological Survey, 2021).

Conclusion

A number of human activities directly affected or threatened GFNMS water quality during the study period, resulting in a status rating of fair. While there were improvements in some indicators, others remained stable or worsened, resulting in an overall mixed trend. Although cargo vessels increased in size over time, they transited fewer miles through the sanctuary. Cruise ships discharged prohibited material, primarily EGCS effluent, but also treated and untreated sewage, desludging material, and food waste, into the sanctuary between 2015–2017. Dredged material spills occurred in sanctuary waters, but both the number of incidents and spill volume declined over time. Land use data indicated only a slight increase in developed land use within the sanctuary watershed. More information on the quantified impacts from vessel sizes, distance traveled and speeds (e.g., sulfur oxide emissions), and the numerous small fuel spills would better inform this question.

Estuarine and Lagoon Region

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

Rationale: There is a limited amount of quantitative data on human activities that may affect water quality in GFNMS estuarine and lagoon habitats. Although remediation has occurred at the inactive Gambonini Mine, mercury remains elevated in Walker Creek and the Walker Creek Delta. Vessel activities, which elevate the risk for petroleum product releases and potentially human waste discharge, remain popular in Tomales Bay. There was a minor increase in developed high-intensity land use, but the associated impacts to water quality in sanctuary estuaries are unknown. Oil releases from vessels and vehicles occurred, but the volumes and impacts are generally unknown.

Findings from the 2010 Condition Report

In the 2010 condition report, the status rating for human activities that influence water quality was fair/poor, and the trend was improving. The rating was based on land use pressures that caused changes to sediment and freshwater regimes; loss of eelgrass beds in Bolinas Lagoon; and increased restoration activities, increased regulations, and best management practices that may allow for improvements.

New Information in the 2010–2022 Condition Report

Information considered for the current assessment included: construction, new development, and changes to land use adjacent to all estuaries; fecal coliform discharges in Tomales Bay; recreational human use of Tomales Bay; and implementation of the Tomales Bay Mooring Program, which includes new requirements for all privately owned moorings and provides additional water quality protections (Table S.P.2.2).

Table S.P.2.2. Summaries for the key indicators related to human activities that may impact water quality in the estuarine and lagoon regions of GFNMS that were discussed during the July 11, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Tables
Watershed activities impacting water quality—mines and ranching	CSWRCB, 2019a, 2022a	Status: All estuaries in GFNMS except Bolinas Lagoon are considered impaired bodies of water. Impairments resulted from mines, dairy farming, and cattle and sheep ranching in the sanctuary's watersheds. Trend: Mercury in Walker Creek and Walker Creek Delta decreased since mine remediation in 2000. The amount of farming/ranching was stable.	N/A

Indicator	Source	Data Summary	Tables
Watershed activities impacting water quality—developed land use	Dewitz & U.S. Geological Survey, 2021	Status: In 2019, there were low levels of Developed High Intensity land use within 2 miles of Estero Americano, Estero de San Antonio, Tomales Bay, and Bolinas Lagoon. Trend: Between 2008 and 2019, Developed High Intensity land use increased slightly in the watersheds of all four estuaries.	N/A
Human waste discharge sources in Tomales Bay	CSWRCB, 2016, 2022a; CDPH, 2019a, 2019b; Lindquist & Roletto, 2022a	Status: A number of human activities are believed to introduce human waste into Tomales Bay; however, data on the levels of most of these activities were not available. Trend: No trend data were available.	N/A
Vessel activities in Tomales Bay	GFNMS, 2022e; Lindquist & Roletto, 2022a	Status: From 2010–2021, motorized vessels were observed at a rate of 0.21–0.66 vessels per mile (0.13–0.41 vessels km^{-1}); non-motorized vessels were observed at a rate of <0.02–1.03 vessels per mile (<0.01–0.64 vessels km^{-1}). Moored vessels are present in Tomales Bay but must be permitted and compliant with GFNMS regulations. In 2016, 130 unpermitted moorings were recorded in Tomales Bay. Between 2016 and 2022, 51 unpermitted moorings were relocated out of eelgrass beds or removed. As of May 2022, three unpermitted moorings were recorded. Trend: In Tomales Bay, motorized vessel use remained stable over time, while non-motorized vessel use increased. The number of unpermitted moorings decreased, and a dump station was made available in 2014.	N/A
Oil release events	GFNMS, 2022d	Status: Minor oil release incidents occurred in Tomales Bay nearly every year since 2014, but these incidents were not frequent (n = 14 from 2014–2022). Most incidents involved the release of unknown petroleum products. No releases have been documented in the other estuaries. Trend: There was no apparent trend in the number of incidents over time, as these were infrequent. A trend in volume of material released could not be assessed due to a lack of data.	S.P.2.3
Data gaps	There is a lack of data on human activities that may impact water quality in Estero Americano, Estero de San Antonio, and Bolinas Lagoon. Data on the number of boats moored or transiting through Tomales Bay are limited. More information is needed on leaking septic systems and illegal discharges of human waste.		

There are four estuaries within GFNMS: Estero Americano, Estero de San Antonio, Tomales Bay, and Bolinas Lagoon (Figure SS.8). Human activities affecting water quality in these estuaries, particularly Tomales Bay, can come from various sources, including, but not limited to:

- Runoff from historic mining activities in the watershed;
- Runoff from dairy, sheep, and cattle ranches;
- Improperly functioning residential septic systems;
- Malfunctioning wastewater treatment facilities (there are eight facilities within the watershed);
- Illegal camping, recreational vehicle camping, or improper disposal of human waste adjacent to Tomales Bay;
- Illegally moored or anchored vessels;
- Overboard discharges from vessels that are moored, anchored, or operated in estuaries, including kayaks, motorboats, and sailboats; and
- Oil pollution from abandoned vessels and vehicles in estuaries.

Activities both within GFNMS boundaries and in sanctuary watersheds were considered. The areas around GFNMS estuaries are generally rural, residential, or agricultural. Because direct measurements of human activities were limited, several of the indicators used for this assessment are proxies for human activities, such as areas listed as impaired bodies of water under the Clean Water Act and by the San Francisco Bay Regional Water Quality Control Board, as well as developed land use.

Watershed Activities Impacting Water Quality—Mines and Ranching

The Walker Creek and Walker Creek Delta within Tomales Bay and its northern watershed is impaired due to high levels of mercury and debris from historic mining (CSWRCB, 2019a). Mercury mining in the Walker Creek watershed occurred in the 1960s and ceased by 1972. The Gambonini Mine was the largest mercury mine in the watershed, operating from 1964–1970. Other inactive mercury mines in the Walker Creek watershed include the Franciscan, Cycle, and Chileno Valley mines. Mercury may also enter water bodies through runoff and atmospheric deposition (i.e., from fossil fuel emissions; Marin Countywide Stormwater Pollution Prevention Program, 2022), however inactive mines, especially the Gambonini Mine, are the source of the majority of mercury in Walker Creek and its delta. In 1999, the San Francisco Regional Water Quality Control Board and U.S. Environmental Protection Agency (EPA) conducted an emergency superfund cleanup at the Gambonini Mine site, which was the greatest source of mercury in the watershed (CSWRCB, 2021a). In 2008, Total Maximum Daily Loads (TMDLs) were established for mercury in Walker Creek (CSWRCB, 2021a). These efforts reduced mercury pollution and improved water quality, although more information is needed (CSWRCB, 2021a).

The most common type of land use in the watersheds of Estero Americano and Estero de San Antonio is livestock agriculture (dairy farming and sheep and cattle ranching), and is also common in Tomales Bay watersheds; this has remained consistent over the past three decades. Runoff from farming and ranching may impair the esteros and Tomales Bay by introducing high levels of nutrients, which can result in low levels of dissolved oxygen, as well as sediment, ammonia, copper, and bacteria (California Coastal Commission, 2019). Pollutants may be introduced as a result of cultivated crops, inadequate storage of animal wastes and manure ponds, as well as a lack of adequate fencing to keep livestock out of the watersheds or estuaries. Increased sediment in runoff can originate from grazing livestock, modified drainage pathways, removal of riparian vegetation, destabilized streambanks, and upland erosion (Gold Ridge Resource Conservation District, 2007). The amount of land used for cultivated crops increased by 0.0178 square miles, for a total of 0.0577 square miles in 2019.

Watershed Activities Impacting Water Quality—Developed Land Use

The areas around GFNMS estuaries are generally rural, residential, or agricultural. The National Land Cover Database (Dewitz & U.S. Geological Survey, 2021) was used to assess changes in land use classified as "Developed High Intensity" (highly developed areas in which impervious surfaces account for 80–100% of total cover) within two miles of GFNMS estuaries between 2008 and 2019. Developed High Intensity land use increased by 0.004 square miles (0.01 km^2) at Estero Americano, 0.002 square miles (0.005 km^2) at Estero de San Antonio, 0.004 square miles (0.01 km^2) at Tomales Bay, and 0.003 square miles (0.008 km^2) at Bolinas Lagoon. In 2019, the total cover of Developed High Intensity land was 0.057 square miles (0.148 km^2) at Tomales Bay, and 0.030 square miles (0.008 km^2) at Bolinas Lagoon. Data were not available for Estero Americano or Estero de San Antonio.

Human Waste Discharge Sources in Tomales Bay

In 2006, Tomales Bay was identified as an impaired water body in accordance with Section 303(d) of the Clean Water Act due to elevated levels of pathogens (EPA, 2007). Tomales Bay and its main tributaries, Lagunitas, Walker, and Olema creeks, are impaired by pathogens from human waste. Human activities that contribute to fecal coliform levels in Tomales Bay likely include improper disposal of human waste from motorized and non-motorized vessels; improper disposal of human waste from iIllegal tent, recreational vehicle, and kayak camping; improperly functioning residential septic systems; and malfunctioning wastewater treatment facilities (there are eight facilities within the watershed) adjacent to Tomales Bay. Prior to 2010, there were no designated disposal stations for human waste from vessels in Tomales Bay. In 2014, the first waste disposal station for Tomales Bay was installed at Miller Park on the east shore, allowing for proper disposal of untreated waste from vessels (although it does not have a pump-out capability for vessels with holding tanks). Since most human activities that may result in the discharge of human waste are not directly measured, limited information was available to assess status and trends; however, vessel activities are described in the section below. Data on the effects of human waste discharge and associated pathogen levels in sanctuary estuaries are presented in Question 9.

Vessel Activities in Tomales Bay

Tomales Bay remains a popular recreational boating location, with vessels moored or anchored in the bay permanently and temporarily (day use); however, data on the number of motorized and non-motorized vessels transiting or moored throughout the bay are limited. As more vessels transit and are moored on the bay, the risk of discharges increases. Motorized vessels were observed at a rate of 0.21–0.66 vessels per mile (0.13–0.41 vessels km^{-1}) within 0.3 miles (0.5 km) of two beaches along Tomales Bay from 2010–2021; the number of vessels observed was stable over time (Lindquist & Roletto, 2022a). Non-motorized vessels were observed at a rate of

<0.02–1.03 vessels per mile (<0.01–0.64 vessels km^{-1}), and increased from 2010–2021 (Lindquist & Roletto, 2022a). The Tomales Bay Mooring Program, developed by GFNMS and the California State Lands Commission and launched in 2013, provides a mechanism for boat owners to obtain permits to moor vessels in the bay (GFNMS, 2024). To obtain a permit, moorings and vessels must meet multiple criteria to reduce the likelihood that a vessel will sink or leak fuel and other materials, thus indirectly protecting water quality. The number of private vessels permanently moored year-round on the bay decreased since 2010 (GFNMS, 2022e). A total of 130 unpermitted vessel moorings were recorded in Tomales Bay in 2016 and consisted of unregulated and potentially toxic materials, such as tires and engine blocks. From 2016 to 2022, unpermitted moorings in Tomales Bay decreased from a total of 130 to a total of three (GFNMS, 2022e), reducing the potential for toxic material to enter the bay from moorings. As of May 2022, there were 59 permitted and installed moorings on the bay (GFNMS, 2022e).

Oil Release Events

Boats and cars have released fuel almost every year in Tomales Bay since GFNMS started to track incidents in 2014 (Table S.P.2.3; GFNMS, 2022d). No incidents were documented in Bolinas Lagoon or the esteros within this timeframe. Since 2014, 14 known incidents involving the release of petroleum products from vessels, automobiles, or other sources have been reported within Tomales Bay. The volume of fuel released was undetermined for 11 of the incidents, with the remaining three releasing an estimated minimum of 170 gallons combined. Because most incidents resulted in the release of an unknown quantity of petroleum products, it was not possible to determine a trend for this metric.

Table S.P.2.3. Known petroleum release events in Tomales Bay since 2014. This information is reported by various sources to GFNMS and subsequently investigated by GFNMS to determine the type of incident and type and amount of fuel spilled. Fuel quantities, if provided, are rough estimates, as the exact amount of fuel aboard a vessel at any given time is typically not well documented. Source: GFNMS, 2022d

Incident Year	Vessel, Automobile, Container, or Other?	Recreational, Commercial, or Other?	Estimated Fuel Capacity (gallons [L])	Fuel Type	Estimated Amount of Fuel Released into the Sanctuary (gallons [L])
2014	Vessel	Recreational	100 (379)	Gasoline	Unknown
2014	Automobile	Other	Unknown	Gasoline	Unknown
2014	Automobile	Other	Unknown	Gasoline	Unknown
2015	Vessel	Recreational	Unknown	Unspecified petroleum product	Unknown
2015	Vessel	Recreational	Unknown	Unspecified petroleum product	Unknown
2015	Vessel	Recreational	Unknown	Unspecified petroleum product	Unknown
2015	Automobile	Commercial	Unknown	Gasoline	Unknown
2016	Vessel	Recreational	15 (57)	Unspecified petroleum product	15 (57)

Incident Year	Vessel, Automobile, Container, or Other?	Recreational, Commercial, or Other?	Estimated Fuel Capacity (gallons [L])	Fuel Type	Estimated Amount of Fuel Released into the Sanctuary (gallons [L])
2016	Automobile	Unknown	Unknown	Gasoline	Unknown
2017	Other	Unknown	5 (19)	Diesel	5 (19)
2018	Vessel	Commercial	Unknown	Unspecified petroleum product	Unknown
2020	Vessel	Commercial	300 (1,136)	Diesel	Unknown
2021	Vessel	Other	Unknown	Diesel	150 (568)
2021	Vessel	Recreational	Unknown	Unknown	Unknown

Conclusion

Human activities within GFNMS and on the land surrounding its estuaries have the potential to adversely affect its water quality. Although mercury mining has ceased and remediation has occurred, other activities that have the potential to affect water quality continued throughout the study period, particularly boating, resulting in a fair status rating. While some activities remained stable during the study period (i.e., farming/ranching, motorized vessel use), others increased (i.e., highly developed land use, non-motorized vessel use) or decreased (e.g., illegal moorings), resulting in a mixed trend rating. More information is needed to understand the status and trends of human activities that result in human waste discharge into Tomales Bay, including the number of leaking septic systems and illegal dumping of human waste. Additional data on vessel use in Tomales Bay and Bolinas Lagoon would also strengthen future assessments of this question. There is also a lack of data on human activities that may impact water quality in Estero Americano, Estero de San Antonio, and Bolinas Lagoon.

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

Coastal and Offshore Region

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

Rationale: Marine debris was documented on beaches regionally and on the surface and the seafloor in GFNMS. The most commonly found type of debris on the seafloor was commercial fishing gear. Trawling and crab fishing activities occur each year through large areas of the sanctuary. In 2020, more areas were opened to trawling in GFNMS. Easy access to some rocky reefs in the sanctuary, such as Duxbury Reef, resulted in comparatively high human visitation. The lack of baseline data for these indicators prevented the determination of a trend.[10]

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question was good/fair and the trend was not changing. While urbanization, visitation, and shipping increased, trawling and chronic oil pollution decreased, discharge of radioactive waste ceased, and regulations to prevent introduced species were established. The 2010 assessment thus concluded that some potentially harmful activities were occurring, but none appeared to have had a negative effect on habitat quality.

New Information in the 2010–2022 Condition Report

Human activities used to evaluate this question included marine debris on beaches adjacent to GFNMS, at the surface, and in the benthic environment; vessel incidents; benthic commercial fishing activities; and visitors at reefs (Table S.P.3.1).

[10] At the 2022 status and trends workshop, experts assigned a status rating of fair/poor with a high confidence score. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and determined that a status rating of fair with low confidence was more appropriate, as the data did not sufficiently show that impacts were severe during the study period. See Appendix C for more information regarding these changes.

Table S.P.3.1. Summaries for the key indicators related to human activities that impact habitat in the coastal and offshore region of GFNMS that were discussed during the July 11, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Beach debris	NOAA Marine Debris Program, 2020; Bimrose et al., 2021	Status: Land-sourced debris (bottle caps, food wrappers, and straws) and, to a lesser extent, ocean-sourced debris (fishing lures, line, rope and tubes) were found at survey sites on beaches adjacent to GFNMS (these sites were considered as indicators of regional debris trends as data for beaches inside GFNMS were unavailable). Trend: The trend for this indicator was undetermined for the study period due to insufficient data.	S.P.3.1
Surface debris	Elliott et al., 2022b	Status: Surface debris is generally sparse but has been observed throughout the sanctuary. Surface debris included 0.03–0.21 crab trap buoys per square mile (0.09–0.54 traps km^{-2}). Trend: There was a spike in surface debris density in 2010, but debris subsequently decreased and remained relatively stable through 2019.	S.P.3.3
Sunken debris in the benthic environment	CDFW, 2020a, 2023a; PFMC, 2013	Status: Fishing gear was the most common type of debris found on the seafloor of GFNMS. Crab pots are known to be lost frequently; approximately 29,200–83,500 traps are set on the seafloor in GFNMS annually, and about 10% of these may be lost. Trend: The trend was undetermined for the study period due to insufficient data.	N/A
Vessel incidents	GFNMS, 2022d; USCG, 2022	Status: A total of 33 vessel incidents occurred in GFNMS from 2012–2021; these incidents affected habitat and water quality. Trend: The annual number of incidents varied with no discernible trend during the assessment period.	S.P.3.4
Benthic commercial fishing activities	CDFW, 2020a; CDFW 2023a	Status: An average of eight trawl vessels per year operated in the sanctuary from 2010–2020. Trend: Trends for trawling were undetermined for the study period due to insufficient data. As of 2020, new seafloor areas in the sanctuary were opened to trawling; however, data were not available to assess whether trawling occurred in these areas during the study period.	S.P.3.5
Visitors at reefs	Lindquist & Roletto, 2022a	Status: Visitor use at Duxbury Reef was high compared to other rocky intertidal sites in Marin County. Trend: Visitor activities at rocky reefs appeared to decrease slightly from 2015–2019.	N/A

Indicator	Source	Data Summary	Figures
Data gaps	More data on marine debris throughout the sanctuary are needed, including sunken marine debris and beach debris, especially at coastal sites in the expansion area of GFNMS, to better determine impacts and trends over time.		

Types of Marine Debris

Marine debris can result from a variety of human activities in and adjacent to the sanctuary, such as construction, littering, plastic manufacturing, hunting, and aquaculture. Because many of these activities are difficult to measure directly and may occur outside the GFNMS region, marine debris prevalence in and adjacent to sanctuary habitats was assessed as a proxy for these activities. Marine debris is defined as “any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or Great Lakes” (33 U.S.C. § 1956). Marine debris may be found in any location throughout the sanctuary including the water column, water surface, beaches, estuaries, and the seafloor. Some of the most common and harmful types of marine debris include plastic, such as cigarette butts, plastic bags, and food wrappers; aquaculture debris; and derelict fishing gear (Office of Response and Restoration, 2023). Marine debris can range in size from microplastics too small to be seen with the human eye to large abandoned and derelict vessels, construction debris, and household appliances that can damage sensitive habitats (Office of Response and Restoration, 2023). Although some of these items may eventually break down, others may never fully degrade and may persist in the marine environment (Office of Response and Restoration, 2023).

Beach Debris

Marine debris monitoring data for GFNMS beaches were not available for this assessment. However, data from beaches adjacent to but outside the sanctuary can provide information on debris trends in the region. Monitoring data were assessed from six sandy beaches just outside of the sanctuary that have all been historically determined to be deposition areas for ocean-sourced debris (e.g., fishing gear; Bimrose et al., 2021). Land-sourced consumer, single-use products (e.g., bottle caps, food wrappers, plastic straws) were the most common type of debris observed on beaches in the region. Ocean-sourced debris was found in lower amounts than land-sourced debris, and fishing gear was the most common type of ocean-sourced debris (e.g., fishing lures, line, rope and separator tubes; Figure S.P.3.1; NOAA Marine Debris Program, 2020; Bimrose et al. 2021).

Photos documenting wood construction products and plastic debris on multiple beaches along the Sonoma Coast have been uploaded to NOAA’s Marine Debris Monitoring and Assessment Project (NOAA Marine Debris Program, 2020). Without ongoing monitoring at these beaches, the status and trend for beach debris in this area is unknown.

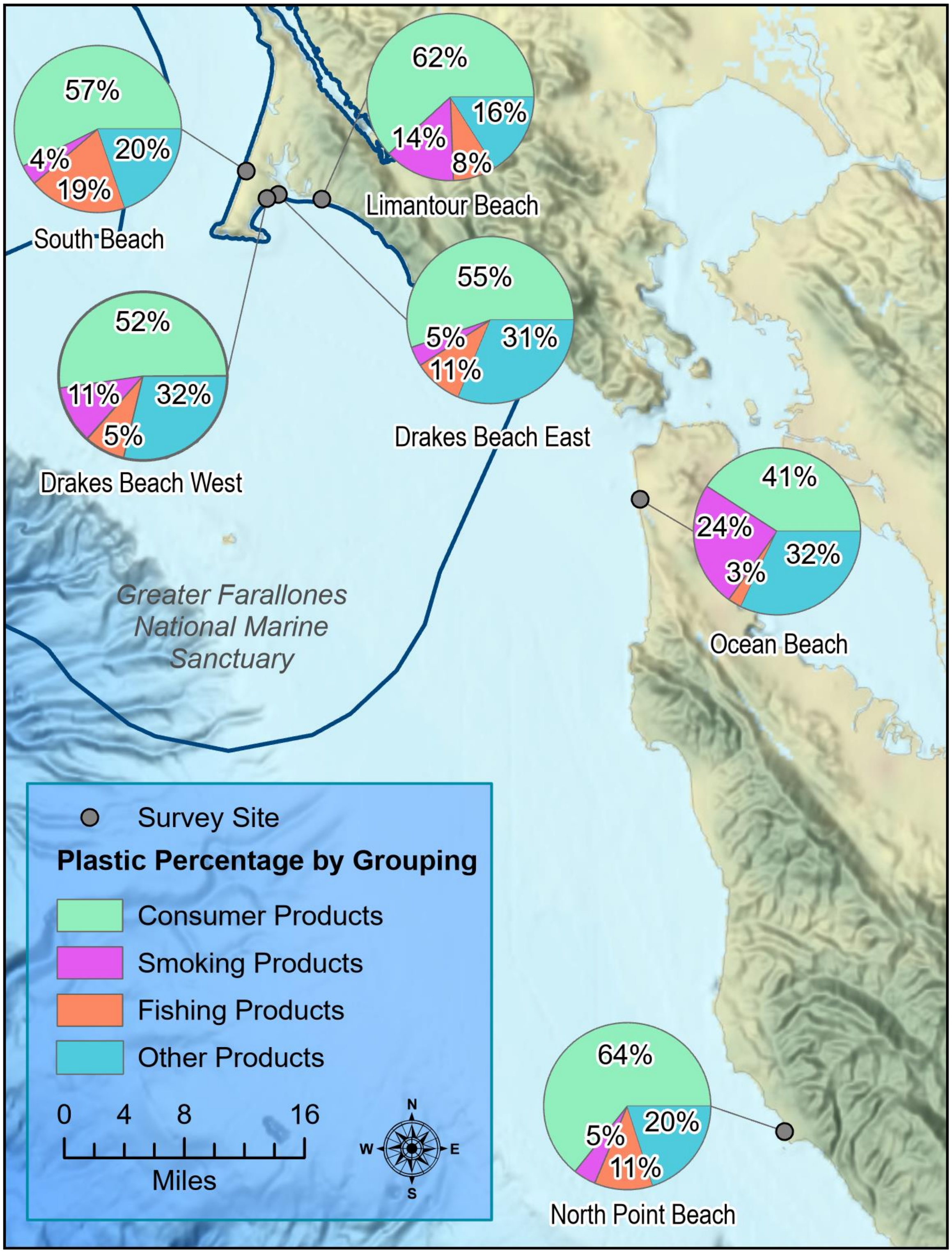


Figure S.P.3.1. Types and percentages of marine debris items found at six shoreline monitoring sites adjacent to GFNMS during 334 surveys conducted from July 2012 through June 2018. Note that data were not readily available for marine debris on beaches within the boundary of the sanctuary. The sites in this figure are located outside of the sanctuary but have been identified as beaches where ocean-sourced debris is likely to accumulate and thus were used as a proxy for beaches in the sanctuary. Image: NOAA; Source: NOAA Marine Debris Program, 2020; Esri, 2020

Box 1: Applied California Current Ecosystem Studies

Applied California Current Ecosystem Studies (ACCESS) is a public-private partnership of GFNMS, CBNMS, and Point Blue Conservation Science to monitor ocean ecosystem health and inform sanctuary management. Since 2004, ACCESS has conducted vessel-based surveys between Bodega Head and Half Moon Bay, spanning over 298 miles (480 km), 16 transects, and 31 water column sample stations in nearshore and offshore regions of GFNMS, CBNMS, and the northern portion of MBNMS. Surveys are conducted approximately three times per year to capture the beginning, peak, and the end of the upwelling season. In some years, sampling efforts extend farther north and south, depending on weather and funding. Additional collaborators involved in ACCESS include Greater Farallones Association, CDFW, National Marine Fisheries Service, U.S. Fish and Wildlife Service, University of California Davis, San Francisco State University, and Monterey Bay Aquarium Research Institute. ACCESS samples for abundance and distribution of birds, mammals, marine debris, nutrients, water properties, ocean acidification, environmental DNA, and quantification of fish, krill, and other zooplankton. ACCESS also provides training and enrichment opportunities for science teachers and undergraduate and graduate students, as well as paid internships. Additionally, ACCESS has provided a platform for collaborator research, like NOAA's ADRIFT in the California Current program, which used drift buoys to record soundscape metrics (including the presence of marine mammal species and human noise sources like vessels). ACCESS data on the status and trend of nearshore and offshore wildlife and human activities have been used for:

- Identification of wildlife hotspots and forage areas to inform management efforts to reduce ship strikes and entanglements (e.g., using data on krill, other zooplankton, birds, and mammals);
- Understanding how climate change is affecting this region of the California Current Ecosystem, particularly in terms of water quality, forage species abundance and distribution, predator responses, ocean acidification, eutrophication, and habitat compression;
- Detection of emerging impacts and anthropogenic influences;
- Providing marine science learning opportunities for teachers, interns, undergraduate and graduate students; and
- Informing oil pollution response activities and Natural Resource Damage Assessments.

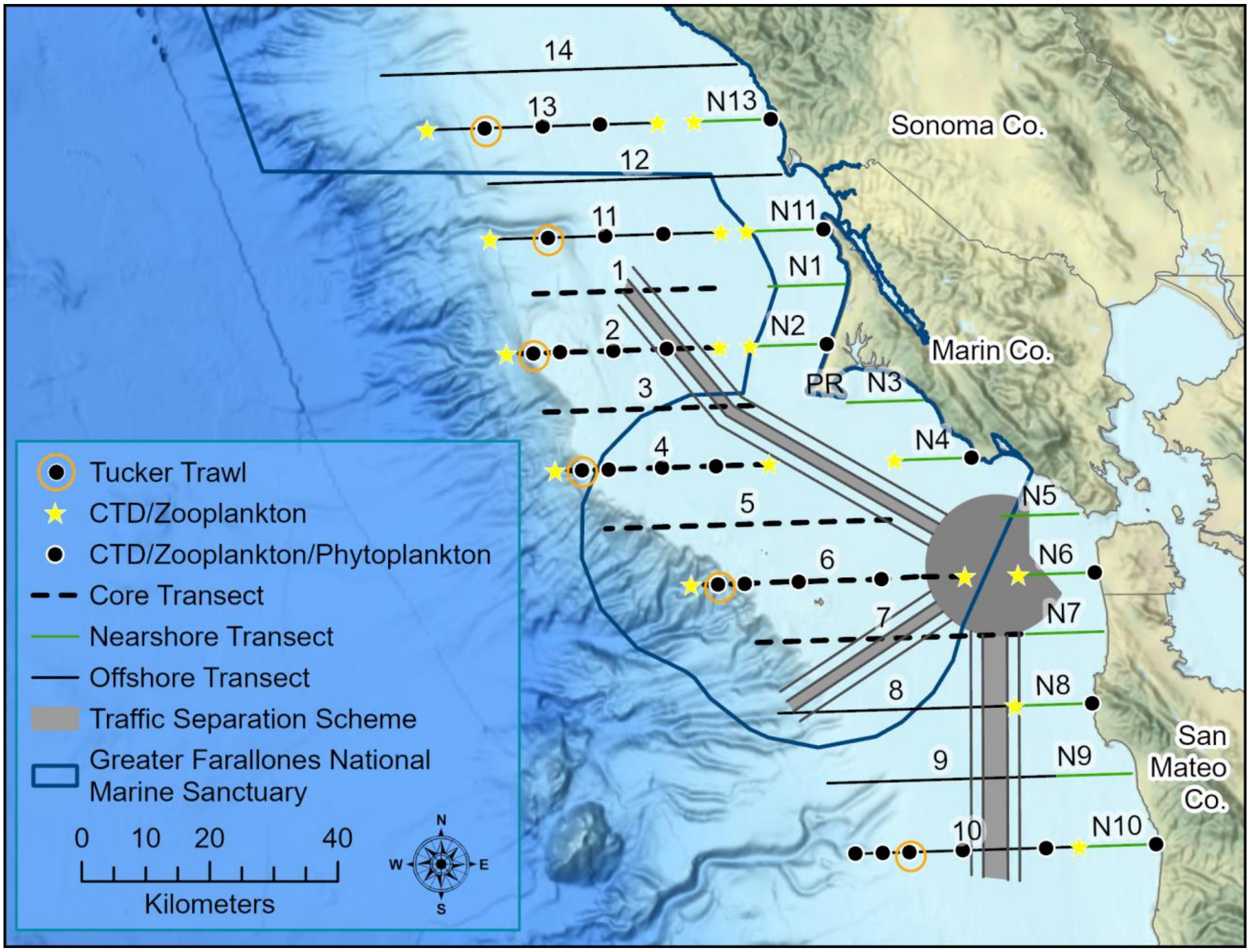


Figure S.P.3.2. ACCESS conducts vessel-based surveys between Bodega Head and Half Moon Bay. These surveys include nearshore and offshore transects and water column sample stations. Image: NOAA; Source: Elliott et al., 2022a; Esri, 2020

Surface Debris

Marine debris at the surface in the offshore environment is monitored through ACCESS (Box 1; Figure S.P.3.2; Elliott et al., 2022b). Surface debris observed included items such as out-of-season crab pot buoys, plastic bags, bottles, floats, balloons, and styrofoam. Floating debris is generally sparse, but has been recorded throughout the sanctuary. Out-of-season crab trap buoys were observed at an average density of 0.07 per square mile (0.19 traps km^{-2}) and ranged from 0.03–0.21 per square mile (0.09–0.54 traps km^{-2}; Elliott et al., 2022b). An unexplained spike in conspicuous surface debris was observed in 2010 but subsequently decreased and has since remained relatively stable (Figure S.P.3.3).

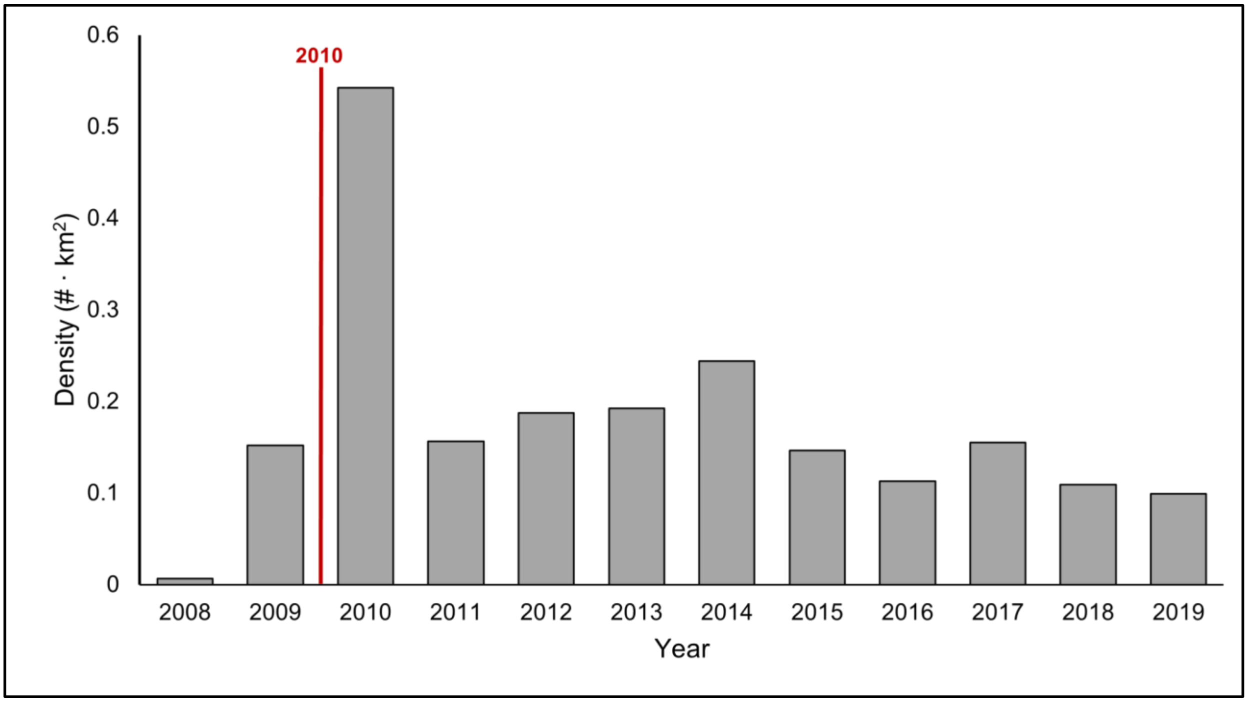


Figure S.P.3.3. Density of floating conspicuous marine debris observed at the surface during ACCESS cruises in GFNMS and CBNMS from 2008–2019. Image: NOAA, Source: Elliott et al., 2022b

Sunken Debris in the Benthic Environment

Fishing gear was the most common category of debris found on the seafloor of GFNMS. A large portion of one type of fishing gear, crab traps, are known to be lost each year. These circular steel traps, commonly called pots, measure 36–48 inches (91–122 cm) in diameter (9.5–12.5 ft [3–4 m] in circumference). The number of trips per vessel can vary each year depending on the length of the season. However, an average of 167 (± 31.5 standard deviation) vessels set crab pots each season with each vessel setting between 175–500 pots per year in GFNMS (CDFW, 2020a, 2023a). This means approximately 29,200–83,500 pots are set on the seafloor each year in GFNMS. The Dungeness crab commercial fishing season typically occurs during the winter months in the North Central California region. Based on anecdotal reports, roughly 10% of pots deployed within the U.S. portion of the California Current Ecosystem may be lost each year due to harsh winter ocean conditions (PFMC, 2013). An approximate 10% loss could mean that an estimated minimum of 2,920 lost pots per year (and as many as 8,350 a year) could impact benthic habitat in GFNMS without interventions to remove lost pots. Impacts to seafloor from fishing gear are discussed in Question 10 of this report.

Vessel Incidents

Sunken and grounded vessels and lost steel shipping containers impact GFNMS benthic habitat. Large objects that sink to the seafloor can crush or smother corals, sponges, and other benthic fauna, cause permanent loss and/or scarring and damage to rocky reef habitat, and reduce carbon storage (i.e., sequestered carbon in the seafloor; Hutto et al., 2021). A total of 33 incidents that resulted in impacts to habitat and/or water quality occurred in GFNMS from 2010–2021, and most of these occurred close to shore (Figure S.P.3.4; GFNMS, 2022d; USCG, 2022). An individual incident can result in extensive, significant, or multiple impacts. Debris generated by these incidents can include styrofoam, wood, metal, plastic, fishing gear, petroleum products, and other hazardous materials, such as heavy metals, polychlorinated biphenyls (PCBs), asbestos, and household cleaners. The number of incidents per year varied with no discernible trend.

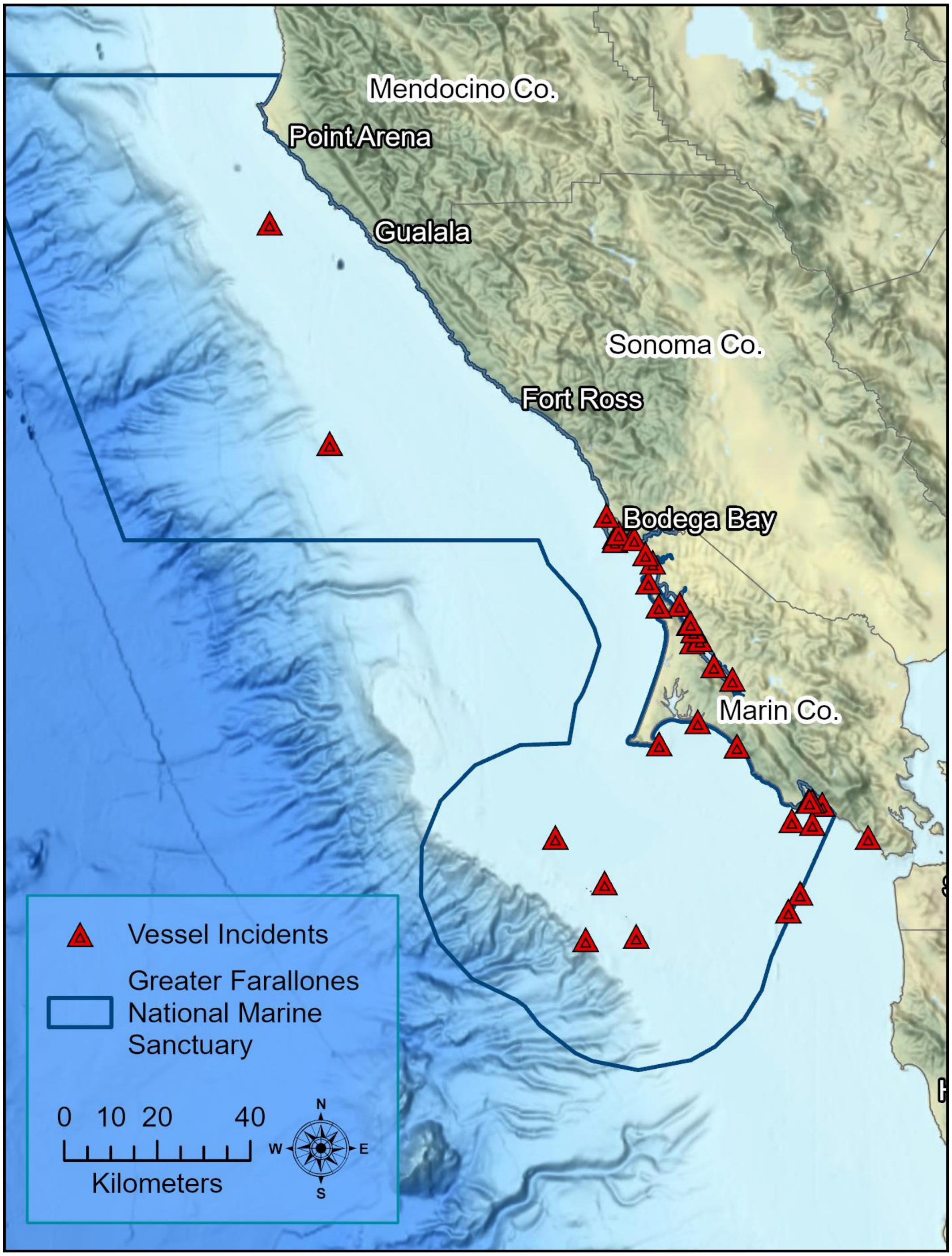


Figure S.P.3.4. The locations where vessel incidents occurred between 2012 and 2021, each of which likely resulted in the release of marine debris. Image: NOAA; Source: GFNMS, 2022d; USCG, 2022; Esri, 2020

Benthic Commercial Fishing Activities

Fishers use a variety of gear types in GFNMS and the surrounding region, including pots/traps, troll gear, trawls, seines, longlines, and hook and line (CDFW, 2020a). The most common types of commercial bottom fishing gear in terms of harvest revenue and pounds landed are pots/traps and trawls (CDFW, 2020a). The commercial Dungeness crab fishery is the largest fishery that uses trap gear in GFNMS (CDFW, 2020a). Dungeness crab fishing occurs at depths of about 50–650 feet (15–200 m), generally in areas of low relief and low complexity (Marine Stewardship Council, 2010). Most commercial Dungeness crab fishing occurs in waters with silty sand to sandy bottoms, so crab pot contact with the seafloor is less likely to impact sensitive benthic species found in more structurally complex habitats (Pacific Marine Fisheries Commission, 1978; Kaiser et al., 2001). However, derelict crab gear may still have an impact on the benthos, especially by continuing to entrap marine life (i.e., “ghost fishing”).

Bottom trawl gear can directly impact benthic habitats through crushing, breaking, and removing rocks or animals and disturbing the top layers of sediments that house infauna, fish, and invertebrates. An average of eight (±1.6 standard deviation) trawl vessels operated in the sanctuary each year from 2010–2020 (CDFW, 2020a), which is significantly fewer than the number of vessels commercially fishing with pots and hook and line. In 2020, new Essential Fish Habitat Conservation Areas were closed to bottom trawling in GFNMS; however, the Rockfish Conservation Area was opened to trawling, making more benthic habitat subject to bottom trawl impacts overall. As a result, benthic habitat protection decreased in 2020 because an additional 150.29 square miles (241.87 km^2) of seafloor was opened to bottom trawling within GFNMS (Figure S.P.3.5; National Centers for Coastal Ocean Science, 2020). In addition to the opening of the Rockfish Conservation Area, a redesign and modification reduced the size of Point Arena Biogenic Area South from 99.06 square miles (256.56 km^2) to 36.09 square miles (93.47 km^2), opening additional seafloor areas to trawling. For the majority of areas where bottom trawling is allowed, there is a lack of data on the types of habitat present, including biogenic habitat (corals, sponges, sea pens, and sea whips). At the time of this assessment, data were not available to indicate the extent of bottom trawling that had occurred in the areas that were opened in 2020, so it cannot be assumed that trawling occurred in the newly open areas during the study period.

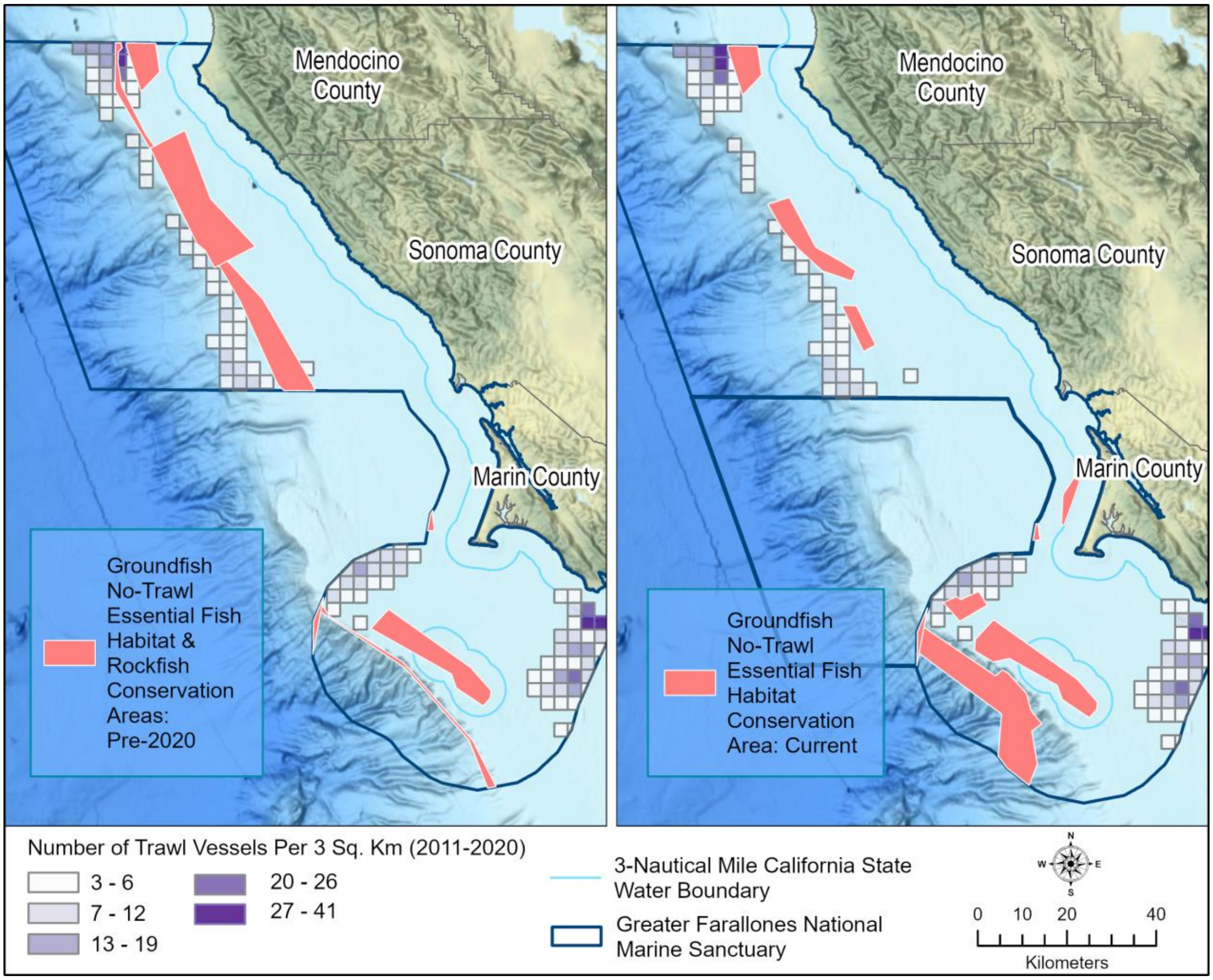


Figure S.P.3.5. Maps of GFNMS showing areas closed to bottom trawling prior to 2020 (left) and after 2020 (right). The number of trawl vessels per three kilometers from 2011 to 2020. Image: NOAA; Source: National Centers for Coastal Ocean Science, 2020; Esri, 2020

Box 2: Beach Watch

Beach Watch is a public-private shoreline monitoring program that is run in partnership by GFNMS and Greater Farallones Association. Since 1993, the Beach Watch program has conducted bimonthly surveys along 40–65 beaches, spanning 210 miles (339 km) from Mendocino County to southern San Mateo County, including Bolinas Lagoon and Tomales Bay. Over the years, staff have partnered with over 10 institutions and agencies, including CDFW, National Marine Fisheries Service, California Academy of Sciences, and the National Park Service. Data are presented as encounter rates or numbers observed standardized by distance surveyed, and are used to identify distribution of, seasonality of, and trends for organisms and activities along the shoreline, out to 984 feet (300 m). The Beach Watch program has trained over 600 volunteers, who collect data on coastal and estuarine wildlife and human activities including:

- Bird and mammal abundance and distribution along the coast;
- Species inventories in county, state, and national parks;
- Seasonal, relative abundance and distribution of beach wrack, an important shoreline biogenic (living structural) habitat;
- Marine debris entanglement;
- Early alerts of mortality events and changing conditions along the coast;
- Resources at risk from coastal human activities like disturbance and oil pollution;
- Predator-prey relationships for breeding coastal birds and mammals; and
- Severity of impacts from oil pollution and boat groundings and length of time to restore lost ecosystem services.

Figure S.P.3.6. Beach Watch survey locations showing the central point of each beach survey segment. Image: NOAA; Source: Lindquist & Roletto, 2022b; Esri, 2020

Human Use at Coastal Reefs

Human use occurs at multiple intertidal reef locations throughout GFNMS. However, Duxbury Reef, which is designated by the state of California as a State Marine Conservation Area, remains the most easily accessible rocky intertidal reef within GFNMS. While it has a high level of use compared to other rocky intertidal sites in Marin County, it has a moderate to low level of visitor use in comparison to rocky reefs in Southern California or San Mateo County. It is a sensitive intertidal habitat where trampling and collecting can cause long-term negative impacts to habitat and species. The Beach Watch project (Box 2; Figure S.P.3.6) provides data on human activities at Duxbury Reef.

From 2015 through 2021, the average visitor rate to the rocky shoreline of Duxbury Reef and Agate Beach was 4.0–12.4 people per mile (2.5–7.7 people km^{-1}). Average visitation was highest in 2015 and lowest in 2019, and decreased slightly during the study period (Lindquist & Roletto, 2022a). The numbers of people on the reef may indicate various impacts, such as trampling, collection, and disturbance to reef organisms.

Conclusion

This question was rated fair based primarily on the fact that marine debris has been found on sandy beaches in the region and on the surface and seafloor throughout the sanctuary, trawling and crab fishing activities occurred annually throughout large areas of sanctuary seafloor, and there is high human use at one rocky intertidal location in GFNMS. Floating debris on the surface was sparse but present throughout the sanctuary. Fishing gear was the most common type of marine debris found on the sanctuary seafloor, and an estimated ~3,000 crab traps may be lost in the sanctuary annually. Approximately 150 square miles (242 km^2) reopened to bottom trawling in GFNMS in 2020, decreasing overall seafloor protections, but data were not available to determine whether bottom trawling has occurred in those areas. High human use continued at Duxbury Reef, with a slight decline from 2015–2019. The trend for this question was undetermined based on a lack of information about long-term trends for a number of the indicators; some appeared to be stable while a trend could not be determined for others without more information. More data are needed on marine debris throughout the sanctuary, including beach debris, especially at coastal sites, and sunken marine debris across a larger area of seafloor to better determine trends over time.

Estuarine and Lagoon Region

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

Rationale: There is limited information on specific human activities that may adversely impact estuarine and lagoon habitat in GFNMS, and ratings were based on a limited number of relevant indicators for which information was available in Tomales Bay. Removal of moorings from eelgrass beds since 2016 reduced the potential for damage to eelgrass habitat. Marine debris was consistently present in Tomales Bay despite some removal efforts. Clamming activities continued to occur, and activity was likely lower compared to historic levels, though data were limited. Little to no data were available for all indicators for Bolinas Lagoon, Estero Americano, and Estero de San Antonio.

Findings From the 2010 Condition Report

In the 2010 condition report, the status for this question in the estuarine and lagoon environment was fair and the trend was not changing. Measurable habitat impacts related to urbanization and poor land use practices continued to occur, but evidence suggested effects were localized, not widespread. However, impacts on eelgrass and the presence of marine debris in Tomales Bay were not considered in the 2010 condition report.

New Information in the 2010–2022 Condition Report

Human activities used to evaluate this question included the use of moorings, marine debris, and recreational clamming in the GFNMS estuarine and lagoon region (Table S.P.3.2).

Table S.P.3.2. Summaries for the key indicators related to human activities that impact habitat in the estuarine and lagoon region that were discussed during the May 17, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Moorings	GFNMS, 2022e; Merkel & Associates, Inc., 2015, 2017a; R. Feris, personal communication, September 26, 2023	Status: From 2016–2022, 51 unpermitted moorings were removed or relocated in Tomales Bay, including 19 that were located in eelgrass beds; three moored docks were also removed from eelgrass beds. In 2022, there were no moorings in eelgrass beds. A small number of moorings exist in Bolinas Lagoon. There are no known moorings in the esteros. Trend: Conditions improved in Tomales Bay. The trend was undetermined in Bolinas Lagoon and the esteros due to a lack of data.	S.P.3.7

Indicator	Source	Data Summary	Figures
Marine debris	GFNMS, 2022d, 2022e; The Coastodian, 2013, 2017	Status: Marine debris has been documented in Tomales Bay and cleanup efforts have occurred since 2014. Bolinas Lagoon had one known marine debris incident during the study period; no data were available for the esteros. Trend: The trend for marine debris was stable in Tomales Bay and Bolinas Lagoon but undetermined in the esteros due to a lack of data.	N/A
Recreational activities: Clamming in Tomales Bay	N/A	Status: Clamming was once popular in Tomales Bay, but decreased prior to 2010. No data on clamming activity were available for the study period. Trend: No trend data were available.	N/A
Data gaps	More data is needed on human activities that may adversely affect habitat in all estuaries, including levels of clamming activity, marine debris prevalence, and boating activities. More data is needed on the impacts to habitat from other recreational fishing activities that may occur in the estuaries (e.g., placing pots on eelgrass), especially Tomales Bay.		

Moorings

Tomales Bay has remained a popular boating location for vessels that are permanently moored or anchored on the bay or transported to the bay from other locations for day use. The number of private vessels permanently moored in the bay decreased substantially since 2016 (GFNMS, 2022e). If not properly designed and sited, moorings can alter or destroy seafloor habitat, such as eelgrass beds. Moorings can also damage habitat if anchors or chains are abandoned on the seafloor as marine debris (Gulf of the Farallones National Marine Sanctuary, 2013).

Up to 130 unpermitted vessel moorings of various materials and sizes existed in Tomales Bay as recently as June 2016, some of which were located in sensitive habitats throughout Tomales Bay (Gulf of the Farallones National Marine Sanctuary & California State Lands Commission, 2013). Since 2016, 51 unpermitted mooring systems (19 of which were in eelgrass beds), three moored docks, and three abandoned vessels were removed from the bay or relocated outside of eelgrass beds, preventing the potential for additional habitat damage from anchor blocks and chain scour and/or the release of marine debris (GFNMS, 2022e).

A small number of moorings exist in Bolinas Lagoon (R. Feris, personal communication, September 26, 2023). Moorings are not known to exist in either of the esteros.

Prior to the introduction of the Tomales Bay Mooring Program in 2015, there were numerous incidents in which vessels broke loose from their moorings in the bay and caused damage to habitats, other vessels, and human-made structures. Since 2017, when mandatory inspections and maintenance of vessel moorings were enacted, there have been no reports of vessels separating from their moorings and causing impacts to habitat or personal property. However, there have been several incidents of vessels at anchor breaking loose and causing damage

(GFNMS, 2022e). For example, in 2019, FV *Marian* broke free of its anchor and damaged approximately 889.74 square feet (82.66 m^2) of eelgrass habitat (EPA, 2021a).

Marine Debris

Marine debris (both land- and ocean-sourced) of various weights, shapes, and sizes is found throughout Tomales Bay, which is consistent with findings from the 2010 condition report. Hundreds of large truck tires were submerged off Marconi Cove as breakwaters in the 1960s (F. Vilicich, personal communication, September 26, 2022). The estimated length of the northern group of tires is at least 50–60 feet laid along the seafloor (15–18 m; Merkel & Associates, Inc., 2015). The length of the southern group is less than 30 feet (9 m). Additional marine debris, including a large steel frame, several abandoned creosote pilings, and numerous pieces of submerged waste left by abandoned aquaculture facilities, has been observed and documented in photos or sidescan sonar data (Merkel & Associates, Inc., 2015).

Land-sourced marine debris that has been removed from Tomales Bay since 2010 includes cars, vessels, a fence, and a berm constructed to divert water for aquaculture purposes. A local citizen has also documented an extensive amount of debris in the bay, including plastic zip ties, mesh bags, and other land-sourced debris resulting from aquaculture operations, and has worked since 2014 (or possibly earlier) independently and with aquaculture operators to remove it (The Coastodian, 2013, 2017). Two cars crashed into Bolinas Lagoon in 2014; these were removed (GFNMS, 2022d), but habitat damage occurred as a result of the incidents. There is no information on the long-term impacts or recovery of the affected areas. There was no apparent trend in marine debris prevalence in either Tomales Bay or Bolinas Lagoon. No marine debris data were available for the esteros.

Recreational Activities: Clamming

Clamming in Tomales Bay occurs on the mudflats when the tide is 0.5 feet (0.15 m) or lower (Lawson’s Landing, 2022). Clam diggers harvest gaper clams, geoducks, littlenecks, basket cockles, and Washington clams (ONMS, 2010). Clamming activities can negatively impact eelgrass habitat through both the digging of holes to extract clams (which creates spots in the a mudflat where eelgrass shoots can no longer grow) and through the trampling of eelgrass as people walk across flats to access clams. While clamming has been a popular activity in the bay for many decades, its extent decreased prior to 2010 after conservation measures by Lawson’s Landing and CDFW were implemented and chartered boat trips from Lawson’s Landing to the mudflats ceased in 2000. These actions may have decreased the harvest of bivalve mollusks, such as clams. There are no data on the status and trend of this activity.

Conclusion

The status rating for this question is fair based on a decrease in unpermitted moorings and the continued presence of marine debris in Tomales Bay, which does not appear to have changed since the last condition report, although some debris has been removed. Recreational clamming activities also continue to occur. The trend was undetermined due to the need for more information on marine debris and fishing, although it appears that levels of recreational clamming in Tomales Bay are lower compared to historical levels.

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

Coastal and Offshore Region

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

Rationale: Vessel activities and trap fisheries affected living resources through ship strikes and entanglement, potentially affecting the recovery of threatened and endangered species. Although these activities do not appear to have substantially changed during the study period, changes in whale distribution increased the risk of ship strikes and entanglements. Pinnipeds and seabirds were also observed entangled in trash and fishing gear during the study period; entanglement trends for these species were variable, and there were no apparent effects on abundance of these species in the sanctuary. Although there were some exceptions, human activities that disturb seabirds and harbor seals generally remained stable or decreased, and did not appear to affect wildlife abundance or use of the sanctuary. There were no substantial oil spills in the sanctuary during the study period, and tar ball deposition was infrequent (and likely resulted from natural seeps).

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was fair and the trend was not changing. The rating was based on impacts from increased urbanization and use of coastal areas. Vessel traffic impacts (discharges and noise) and wildlife disturbances increased, but trawling and fishing pressure decreased, and new marine zones were established.

New Information in the 2010–2022 Condition Report

Human activities used to evaluate this question included distance traveled by large vessels, ships strikes, commercial fishing gear and whale entanglement, entanglement of pinnipeds and seabirds in trash and fishing gear, wildlife disturbance, and oil pollution (Table S.P.4.1).

Table S.P.4.1. Summaries for the key indicators related to human activities that impact living resources in the coastal and offshore region of GFNMS that were discussed during the July 11, 2022 virtual status and trends workshop.

Indicator	**Source**	**Data Summary**	**Figures and Tables**
Vessel traffic and ship strikes	BOEM & NOAA, 2022; NOAA Fisheries, 2020a, 2022b; Rockwood et al., 2017, 2020b; Vanderlaan & Taggart, 2007; Santora et al., 2020; Elliott et al., 2022b	Status: Up to 1,243 large vessels transited the sanctuary each year from 2016–2020. Ship strikes occurred annually in the region, and may be impacting the recovery of endangered and threatened whale populations. Trend: The number of large vessels varied and the distance traveled by and speed of large vessels decreased during the study period. The number of confirmed ship strikes increased in the region.	Figure S.P.4.1; Figure S.P.4.2
Benthic traps and entanglement	Scholz et al., 2004; NOAA Fisheries, 2020a; Rockwood et al., 2020b; Elliott et al., 2022b; Santora et al., 2020; Ingman et al., 2021; CDFW, 2020a; Gulland et al., 2022	Status: Dungeness crab gear is common in GFNMS and the surrounding region; entanglement of whales occurred annually and may be impacting recovery of endangered and threatened whales. Trend: Commercial Dungeness crab fishing effort was stable in the first half of the study period and declined in the latter half of the study period. The amount of spatial and temporal overlap between the commercial Dungeness crab fishery and foraging humpback whales increased.	Figure S.P.4.3; Figure S.P.4.4; Table S.P.4.2
Trash and entanglement	Lindquist & Roletto, 2022a; Warzybok, 2022; Shaffer et al., 2017	Status: Entanglements occurred primarily among California and Steller sea lions (most often entangled in fishing gear) and western gulls (most often entangled in trash); these entanglements did not appear to impact pinniped or seabird abundance in the sanctuary. Trend: Wildlife entanglements appeared to decrease during the study period.	Figure S.P.4.5; Table S.P.4.3; Figure S.P.4.6

Indicator	Source	Data Summary	Figures and Tables
Wildlife disturbance	GFNMS, 2022c; Lindquist & Roletto, 2022a, 2022b; Codde, 2020	Status: Disturbance to birds occurred primarily from low-flying aircraft, but did not appear to impact population sizes or bird use of the sanctuary. Disturbance to harbor seals from humans, motorboats, and other sources occurred, but did not appear to impact population sizes or harbor seal use of the sanctuary. Trend: Reports of disturbances to birds appeared to be stable or declining. Harbor seal disturbance reports were generally stable but increased recently at one location. Overall levels of wildlife disturbance in recent years were lower compared to the previous decade.	Figure S.P.4.7; Figure S.P.4.8
Vessel traffic: Oil pollution	USCG, 2022	Status: Eight incidents that may have resulted in oil pollution were reported. Trend: No trend data were available.	Figure S.P.4.1; Figure S.P.2.2
Data gaps	There is a lack of data pertaining to human activities that affect biodiversity or wildlife densities. More analyses of available data are needed for vessels transiting the sanctuary, including data categorized by vessel type, vessel speeds, and rates of vessel discharges. Long-term trend data and analysis of vessel speeds and types near the entrance to San Francisco Bay are particularly needed due to the eastward/nearshore shift of whales and their prey species. Quantification of visitation at rocky reefs and the impacts of trampling, tide pooling, and extraction are needed. There are limited data on the prevalence of human activities that elicit disturbance behaviors (e.g., tide pooling, extraction, low-flying motorized aircraft, jet skis, boating activities), making it difficult to assess the extent of and trends in these activities. There are limited data on the amount of oil pollution released when vessels are grounded or sink. More data are also needed on noise impacts to living resources in GFNMS.		

Vessel Traffic and Ship Strikes

Vessel traffic impacts living marine resources through ship strikes to whales. The risk of fatal ship strikes to whales is influenced by the number, size, and speed of vessels, as well as the extent to which vessel traffic overlaps with preferred whale habitat. Annually, from 2016–2020, 834–2,003 vessels transited through GFNMS. The number of large vessels (>300 gross tons [305 metric tons]) transiting the sanctuary and within the TSS (see Figure SS.1) varied each year from 2016–2020, and was highest in 2016 (n = 1,243) and lowest in 2020 (n = 942; BOEM & NOAA, 2022). In 2019 and 2020, the majority of large vessels were cargo carriers (1,988), tank vessels (852), and tug tow vessels (108; BOEM & NOAA, 2022). The distance large vessels traveled through the sanctuary decreased slightly from 2016–2020 (BOEM & NOAA, 2022; Figure S.P.4.1).

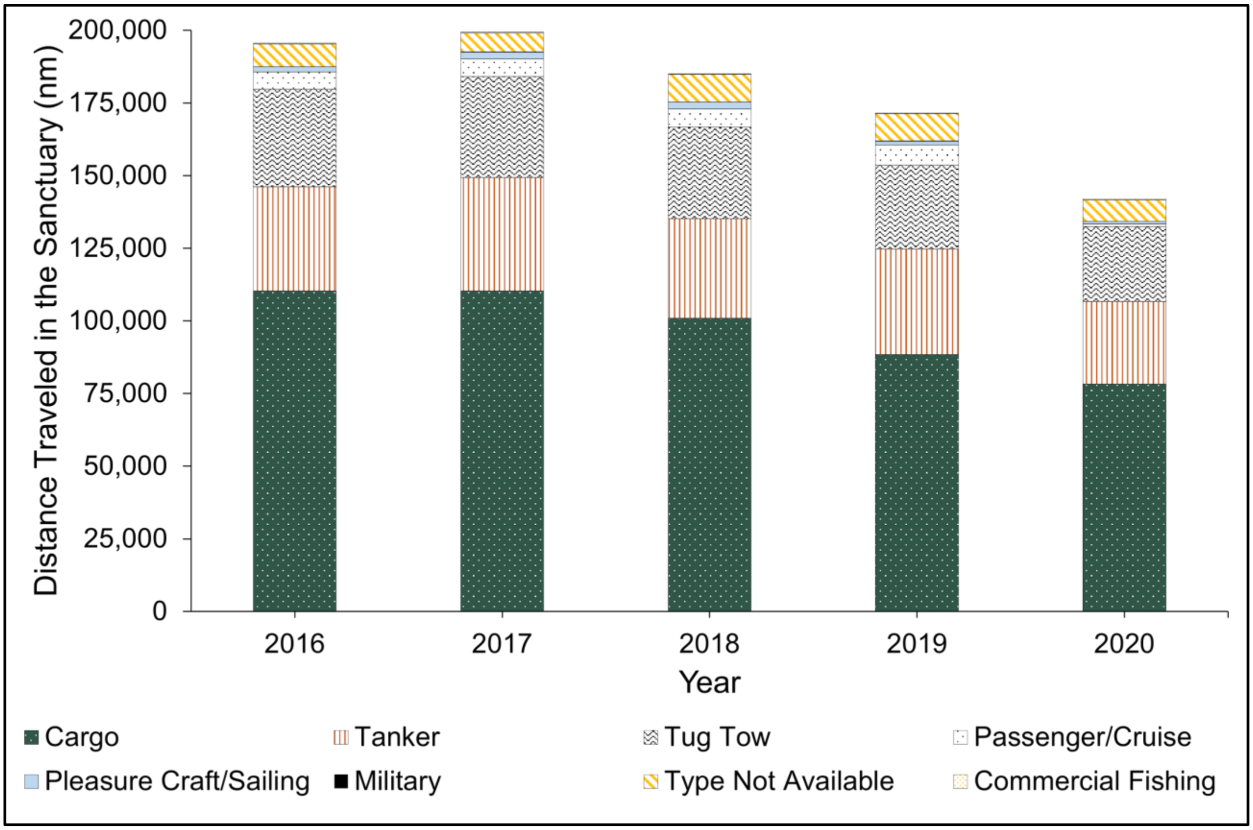


Figure S.P.4.1. Total distance traveled through GFNMS by vessels greater than 300 gross tons (305 metric tons), 2016–2020. Source: BOEM & NOAA, 2022

Vessel speed is used as a proxy for increased risk of lethal ship strikes on baleen whales. As vessel size and speed increases, lethality of a vessel striking a whale increases (Moore et al., 2018; Vanderlaan & Taggart, 2007; Rockwood et al., 2017). Overall, the mean speed for large vessels ≥300 gross tons (305 metric tons) declined between 2009–2016 (BOEM & NOAA, 2022).

Confirmed ship strikes represent a small percentage of the actual number of animals struck; about 2% for blue whales and 10% for humpback whales (Carretta et al., 2021). Deaths due vessel collisions are verified through necropsies of stranded whales and are listed in the Marine Mammal Health and Stranding Response Program's National Stranding Database (NOAA Fisheries, 2022b). Although necropsies are an imperfect metric for assessing ship strikes, and it is unknown how necropsy effort may have varied over time, this approach provides an estimate of confirmed ship strike mortality. Even though vessel speeds have declined, there was an increase in the number of whales confirmed by necropsy to have been killed by vessel collisions in and adjacent to GFNMS between 2010–2019 (Figure S.P.4.2; NOAA Fisheries, 2022b). This trend may have been influenced by compression of forage habitat (Santora et al., 2020) and increased co-occurrence of ships and foraging areas for humpback whales (Rockwood et al., 2020b) during and following the 2014–2016 MHW. Questions 8 and 13 in this report provide more information on how habitat compression influences water quality and the redistribution of whales and the distribution of their forage species. Ship strikes may be impacting the recovery of endangered and threatened whales (Rockwood et al. 2017; NOAA Fisheries, 2020a).

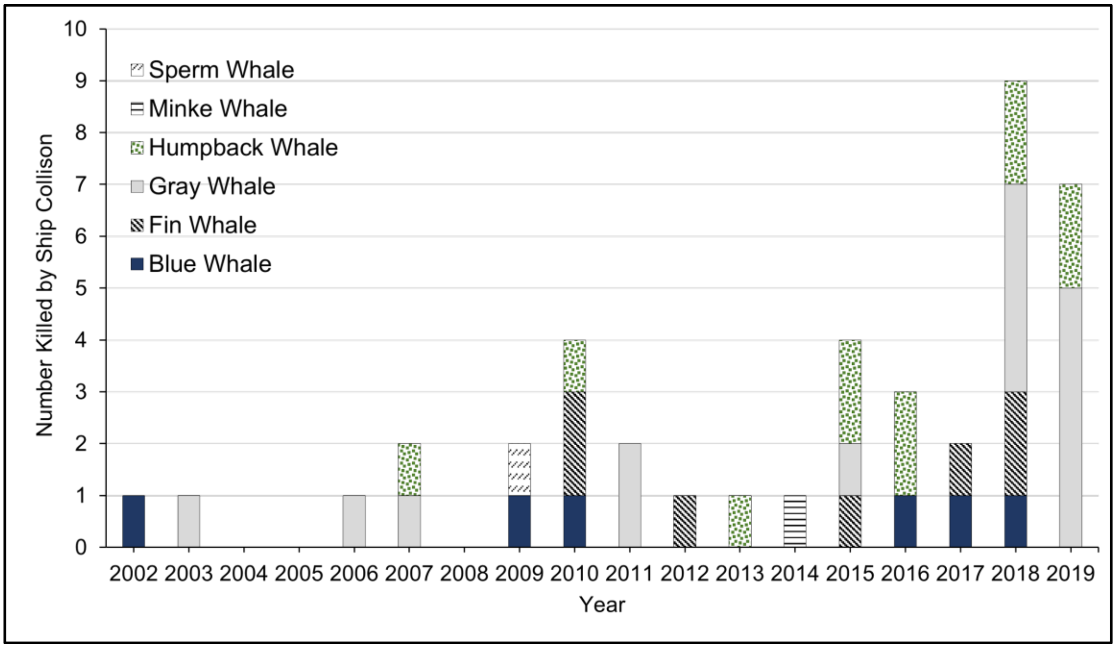


Figure S.P.4.2. Number of whales confirmed to have been killed by vessel collisions from 2002–2019 in or adjacent to GFNMS. Data from 2020 and 2021 were not included due to a reduction in necropsies performed during the pandemic. Source: NOAA Fisheries, 2022b

Benthic Traps and Entanglement

Entanglement in fishing gear is a significant threat to marine wildlife. Approximately 29,200–83,500 commercial Dungeness crab traps are set on the seafloor each year in GFNMS (CDFW, 2020a). An average density of 0.12 traps per square mile (0.3 traps km^{-2}), ranging from 0.04–0.15 traps per square mile (0.1–0.4 traps km^{-2}), were observed during ACCESS cruises (May–September, which includes active and inactive fishing periods; Elliott et al., 2022b). Entanglement of whales in Dungeness crab gear occurred annually in the region and may have impacted the recovery of endangered and threatened whales. Baleen whales are particularly vulnerable to entanglement because their habitat overlaps areas of intensive fishing and they use the water column when diving, increasing their likelihood of encountering lines; humpback whales continue to be the most common species entangled (NOAA Fisheries, 2020a; Figure S.P.4.3). Reports of entangled whales were opportunistic throughout the study period; there was a notable decrease in the number of reports in 2020 and 2021 during the COVID-19 pandemic (however, this may have resulted from a decrease in observation effort during the pandemic). Dungeness crab gear was the most common fishing gear involved in whale entanglements. The area of the Dungeness crab commercial fishery in GFNMS was consistent from 2010–2020; effort was stable in the first half of the study period but declined in recent years (CDFW, 2020a). However, in the past several years, the main foraging area for humpback whales shifted from the shelf break (328–656 ft [100–200 m]) to shallower waters and closer to the mainland (i.e., habitat compression). This redistribution of whales meant there was increased co-occurrence of whales with the commercial Dungeness crab fishery across the shelf (Elliott et al., 2022b; Santora et al., 2020), increasing the risk of entanglements for humpback whales (Santora et al., 2020; Ingman et al., 2021; Gulland et al., 2022). There was a peak in fishing-gear-related whale entanglement during the 2014–2016 MHW, when habitat compression occurred.

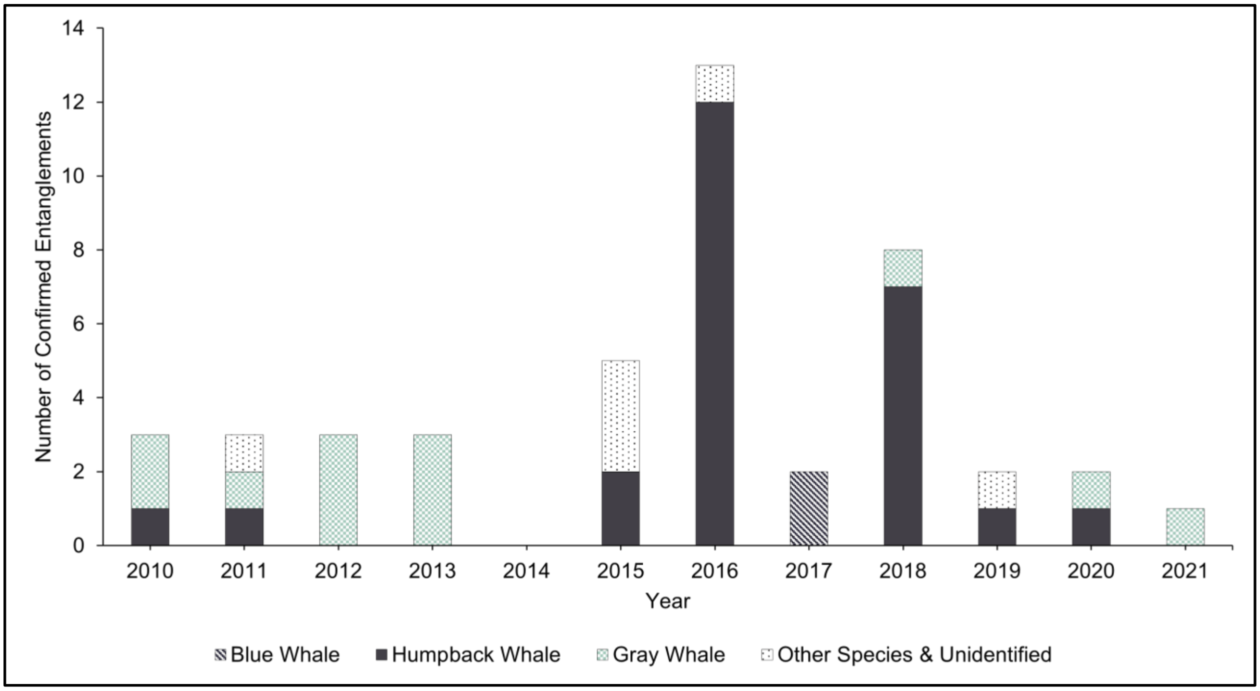


Figure S.P.4.3. Number of confirmed entanglements by species within and adjacent to GFNMS, 2010–2021. There was a notable decrease in the number of reports in 2020 and 2021, which may be attributable to a decrease in effort during the COVID-19 pandemic. Source: NOAA Fisheries, 2020a

In addition to a shift in spatial distribution of whales, there was a shift in the timing of arrival of whales to forage in GFNMS. In comparison to 1993, humpback whales arrived 120 days earlier in 2017, thus increasing the number of days whales were present in the sanctuary during commercial Dungeness crab fishing, which generally takes place November 15–June 30 (Ingman et al., 2021). In some seasons (e.g., 2015–2016 season), the opening of the fishery was delayed as a result of the presence of domoic acid. The delay meant that the highest levels of fishing activity occurred later in the spring of 2016 when more whales were present, and thus there were high levels of entanglement (Table S.P.4.2; Figure S.P.4.4). During the 2015–2016 season, observations of dead whales reported to have been entangled in fishing gear occurred throughout the Central California region but were concentrated in the Gulf of the Farallones region.

Efforts to reduce the risk of entanglement were underway during the study period through the Large Whale Entanglement Response Network, coordinated by NOAA (NOAA Fisheries, 2020a). In addition, the Risk Assessment and Mitigation Program California Dungeness Crab Fishing Gear Working Group worked to reduce the overlap in timing of Dungeness crab fishing and whale presence, as well as modify fishing gear to reduce the risk of entanglement (CDFW, 2022a). In recent years, the opening of the commercial Dungeness crab fishery was delayed twice and closed early three times due to the increased risk of entanglement (Table S.P.4.2).

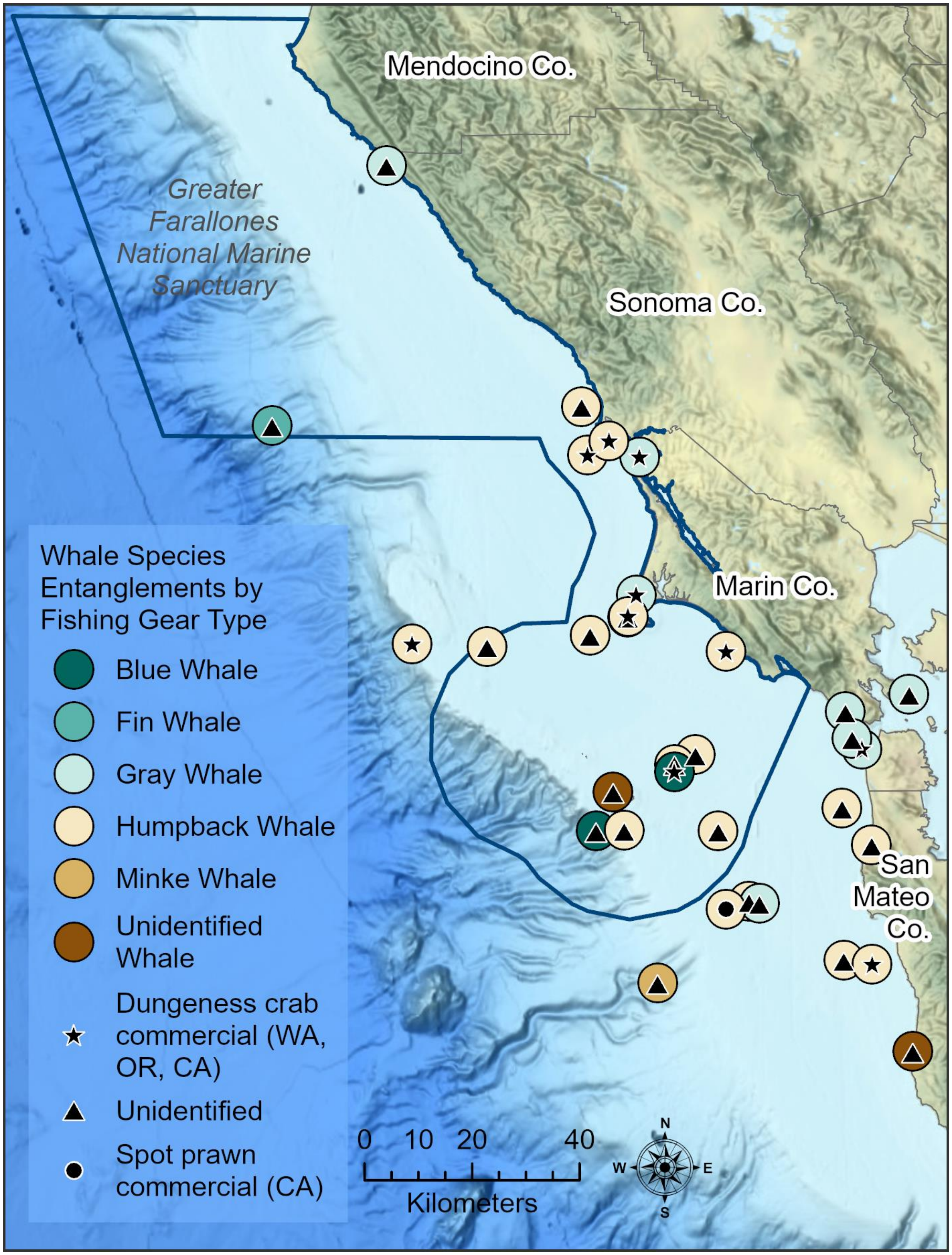


Figure S.P.4.4. Areas of commercial Dungeness crab catch and observations of entangled whales (2010–2021). Image: NOAA; Source: Scholz et al., 2004; NOAA Fisheries, 2020a; Esri, 2020

Table S.P.4.2. Bolded dates denote years when the Dungeness crab fishery opening was delayed or there was an early closure due to the presence of humpback whales and increased risk of entanglement in the region that includes GFNMS. Source: Pacific States Marine Fisheries Commission [PSMFC], 2022a; CDFW, 2022a

Season	Date Commercial Fishery Opened	Reason for Delay	Date Commercial Fishery Closed	Reason for Early Closure
2010–2011	15-Nov		30-Jun	
2011–2012	15-Nov		30-Jun	
2012–2013	15-Nov		30-Jun	
2013–2014	15-Nov		30-Jun	
2014–2015	15-Nov		30-Jun	
2015–2016	**30-Mar**	Domoic acid	30-Jun	
2016–2017	15-Nov		30-Jun	
2017–2018	15-Nov		30-Jun	
2018–2019	15-Nov		**15-Apr**	Entanglement risk
2019–2020	**15-Dec**	Regional entanglement risk and regional domoic acid	**15-May**	Entanglement risk
2021–2022	**18-Jan**	Entanglement risk	**8-April**	Entanglement risk

Trash and Entanglement

Entanglement is also a risk to other sanctuary wildlife, such as pinnipeds and seabirds, which can become entangled in fishing gear, debris, and trash (Figure S.P.4.5). Data from Southeast Farallon Island, an important breeding ground for seabirds and marine mammals, showed that a total of 1,020 entangled birds and mammals were observed between 2013 and 2021. A peak in entanglement occurred in 2014, and the fewest entanglements were observed in 2018, but entanglements increased again from 2019–2021, indicating a variable trend (Warzybok, 2022). The vast majority of entangled species were California sea lions (n = 867), Steller sea lions (n = 75), and western gulls (n = 31). Mainland shoreline surveys of dead birds and mammals from 2010–2019 indicated a wide variety of entanglement types (e.g., fishing line, hooks, monofilament nets, packing straps, plastic bags, toys, trash). Data from biweekly Beach Watch surveys (see Box 2; Figure S.P.3.6) indicated entanglement rates of 0.006 birds per mile (0.004 km^{-1}) surveyed and 0.0003 mammals per mile (0.0002 km^{-1}) surveyed. On mainland beaches, entangled species included common murres, cormorants, western gulls, loons, grebes, and sea lions (Lindquist & Roletto, 2022a).

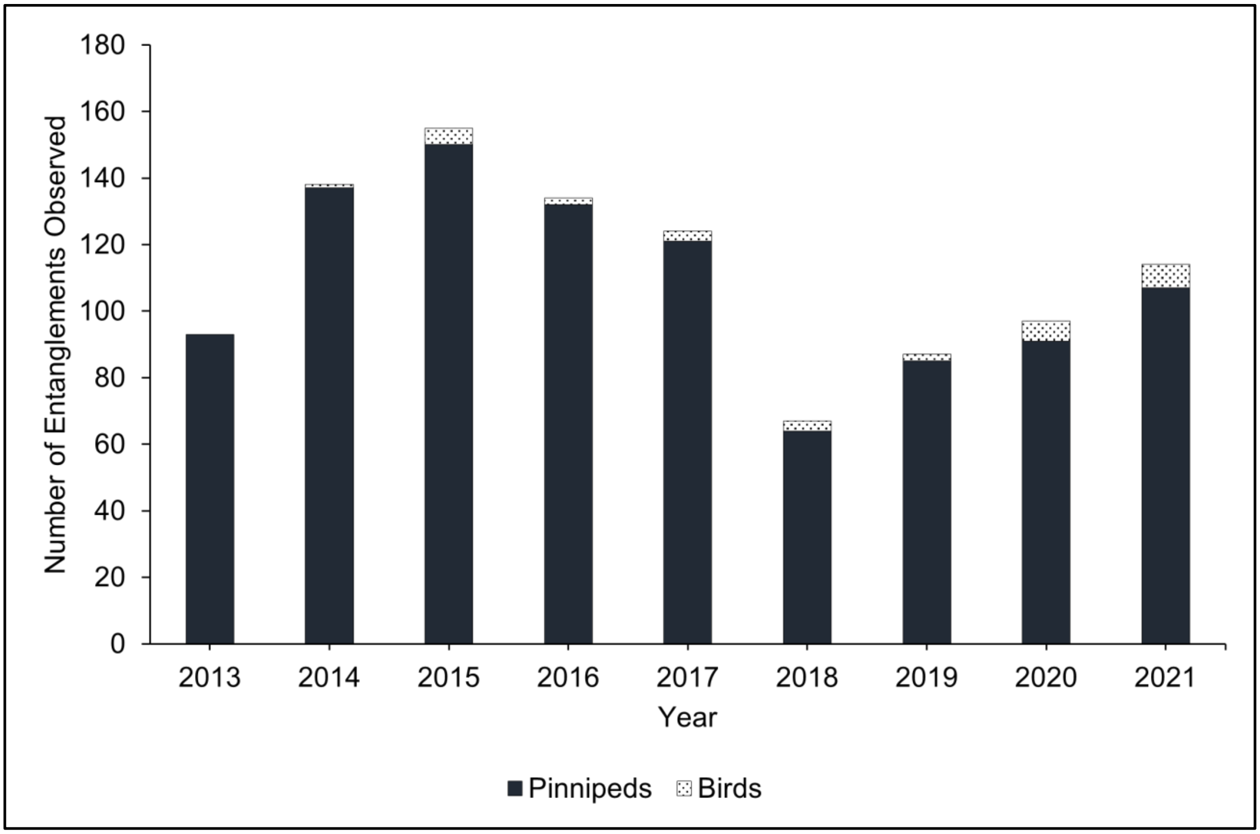


Figure S.P.4.5. Number of pinnipeds and birds observed to be entangled on Southeast Farallon Island from 2013–2021. Source: Warzybok, 2022

Wildlife are entangled in a wide variety of fisheries-related and non-fisheries-related materials (Table S.P.4.3). At Southeast Farallon Island, pinnipeds were primarily entangled in materials associated with sport and commercial fishing (Warzybok, 2022). Gulls were primarily entangled in trash, likely from municipal dumps and recycling facilities that are within a one-day flight range. There are 36 municipal waste and recycling facilities in the vicinity of the typical flight distance of gulls to and from Southeast Farallon Island (Figure S.P.4.6). Tracking studies found that during the breeding season, western gulls forage closer to Southeast Farallon Island than other times of the year, staying within 33 miles (53 km), and that 30% of western gulls' foraging trips were to landfills. Outside of the breeding season, they may forage further. Favored landfills were the Recology facility in South San Francisco, Waste Management in Oakland, and City of Santa Cruz Resource Recovery Center (Warzybok, 2022; Shaffer et al., 2017; Figure S.P.4.6). Entanglements did not appear to impact the abundance of seabirds or pinnipeds in the sanctuary.

Table S.P.4.3. Types of materials that entangled birds and pinnipeds on Southeast Farallon Island, 2010–2021. “Unknown” indicates that the observer could not see or determine the type of material. “Other fishing-related materials” included lures, hooks, lines, and/or rope. “All other materials and trash” included rubber straps, fabrics, six-pack holders, balloons, plastic toys, trash, or wires. The sources of materials were not documented. Source: Warzybok, 2022

Material	Count
Unknown	465
Monofilament	359
Other fishing-related materials	59
Plastic strap	57
Rope	41
All other materials and trash	68

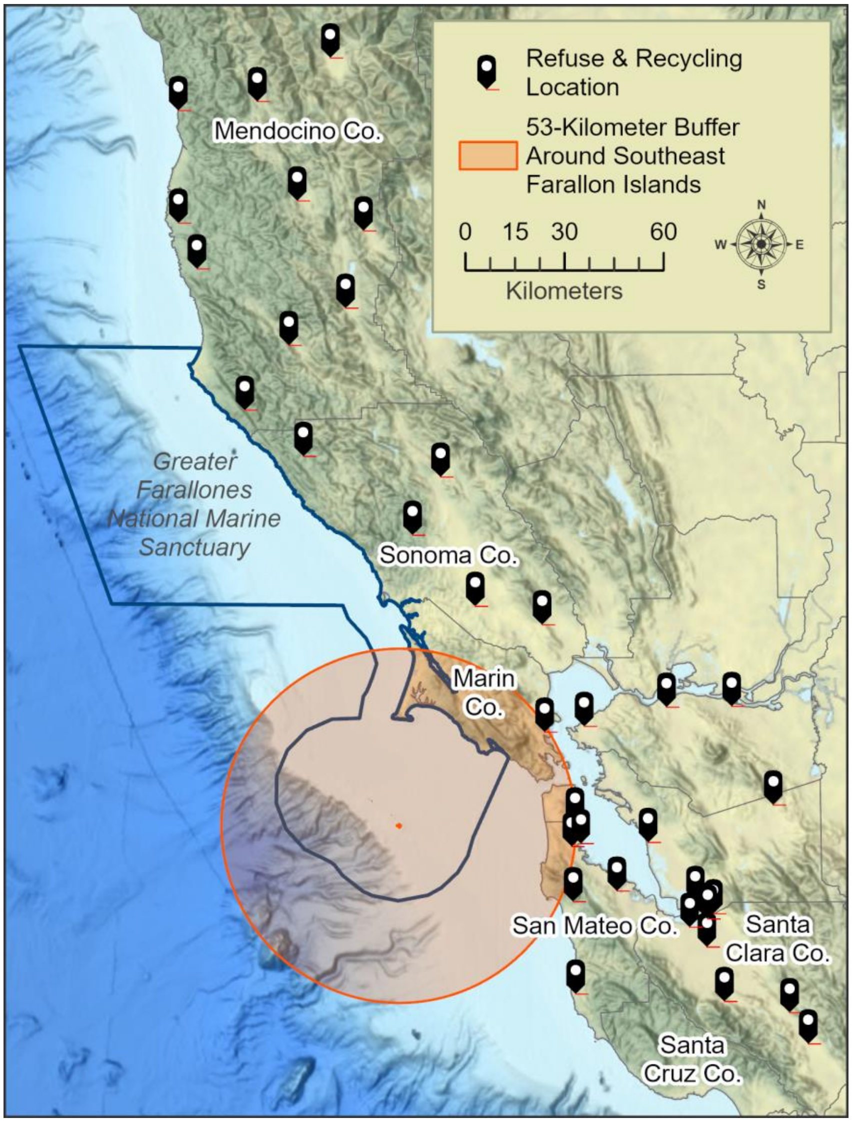


Figure S.P.4.6. Map of municipal dumps and recycling facilities within a one-day flight range (30 miles [48 km], indicated by shaded circle) of western gulls during their breeding period. Flight range is extended in the non-breeding season. Image: NOAA; Source: Esri, 2020

Wildlife Disturbance

The co-occurrence of human activities and wildlife can cause disturbance, which can disrupt feeding, resting, breeding, and nesting behavior; cause stress; and expose wildlife to predators (Lindquist, 2022). Disturbance events for seabirds and harbor seals, both abundant in the sanctuary, were selected as indicators for this question. The seabird breeding colony at the South Farallon Islands, the largest of which are Southeast Farallon Island and Maintop Island, is the densest population of breeding seabirds in the continental U.S., and at least 20% of California's harbor seals breed in the Gulf of the Farallones region (Carretta et al., 2022; Codde, 2020). Disturbance data for the coast and open ocean were collected by two projects in the sanctuary: 1) the Seabird Protection Network, which catalogs reports of wildlife disturbances from researchers on the Farallon Islands, Beach Watch surveyors (see Box 2), and ad hoc reports from the public; and 2) the harbor seal monitoring program led by staff from Point Reyes National Seashore (Codde, 2020). Of the 78 reports of wildlife disturbance that GFNMS received from 2012–2021, 53 were associated with low-flying aircraft. Most of the wildlife disturbance events reported to GFNMS were medium or large incidents, impacting 10–1,000 individuals. Bird disturbance reports appeared to be stable or declining (GFNMS, 2022c). Data from Beach Watch surveys indicated that human activities and the presence of dogs, which may affect the presence of shorebirds, has been stable or decreasing until recent years (2018–2019; Lindquist & Roletto, 2022a, 2022b; Figure S.P.4.7). On average, harbor seals were disturbed from their haul-outs 0.21 times per hour (Codde, 2020). The majority of disturbances were associated with humans on the beach, unknown sources, and motorboats (Figure S.P.4.8). Disturbance rates appeared to be consistently lower compared to the previous decade. From 2010–2019, disturbances at outer coast beaches appeared to be stable, with an uptick in recent years at Double Point (Codde, 2020). Although disturbance to wildlife occurred on a regular basis, the level of disturbance did not appear to affect wildlife abundance or use of the sanctuary (Codde, 2020; Lindquist & Roletto, 2022b).

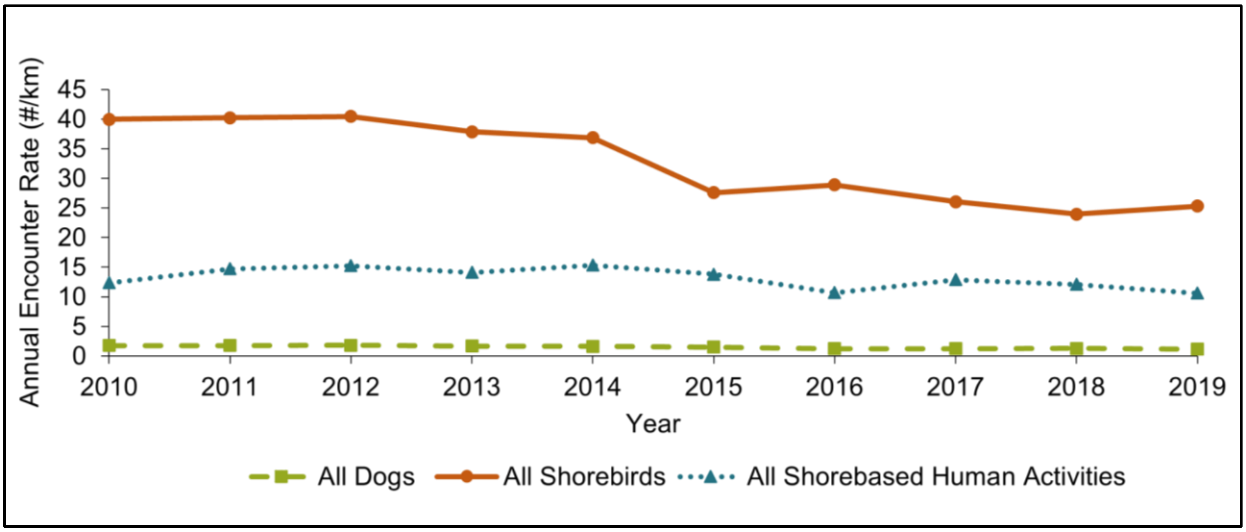


Figure S.P.4.7. Encounter rates for dogs, human activities, and all shorebird species along sanctuary beaches, 2010–2019. Source: Lindquist & Roletto, 2022a, 2022b

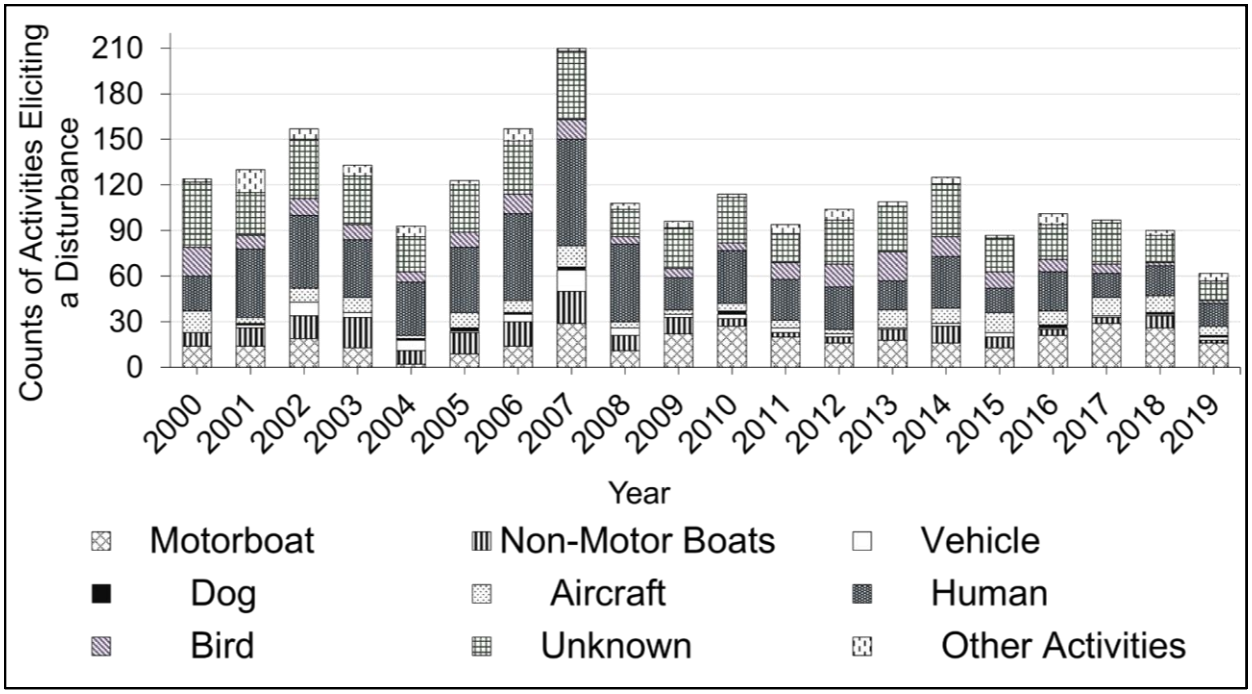


Figure S.P.4.8. Counts of activities known to disturb harbor seals by activity type and year. Source: Codde, 2020

Vessel Traffic and Oil Pollution

Vessel traffic is also a concern for wildlife because of the risk of oil spills (Jägerbrand et al., 2019), which can cause fouling of feathers and fur, hyperthermia, and internal organ damage. Distance ships traveled through the sanctuary is an indicator of risk for oil pollution from vessels; as noted above, this declined slightly during the study period (Figure S.P.4.1). Question 2 in this report reviews oil release events. There were no substantial oil pollution events in GFNMS during the study period, and only infrequent deposition of tarballs, many which were likely the result of natural seeps (S.P.2.2). The last large oil spill that impacted the sanctuary occurred in 2007 (MV *Cosco Busan*; ONMS, 2010). From 2010–2020, eight incidents that may have resulted in oil pollution were reported to the U.S. Coast Guard, but the amount of discharged oil was not documented (USCG, 2022).

Conclusion

Some human activities, such as vessel strikes to whales and whale entanglement in commercial fishing gear, impacted living resources in GFNMS during the study period, resulting in a status rating of fair. Shifts in the distribution of baleen whales since the 2014–2016 MHW increased the risk of entanglement and ship strikes. Pinnipeds and seabirds were entangled in fishing gear and trash and disturbed on beaches and rocky shores, although these incidents did not appear to affect the abundance of these species or their use of the sanctuary. Some evidence of oil pollution was observed during the study period, but no substantial oil spills were documented, and tarballs observed were likely attributable to natural seeps. Given that some indicators, such as documented ship strikes and entanglements, worsened while others, such as oil pollution and disturbance to birds and mammals, improved, the trend for this question was mixed. There is a lack of data on the prevalence of human activities that elicit disturbance behaviors (e.g., tide pooling, extraction, low-flying motorized aircraft, jet skiing, boating), making it difficult to assess the extent of and trends in these activities. Data on vessel speeds within the TSS and entrance to San Francisco Bay are available, but need to be analyzed. There are limited data on the amount of oil released when vessels are grounded or sink. More data are also needed on noise impacts to living resources in GFNMS.

Estuarine and Lagoon Region

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

Rationale: Disturbances to wildlife were documented, but these did not appear to hinder use of the sanctuary by wildlife. Human activities in GFNMS estuarine habitats were stable from 2010–2019, but increased in 2020–2021. Oil pollution from vessels and vehicles was observed but not quantified in Bolinas Lagoon and Tomales Bay.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair/poor and the trend was worsening. The basis for judgment was increased urbanization and wildlife disturbances linked to visitation.

New Information in the 2010–2022 Condition Report

Indicators used to rate this question included wildlife disturbance, along with oil pollution and entanglement (Table S.P.4.4). Data on these activities and their impacts to wildlife were available for two of the sanctuary's estuaries, Bolinas Lagoon and Tomales Bay (Figure SS.8).

Table S.P.4.4. Summaries for key indicators related to human activities that impact living resources in the estuarine and lagoon region of GFNMS that were discussed during the May 17, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures and Tables
Wildlife disturbance	GFNMS, 2022c; Lindquist & Roletto, 2022a, 2022b; Codde, 2020	Status: Six disturbances affecting seabirds were reported in Tomales Bay and Bolinas Lagoon from 2012–2021; most disturbances affected 10–1,000 birds. Disturbances to harbor seals were more frequent in Tomales Bay and Bolinas Lagoon; the most common disturbances were from motorboats and humans on foot. Trend: Human activities along the shorelines of Tomales Bay and Bolinas Lagoon were stable from 2010–2019 and increased slightly in 2020–2021. Disturbances to harbor seals were variable at both sites during the study period.	Table S.P.4.5; Figure S.P.4.9; Figure S.P.4.10

Indicator	Source	Data Summary	Figures and Tables
Oil pollution and entanglement	USCG, 2022; Lindquist & Roletto, 2022a	Status: Oil pollution from vessels and vehicles in Bolinas Lagoon and Tomales Bay was observed but not quantified. Marine debris was present in sanctuary estuaries, but no entanglements were reported. Trend: No trend data were available.	N/A
Data gaps	There are no data on human activities or impacts to wildlife in Estero Americano or Estero de San Antonio. There are limited data on the levels of human activities (e.g., clamming, extraction, vessel activities, low-flying motorized aircraft use, jet skiing) that are associated with or known to elicit wildlife disturbance. There are limited data pertaining to human activities that can be correlated with changes in biodiversity or densities of wildlife, rates of vessel discharges, and particularly trampling from clamming, extraction, or other activities that may negatively impact living resources in the intertidal habitat. There are limited data on the amount of oil pollution released when vessels are grounded or sink.		

Wildlife Disturbance

Various human activities, including walking dogs on the beach, can disturb wildlife, particularly shorebirds (U.S. Fish and Wildlife Service, 2007). Disturbance can disrupt feeding, resting, breeding, and nesting behavior; cause stress; and expose wildlife to predators. Data from the Seabird Protection Network indicated there were six disturbance events that affected birds in Tomales Bay and Bolinas Lagoon from 2012 to 2021 (Table S.P.4.5; GFNMS, 2022c). Most disturbances were medium to large (i.e., 10–100 or 100–1,000 animals disturbed). Data from bi-monthly Beach Watch (Box 2) surveys showed that the rates of human activities along the shorelines of Tomales Bay and Bolinas Lagoon were stable from 2010–2019, then increased slightly in 2020 and 2021 (during the COVID-19 pandemic), with a concurrent slight increase in shorebird abundance (Lindquist & Roletto, 2022b).

Table S.P.4.5. The number of disturbances to seabirds in Tomales Bay and Bolinas Lagoon, as reported by the public, from 2012–2021. Source: GFNMS, 2022c

Size of Incident	Number of Animals Disturbed
Very large (>1,000 animals disturbed)	0
Large (100–1,000 animals disturbed)	2
Medium (10–100 animals disturbed)	2
Small (1–10 animals disturbed)	0
Size not reported	2

Disturbances of harbor seals in Tomales Bay and Bolinas Lagoon are documented as part of a monitoring project led by Point Reyes National Seashore (Codde, 2020; Figure S.P.4.9; Figure S.P.4.10). Most disturbances affected harbor seals hauled out at Clam and Seal islands in Tomales Bay and were associated with motorboats coming too close to the haul-outs. Humans on foot, usually digging for clams, ranked second. In Bolinas Lagoon, harbor seal disturbances were mostly associated with humans on foot. Non-motorized boats and vehicles on the nearby road (Highway 1) ranked second. Even though disturbances to harbor seals were common in Tomales Bay and Bolinas Lagoon, the harbor seal population and pupping rates appeared to be stable or slightly increasing (Codde, 2020).

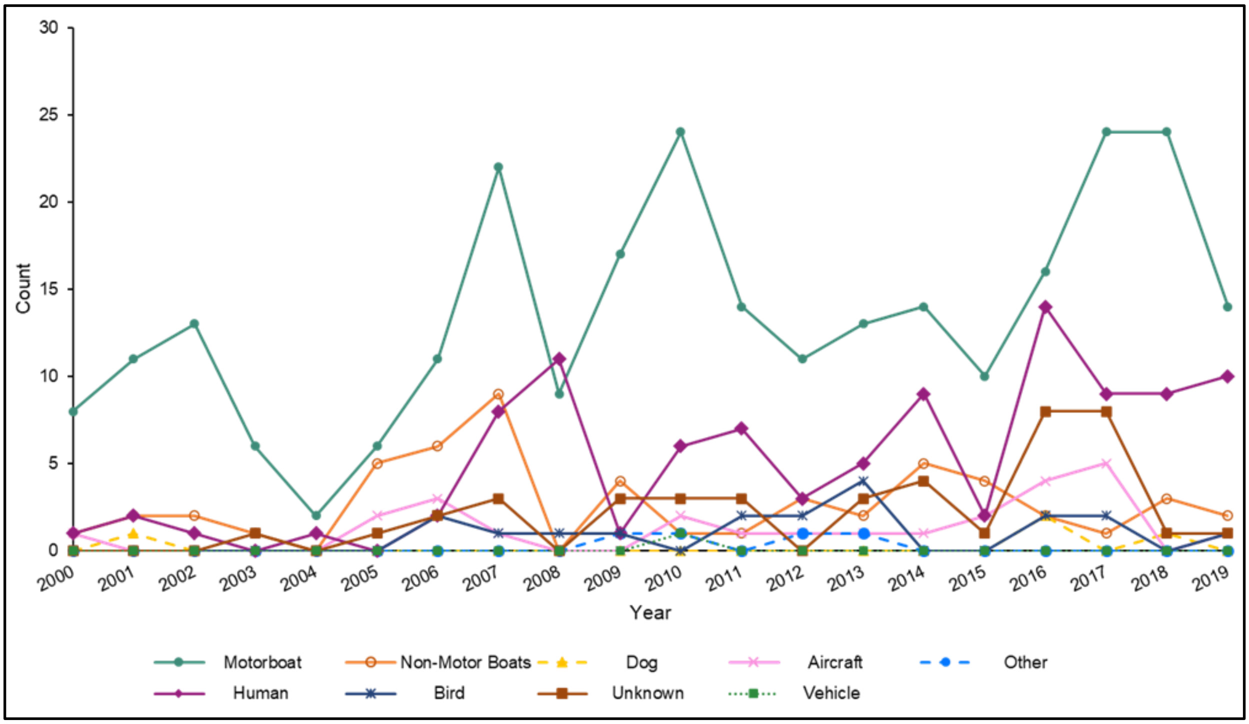


Figure S.P.4.9. Counts of disturbance events (standardized by effort) affecting harbor seals by activity from 2000–2019 at Clam and Seal islands in Tomales Bay. Source: Codde, 2020

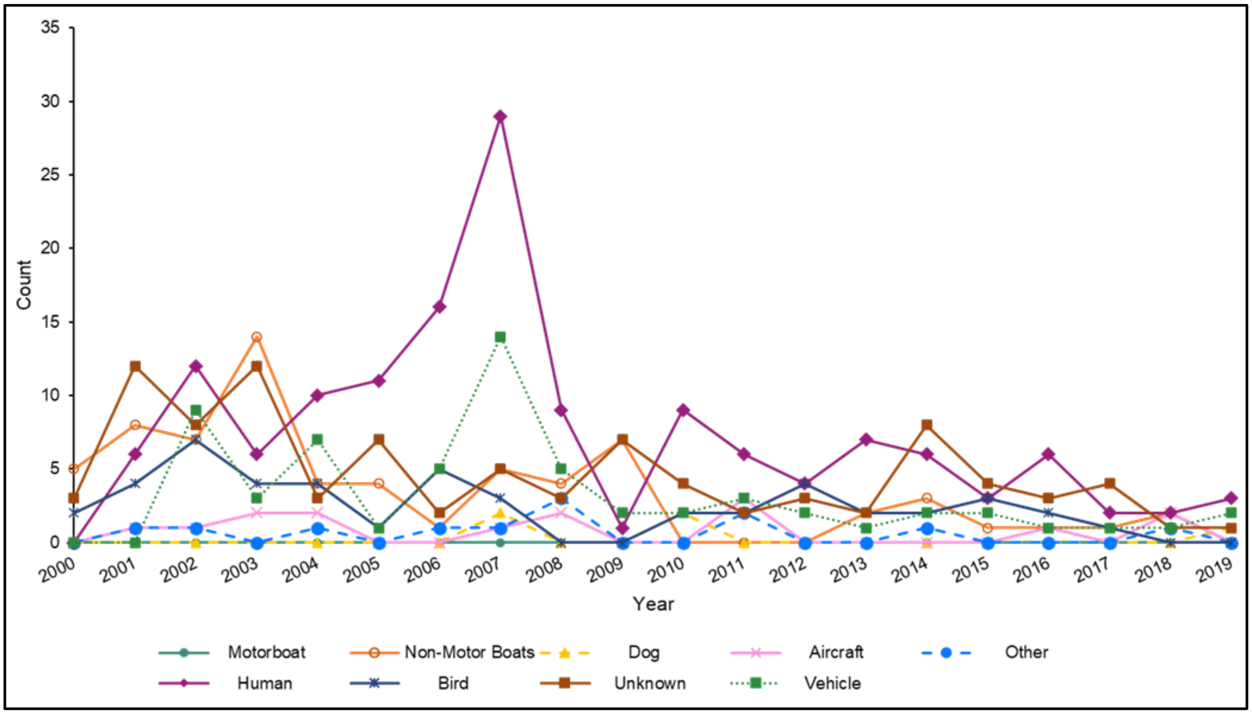


Figure S.P.4.10. Counts of disturbance events (standardized by effort) affecting harbor seals by activity from 2000–2019 in Bolinas Lagoon. Source: Codde, 2020

Oil Pollution and Entanglement

Oil pollution from boating, vessel groundings, sinkings, and vehicles has been observed but not quantified (USCG, 2022). There were no reports of oiled wildlife in Tomales Bay or Bolinas Lagoon from 2010–2022 (Lindquist & Roletto, 2022a). Marine debris was present in sanctuary estuaries during the study period, but there were no reported wildlife entanglements (Lindquist & Roletto, 2022a).

Conclusion

Some potentially harmful activities exist in the estuarine and lagoon region of the sanctuary, but they have not been shown to degrade living resource quality. Therefore, the response for this question is rated good/fair, based on data on activities that disturbed birds, such as aircraft and humans on beaches, and disturbances of harbor seals primarily by motorized and non-motorized boats, vehicles, humans on foot, and clamming activity. There was no discernible trend for these indicators. Oiling and entanglement of wildlife in the sanctuary's estuaries were not observed (Lindquist & Roletto, 2022a). There is a lack of data pertaining to human activities that are not associated with wildlife disturbance, making it difficult to determine the percent of activities associated with disturbances.

Question 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. Human activities that pose threats to maritime heritage resources worldwide include looting, inadvertent damage by divers, development, vessel anchoring, vessel groundings, fishing activities, and more. The responses to this question focuses on indicators of human activities that may threaten the condition of the known, tangible maritime heritage resources in the sanctuary (see Question 16 for the conditions of maritime heritage resources).

Given the sanctuary's expansion in 2015, its boundaries now include more shipwrecks and doghole port sites that may be impacted by human uses, based on data available on and studies of such resources within the sanctuary, including analysis of the California Historical Resources Information System (California Office of Historic Preservation, 2022; contains a wide range of documents and materials relating to historical resources) summary records and other sources. The area added to the sanctuary in 2015 is also now covered by sanctuary regulations, including prohibitions on possessing, moving, removing, or injuring, or attempting to possess, move, remove or injure, a sanctuary historical resource.

Coastal and Offshore Region

Status Description: Some potentially damaging activities exist, but they have not been shown to degrade maritime heritage resource condition.

Rationale: The levels of human activities that may adversely affect maritime heritage resources are not thought to have caused widespread impacts during the study period; for some indicators, no adverse impacts are known. Potentially damaging human activities in the coastal and offshore region of the sanctuary have occurred, including scuba diving and commercial fishing, but these are not thought to have caused widespread impacts during the study period. Anecdotal information from divers indicated a decrease in looting at maritime heritage sites since sanctuary designation, and no looting was documented during the study period. Additionally, there was no new nearshore or offshore development in the coastal and offshore region of GFNMS. A few adverse impacts were observed; for example, commercial fishing gear was documented on two shipwrecks, the SS *Selja* and the TV *Puerto Rican*. Climate impacts are likely occurring and are of concern, but difficult to measure without comprehensive site baseline data or regular monitoring. The lack of systematic monitoring of all GFNMS maritime heritage sites limited this assessment.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status rating for this question in the coastal and offshore region was good/fair and the trend was undetermined due to a lack of monitoring. Activities considered included trawling, anchoring or dragging of anchors, ship groundings, diving, removal of artifacts from archeological sites, and laying submerged cables, but none appeared to have had an adverse impact on maritime archaeological resource integrity. Note, however, that the wording of this question has changed slightly since the 2010 report (see Appendix A).

New Information in the 2010–2022 Condition Report

Indicators used to rate this question included commercial fishing, research allowed by sanctuary permits that involved contact with the submerged lands, vessel anchoring and moorings, discharges, scuba diving, development, and climate change (Table S.P.5.1).

Table S.P.5.1. Summaries for key indicators related to human activities that may adversely affect maritime heritage resources in the coastal and offshore region of GFNMS that were discussed during the July 6, 2022 virtual workshop.

Indicator	Source	Data Summary	Figures
Commercial fishing	National Centers for Coastal Ocean Science, 2020	Status: From 2011–2020, trawl vessel speed data (proxy) indicated one trawl may have occurred near one shipwreck; however, impacts are unknown. Video documented fishing debris on two shipwrecks. Trend: No trend data were available.	S.P.5.1; S.P.5.2
Research involving contact with submerged lands	ONMS, 2022a	Status: From 2014–2021, of 22 projects of this type with sanctuary permits, 11 involved activities within 100 feet (30 m) of known maritime heritage resources; however, no impacts are known. Trend: No trend data were available.	S.P.5.3
Vessel anchoring and moorings	N/A	Status: No data were available for anchoring; however, no known anchoring impacts occurred. No vessel moorings were present in the coastal and offshore region of the sanctuary. Trend: No trend data were available.	N/A
Discharges	USCG, 2022; GFNMS, 2022d	Status: From 2010–2021, smaller discharges of fuel or oil occurred; there were two incidents of lost shipping containers; zero full barge-loads of dredged material lost; and eight vessels sunk or grounded, but none of these events had known impacts on maritime heritage resources. Trend: No trend data were available.	N/A
Scuba diving	R. Schwemmer/NOAA, personal communication, January 19, 2022; Lindquist & Roletto, 2022a	Status: From 2010–2022, diving occurred at at least three wrecks; no looting was documented during the study period. Trend: No trend data were available.	N/A

Indicator	Source	Data Summary	Figures
Development	ONMS, 2022a	Status: Between 2014–2021, there were no permits for new infrastructure; two certifications were issued for ongoing activities related to an existing submarine cable and water intake/outflow infrastructure; these activities have not resulted in known impacts to maritime heritage resources. Trend: No trend data were available.	N/A
Climate change	Roth, 2021	Status: The impacts of climate change on maritime heritage resources in GFNMS are of concern, but are not well understood or monitored. Trend: No trend data were available.	N/A
Data gaps	There is no systematic monitoring of known maritime heritage resources and sites or the impacts of human activities on them in the GFNMS coastal and offshore region; thus, there is a lack of information for all selected indicators. For commercial fishing, actual activity of vessels is unknown, and there have been few video surveys of wreck sites. No information is available on fishing effects at doghole ports or other sites. For research that involves contact with submerged lands, there are gaps in data sets, as well as lack of knowledge of actual activities and any associated impacts. No anchoring data are available. There are gaps in some data sets for discharges. There is no comprehensive, systematic monitoring data for scuba diving. Similarly, there is no comprehensive, systematic monitoring data on the effects of climate change on maritime heritage resources.		

Commercial Fishing

Commercial fishing can cause mechanical damage to and entanglement on maritime heritage resources from bottom trawling, traps, nets, lines, and hooks. NOAA VMS data (from 2011–2020; National Centers for Coastal Ocean Science, 2020) were used to identify locations at which fishing vessels were underway at speeds likely used for trawling (as a proxy for trawl track locations). A limited amount of remotely operated vehicle (ROV) video footage of known wrecks was also reviewed. The vessel speed data indicated only one potential bottom trawl track came within 0.5 miles (0.8 km) of a known wreck but did not pass over the wreck location. Examination of video footage documented fishing debris on two shipwrecks. A 2014 ROV video survey of the SS *Selja*, a steel hull vessel that sank after a collision with the SS *Beaver*, showed commercial crab pots and buoy lines on the wreck (Figure S.P.5.1; Figure S.P.5.2). A brief 2021 ROV video survey of the stern of the TV *Puerto Rican*, a steel vessel that sank in 1984 after an explosion on board, showed the stern was covered in commercial fishing nets. No information on the effects of fishing on other shipwrecks or doghole port sites was available.

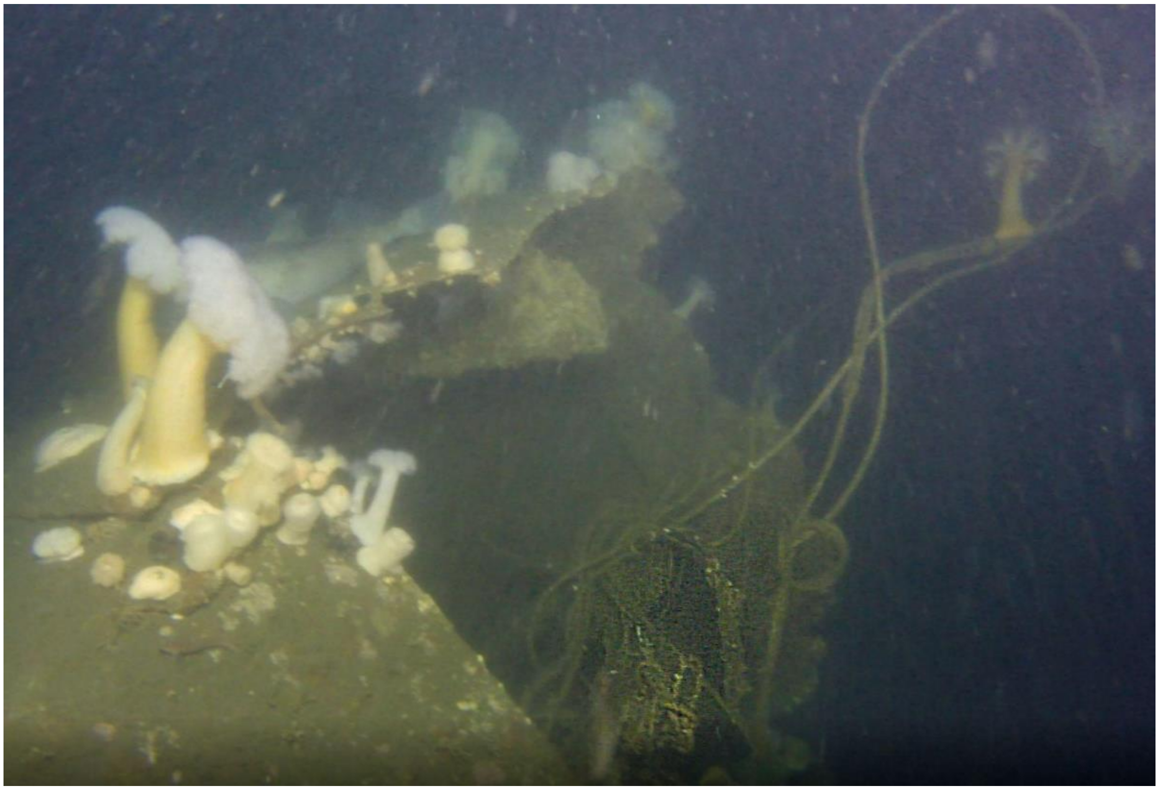


Figure S.P.5.1. Site of the SS *Selja* shipwreck, surveyed in 2014, with commercial fishing gear and buoy lines visible. Photo: NOAA

Figure S.P.5.2. Site of the SS *Selja* shipwreck, surveyed in 2014, with commercial crab pots visible. Photo: NOAA

There are gaps in the data available on the levels of commercial fishing activities at maritime heritage resource sites and on debris from commercial fishing (a proxy) on maritime heritage resources, as surveys have not been completed for all known resources in GFNMS. Also, subsequent site monitoring surveys have not yet been conducted on the SS *Selja* and the TV *Puerto Rican*, precluding the assessment of possible changes over time.

NOAA Fisheries continues to manage Groundfish Essential Fish Habitat with stakeholder input (GFNMS, 2022f). Decisions to protect sanctuary habitats from bottom trawling also protect maritime heritage resources within Essential Fish Habitat.

Research Involving Contact with Submerged Lands

Research activities in GFNMS that would alter submerged lands require an ONMS permit. Examining projects allowed under ONMS permits between 2014–2021, 22 of those projects allowed contact with submerged lands, and thus potentially with submerged maritime heritage resources. The permits often required the permitted researchers to avoid or mitigate damage to maritime heritage resources. The projects, conducted to learn more about fisheries stocks, sea conditions, benthic character, and more, involved bottom trawling; installation, maintenance and removal of buoy moorings and scientific equipment; geological and biological sample collection; ROV bottom contact or placement on submerged lands; alternative (experimental) fishing gear testing; and abandonment of non-recoverable items.

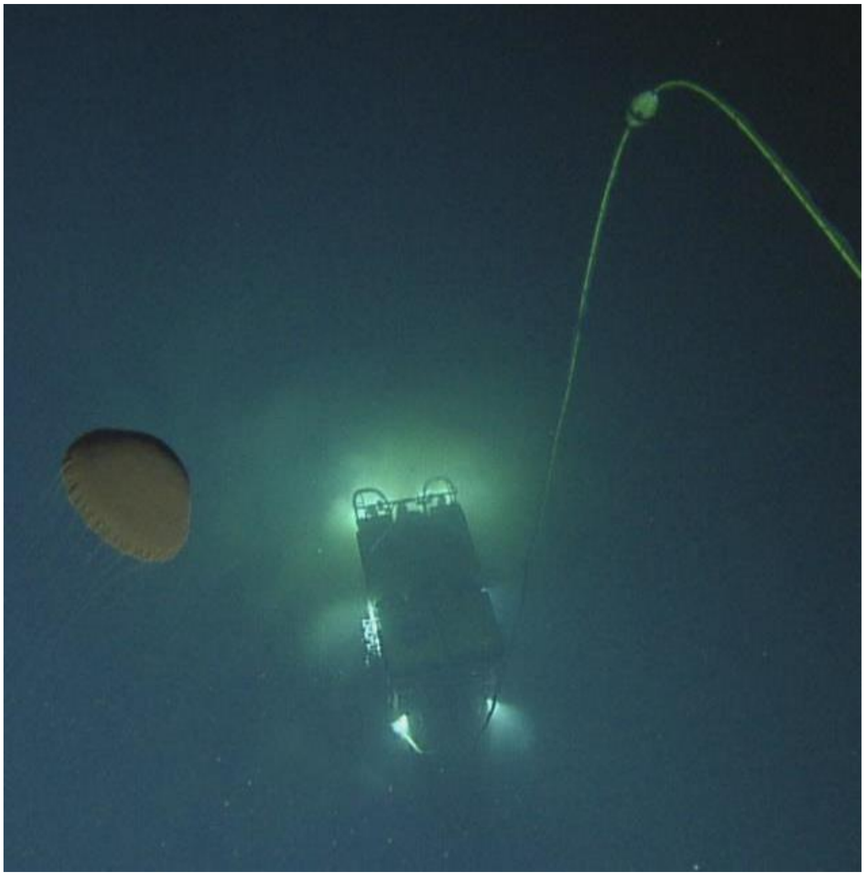


Figure S.P.5.3. Research using ROVs may involve contact with the bottom and potentially with submerged maritime heritage resources. Photo: NOAA

Comparing the permitted project areas and the general locations of known maritime heritage resources, 11 projects could have included activities on or within 100 feet (30 m) of known shipwrecks and doghole port sites; however, activities were not mapped for several years during the rating period in which relevant permits were effective (2010–2013 and 2022). There is the possibility that adverse impacts on resources occurred from some of the projects; however, there is no documentation or permittee reports of impacts actually taking place. To date, permit processing has not required pre-permit field surveys by applicants for the presence of maritime heritage resources in the permitted areas or post-research activity surveys by permittees in GFNMS.

Vessel Anchoring and Moorings

In the 2010 condition report, anchor damage was considered to be a threat to maritime heritage resources, though it was not assessed. From 2010–2022, there were no vessel moorings in the coastal and offshore region of GFNMS, and no adverse impacts from anchoring on maritime heritage resources are known to have occurred. Anchoring does take place in Drakes Bay; however, most of the Drakes Bay nearshore area where vessels anchor is outside of the sanctuary's boundaries. No data on anchoring by location and frequency was available.

Discharges

Discharges and deposits of items (other than from fishing) were not discussed in the 2010 report. This activity includes large-scale spills of crude oil or refined oil products, which could coat or otherwise degrade submerged maritime heritage resources; diesel and gasoline spills were not included for purposes of this report, as those spilled products tend to evaporate quickly. Discharges also include accidental loss of barge loads of dredge spoil materials, which could bury or damage submerged maritime heritage resources. Similarly, vessel sinkings and groundings can result in discharges, as well as physical adverse effects to maritime heritage resources. Though there are some data gaps, there were no documented adverse impacts from smaller discharges of fuel or other material on maritime heritage resources from 2010–2022. Smaller-scale, periodic discharges of fuel or oil occurred; two shipping containers were lost; and eight vessels sank or were grounded in the region, but none were in the vicinity of known maritime heritage resources (USCG, 2022; GFNMS, 2022d).

Scuba Diving

Scuba diving by recreational divers could result in incidental damage to maritime heritage resources through contact with a shipwreck or artifacts (e.g., from tanks, fin kicks, touching or moving items); however, no comprehensive data set for this indicator was available, which was a concern for some workshop experts, and no data on damage of this type has been found. Limited Beach Watch data (Lindquist & Roletto, 2022a) from 2014–2021 recorded five instances of nearshore scuba diving at different beaches observed from shore, but it was not possible to determine from that data whether this activity resulted in any impacts on maritime heritage resources. Diving at some sites is thought to have decreased since a kelp forest decline that began around 2014 (D. Jaffke/Far Western Anthropological Research Group, Inc., personal communication, March 1, 2023). The decline in the kelp forest may have decreased divers' interest in sites that formerly had healthy stands of kelp (and thus more to see). No looting of sites is known to have been documented in the study period. Anecdotal evidence indicates non-permitted collection of some artifacts and ship debris within the sanctuary may have occurred, with beachcombing (though not a selected indicator) also potentially of concern, particularly for artifacts and ship fragments deposited on beaches after big storm surges and king tides (D. Jaffke/Far Western Anthropological Research Group, Inc., personal communication, March 1, 2023). Extensive site looting of shipwreck artifacts occurred before 2010, especially before sanctuary designation in 1981 (R. Schwemmer/NOAA, personal communication, January 19, 2022). Since 2010, it is believed little or no looting has occurred based on 2016–2017 monitoring of the shipwreck SS *Pomona* and anecdotal information from the sport diving community. Recreational scuba diving occurs at SS *Pomona*, SS *Norlina*, and SS *Crescent City*, and anecdotal information suggests infrequent diving also occurs at other sites with historical resources. SS *Pomona* is monitored by California State Parks and SS *Norlina* was documented by the Sonoma Coast Historical and Undersea Nautical Research Society. Experts who were consulted were not aware of any documented looting by divers at doghole port sites during the study period.

Development

No new nearshore or offshore development has taken place in the coastal and offshore region of GFNMS since 2010. Existing approvals for two ongoing activities were certified by ONMS following the sanctuary expansion. This allowed continuation of activities related to an existing submarine cable and a research facility's water intake/outflow infrastructure. No effects on any maritime heritage resources are known to have resulted. GFNMS's regulatory prohibitions, including disturbance of submerged lands, which typically occurs from development, were extended to the expanded area of the sanctuary in June 2015.

Climate Change

Although there was no existing monitoring of climate change impacts to maritime heritage resources in GFNMS, human-caused climate-related changes to the ocean, such as ocean acidification, changing water temperatures, and sea level rise, are recognized to have the potential to adversely affect maritime heritage resources in the sanctuary. Impacts on submerged maritime heritage resources could result from ocean acidification, which can increase rates of deterioration; changing water temperatures, which alter conditions for protective and/or destructive organisms; changing or rising water levels, which may enhance mechanical degradation; and changing weather patterns, which may physically alter sites and their protective overburden (Roth, 2021). Climate-related changes have been documented in the sanctuary, but data specific to impacts on maritime heritage resources have not been gathered nor assessed, which was a concern for some workshop experts.

Conclusion

The rating of good/fair was based on the limited human activities in the selected indicators that are likely to affect maritime heritage resources and the limited known adverse impacts on those resources. Human activities that could adversely affect maritime heritage resources include commercial fishing, research involving contact with the submerged lands, vessel anchoring, discharges, scuba diving, development, and climate change. With sanctuary expansion, more maritime heritage resources are now within sanctuary boundaries and protected by sanctuary regulations. Commercial bottom trawl fishing, anchoring, and removal of artifacts, which were concerns previously, were not documented to have affected maritime heritage resources during this study period, though fishing gear was observed on two shipwrecks and anecdotal evidence indicates some non-permitted artifact and ship debris collection occurred. No other adverse effects from human activities were documented, though beachcombing, which was not a selected indicator, was raised by an expert as a potential concern. The trend was improving due to the decrease in artifact looting, few observed impacts from fishing, and a lack of new nearshore or offshore development. There has been no systematic monitoring in this region of known maritime heritage resources and sites or of the impacts of human activities upon them, leading to data gaps for all of the indicators, with particular note made by experts of limited scuba diving data and a lack of information on the effects of climate change on sanctuary maritime heritage resources.

Estuarine and Lagoon Region

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

Rationale: There is one known historic maritime heritage resource in the estuaries of GFNMS, the shipwreck *Oxford*. The remains of the wreck are submerged and buried under sediment, which provides a measure of protection from human activities. During the study period, only one research activity allowing contact with the submerged lands at the shipwreck site was permitted, to confirm the wreck's presence. This research activity likely had negligible adverse impacts on the wreck. The site has not been revisited for further research. *Oxford* is not located where vessels are known to anchor. Commercial herring fishing was low during the study period compared to historic levels and has not resulted in known adverse impacts on the wreck. There are data gaps for all indicators, particularly related to climate change, and there is a need to determine if there are other maritime heritage resources in the GFNMS estuarine and lagoon region.

Findings From the 2010 Condition Report

In 2010, the status rating for this question in the estuarine and lagoon region was good/fair and the trend was undetermined due to a lack of monitoring. Seven loss records for ships were mentioned, but none had been investigated. At that time, the report noted commercial bottom fishing (primarily for herring), aquaculture, new piers, anchoring, and mooring as activities that could affect the quality of maritime heritage resources. Some potentially relevant human activities existed (e.g., restoration of oysters and seagrass beds, establishment of long-term mooring areas, and removal of derelict vessels), but these did not appear to have had a negative effect on maritime archaeological resource integrity.

New Information in the 2010–2022 Condition Report

Indicators used to rate this question included commercial fishing, research involving contact with submerged lands, vessel anchoring and moorings, discharges, scuba diving, nearshore development, and climate change (Table S.P.5.2).

Table S.P.5.2. Summaries for key indicators related to human activities that may adversely affect maritime heritage resources in the estuarine and lagoon region of GFNMS that were discussed during the July 6, 2022 virtual workshop.

Indicator	**Source**	**Data Summary**
Commercial fishing	CDFW, 2019a, 2022b; National Centers for Coastal Ocean Science, 2020	Status: Herring fishing was low in Tomales Bay compared to historic levels, and the herring fishery was closed for the 2009–2010 season. Take of herring for both sac roe and fresh fish markets using gill nets was allowed; however, no herring were landed between 2010 and 2017 in the Tomales Bay area. Trend: Herring fishing remained low in Tomales Bay.
Research involving contact with submerged lands	ONMS, 2022a; J. Delgado/NOAA, personal communication, February 6, 2015;	Status: Between 2014–2021, only one research project allowed activities on or within 100 feet (30 m) of one wreck; negligible adverse impacts may have occurred during probing. Trend: No trend data were available.
Vessel anchoring and moorings	GFNMS, 2018	Status: Vessel anchoring is likely not impacting wreck and no moorings are near it. Trend: No trend data were available.
Discharges, scuba diving, development, and climate change	USCG, 2022; GFNMS, 2022d; Lindquist & Roletto, 2022a; ONMS, 2022a; Roth, 2021	Status: Between 2010–2021, there were no large-volume oil spills; smaller-scale, periodic discharges of fuel or oil occurred but were not believed to affect the wreck. No containers or dredged material were lost, and four vessels sunk or grounded (but these were not near *Oxford*). Little or no diving is thought to occur in the region. No nearshore development was permitted near *Oxford*. Climate change impacts on *Oxford* are of concern, but not well understood or monitored. Trend: No trend data were available.
Data gaps	There is no systematic monitoring in this region of the known maritime heritage resource or the impacts of human activities upon it; thus, there is a lack of information for all of the indicators. For commercial fishing, there is a lack of relevant data on possible impacts from other fisheries. For research that involves contact with submerged lands, there is no video or other surveys of *Oxford* aside from one hydraulic probe survey; there are gaps in data on permitted research. No anchoring data were available. There are gaps in some data sets on discharges. There is no comprehensive, systematic monitoring of scuba diving activity. There are no comprehensive, systematic monitoring data for effects of climate change on the maritime heritage resource.	

No new estuaries or lagoons were added to GFNMS as part of the 2015 expansion. A survey conducted in 2014 under an ONMS permit indicated the presence of remains of one shipwreck, *Oxford*, a wooden sailing ship stranded in 1852 in Tomales Bay, in what is now the sanctuary. Though there are loss records of other shipwrecks in the estuarine and lagoon region, no other known maritime heritage resources have been ascertained.

Commercial Fishing

From 2010–June 2022, no commercial herring fishing catch reports were posted by CDFW (CDFW, 2022b) and there was no commercial bottom trawling for fish in Tomales Bay or the other estuaries and lagoon in this region (National Centers for Coastal Ocean Science, 2020). Herring fishing declined in Tomales Bay from higher historic levels and the fishery was closed for the 2009–2010 season. Take of herring for both sac roe and fresh fish markets using set gill nets, which contact the bottom, was allowed, up to a quota of 350 tons (318 metric tons) in Tomales Bay (CDFW, 2022b); however, no herring were landed between 2010 and 2017 in the Tomales Bay area according to the 2019 *California Pacific Herring Fishery Management Plan*, which summarized landing data from 1972–2017 (CDFW, 2019a). No data were obtained by staff on other fisheries in the GFNMS estuarine and lagoon region. The remains of *Oxford* were determined to be submerged under four feet (1.2 m) of water at high tide and underneath a mud and sand shoal (J. Delgado/NOAA, personal communication, February 6, 2015). No impacts from commercial fishing to the wreck remains are known, and because of its location, it is unlikely that such activities have had an adverse impact.

Research Involving Contact with Submerged Lands

Research activities in GFNMS that would alter submerged lands require an ONMS permit, which often requires permitted researchers to avoid or mitigate damage to maritime heritage resources. From 2014–2021, only one such research project was permitted in the GFNMS estuarine lagoon research, allowing research that could disturb the estuary bottom within 100 feet (30 m) of *Oxford* in 2014 (ONMS, 2022a). The permitted project, led by NOAA archaeologists, aimed to determine the presence of *Oxford*; the method used was a systematic hydraulic probe survey of the site. The probe holes, on average, went 12 feet (3.6 meters) below the mudline for approximately 105 feet (32 meters). The probing indicated contact was made not with solid wood, but rather a “crunchy” mass, consistent with other site formation processes of other buried wooden vessels observed by the project lead (Delgado et al., 2020). Negligible adverse physical impacts on the wreck may have occurred as a result of the approximately 20 or fewer probe holes, which were 3/4 inch (1.9 cm) in diameter (J. Delgado/NOAA, personal communication, February 6, 2015). Expert opinion provided at the workshop was that the probing probably introduced some oxygen, which could increase the rate of the wreck’s physical degradation, into the *Oxford* site on a short-term basis until the sediment filled in again. The wreck site has not been revisited by researchers since 2014, so the extent of any adverse impacts on the wreck from the research or other activities is undetermined.

Vessel Anchoring and Moorings

No effects on *Oxford* from anchoring or mooring are thought to have occurred during the study period because it is submerged under a shoal and is not in a location where vessels are known to anchor (GFNMS, 2022f). Following the creation of a mooring plan in 2013 (Gulf of the Farallones National Marine Sanctuary & California State Lands Commission, 2013), mooring areas where vessels could moor if they met specified criteria were designated in Tomales Bay. No mooring areas were in the vicinity of the wreck and the environmental assessment found no adverse effects to archaeological, paleontological, or cultural resources. There were no designated mooring areas in other parts of the GFNMS estuarine and lagoon region (GFNMS, 2018). No anchoring data sets were available for this region.

Discharges, Scuba Diving, Development, and Climate Change

There were no large-volume oil spills from vessels in the GFNMS estuarine and lagoon region. Smaller-scale discharges of fuel or oil occurred periodically, but no effects on *Oxford* were deemed to have occurred (USCG, 2022; GFNMS, 2022d). There were no losses of containers or dredged material in this region. Four vessels sank or grounded (some were salvaged or partially salvaged), but none of these were near *Oxford*. Scuba diving was not documented at the *Oxford* site (Lindquist and Roletto, 2022a), with site conditions, including turbidity, not thought to be conducive to diving in that area. A review of sanctuary permit records for the study period indicated no nearshore development was permitted near *Oxford* (ONMS, 2022a). Human-caused climate-related changes to the ocean such as ocean acidification, changing water temperatures, and sea level rise are recognized to have the potential to have adverse impacts on maritime heritage resources (Roth, 2021), including *Oxford*; however, any such impacts remain unknown as changes to the shipwreck's condition are not monitored.

Conclusion

Overall, the status of these human activities was determined to be good, as only one human activity was identified during the study period that might have had negligible adverse impacts on the one known tangible maritime heritage resource, the shipwreck *Oxford*. That activity was the research survey that determined its presence using a hydraulic probe. There was an improving trend during the study period, as levels of these human activities declined. There was no herring fishing, bottom trawling, or nearshore development in the region, and no known scuba diving near *Oxford*. Noted data gaps and the fact that there was just one survey of the *Oxford* site contributed to scores of medium confidence for both the status and the trend. There is a lack of information for all of the indicators for this question; workshop experts particularly highlighted the data gap for climate change impacts on the maritime heritage resource and the need to determine if there are other maritime heritage resources in the region.

Status and Trends of Sanctuary Resources

This section provides summaries of resource status and trends in two regions of the sanctuary: the coastal and offshore region and the estuarine and lagoon region. Resources are grouped into four categories: water quality, habitat, living resources, and maritime heritage resources. Virtual expert workshops were convened by GFNMS staff on various dates from May–July, 2022 (see Appendix A and Appendix C) to discuss the series of questions about each resource category. It is important to note that, in general, the assessments of the status and trends of key habitat indicators in GFNMS are for some portion of the period from 2010–2022. Responses to each question include summaries of key indicators, supporting data, and the 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 (i.e., through 2022). However, in some instances, authors later incorporated newly available data in order to more accurately describe the current status and trends of resources. When more recent data (i.e., 2023) became available during editing of this report, this was noted in the text. Situations where data were used by authors to support a rating but were not presented or discussed during the workshop are also noted in the text.

In order to effectively assess the considerable differences in sanctuary resources, key indicators and relevant data sets for each of the 16 questions were assessed for two separate regions of the sanctuary: the coastal and offshore region and the estuarine and lagoon region (see Figures SS.1 and SS.8). Each of these regions include a variety of habitat types.

The GFNMS coastal and offshore region includes the rocky shore, sandy shore, kelp forest, and open ocean. The GFNMS estuarine and lagoon region includes Estero Americano, Estero de San Antonio, Bolinas Lagoon, and Tomales Bay. These areas are characterized by habitats that include bays, mudflats, and marshes.

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 GFNMS for 2010–2022. We have noted where more recent data (e.g., 2023) became available during editing of this report.

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 (e.g., from bacteria, chemicals, 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 acidity. 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.

Because of the considerable differences in environmental pressures and responses between the coastal and offshore region and the estuarine and lagoon region, each question was assessed twice in order to represent these two environment types separately.

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

Coastal and Offshore Region

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

Rationale: Eutrophication was not detected in the coastal and offshore region of GFNMS based on nutrient concentration, phytoplankton community composition, chlorophyll *a* concentration, and net primary productivity. There was no evidence to suggest that there have been major influxes of nutrients into these areas of the sanctuary. A lack of year-round data for most indicators limited the assessment of trends during the study period.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good and the trend was not changing. There was no known eutrophication in the coastal and offshore region of GFNMS; therefore, conditions did not appear to have the potential to negatively affect living resources or habitat quality. In addition, the phytoplankton assemblage in the sanctuary was typical of surrounding coastal areas. However, the 2010 report was limited by a lack of long-term, in situ data for phytoplankton and nutrients.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included nutrients (nitrate and nitrite, phosphate, and silicate), phytoplankton (diatoms/dinoflagellates) relative abundance index (RAI), chlorophyll *a*, net primary productivity (NPP), and dissolved oxygen (Table S.WQ.6.1).

Table S.WQ.6.1. Summaries for the key indicators related to eutrophication in the coastal and offshore region of GFNMS that were discussed during the May 16, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Nutrients	Elliott et al., 2022a	Status: Nutrient (nitrate/nitrite, phosphate, silicate) concentrations were low from 2014 to present. Trend: Nutrient concentrations decreased, with mostly negative anomalies from 2014–2020.	S.WQ.6.1
Phytoplankton RAI	Elliott et al., 2022a	Status: Low RAI for diatoms and dinoflagellates in 2019 and 2021. *Psuedo-nitzschia* spp. were present during the study period, but remained below the HAB threshold of 10,000 cells/L. Trend: There was an apparent increase in RAI from 2010–2017 followed by a decrease through 2021. The ratio of diatoms to dinoflagellates decreased.	S.WQ.6.2
Chlorophyll *a* concentration	NOAA Fisheries, 2022c; O'Brien & Oakes, 2020	Status: Primarily positive anomalies were detected from 2011–2019, excluding 2012 and 2016. Trend: There was no significant change from 2010–2019.	S.WQ.6.3
Net primary productivity	NOAA Fisheries, 2022c; O'Brien & Oakes, 2020	Status: Positive anomalies occurred from 2011 to 2019, excluding 2017. Trend: No significant trend was detected.	N/A
Data gaps	No in situ chlorophyll *a* data were available. Although HAB data exist (i.e., California-Harmful Algae Risk Mapping model, California HAB Bulletin), there was an analysis gap for these data sets at the time of report development.		

Nutrients

The ACCESS project (see Box 1) collects surface water samples for nutrients and physical and biological parameters in the sanctuary (Elliott et al., 2022a; Figure S.P.3.2). Nutrients, including nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), and silicate (SiO_4^{4-}), were measured at the surface, and mean concentrations were calculated for monitoring stations in GFNMS. Nitrate, nitrite, phosphate, and silicate concentrations have been low from mid-2014 (coinciding with a MHW) to 2021. Concentrations of all nutrients decreased during the study period (Figure S.WQ.6.1). Additionally, ACCESS monitoring revealed low nutrient concentrations (negative monthly anomalies) associated with warm water events in 2005–2006 and MHWs in 2014–2016 and 2019. In contrast, high concentrations (positive monthly anomalies) were associated with cold water regimes in 2007–2008 and early 2009 (Elliott et al., 2022a).

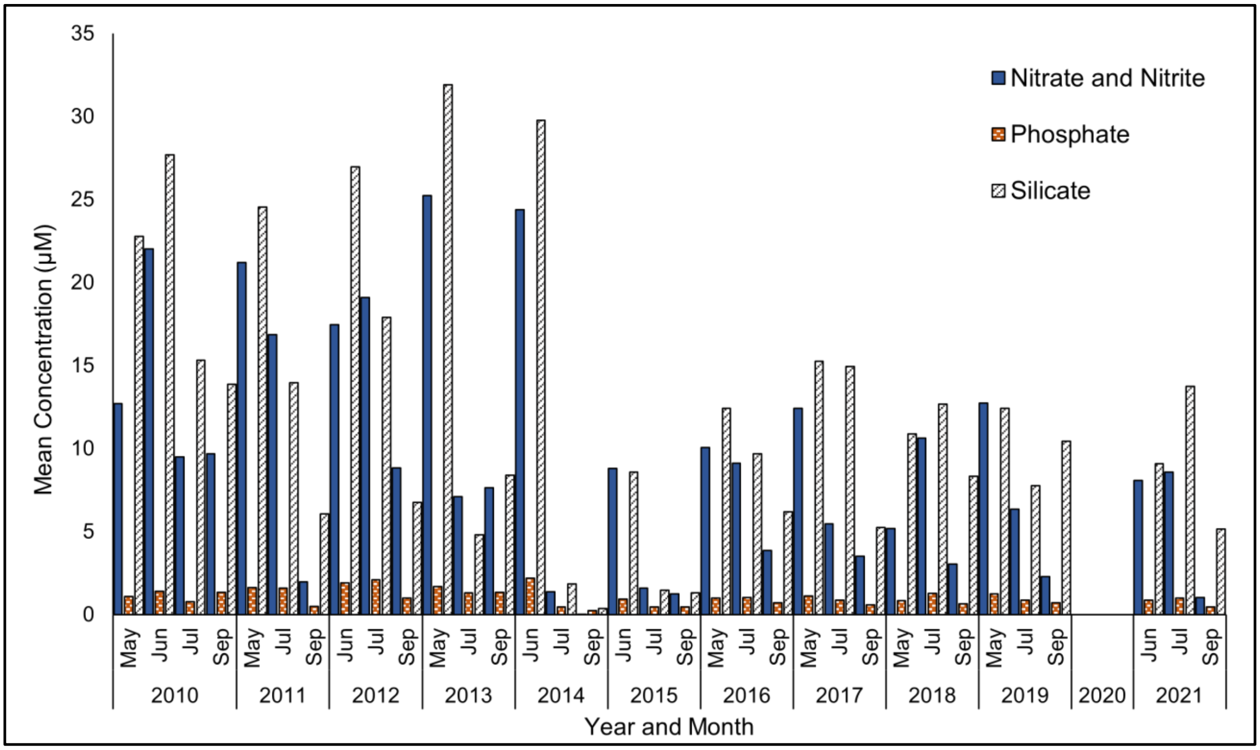


Figure S.WQ.6.1. Mean nutrient (nitrate and nitrite, phosphate, and silicate) concentration in surface water at ACCESS monitoring stations in GFNMS from 2010–2021. Source: Elliott et al., 2022a

Phytoplankton

Phytoplankton was sampled by ACCESS at the same locations as nutrients and analyzed by the California Department of Public Health (CDPH) to evaluate HAB species and phytoplankton community composition. The composition of the phytoplankton community provides insight into ecosystem productivity, where fewer diatoms than dinoflagellates could indicate low-productivity ocean waters. CDPH uses the RAI to monitor temporal changes in diatoms and dinoflagellates in surface water. The RAI in GFNMS varied from 2010–2021, peaking in 2017 (Figure S.WQ.6.2). The elevated RAI in 2017 was due to an abundance of the HAB diatom *Pseudo-nitzschia* spp. at one sampling site; *Pseudo-nitzschia* spp. produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning.

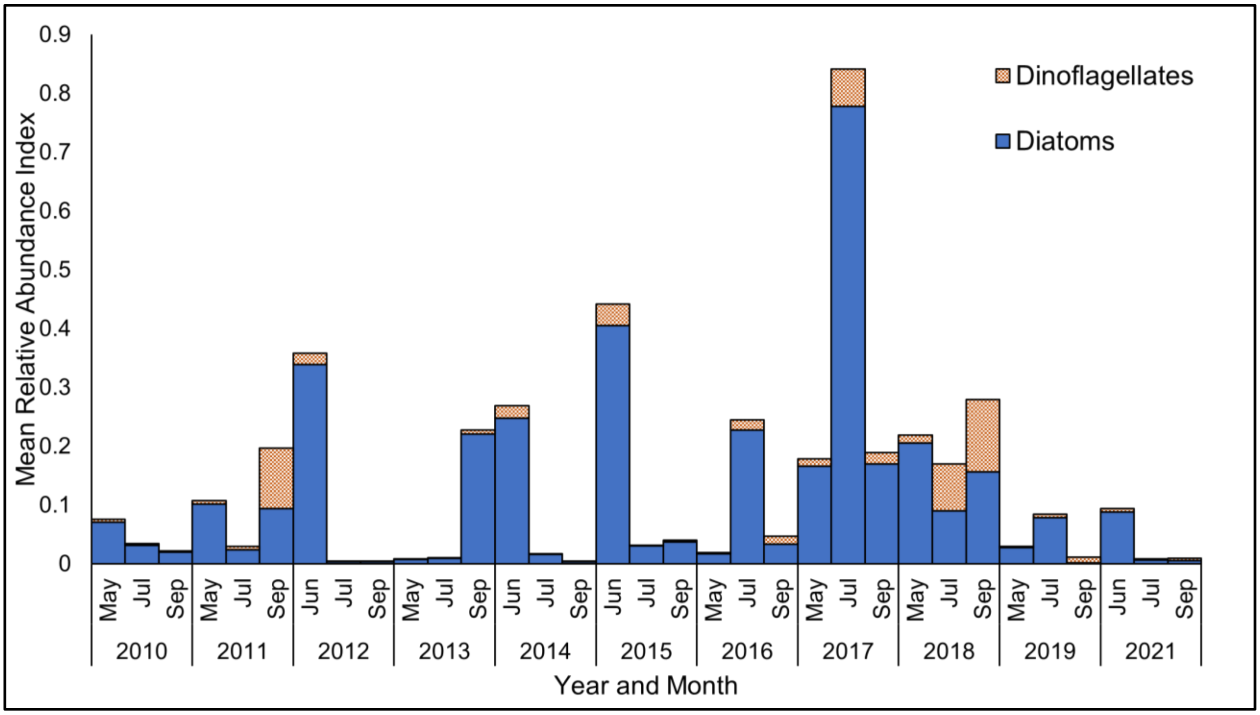


Figure S.WQ.6.2. Mean RAI for phytoplankton (diatoms and dinoflagellates) in surface water at ACCESS monitoring stations inside GFNMS from 2010 to 2021. RAI is defined as (a*b)/c, where a is percent composition, b is settled volume, and c is tow length. Source: Elliott et al., 2022a

The California Harmful Algal Bloom Monitoring and Alert Program started monitoring *Pseudo-nitzschia* spp. in 2019, with three sampling stations in the coastal and offshore region of GFNMS (Bodega Marine Lab intake, Bodega Marine Lab buoy, and Horseshoe Cove). Despite the high occurrence of *Pseudo-nitzschia* spp. in 2017, available data from 2020 to 2022 showed that abundances at these stations were below the HAB threshold of 10,000 cells/L (Largier, 2022).

Chlorophyll *a* Concentration

Data on chlorophyll *a* concentration in surface water were acquired from the Spatiotemporal Data and Time Series Toolkit, which relies primarily on satellite data (NOAA Fisheries, 2022c; O'Brien & Oakes, 2020). Data acquired from the toolkit encompassed offshore areas of GFNMS and CBNMS. Annual chlorophyll *a* anomalies were mainly positive from 2010–2019, with a stable trend (Figure S.WQ.6.3).

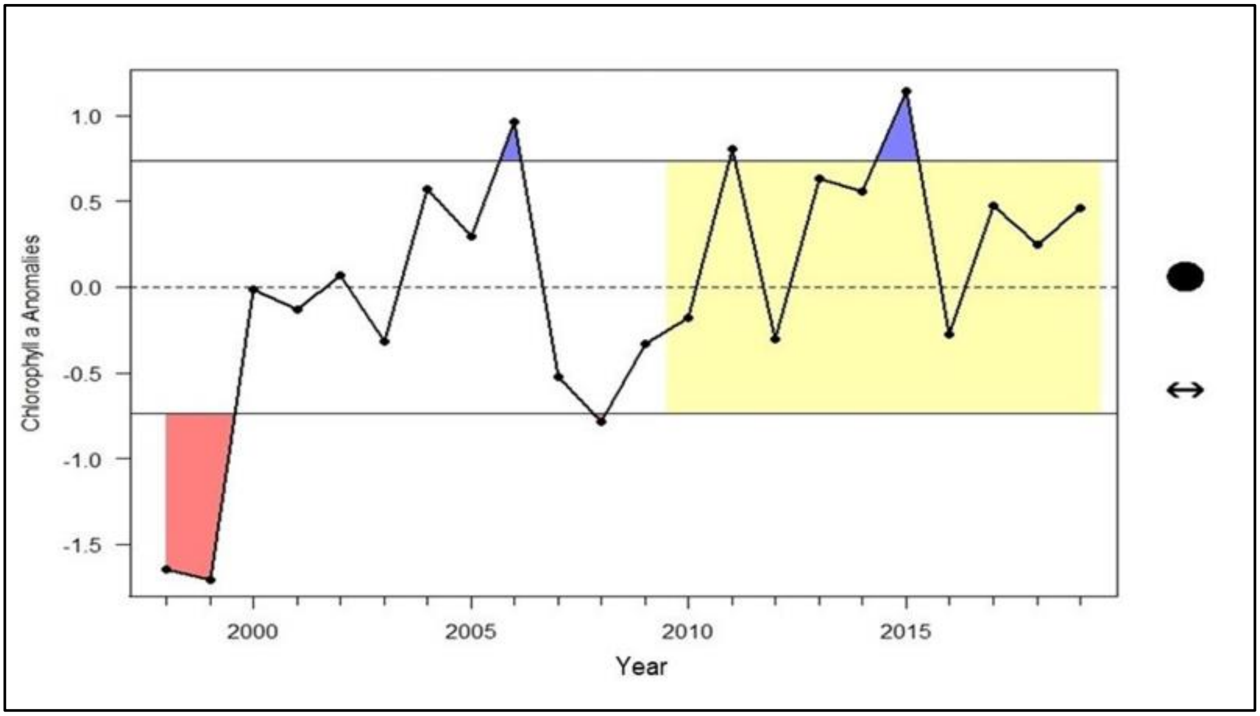


Figure S.WQ.6.3. Annual chlorophyll *a* anomalies for the coastal and offshore region of GFNMS. The shaded area in yellow represents the period used for the trend analysis; for this time period, the mean was within the one standard deviation of the long-term mean (●) and the trend was neutral (↔). Red and blue shaded areas show years for which the indicator value was below or above one standard deviation from the mean, respectively. Image: M. Karnauskas & A. Mabrouk/NOAA; Source: NOAA Fisheries, 2022c; O'Brien & Oakes, 2020

Net Primary Productivity

Net primary productivity (NPP), which indicates how much carbon is generated from marine phytoplankton, was also measured (NOAA Fisheries, 2022c; O'Brien & Oakes, 2020). Positive NPP anomalies occurred from 2011 to 2019, excluding 2017. There was no significant trend in NPP. Additionally, upwelling (not eutrophication) was thought to be the main reason for low bottom dissolved oxygen and hypoxia observed inside the sanctuary (see Question 8 for more detail).

Conclusion

From 2010–2021, eutrophic conditions did not occur in the coastal and offshore region of GFNMS, supporting a good status rating. Because year-round data were not available for nutrients and phytoplankton, the trend for this question was undetermined. Based on available data, levels of phytoplankton and chlorophyll *a* were within normal levels and had no apparent trend during the study period, and nutrients decreased. RAI was variable during the study period, with a peak in 2017. Additional relevant data gaps for this question include the extent, duration, and frequency of HABs, as well as in situ NPP and chlorophyll *a* concentration data.

Estuarine and Lagoon Region

Status Description: Eutrophication is suspected and may degrade some attributes of ecological integrity, but has not yet caused measurable degradation.

Rationale: Data documenting eutrophication were limited. While spikes in chlorophyll *a* and dinoflagellate/diatom relative abundance index and low dissolved oxygen occurred in some years, this was generally sporadic and did not suggest widespread eutrophication throughout the study period, and no signs of negative effects on ecological integrity were detected. However, Tomales Bay, Estero Americano, and Estero de San Antonio have been listed as impaired water bodies due to high levels of nutrients.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was good/fair and the trend was undetermined. There were high levels of nutrients in GFNMS estuaries, but there had been no known mortality events among fish or invertebrates due to eutrophication. There were anecdotal reports of macroalgal blooms in sanctuary estuaries, but no regular surveys to fully assess this.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included chlorophyll *a* in Tomales Bay, phytoplankton RAI in Tomales Bay and Bolinas Lagoon, and nutrients and dissolved oxygen in the Tomales Bay watershed (Walker Creek and Lagunitas Creek; Table S.WQ.6.2).

Table S.WQ.6.2. Summaries for the key indicators related to eutrophication in the estuarine and lagoon region of GFNMS that were discussed during the May 16, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Chlorophyll *a* concentration	Bodega Ocean Observing Node [BOON], 2022a	Status: There was an annual pattern of elevated chlorophyll *a* in spring/summer, with peaks exceeding the threshold for increased risk of eutrophication (25 µg/L) in July of 2013, 2014, and 2018 and May of 2017. In 2019, two peaks were detected in April and November. Trend: Chlorophyll *a* concentration increased slightly during the study period.	S.WQ.6.4
Phytoplankton	Zubkousky-White, 2022	Status: RAI was high in Tomales Bay compared to Bolinas Lagoon, especially in 2016 and 2017. Trend: There was no trend in RAI for either Tomales Bay or Bolinas Lagoon.	S.WQ.6.5

Indicator	Source	Data Summary	Figures
Nutrients	CSWRCB, 2019b, 2019c	Status: In 2017, nutrient levels were high in Walker Creek and its tributaries, but low in Lagunitas Creek. Tomales Bay, Estero Americano, and Estero de San Antonio were listed as impaired water bodies due to high nutrient levels under the Clean Water Act and by CSWRCB. Trend: No trend data were available.	S.WQ.6.6
Dissolved oxygen	CSWRCB, 2019c	Status: Minimum dissolved oxygen conditions for cold-water fish were not met upstream of Tomales Bay in Walker Creek and Lagunitas Creek on one occasion for which data were available. Trend: No trend data were available.	N/A
Data gaps	Data on nitrogen, phosphorus, and silicate concentrations; chlorophyll *a* levels; and dissolved oxygen levels are needed for all GFNMS estuaries.		

Chlorophyll *a* Concentration

Data on chlorophyll *a* concentration were obtained from an oceanographic buoy located south of Hog Island in Tomales Bay and jointly operated by the University of California Davis Bodega Marine Laboratory, Point Reyes National Seashore, and ONMS (Bodega Ocean Observing Node [BOON], 2022a). Data from the buoy were available for 2013–2021, although some 2016 data were missing. Chlorophyll *a* concentrations showed an annual pattern of elevated chlorophyll *a* in spring/summer, with peaks in July of 2013, 2014, and 2018 and May of 2017 that exceeded the threshold of 25 µg/L, above which the risk of eutrophication is considered high (Sutula et al., 2017). In 2019, this threshold was exceeded twice, in April and November. Trend analysis indicated a slight increase in chlorophyll *a* concentration over time (Figure S.WQ.6.4).

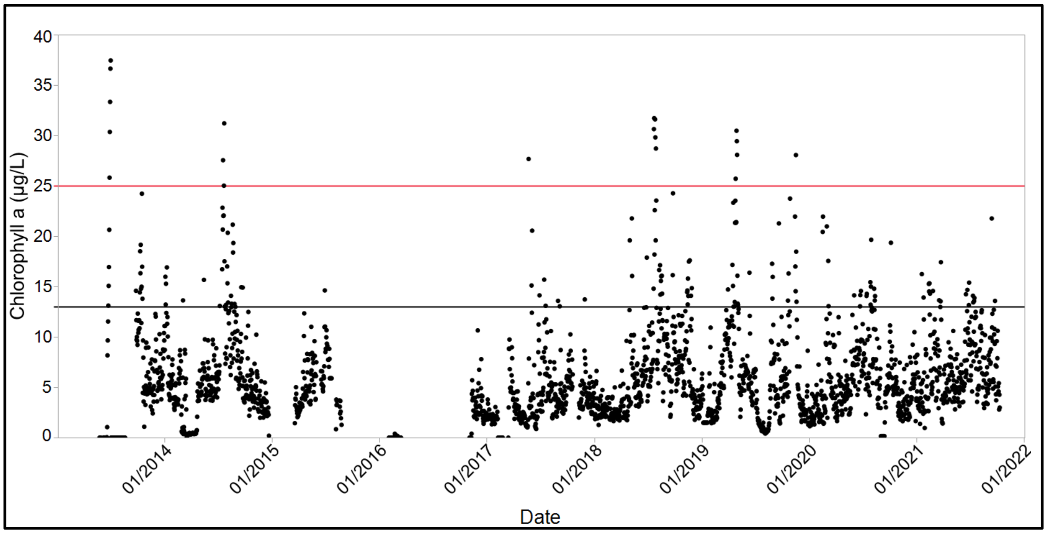


Figure S.WQ.6.4. Chlorophyll *a* concentration from the Tomales Bay buoy, 2013–2021. The black line represents a protective threshold (13 µg/L), below which the probability of eutrophication is reduced. The red line is an at-risk threshold (25 µg/L), above which the probability of eutrophication is high (Sutula et al., 2017). Source: BOON, 2022a; Image: A. Mabrouk/NOAA

Phytoplankton

RAI of diatoms and dinoflagellates was measured by CDPH in Tomales Bay and Bolinas Lagoon. RAI in Tomales Bay was high, especially in 2016 and 2017, but no algal bloom was recorded (Figure S.WQ.6.5). In Bolinas Lagoon, RAI was low compared to Tomales Bay (Figure S.WQ.6.6).

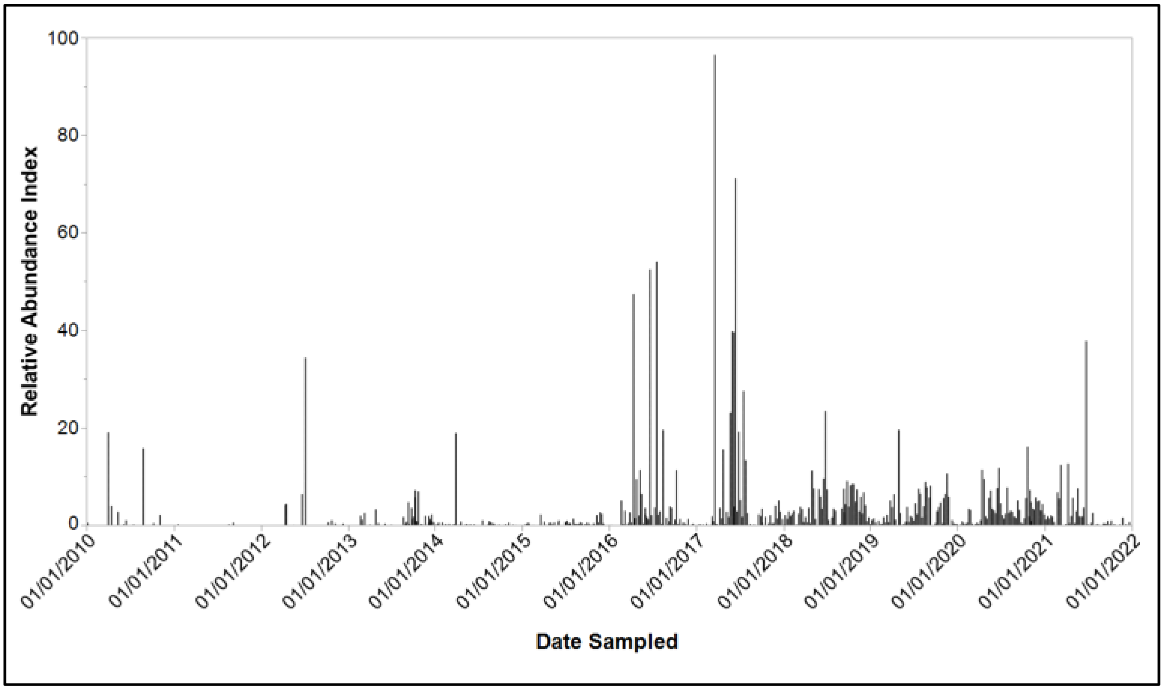


Figure S.WQ.6.5. Tomales Bay phytoplankton RAI from 2010 to 2021. Few samples (9 to 18 per year) were collected from 2010–2013; from 2013–2021, samples ranged from 53 to 90 per year. No significant trend was detected during the study period. Source: Zubkousky-White, 2022; Image: A. Mabrouk/NOAA

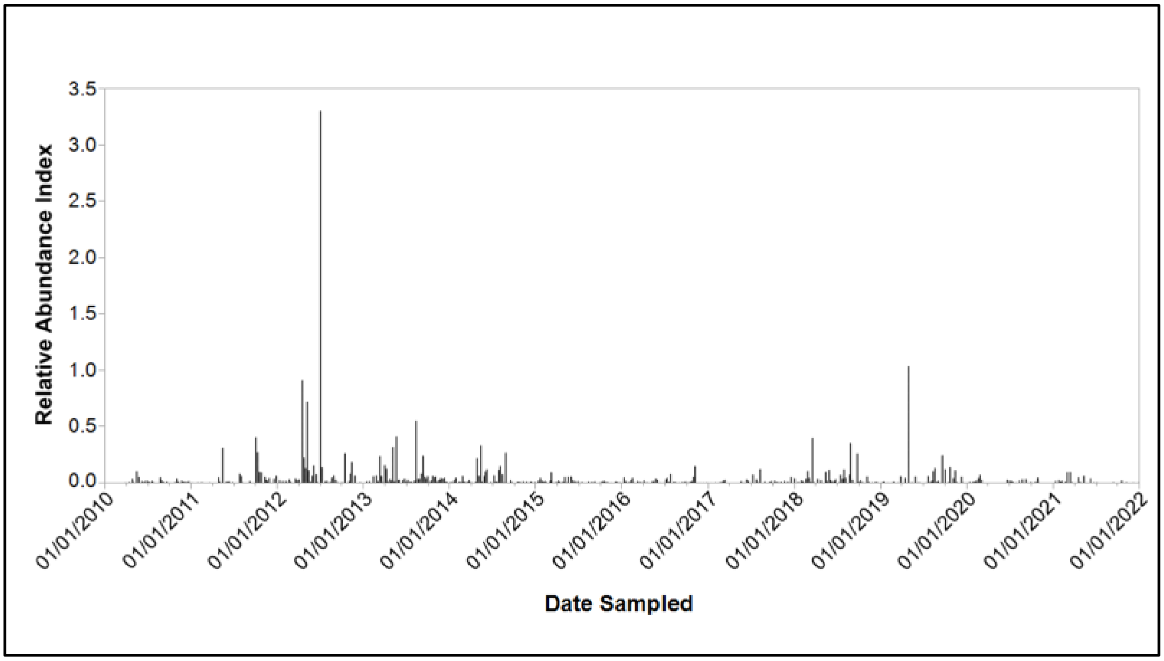


Figure S.WQ.6.6. Bolinas Lagoon phytoplankton RAI from 2010 to 2021. A high number of samples (273 to 665 samples per year) were collected compared to Tomales Bay. RAI values were low compared to Tomales Bay (note the difference in the y-axis scale on graphs), with higher RAI in spring (peaking in July 2012). No trend was detected over the study period. Source: Zubkousky-White, 2022; Image: A. Mabrouk/NOAA

Nutrients

Tomales Bay, Estero Americano, and Estero de San Antonio had high nutrient levels, originating from dairy farms and runoff, and, as a result, these estuaries were listed as impaired waters under the Clean Water Act (ONMS, 2010). These estuaries were also listed by the California State Water Resources Control Board (CSWRCB) as impaired due to high nutrient levels in its last three integrated reports (CSWRCB, 2019d, 2021b, 2022b). Although nutrients are one of the main indicators of eutrophication in the sanctuary's estuaries, long-term data sets were not available and this is considered to be a data gap. Data on nutrients (total phosphorus and total nitrogen) were available only for Tomales Bay's watershed (Walker Creek and Lagunitas Creek) through CSWRCB report cards released in 2019. The report cards assessed nutrients and other eutrophication indicators in both creeks from water samples collected in 2017, and high nutrient levels were found in Walker Creek and its tributaries, exceeding the threshold for eutrophication; however, nutrient levels were low in Lagunitas Creek (CSWRCB, 2019b, 2019c).

Dissolved Oxygen

Eutrophication can lead to low dissolved oxygen or hypoxia. Data on dissolved oxygen for the estuaries and lagoons of GFNMS were limited. However, dissolved oxygen at Walker Creek and Lagunitas Creek did not meet requirements for cold-water fish (coho salmon and steelhead trout) and exceeded the eutrophication threshold as of 2019 (CSWRCB, 2019b, 2019c).

Conclusion

The status of eutrophic conditions in the estuarine and lagoon region of GFNMS from 2010–2022 was good/fair. Although Tomales Bay (and Walker Creek, its tributary), Estero Americano, and Estero de San Antonio were listed as impaired water bodies due to high nutrient levels, indicators of eutrophication were sporadic, and did not appear to negatively affect ecological integrity during the study period. The trend was undetermined because of a lack of time series data for nutrients and dissolved oxygen. Although there were more and newer data sets in this assessment compared to the 2010 assessment, these were limited to Tomales Bay and Bolinas Lagoon. Specific data gaps include a lack of long-term in situ data for phytoplankton abundance, macroalgae cover, chlorophyll *a* concentration, and nutrient concentration in all GFNMS estuaries.

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

Coastal and Offshore Region

Status Description: Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.

Rationale: The presence of biotoxins posed a threat to human health and resulted in fishery closures during the study period. In addition, swimming advisories were issued for some beaches adjacent to the sanctuary due to elevated levels of pathogenic bacteria; however, no beaches were listed as impaired water under the standards of the Clean Water Act. Mercury and PCBs were below regulatory thresholds during the study period except in 2010 and 2015, respectively. Although there were some improvements in beach water quality, worsening levels of biotoxins and fishery closures were of concern.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good/fair and the trend was not changing. This rating was based on inputs from urban areas into coastal and offshore waters of GFNMS that had the potential to affect human health, as well as a lack of reported disease. It also considered the concentration of domoic acid in shellfish, impaired water at beaches and beach closures, and organic pollutants in sediment. It is important to note that HABs and biotoxins in shellfish occur naturally in the sanctuary and result in periodic shellfish closures.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included biotoxin levels in bivalves and crabs, shellfisheries closures, impaired water bodies, beach closures for swimming, and heavy metals and organic pollutant contaminants in crabs (Table S.WQ.7.1).

Table S.WQ.7.1. Summaries for the key indicators related to human health risks from waters in the coastal and offshore region of GFNMS that were discussed during the May 16, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Biotoxins and fishery closures	Zubkousky-White, 2022; Moore et al., 2019; Free et al., 2022	Status: Saxitoxin in bivalves exceeded regulatory thresholds set by CDPH in multiple years; the highest levels were detected in 2018. Domoic acid exceeded regulatory thresholds seasonally in Dungeness crab; the highest levels during the study period occurred in 2015–2016, resulting in a fishery closure. Fishery closures due to elevated domoic acid also occurred in 2016–2017 and 2018. Trend: Saxitoxin in bivalves appeared to increase during the study period. There were insufficient data to assess a trend in the number of Dungeness crab fishery closure days due to domoic acid during the study period.	S.WQ.7.1; S.WQ.7.2
Impaired water and beach advisories	CSWRCB, 2022c; EPA, 2022	Status: From 2014–2022, no beaches along the GFNMS coast were listed as impaired water bodies. Bolinas Beach, which was considered impaired as of 2010, was delisted. Beach advisory days due to elevated pathogenic bacteria were relatively high in Marin County and low in Sonoma County. Trend: Impaired water body listings improved due to the delisting of Bolinas Beach. There was no apparent trend in beach advisory days in Marin County; beach advisory days in Sonoma County decreased following a spike in 2010 and remained low through 2019.	S.WQ.7.3
Contaminants in shellfish	San Francisco Public Utilities Commission [SFPUC], 2014, 2021	Status: Mercury in Dungeness crab tissues (collected outside of but adjacent to GFNMS) was below the California contaminant limit in every year of the study period except 2010. PCBs in Dungeness crab hepatopancreas exceeded FDA limits in 1998 and 2015, but were below the limit in muscle tissue throughout the study period. DDT was higher in hepatopancreas than in muscle, but did not exceed FDA and EPA limits. Trend: No trend was apparent during the study period.	S.WQ.7.5; S.WQ.7.6
Data gaps	Data on organic pollutant and heavy metal levels in crabs, mussels, and fish in the sanctuary were not available.		

Biotoxins and Fishery Closures

HABs continue to be a concern for human health and the regional economy in California. HAB-producing phytoplankton generate toxins that accumulate in shellfish and can cause illness when ingested by humans. The most concerning HAB phytoplankton are dinoflagellates of the genus *Alexandrium* that produce the neurotoxin saxitoxin, which causes paralytic shellfish poisoning (PSP), and diatoms of the genus *Pseudo-nitzschia* that produce the neurotoxin domoic acid, which causes amnesic shellfish poisoning (Anderson et al., 2019; ONMS, 2010). HABs occur naturally in GFNMS, and saxitoxin and domoic acid are periodically detected in shellfish, which sometimes results in trophic transfer of these biotoxins to predators like marine mammals and seabirds (ONMS, 2010).

CDPH manages a coastal shellfish monitoring program that measures the concentrations of the biotoxins domoic acid and saxitoxin in shellfish. Saxitoxin concentration in mussels, clams, and oysters exceeded the regulatory threshold of 80 µg/100 g seasonally from 2010–2022 for all years except 2010 and 2011, with the highest values in 2018. The trend appeared to be worsening (Zubkousky-White, 2022; Figure S.WQ.7.1). Domoic acid in the viscera of crabs was also at concentrations that exceeded the regulatory threshold (30 ppm) seasonally. The highest levels were recorded in 2015–2016, and this caused the longest closure of the Dungeness crab fishery since the HAB-related exceptional closure event in 2005–2006 (Moore et al., 2019; Zubkousky-White, 2022; Figure S.WQ.7.2).

CDFW, which manages the Dungeness crab fishery in California, implements an annual quarantine for the Dungeness crab commercial and recreational fishery from July to November due to the presence of domoic acid. The annual quarantine was extended into the open season due to elevated levels of domoic acid for 142 days in 2015–2016, 18–55 days in 2016–2017 (length varied by location), and 23 days in 2018 (Moore et al., 2019; Free et al., 2022).

Because of the coordinated management efforts by CDPH, CDFW, and the California Office of Environmental Health Hazard Assessment to monitor and implement advisories and closures, actual human health impacts have been minimized. Only one case of PSP, diagnosed after an individual consumed mussels from Dillon Beach, was confirmed by the County of Marin Department of Health and Human Services (V. Zubkousky-White, personal communication, May 16, 2022).

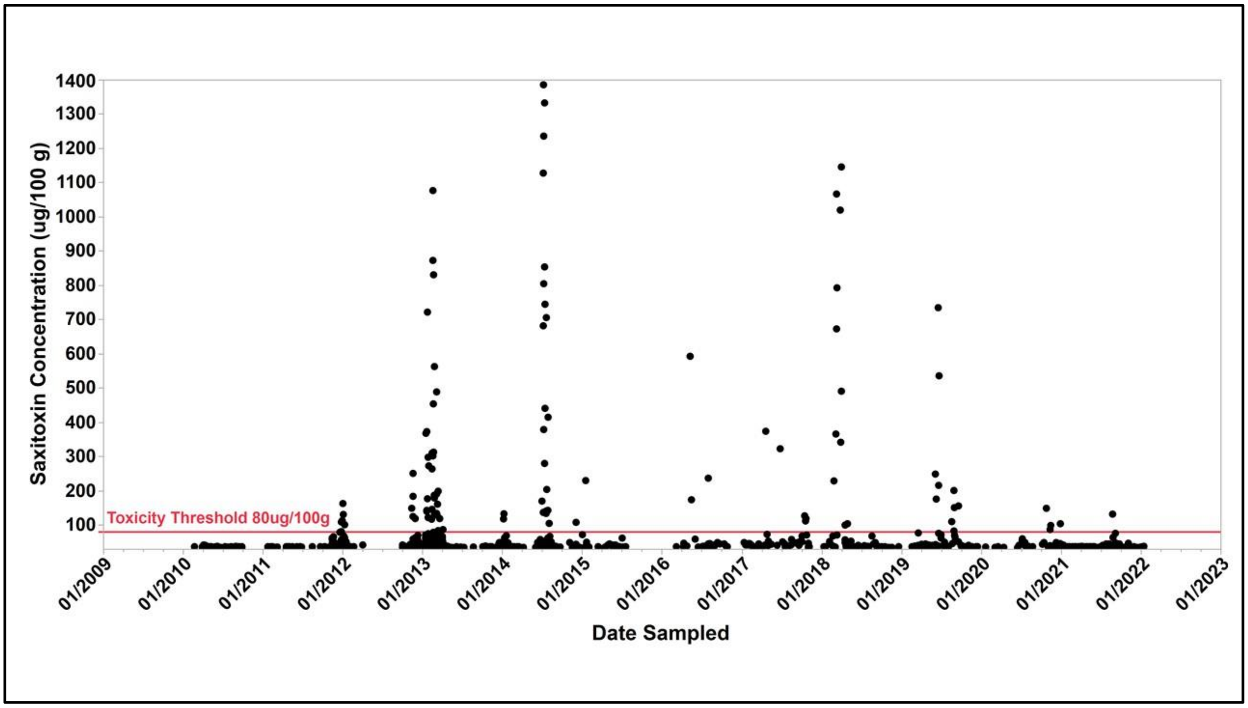


Figure S.WQ.7.1. Saxitoxin concentration in bivalves (mussels, clams, and oysters) for Sonoma and Marin counties from 2010–2022. The red line is the regulatory limit (80 µg/100 g) set by CDPH. Concentrations of zero indicate that saxitoxin was not detected. Note that four outlier values were removed: 2,134 µg/100 g, measured on 7/14/14; 3,170 µg/100 g, measured on 3/5/18; 4,760 µg/100 g, measured on 3/19/18; and 4,672 µg/100 g, measured on 3/15/18. Source: Zubkousky-White, 2022; Image: A. Mabrouk/NOAA

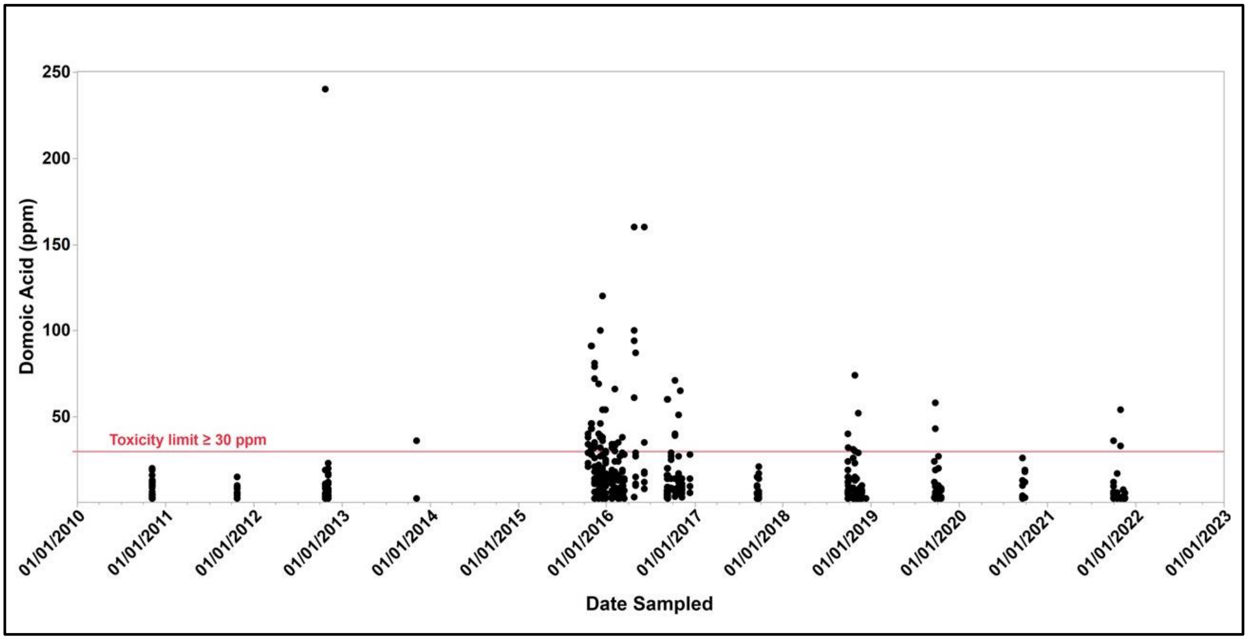


Figure S.WQ.7.2. Domoic acid levels in Dungeness and rock crab viscera for Sonoma and Marin counties from 2010–2021. The red line is the regulatory limit (30 ppm) set by CDPH. Source: Zubkousky-White, 2022; Image: A. Mabrouk/NOAA

Impaired Water and Beach Advisories

CSWRCB's integrated assessment reports for the years 2014–2016, 2018, and 2020–2022 showed that beaches along the sanctuary coast that were assessed for water quality were not considered impaired bodies of water in accordance with Section 303(d) of the Clean Water Act (CSWRCB, 2022c). This is an improvement from the 2010 condition report, when Bolinas Beach was listed as an impaired water body. However, regular water quality monitoring of the coastal beaches in Sonoma and Marin counties resulted in advisory days due to elevated pathogenic bacteria that exceeded the health standards for swimming. Among the beaches regularly monitored in Sonoma County, only Black Point Regional Park Beach had a substantial number of advisory days (192), all of which occurred in 2010. Since then, there have only been two advisory days, both at Doran Regional Park Beach in 2016. In Marin County, Bolinas and Stinson beaches had advisory days ranging from 7–37 and 7–42, respectively, almost each year; however, there was no clear trend in the number of advisory days during the study period. Advisory days also occurred, albeit less frequently, at Dillon Beach (EPA, 2022; Figure S.WQ.7.3).

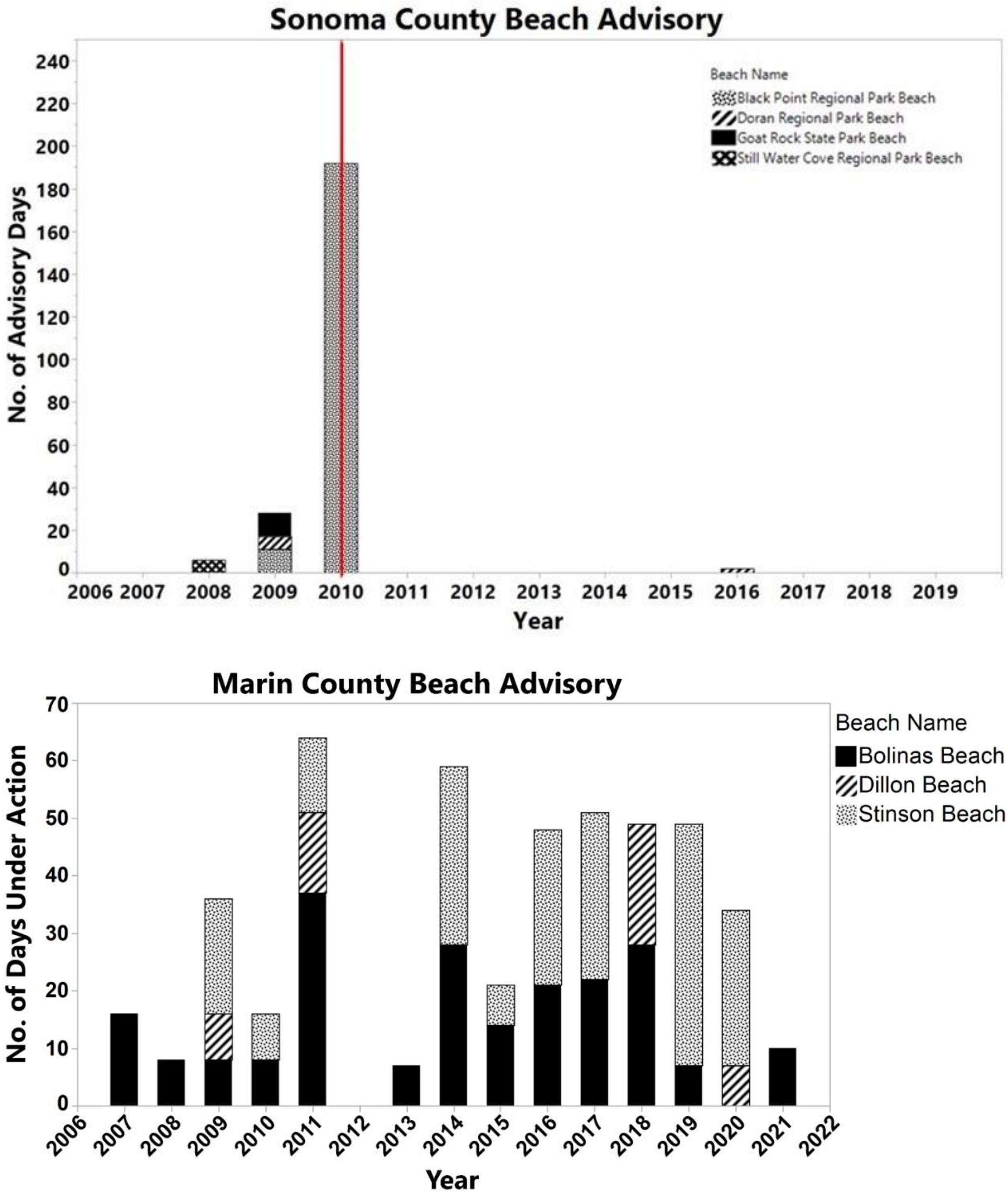


Figure S.WQ.7.3. Number of beach advisory days (days in which pathogenic bacteria were elevated) in Sonoma (top) and Marin (bottom) counties. The vertical red line indicates the year of the last GFNMS condition report (2010). Source: EPA, 2022; Image: A. Mabrouk/NOAA

Contaminants in Shellfish

Since 1997, the San Francisco Public Utilities Commission (SFPUC) has monitored organic and heavy metals pollutants in Dungeness crab as part of the Southwest Ocean Outfall Regional Monitoring Program. The goal of this program is to detect environmental impacts from the discharge of treated combined sewer effluent from the offshore Southwest Ocean Outfall and shoreline facilities. Of the 44 monitoring sites in the region, five are located in GFNMS.

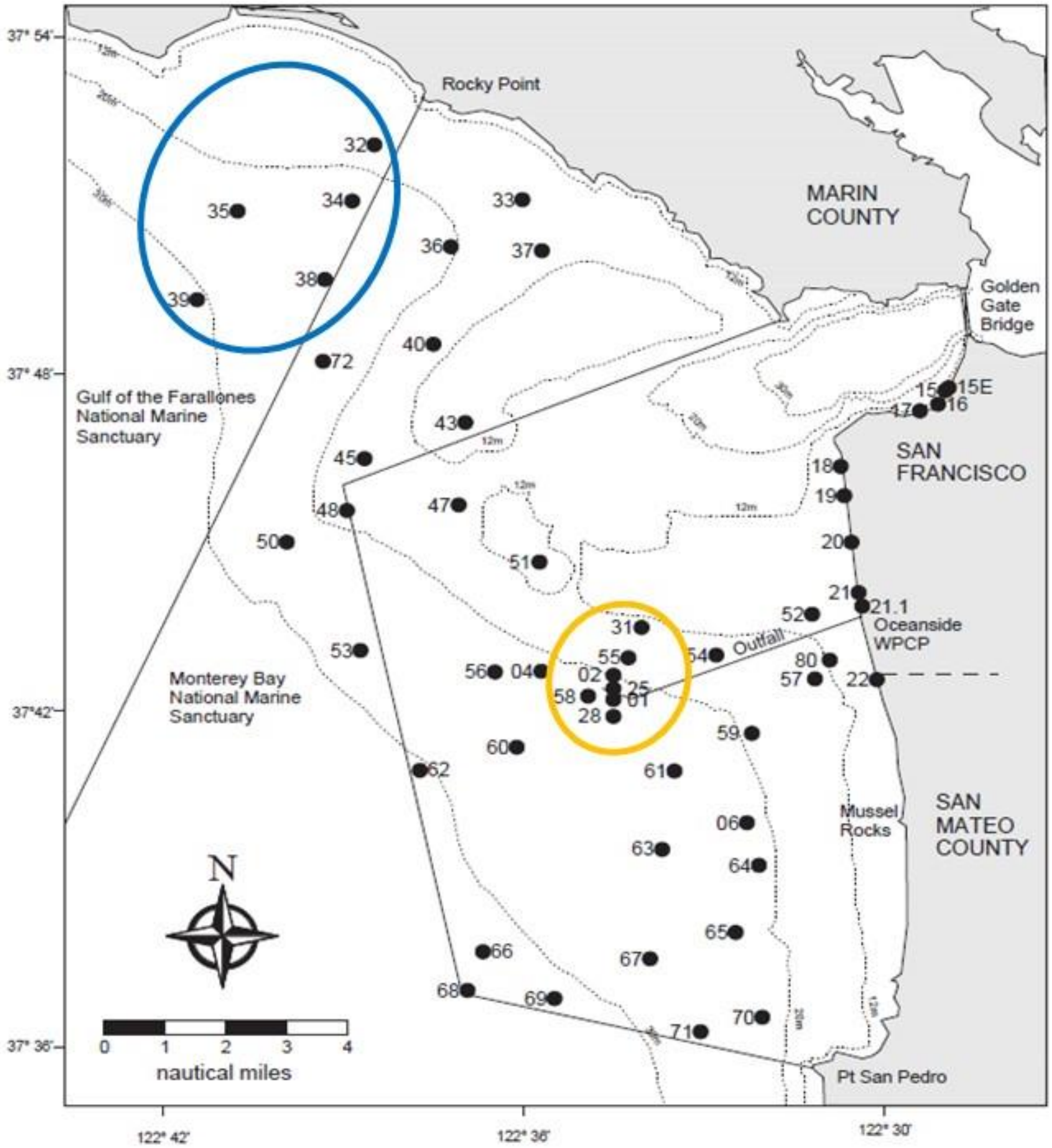


Figure S.WQ.7.4. Locations of Southwest Ocean Outfall Regional Monitoring Program monitoring stations. Monitoring stations in the sanctuary (n = 5) are shown in the larger blue oval, and those in close proximity to the outfall (n = 7) are shown in the smaller gold oval. The remainder of the sites are considered reference stations. Image: Modified from SFPUC, 2021

From 1997–2020, organic pollutants and heavy metals were measured from Dungeness crab muscle and hepatopancreas samples collected at monitoring site 01 and at reference site 06 only (both located outside the sanctuary; Figure S.WQ.7.4). Mercury concentrations in Dungeness crab tissues have been below the California contaminant goal for fish (0.22 µg/g) since 2001, with the exception of 2010 when mercury levels in crab hepatopancreas at the outfall site exceeded this threshold (Figure S.WQ.7.5). PCB concentrations were relatively high in Dungeness crab hepatopancreas and exceeded the U.S. Food and Drug Administration (FDA) limit (200 ppb) in 1998 and 2015, but very low (and consistently below the FDA limit) in muscle tissue (Figure S.WQ.7.6). Dichlorodiphenyltrichloroethane (DDT) was also higher in hepatopancreas than in muscle but did not exceed the FDA and EPA limit (5000 ppb).

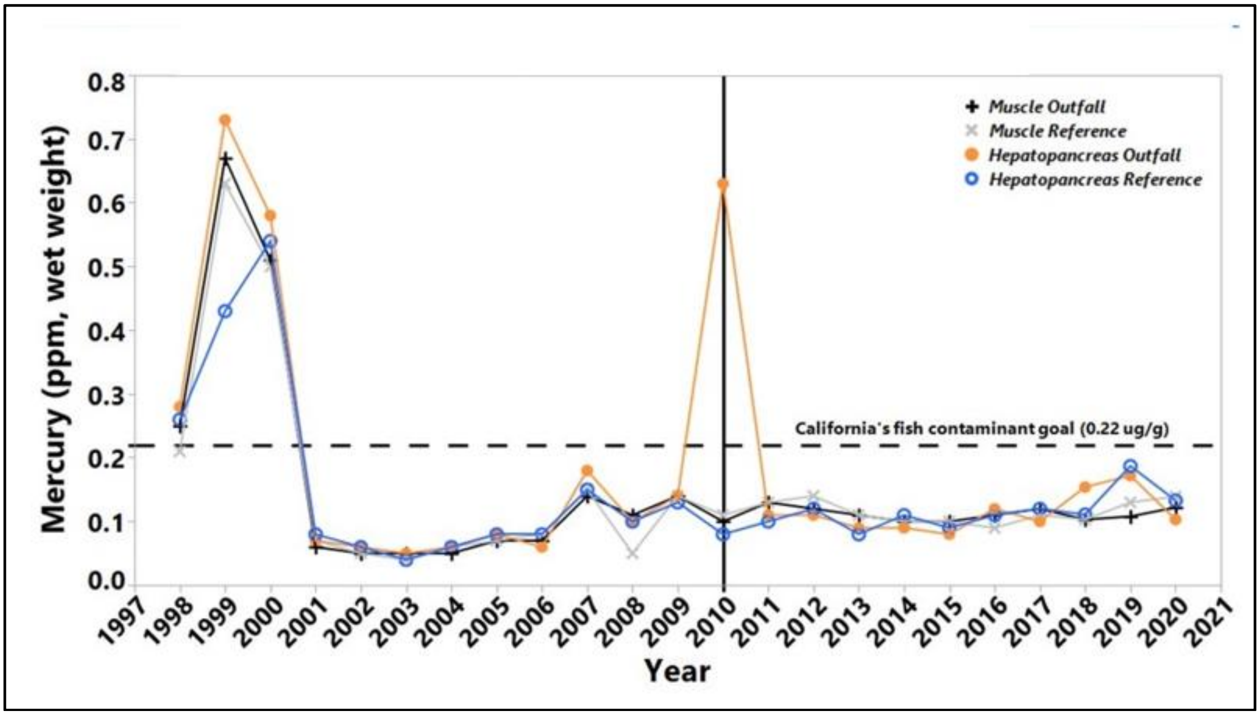


Figure S.WQ.7.5. Mercury concentration in Dungeness crab at outfall station 01 and reference station 06 from 1997–2020. The vertical black line indicates the year of the last condition report (2010), while the horizontal dashed line shows California's fish contaminant goal for mercury (0.22 µg/g). Source: SFPUC, 2014, 2021; Image: A. Mabrouk/NOAA

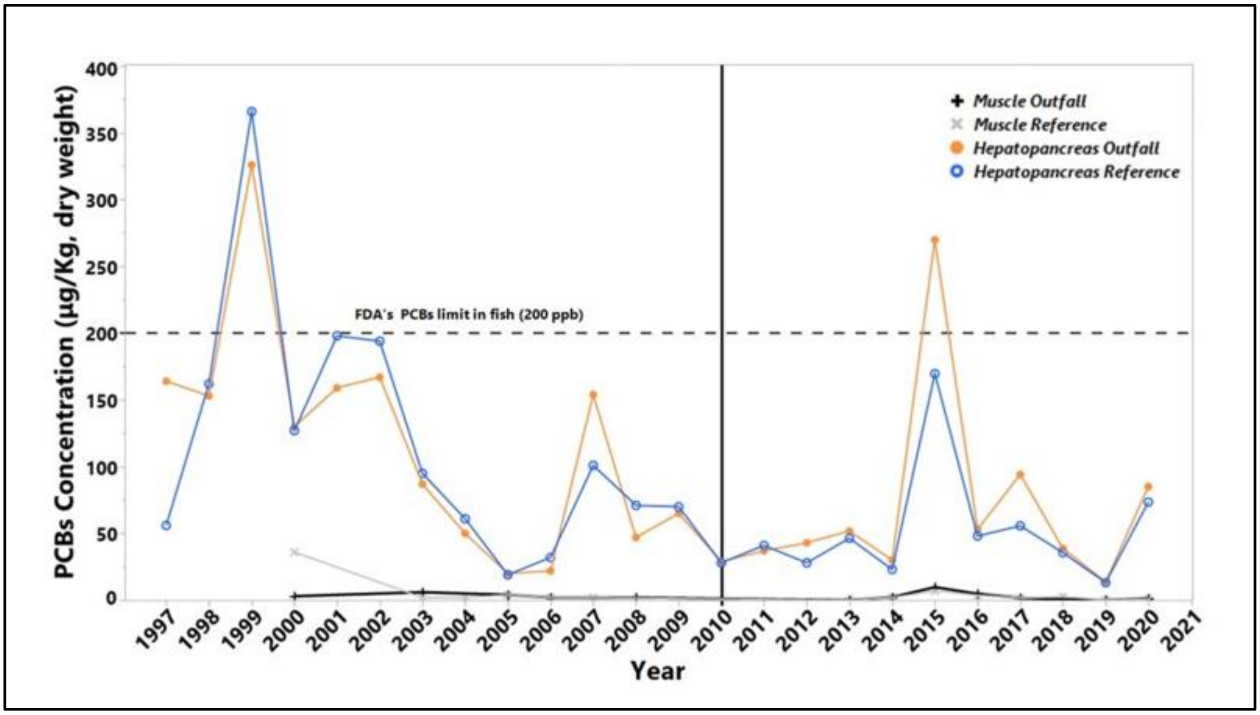


Figure S.WQ.7.6. PCB concentration in Dungeness crab at outfall station 01 and reference station 06 from 1997–2020. The vertical black line indicates the year of the last condition report (2010), while the horizontal dashed black line shows the FDA's limit for PCBs in fish (200 ppb). Source: SFPUC, 2014, 2021; Image: A. Mabrouk/NOAA

Conclusion

For the period from 2010–2022, the status of human health risks posed by sanctuary waters in the coastal and offshore region of GFNMS was rated fair based largely on a documented PSP illness case in 2018 and shellfish closures in 2015–2016 caused by domoic acid in bivalves and crabs. Sanctuary beaches were not listed as impaired water bodies; however, a few beaches in Marin County did have elevated counts of pathogenic bacteria but there were no beach closures. The mixed trend was based on some improvements, such as the removal of Bolinas Beach from the list of impaired water bodies and decreased beach advisories in some areas, while other indicators were worsening, such as biotoxin levels in shellfish. Although there were more indicators and data assessed in the current report compared to the 2010 condition report, data gaps remain, including levels of organic and heavy metal pollutants in crabs, mussels, and fish from the sanctuary; the only data available for this report were for Dungeness crab at locations outside the sanctuary.

Estuarine and Lagoon Region

Status Description: Water quality problems have caused measurable human impacts, but effects are localized and not widespread or persistent.

Rationale: Saxitoxin exceeded thresholds in some years in Tomales Bay, but domoic acid was consistently below the detection limit. Shellfishery closures occurred regularly in Tomales Bay, primarily due to rainfall, but also as a result of norovirus, Vibrio, or saxitoxin. A norovirus outbreak linked to oysters cultured in Tomales Bay sickened 44 people in 2018–2019. Tomales Bay, Estero Americano, and Estero de San Antonio were listed as impaired bodies of water, and beach advisories were issued for Tomales Bay throughout the study period without a clear trend. Mercury contaminant levels were high for some species in Tomales Bay, and recommendations to limit consumption were issued. Data were generally unavailable for human health indicators in Estero Americano, Estero de San Antonio, and Bolinas Lagoon.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair/poor and the trend was undetermined. This rating was based on the status of Tomales Bay, Estero Americano, and Estero de San Antonio as impaired water under the Clean Water Act, the number of shellfishery closures due to rainfall, and norovirus outbreaks in Tomales Bay.

New Information in the 2010–2022 Condition Report

This question considered biotoxins in bivalves, shellfishery closures, beach advisories, pathogenic bacteria, impaired water bodies, and mercury contamination in biota (Table S.WQ.7.2). This assessment was largely focused on Tomales Bay, where data were available for the selected indicators. Data were not available for many of these indicators in Estero Americano, Estero de San Antonio, or Bolinas lagoon.

Table S.WQ.7.2. Summaries for the key indicators related to human health risks from waters in the estuarine and lagoon region of GFNMS that were discussed during the May 16, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Biotoxins and shellfishery closures	Zubkousky-White, 2022	Status: Saxitoxin was high in oysters and mussels from Tomales Bay, and exceeded the CDPH regulatory threshold in 2013, 2014, 2017, 2018, and 2019; domoic acid was below the detection limit. Shellfishery closures occurred frequently, primarily due to rainfall, but also occasionally due to the presence of saxitoxin, *Vibro*, and norovirus. Trend: No trend in biotoxin concentration or shellfishery closures was apparent.	S.WQ.7.7; S.WQ.7.8

Indicator	Source	Data Summary	Figures
Impaired water and beach advisories	CSWRCB, 2022b; EPA, 2022	Status: Tomales Bay, Estero Americano, and Estero de San Antonio remain on the list of impaired water bodies. From 2010–2021, fecal coliform levels exceeded accepted thresholds on 131 occasions in Tomales Bay. Advisories were issued for Tomales Bay beaches due to elevated levels of pathogenic bacteria that did not meet the health standards for swimming. Trend: The impaired water status of Tomales Bay, Estero Americano, and Estero de San Antonio did not change during the study period. There was no clear trend in the number of beach advisory days throughout the study period, but recent years (e.g., 2018, 2020, 2021) were relatively high compared to some previous years (e.g., 2015).	S.WQ.7.9
Mercury in biota	California Office of Environmental Health Hazard Assessment, 2018; CSWRCB, 2019a, 2021a	Status: Recommendations to limit consumption of fish and crab from Tomales Bay were issued due to high levels of mercury. Mercury levels exceeded contaminant thresholds in some fish species from Walker Creek Delta. Trend: Trends for mercury in biota could not be determined because samples were limited to two or three time points.	S.WQ.7.10; S.WQ.7.11
Data gaps	Long-term data on organic pollutants and heavy metals in crabs, mussels, and fish are needed for all GFNMS estuarine and lagoon habitats.		

Biotoxins and Shellfishery Closures

Consumption of seafood from GFNMS estuaries, particularly Tomales Bay, may result in the ingestion of or exposure to HAB biotoxins (i.e., saxitoxin and domoic acid), norovirus, or pathogenic bacteria (i.e., fecal coliforms and *Escherichia coli*), thus threatening human health (ONMS, 2010). In Tomales Bay, saxitoxin was measured in cultured oysters and mussels. Saxitoxin concentration exceeded the CDPH regulatory threshold (80 µg/100 g) in 2013, 2014, 2017, 2018, and 2019, but there was no clear trend (Zubkousky-White, 2022; Figure S.WQ.7.7). In the few bivalve samples tested from Tomales Bay (97 samples from 2010–2022), domoic acid was below the detection limit of 2.5 µg/100 g. However, four types of shellfishery closures (due to rainfall,[11] PSP, *Vibrio*, and norovirus) occurred in Tomales Bay based on annual sanitary survey update reports from CDPH. Closure days were calculated for the four types from the CDPH patrol logs and summary reports (Rankin, 2022; Figure S.WQ.7.8). Closure days due to rainfall were the most common closure type and occurred annually with no apparent trend, while norovirus closures occurred only in December of 2018 and January and April of 2019 due to an outbreak in a Tomales Bay oyster aquaculture operation. These outbreaks caused illness in

[11] Heavy rainfall can lead to increased runoff and pollutants from land in coastal waters, which accumulate in shellfish. Rainfall closures are preemptive based on forecasts and previous testing data to prevent human health impacts from contaminated shellfish consumption (Rankin, 2022).

44 people who ate oysters from Tomales Bay and caused CDPH to temporarily close oyster harvesting in Tomales Bay (Larsen, 2019); however, the source of these outbreaks was not found. Additional impacts on human health were minimized by effective monitoring and closures instituted by CDPH with cooperation from the commercial shellfish aquaculture companies operating in Tomales Bay.

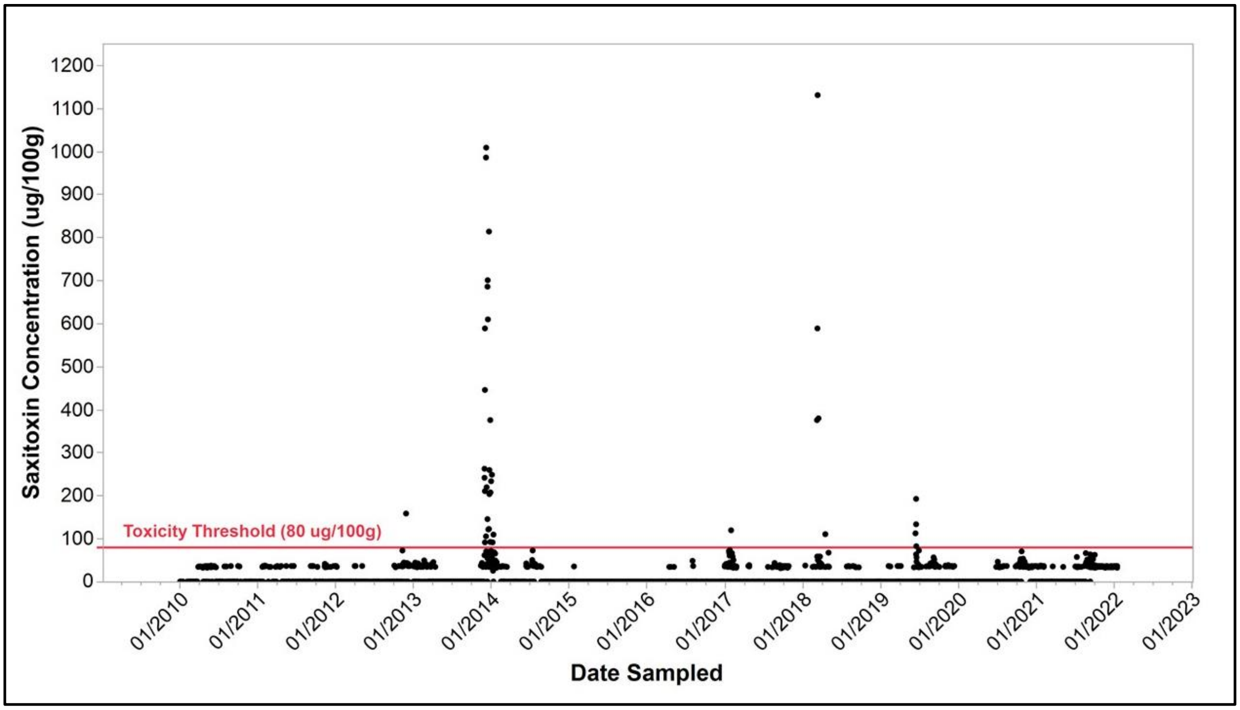


Figure S.WQ.7.7. Saxitoxin concentration in mussels and oysters cultured in Tomales Bay from 2010–2022. The red line is the regulatory limit (80 µg/100 g) set by CDPH. Concentrations of zero represent non-detection of saxitoxin. Source: Zubkousky-White, 2022; Image: A. Mabrouk/NOAA

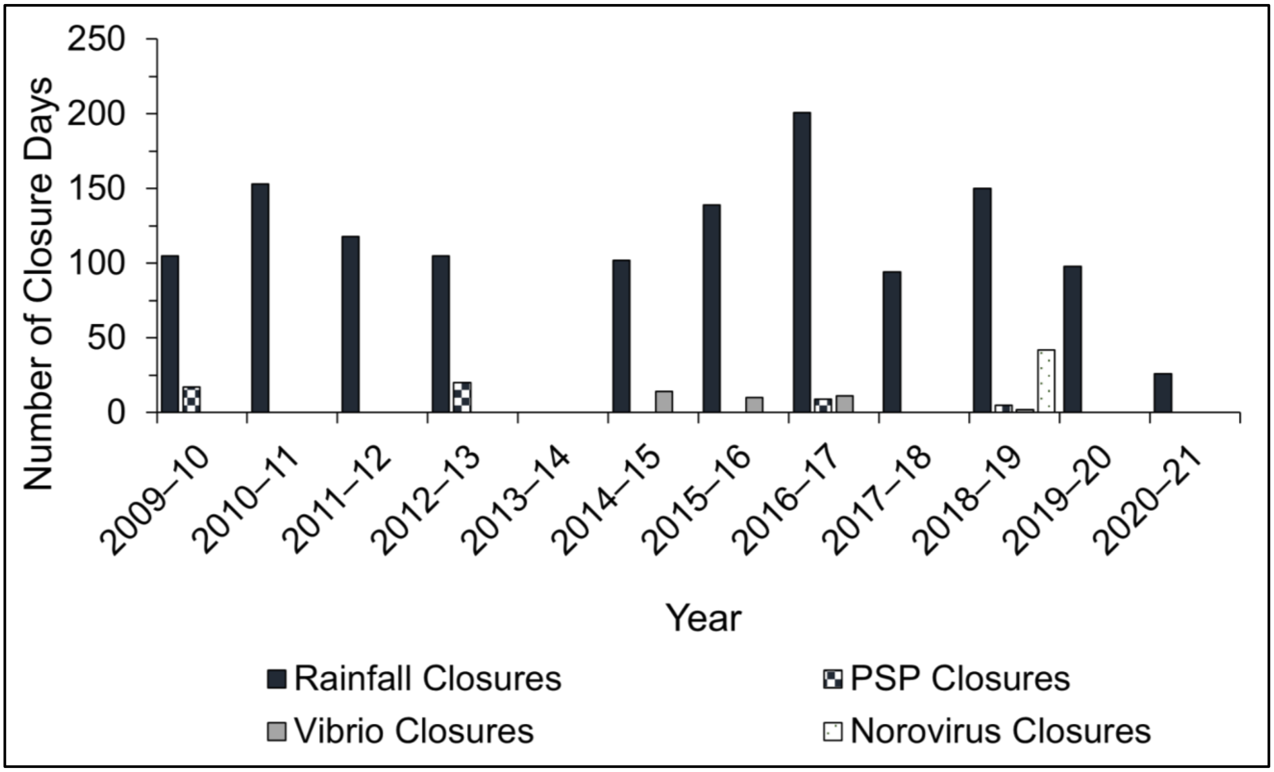


Figure S.WQ.7.8. Tomales Bay shellfishery closures by type (rainfall, PSP, *Vibrio*, and norovirus). Data were unavailable for 2013–2014. Source: Rankin, 2022; Image: A. Mabrouk/NOAA

Impaired Water and Beach Advisories

CSWRCB's integrated assessment reports for the years 2018 and 2020–2022 showed that Tomales Bay, Estero Americano, and Estero de San Antonio were listed as impaired water bodies under Section 303(d) of the Clean Water Act; Bolinas Lagoon was not assessed. Tomales Bay was impaired due to sedimentation/siltation, nutrients, mercury, and pathogens, while Estero Americano and Estero de San Antonio were impaired due to nutrients and sedimentation.

Elevated levels of pathogenic bacteria that did not meet the health standards for swimming were detected during regular water quality monitoring of Tomales Bay, resulting in advisories. From 2010–2021, fecal coliform thresholds were exceeded on 131 occasions. The number of advisory days was the highest in 2011, decreased and was lowest in 2015, and then increased recently, particularly at Chicken Ranch Beach (EPA, 2022; Figure S.WQ.7.9).

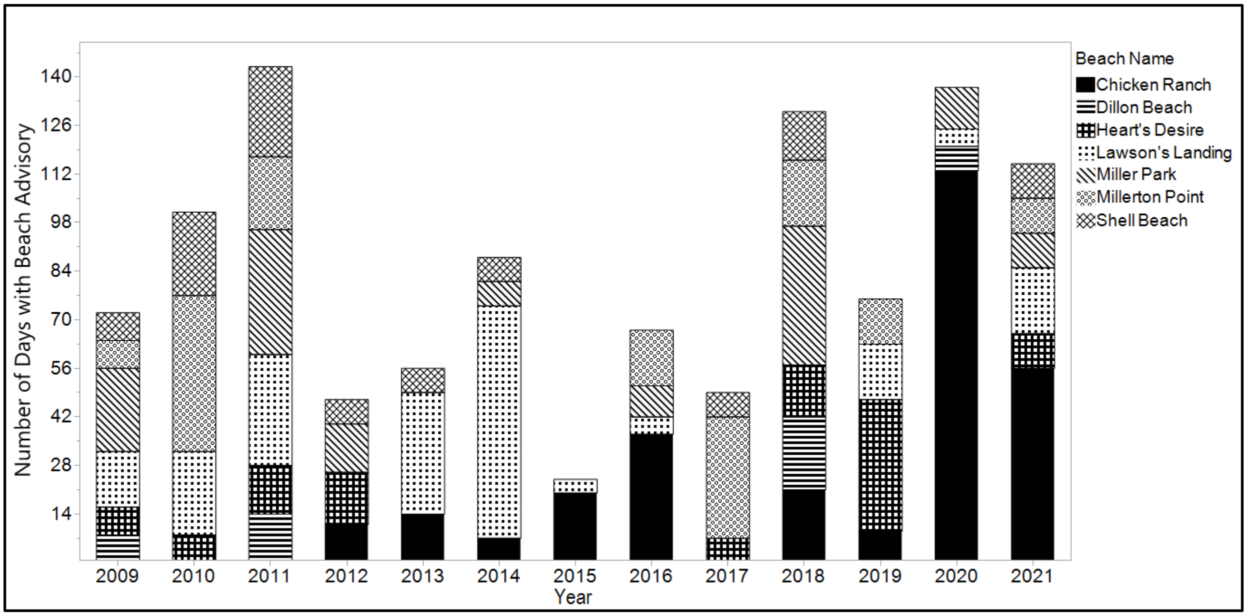


Figure S.WQ.7.9. Number of advisory days (those in which pathogenic bacteria did not meet health standards) at Tomales Bay beaches, 2009–2021. Source: EPA, 2022; Image: A. Mabrouk/NOAA

Mercury in Biota

The California Office of Environmental Health Hazard Assessment developed guidelines for Tomales Bay that recommend restricting fish consumption based on the sex and age of the consumer. These recommendations were developed primarily due to high concentrations of mercury in fish and shellfish (Gassel et al., 2004). Recommendations for some species, like rays and sharks, are to avoid consumption regardless of the consumer's age and sex (Figure S.WQ.7.10). Others, including California halibut, red rock crab, jacksmelt, and surfperch, may be eaten in moderation (California Office of Environmental Health Hazard Assessment, 2018; Figure S.WQ.7.10).

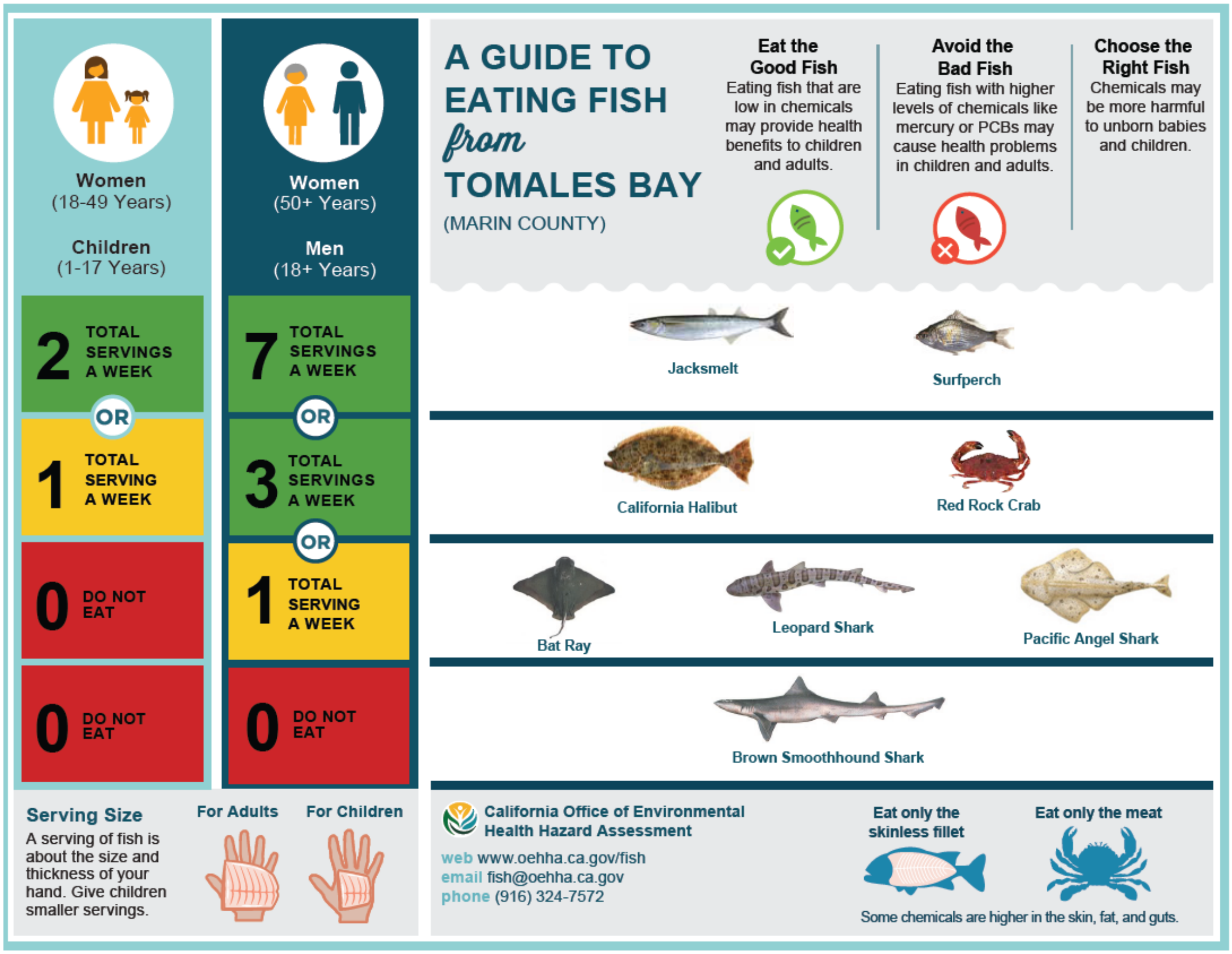


Figure S.WQ.7.10. Guidelines for consumption of fish and crustaceans from Tomales Bay. Image: California Office of Environmental Health Hazard Assessment, 2018

The main source of elevated mercury in Tomales Bay biota is the former Gambonini mercury mine upstream of Walker Creek. Mercury concentrations in biota were assessed at the Walker Creek Delta before and after cleanup and remediation of the mine in 1999–2000. The results showed that oysters had a mercury concentration below the goal set for human consumption by CSWRCB (0.22 µg/g), although mercury levels were higher in 2019–2020 than in 1998–2001. California halibut consistently had mercury concentrations at or below the goal at the three time points measurements occurred, and concentrations were lowest in 2019–2020. In contrast, leopard sharks had high mercury concentrations that exceeded the goal and were higher in 2019–2020 than in 1998–2001 (CSWRCB, 2021a; Figure S.WQ.7.11).

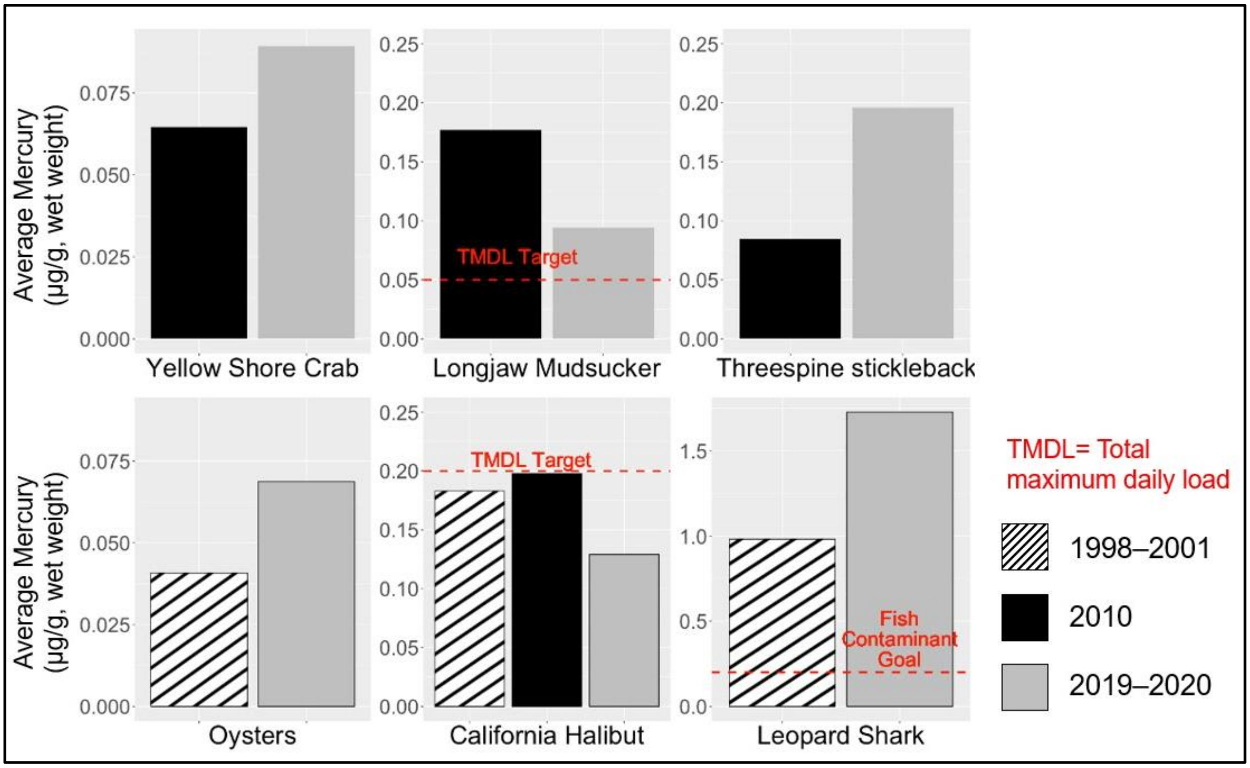


Figure S.WQ.7.11. Mercury levels in biota (µg/g, wet weight) sampled near the Walker Creek Delta prior to (1998–2001) and after (2010; 2019–2020) remediation of the Gambonini Mine. Total maximum daily load (TMDL) target and fish contaminant goal refer to the acceptable levels of contaminants set by the CSWRCB. Note that the vertical axis scale varies by species. Image: Adapted from CSWRCB, 2021a

Conclusion

Water quality problems caused measurable human impacts during the study period, resulting in a fair status rating. In one notable but localized incident, 44 people contracted norovirus in late 2018 and early 2019 after eating oysters from Tomales Bay. Additionally, there were intermittent restrictions on fish and shellfish consumption at Tomales Bay due to PSP, norovirus, *Vibrio*, rainfall, and mercury contamination. Tomales Bay, Estero Americano, and Estero de San Antonio were listed as impaired bodies of water, and beach advisories were issued annually for Tomales Bay. This assessment focused mainly on Tomales Bay, as data from other sanctuary estuaries were generally not available; this lack of information resulted in an undetermined trend rating. Data from the other estuaries, including long-term measurements of organic pollutants and heavy metals in biota and regular water quality monitoring, are needed to conduct a comprehensive assessment.

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

Coastal and Offshore Region

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

Rationale: Increased positive sea surface temperature anomalies were associated with two marine heatwave events during the study period. The marine heatwave in 2014–2016 resulted in unprecedented ecological and economic impacts. Habitat compression was high during the 2014–2016 and 2019 marine heatwaves, but there was no change in the habitat compression index during the study period. Low dissolved oxygen was observed at multiple sampling depths in multiple years, and hypoxic events were observed, typically in deeper water. Low aragonite saturation corresponding to corrosive conditions was observed, especially at deeper locations.

Findings From the 2010 Condition Report

This question is new and was not assessed in the 2010 condition report. Instead, climate change was assessed in a separate report, *Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries* (Largier et al., 2010). Key climate impacts to the sanctuary documented in that report included sea level rise, decreased freshwater runoff, increased precipitation variability, increased offshore SST, increased winds and associated changes to oceanographic conditions, increased extreme weather events, and a northward range shift for key species; additionally, effects that were anticipated, but not yet observed, included increased coastal erosion, decreased seawater pH, a shift in phytoplankton community composition, and compounded impacts from local human activities.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included climate and basin-scale indices, upwelling indices, SST, MHW measurements, hypoxia, ocean acidification (aragonite saturation), and the habitat comparison index (Table S.WQ.8.1).

Table S.WQ.8.1. Summaries for the climate indicators in the coastal and offshore region of GFNMS that were discussed during the June 6, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Basin-scale indices	NOAA, 2022b	Status: Recent means for the PDO and NPGO were within one standard deviation of the long-term mean. Trend: Mean PDO was neutral and mean NGPO decreased during the study period.	S.WQ.8.1; S.WQ.8.2
Upwelling indices	NOAA, 2022b	Status: Recent means for LUSI and the CUTI were within one standard deviation of the long-term mean. Trend: Both indices were neutral during the study period.	N/A

Indicator	Source	Data Summary	Figures
SST and MHWs	Elliott et al., 2022a; NOAA, 2022c	Status: Positive SST anomalies occurred during the study period and particularly corresponded to MHWs in 2014–2016 and 2019. Trend: There was an apparent increase in positive SST anomalies during the study period.	S.WQ.8.3; S.WQ.8.4
Habitat compression index	NOAA, 2022b	Status: Mean habitat compression index from 2012–2022 was within one standard deviation of the long-term mean. Trend: The trend was neutral from 2012–2022.	S.WQ.8.7
Dissolved oxygen and hypoxia	Elliott et al., 2022a	Status: Hypoxic events and low oxygen levels approaching the hypoxia threshold were detected. Hypoxic events occurred more frequently in deep water (>125 m). Trend: There was no apparent trend during the study period.	S.WQ.8.5; S.WQ.8.6
Ocean acidification	Elliott et al., 2022a	Status: Corrosive conditions were documented at depths of 25 and 100 m, and were less frequent at a depth of 10 m. Trend: There was no apparent trend during the study period.	S.WQ.8.7
Data gaps	Data on bottom temperature and salinity were unavailable.		

The central California Current Ecosystem naturally experiences exceptional climate variability due to upwelling and has also experienced climate change impacts such as MHWs (Elliott et al., 2022a; Harvey et al., 2021). Climate change impacts on coastal and offshore habitats, such as coastal erosion from increased wave action, increased riverine sediment loads, increased water temperature, and ocean acidification, have multi-faceted impacts on wildlife due to their synergistic and cascading effects, and the connectivity and fluidity of the coastal marine environment. Climatological disturbances to GFNMS ecosystems could potentially result in habitat loss and degradation and declines in abundance or redistribution of important marine species. Climate and ocean indicators, such as regional upwelling and water chemistry indicators, can support characterization of ecosystem productivity and ecological integrity in GFNMS.

Basin-Scale Indices

GFNMS waters are influenced by both large-scale and local conditions. Two basin-scale indices that affect productivity in GFNMS were used to understand large-scale variability in the region. These are the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). Positive PDO values indicate warmer water and lower productivity, while positive NPGO values are associated with increased equatorward flow and higher surface salinities, nutrients, chlorophyll *a*, and productivity (Harvey et al., 2021). Mean PDO and NPGO for the last 10 years were within one standard deviation of long-term means for these indices. During the same time period, PDO was stable while NPGO decreased, resulting in reduced productivity overall (NOAA, 2022b; Figure S.WQ.8.1; Figure S.WQ.8.2).

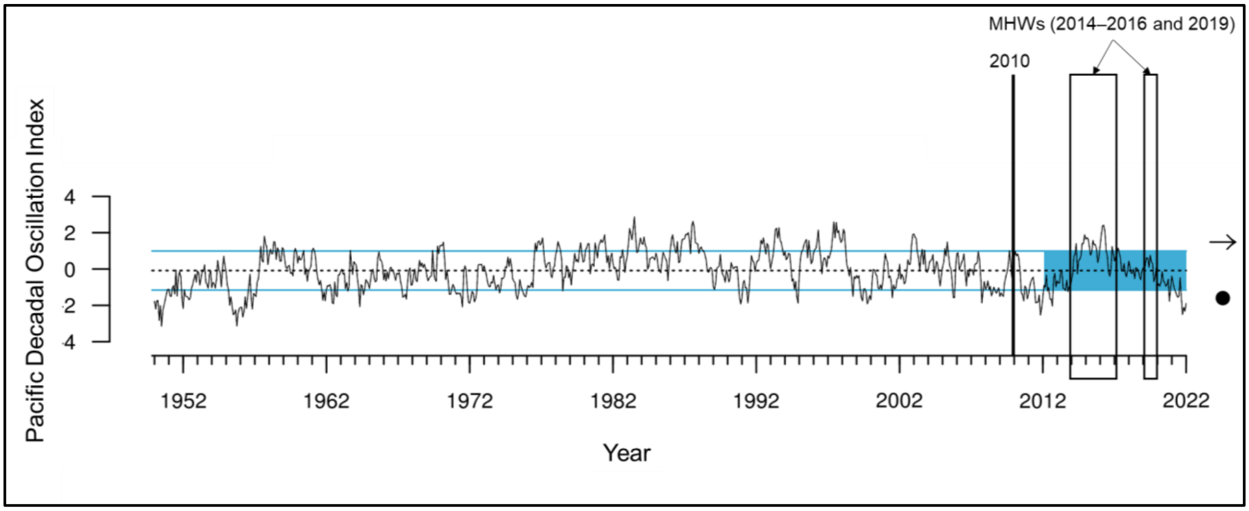


Figure S.WQ.8.1. Monthly PDO index. The vertical black line indicates the year of the last condition report (2010). The mean for the last 10 years (blue shaded area) was within one standard deviation of the long-term mean since 1950 (indicated by the black dot) and the trend for the last 10 years was neutral (→). The dashed black line represents the long-term mean and the blue lines are ± one standard deviation. The black rectangles show the marine heatwaves of 2014–2016 and 2019. Source: NOAA, 2022b

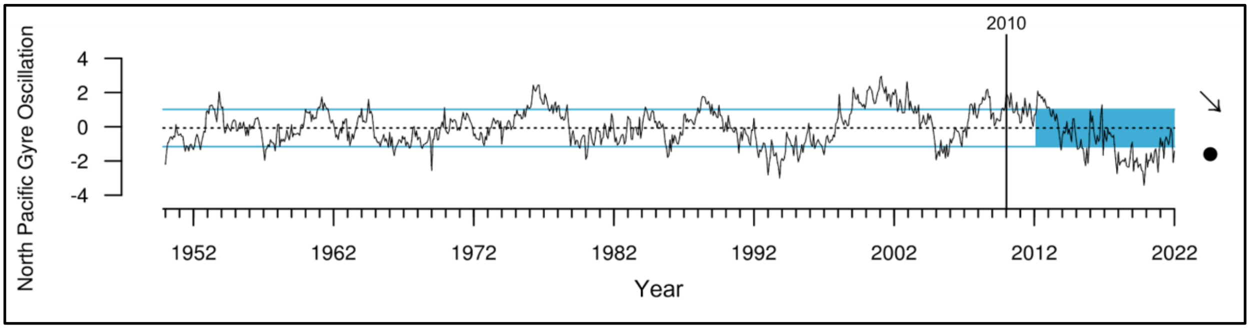


Figure S.WQ.8.2. Monthly NPGO index. The vertical black line indicates the year of the last condition report (2010). The mean for the last 10 years (blue shaded area) was within one standard deviation of the long-term mean since 1950 (indicated by the black dot) and the trend for the last 10 years trend was decreasing (↘). The dashed black line represents the long-term mean and the blue lines are ± one standard deviation. Source: NOAA, 2022b

Upwelling Indices

Two indices were used to describe upwelling in GFNMS, the Length of Upwelling Season Index (LUSI) and the Coastal Upwelling Transport Index (CUTI). LUSI is defined as the total number of days between the observed start date and the observed end date of the upwelling season. The lowest number of upwelling days in the last 10 years was associated with the 2014–2016 marine heatwave. However, mean LUSI for the last 10 years was within one standard deviation of the long-term mean, and the trend was neutral. CUTI estimates vertical transport near the coast. A positive index indicates upwelling, and a negative index indicates weak upwelling or downwelling conditions. The mean CUTI for the last 10 years was also within one standard deviation of the long-term mean, and the trend was neutral (NOAA, 2022b).

Sea Surface Temperature and Marine Heatwaves

In 2014–2016, the central California Current Ecosystem experienced an extensive MHW. This event caused rapid and abundant positive SST anomalies that began in early 2014 and persisted through mid-2016 (Figure S.WQ.8.3; Figure S.WQ.8.4). This heatwave overlapped with the 2015–2016 El Niño event (Gentemann et al., 2017; Jacox et al., 2019), resulting in the largest MHW detected since NOAA satellites started keeping track in 1981 (NOAA Fisheries, 2020b). Another smaller, shorter-lived MHW developed offshore of GFNMS in 2019. Figure S.WQ.8.3 depicts monthly SST anomalies based on local buoy data in GFNMS and CBNMS (Elliott et al., 2022a) and shows that positive anomalies increased in number and magnitude since 2014, associated with prolonged and more frequent MHWs, while Figure S.WQ.8.4 shows MHW coverage, intensity, and cumulative intensity at GFNMS from satellite data.

MHWs caused severe impacts on marine life in the California Current Ecosystem (Holbrook et al., 2019). Warmer water associated with the MHW also contributed to an unprecedented HAB on the GFNMS coast in 2015–2016. This HAB event, caused by the diatom *Pseudo-nitzschia*, resulted in increasing domoic acid toxins in shellfish, especially Dungeness crab, leading to the most prolonged shellfishery closure since 2006 in 2015–2016 and poisoning seabirds and marine mammals (Trainer et al., 2017, 2020; Anderson et al., 2019). The MHW also caused other ecological changes in GFNMS. The geographic distributions of many southern coastal species shifted northward along the California coast (Sanford et al., 2019; Beas-Luna et al., 2020). Krill and forage fish abundance declined, and as a result, humpback whale feeding shifted from offshore (where they normally consume krill) to inshore (anchovy). This resulted in more whale entanglements in crab traps (NOAA Fisheries, 2020b).

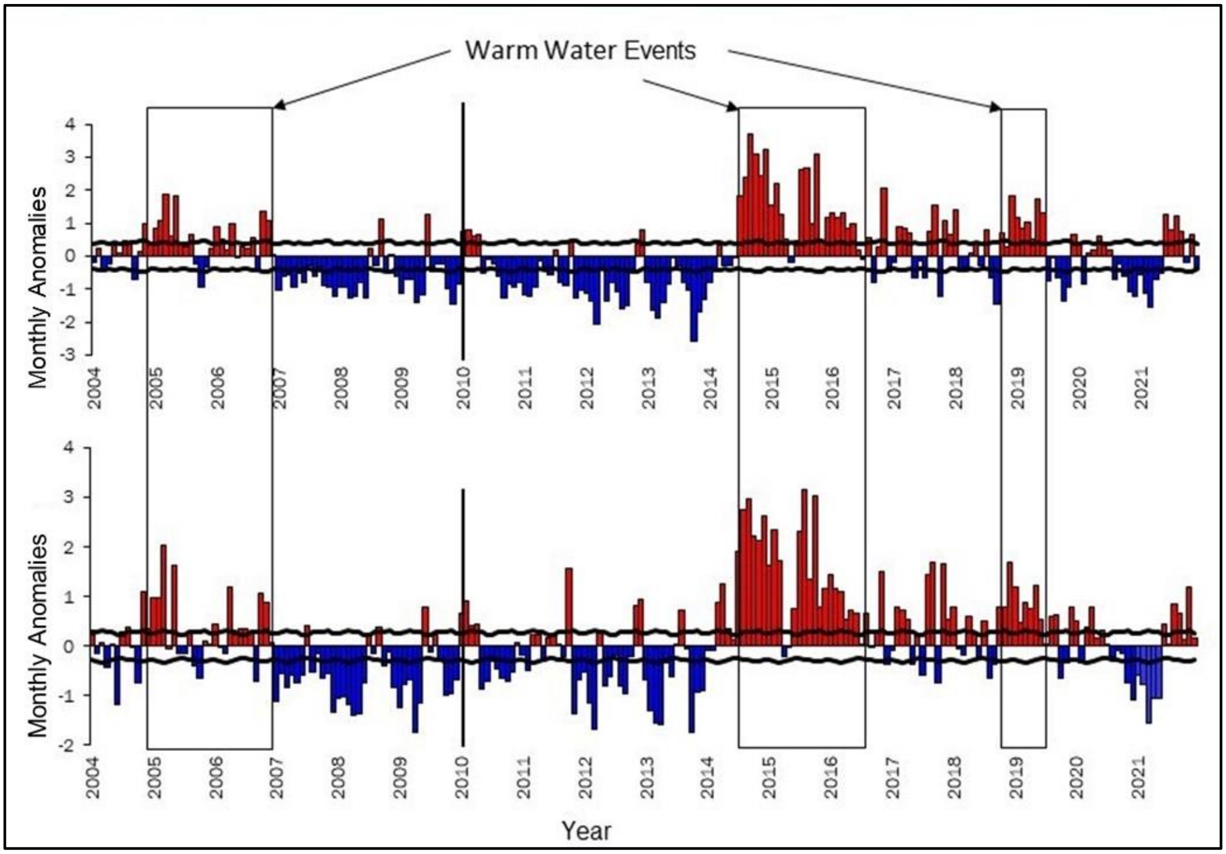


Figure S.WQ.8.3. Monthly SST anomalies from NOAA buoy data in GFNMS and CBNMS (top) and Southeast Farallon Island (bottom). Black rectangles show the warm water events associated with positive anomalies. The vertical black lines indicate the year of the last condition report (2010), while the horizontal black lines represent 99% confidence intervals around the long-term monthly means. Source: Elliott et al., 2022a

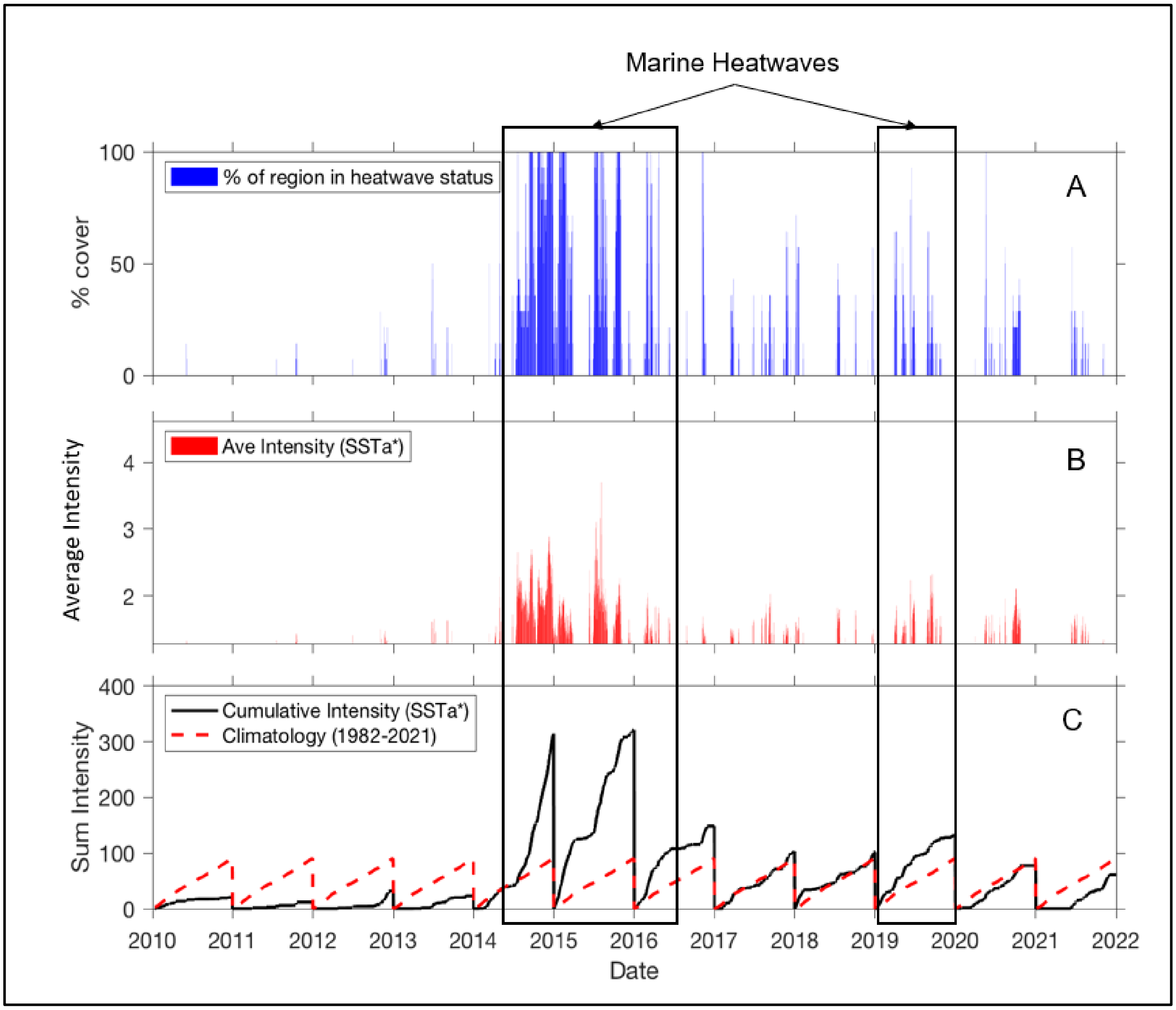


Figure S.WQ.8.4. MHW measurements for the surface water of GFNMS, including (A) daily % cover, (B) daily intensity, and (C) cumulative intensity (accumulated heat in the sanctuary over the year [solid black line] compared to the climatology average [red dashed line]). Black rectangles indicate MHW events in 2014–2016 and 2019. The highest MHW cover, intensity, and cumulative intensity occurred in 2014 and 2015. Image: A. Leising/NOAA; Source: NOAA, 2022c

Habitat Compression Index

The habitat compression index tracks cool water thermal habitat in the California Current Ecosystem, which may be compressed by MHWs (Santora et al., 2020; Schroeder et al., 2022). Cooler, low-compression conditions (corresponding to a high habitat compression index) support high biodiversity and abundance of coastal organisms like young-of-the-year groundfish and krill. In the central California Current Ecosystem, such conditions were present in 2007, 2008, and early 2009. A shift in the pelagic ecosystem occurs under high-compression conditions (corresponding to a low habitat compression index), which support an increase in the abundance and distribution of forage species like anchovy and a decrease in the abundance and distribution of krill. This shift was observed during the MHWs in 2014–2016 and 2019, and also during El Niño in 1982–1983 and 1997–1998 (NOAA, 2022c; Santora et al., 2021a). Mean habitat compression index from 2012–2022 was within one standard deviation of the long-term mean, the trend was neutral during that time period (Figure. S.WQ.8.5).

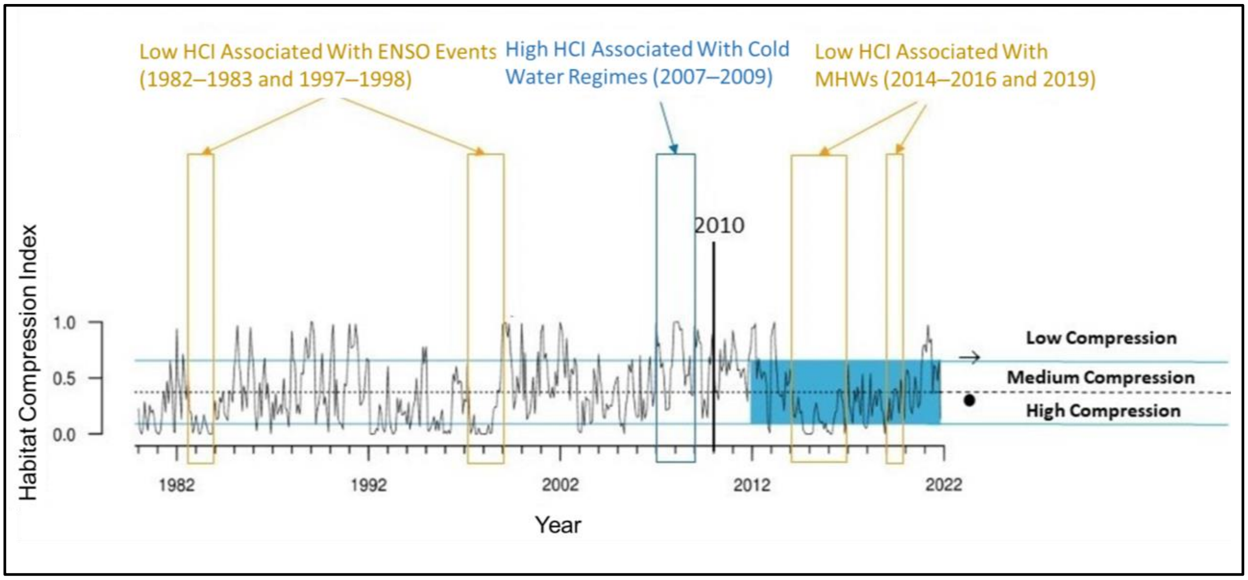


Figure S.WQ.8.5. Habitat compression index (HCI) for the central California Current Ecosystem. The vertical black line indicates the year of the last condition report (2010). Mean habitat compression index from 2012–2022 (shaded area) was within one standard deviation of the long-term mean (indicated by the black dot) and the trend for this time period was neutral (→). The dashed line represents the long-term mean and the solid blue lines are ± one standard deviation. The orange rectangles indicate warm water events associated with El Niño (1982–1983, 1997–1998) and MHWs (2014–2016, 2019). Image: Modified from NOAA, 2022b; Santora et al., 2021a

Dissolved Oxygen and Hypoxia

Dissolved oxygen in the region is affected by upwelling that usually occurs from May to July (Garcia-Reyes & Largier, 2012; J. Largier/University of California Davis, personal communication, June 6, 2022). Upwelled water from deeper ocean sources tends to be low in dissolved oxygen, and microbial decomposition of organic matter increases overall system respiration and oxygen consumption, particularly closer to the seafloor (Harvey et al., 2021). Dissolved oxygen concentrations at ACCESS stations 6-E (nearshore) and 6-W (offshore; see Figure S.P.3.2 for station locations) were always above the hypoxia threshold (2 mg/L; Vaquer-Sunyer & Duarte, 2008) with the exception of one deep sample at station 6-E in 2010 (Figure S.WQ.8.6). However, dissolved oxygen was often only slightly above the threshold in deeper water, generally between 2–5 mg/L, especially at a depth of 100 m at the offshore site. In contrast, dissolved oxygen at a depth of 10 m at the offshore site was higher than that of the nearshore site. Of note, low oxygen levels approaching the hypoxia threshold occurred in the shallow samples at the nearshore site in 2011 and to a lesser degree in 2018, as well as in the deeper samples in most years at both sites (Figure S.WQ.8.6). Additionally, hypoxic events were observed more frequently in deeper water (>125 m) samples taken in spring and summer at the offshore site (Elliott et al., 2022a; not illustrated in Figure S.WQ.8.6).

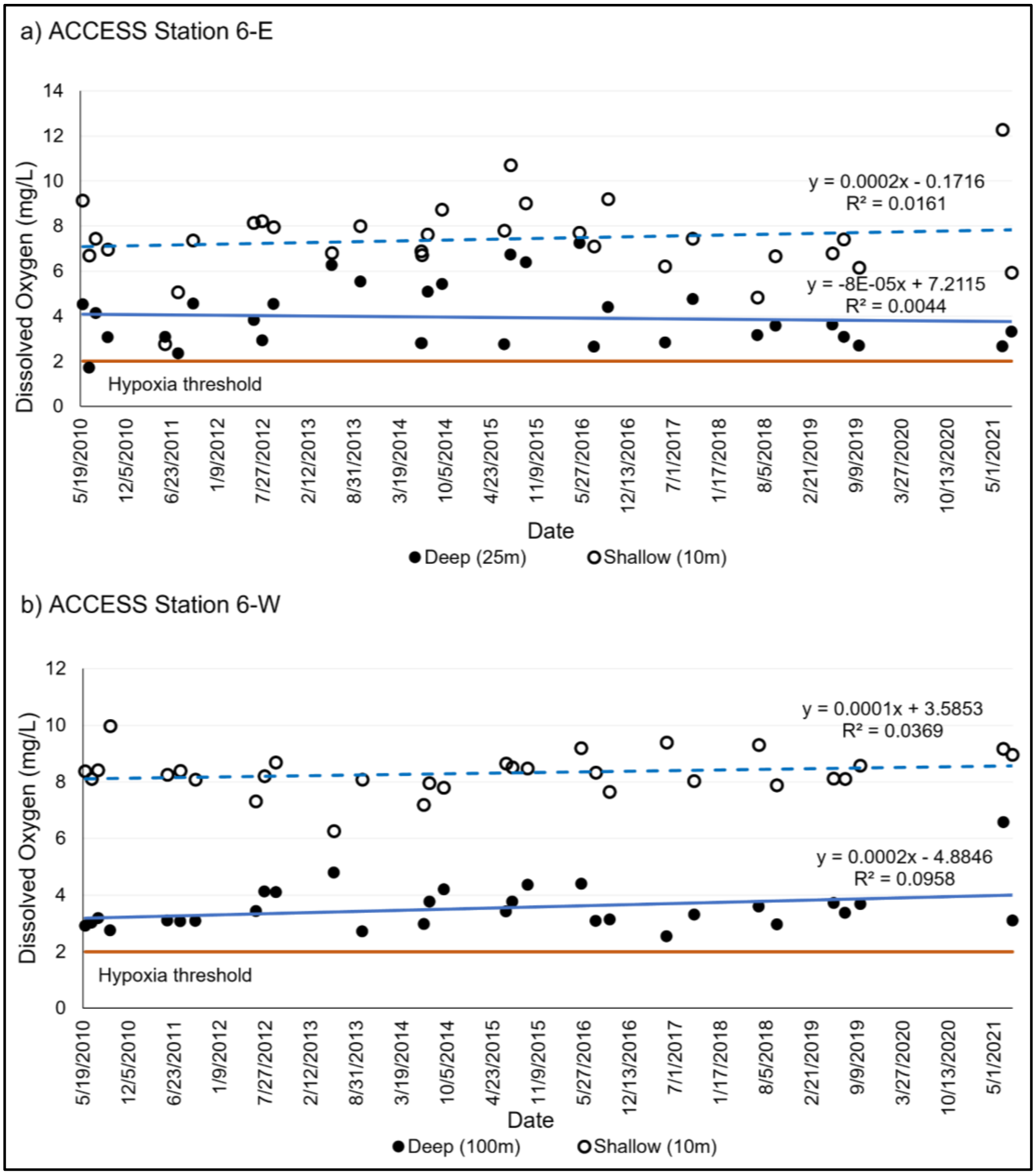


Figure S.WQ.8.6. Dissolved oxygen concentrations at station 6-E (top) and station 6-W (bottom). The blue solid line is the linear trend for deep dissolved oxygen at (25 m at Station 6-E, and 100 m at Station 6-W), while the dashed blue line is the linear trend for shallow dissolved oxygen (10 m at both sites). The horizontal orange line is the threshold for hypoxia (2 mg/L). Image: Elliott et al., 2022a

Ocean Acidification

Ocean acidification results from oceanic absorption of CO_2 from the atmosphere, reducing pH and carbonate ion levels in seawater. This process increases acidity and decreases carbonate availability. Saturation of aragonite, a form of calcium carbonate that is sensitive to increasing CO_2, is considered a key indicator of ocean acidification. Acidification slows the growth of calcium carbonate structures and can dissolve these structures faster than they form, impacting California Current Ecosystem species like oysters, crabs, and pteropods when aragonite saturation is <1.0 (considered corrosive conditions; Feely et al., 2008; Barton et al., 2012; Bednaršek et al., 2014; Marshall et al., 2017; Hodgson et al., 2018).

Corrosive conditions were characteristic of deep depths (25 m) at ACCESS nearshore station 6-E, except for some records in the years 2014–2016 that were associated with the MHW (Figure S.WQ.8.7). Aragonite saturation also consistently indicated corrosive conditions at deep depths (100 m) at offshore station 6-W. At shallow depths (10 m), both stations had higher aragonite, and corrosive conditions occurred less frequently.

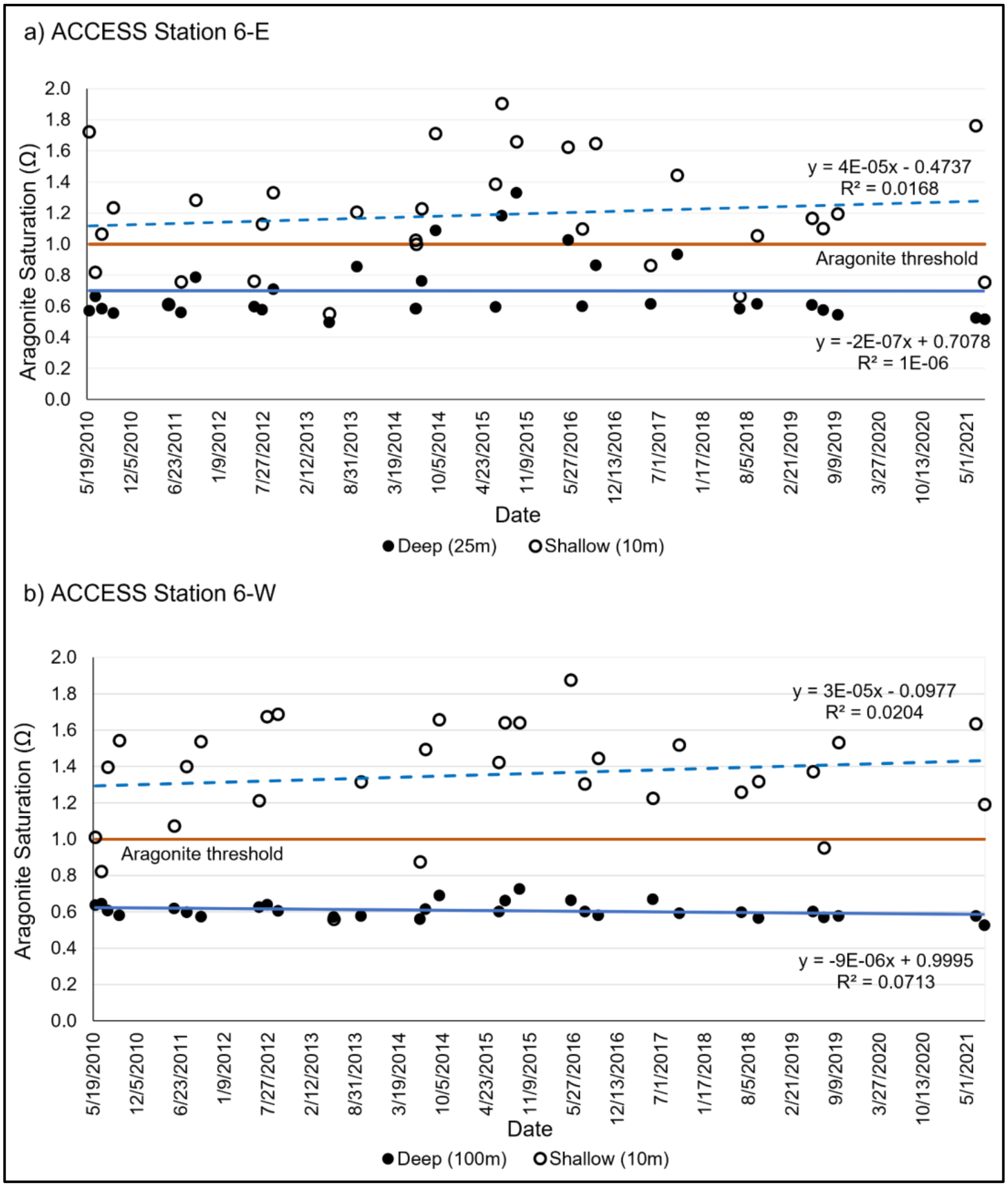


Figure S.WQ.8.7. Aragonite saturation at station 6-E (top) and 6-W (bottom). The solid blue line indicates the linear trend for aragonite at deep depths (25 m at Station 6-E, and 100 m at Station 6-W), while the dashed blue line indicates the linear trend for aragonite at shallow depths (10 m at both sites). The orange line is the threshold for aragonite saturation (values below this threshold indicate corrosive conditions). Image: Elliott et al., 2022a

Conclusion

This question was rated fair with a worsening trend. A prolonged and intense MHW in 2014–2016 and a shorter MHW in 2019 contributed to HABs and a shift in the pelagic ecosystem that severely impacted the Dungeness crab fishery, and also resulted in habitat compression. Dissolved oxygen decreased with depth, but hypoxia generally occurred only offshore at depths >125 m (with the exception of one sample at 25 m in 2010). Aragonite saturation state indicated consistently corrosive conditions offshore at a depth of 100 m; while these conditions were also observed nearshore at a depth of 25 m, they occurred less frequently. The worsening trend was primarily based on the increase in the number and magnitude of monthly positive SST anomalies that were associated with an increase in MHWs. Additional data, including long-term data on sea surface salinity and bottom temperature, would support a more inclusive assessment.

Estuarine and Lagoon Region

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

Rationale: Data were only available for Tomales Bay, limiting the ability to assess this question. Sea surface temperature increased significantly during the study period, and positive anomalies were associated with marine heatwaves in 2014–2016 and 2019. Aragonite saturation increased during the study period, but was seasonally low enough to result in corrosive conditions. Stream flow into Tomales Bay decreased over time, and was lower than historical median discharge values in some years; salinity increased during the study period.[12]

Findings From the 2010 Condition Report

This question is new and was not assessed in the 2010 condition report. Instead, climate change was assessed in a separate report, *Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries* (Largier et al., 2010). Key climate impacts to the entirety of the sanctuary documented in that report included sea level rise, decreased freshwater runoff, increased precipitation variability, increased offshore SST, increased winds and associated changes to oceanographic conditions, increased extreme weather events, and a northward range shift for key species; additionally, effects that were anticipated, but not yet observed, included increased coastal erosion, decreased seawater pH, a shift in phytoplankton community composition, and compounded impacts from local human activities.

[12] Status and trend ratings and associated confidence scores were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status and trend ratings and associated confidence scores.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included SST, ocean acidification (aragonite saturation), salinity, and stream flow (Table S.WQ.8.2).

Table S.WQ.8.2. Summaries for key climate indicators in the estuarine and lagoon region of GFNMS that were discussed during the June 6, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
SST	University of California Davis Bodega Marine Lab, 2022a; BOON, 2022b	Status: Positive SST anomalies occurred in Tomales Bay and were associated with marine heatwaves in 2014–2016 and 2019. Trend: SST increased significantly during the study period.	S.WQ.8.8
Aragonite saturation	University of California Davis Bodega Marine Lab, 2022b	Status: Aragonite saturation in Tomales Bay exhibited a seasonal pattern in which it was highest in summer and lowest, often below the threshold for corrosive conditions, in winter. Trend: Aragonite saturation increased significantly during the study period.	S.WQ.8.9
Stream flow and salinity	U.S. Geological Survey, 2022a, 2022b; BOON, 2022c	Status: Stream flow into Tomales Bay was high in the wet season (winter; highest in 2017 and 2019) and low in summer (lowest in 2020 and 2021; in both years, values were below the median daily statistic for the past 38 years). There was an inverse relationship between stream flow and salinity in which salinity was lowest in winter (lowest in 2017 and 2019) and highest in summer. Trend: Stream discharge into Tomales Bay significantly decreased and salinity significantly increased during the study period.	S.WQ.8.10; S.WQ.8.11
Data gaps	Lack of long-term data and trend analysis for SST, aragonite saturation, DO, and hypoxia for estuarine and lagoon habitats in GFNMS.		

Sea Surface Temperature

SST data for Tomales Bay from 2013–2021 were obtained from the Tomales Bay buoy (BOON, 2022b; Figure S.WQ.8.8). However, some data were missing or did not pass quality assurance and quality control (University of California Davis Bodega Marine Lab, 2022a). Positive SST anomalies were associated with MHWs in 2014–2016 and 2019. Further analysis of the buoy data showed a seasonal pattern in which SST was highest in summer and lowest in winter. Linear trend analysis indicated that SST increased significantly during the study period (BOON, 2022b).

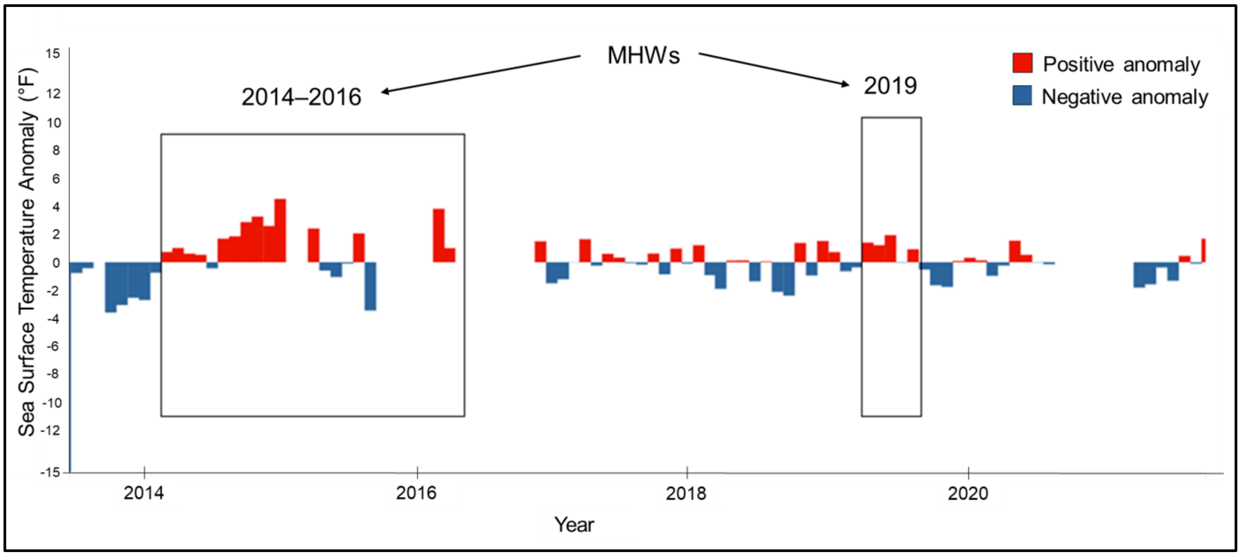


Figure S.WQ.8.8. Monthly SST anomalies in Tomales Bay. The black rectangles highlight positive anomalies associated with MHWs. Image: Modified from University of California Davis Bodega Marine Lab, 2022a

Aragonite Saturation

Aragonite saturation was measured in Tomales Bay at the Hog Island Oyster Company hatchery. From 2014–2019, a seasonal pattern in daily mean aragonite saturation was detected; aragonite increased in summer then decreased in winter, dipping below the aragonite saturation threshold (<1.0; University of California Davis Bodega Marine Lab, 2022b). Aragonite saturation conditions <1.0 are considered corrosive and make shell formation more difficult. However, linear trend analysis showed an overall significant increase in aragonite saturation since 2014, which is more favorable for shell-forming organisms (Figure S.WQ.8.9).

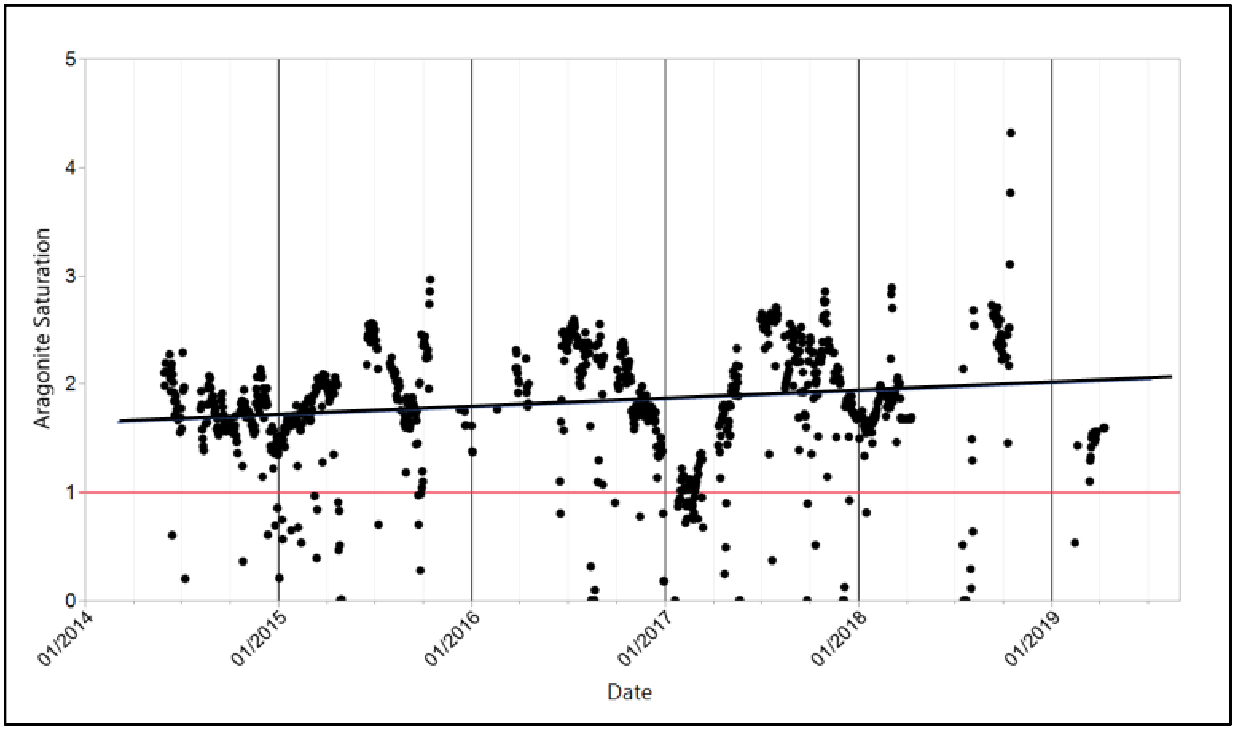


Figure S.WQ.8.9. Daily mean aragonite saturation at the Hog Island Oyster Company hatchery in Tomales Bay, 2014–2020. The black line indicates the linear trend and the horizontal red line indicates the aragonite saturation threshold. Source: University of California Davis Bodega Marine Lab, 2022b; Image: Ayman Mabrouk/NOAA

Stream Flow and Salinity

Annual precipitation levels vary considerably in the sanctuary region depending on weather patterns and climate conditions. Precipitation regulates streamflow in Tomales Bay, which in turn influences salinity levels. Stream flow into Tomales Bay was assessed as the amount of water discharged from the two main tributaries of Tomales Bay, Walker Creek and Lagunitas Creek (U.S. Geological Survey, 2022a, 2022b). For Walker Creek, stream flow had a seasonal pattern of high discharge in winter (highest in 2017 and 2019) and low discharge in summer (lowest in 2014, 2020, and 2021 and below the median daily discharge for the last 38 years; U.S. Geological Survey, 2022a). The same seasonal pattern was found at Lagunitas Creek (discharge was also highest in 2017 and 2019 and was lowest and below the median daily discharge for the last 38 years in 2020 and 2021; U.S. Geological Survey, 2022b). Discharge from both streams decreased over time (Figure S.WQ.8.10).

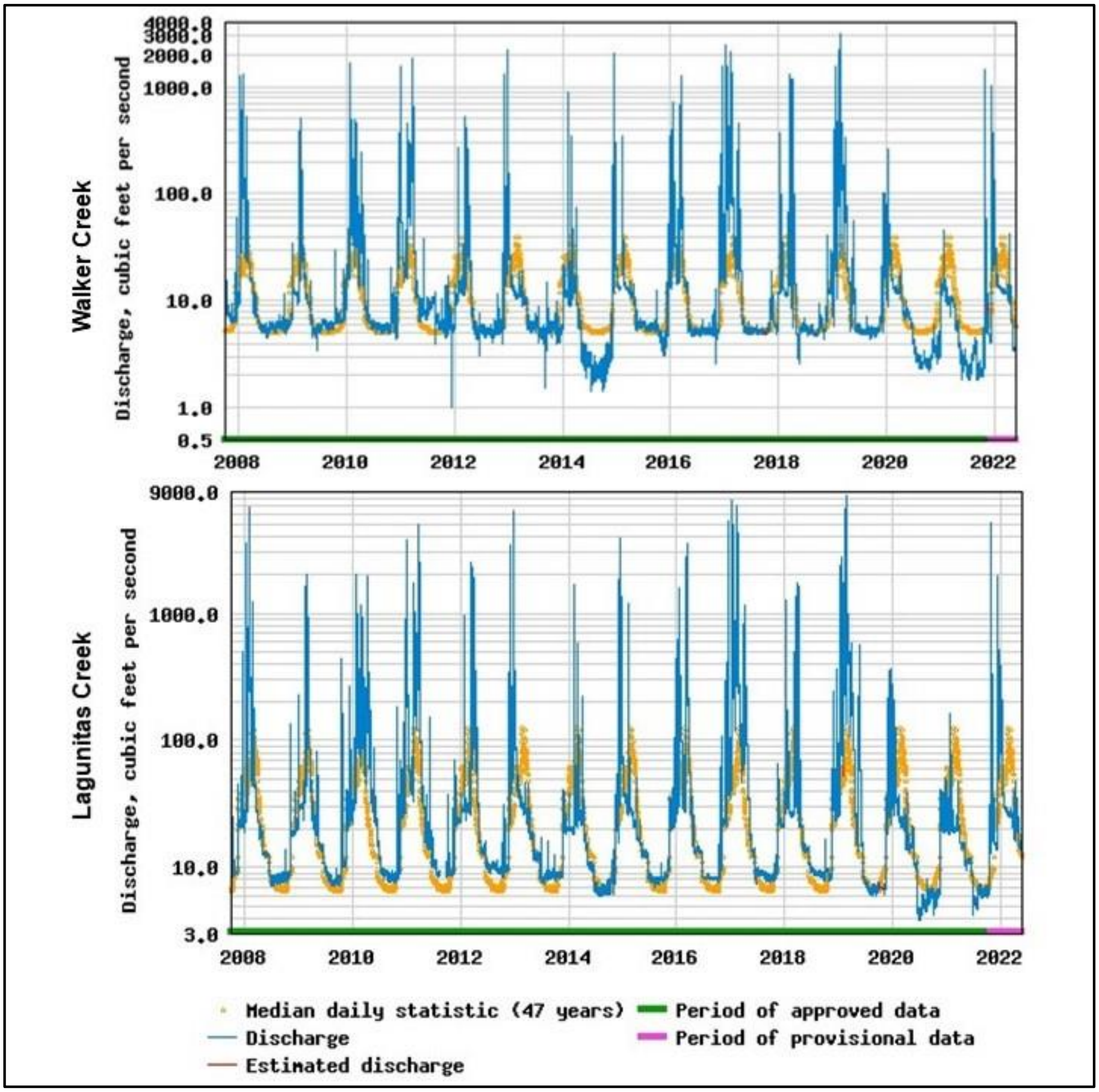


Figure S.WQ.8.10. Stream flow from Walker Creek and Lagunitas Creek, 2008–2022. Source: U.S. Geological Survey, 2022a, 2022b

Salinity can affect estuarine fauna; for example, prolonged exposure to low salinity was found to be significantly and positively correlated with oyster mortality in studies from Texas (Du et al., 2021). Daily mean salinity at the Tomales Bay buoy from 2013–2022 exhibited a seasonal pattern in which salinity decreased in winter (the wet season). Salinity was lowest in 2017 and 2019 due to high precipitation in those years. However, salinity didn't decrease below the survival and growth threshold (10 ppt) for the commonly cultured species in the bay, the Pacific oyster (*Crassostrea gigas*). Salinity increased significantly during the study period (BOON, 2022c; Figure S.WQ.8.11), consistent with the observations of decreased stream discharge described above.

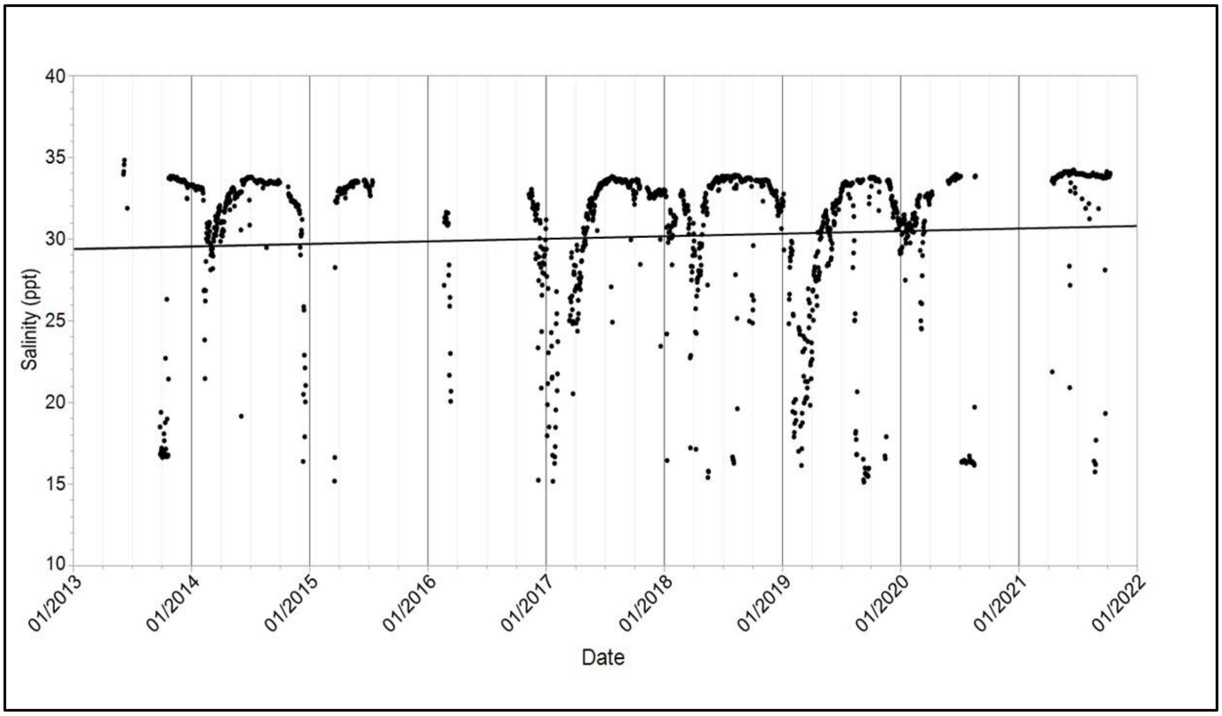


Figure S.WQ.8.11. Daily mean salinity in Tomales Bay, 2013–2022. The black line shows the linear trend for salinity. Source: BOON, 2022c; Image: Ayman Mabrouk/NOAA

Conclusion

The status of climate-altered water conditions in GFNMS estuarine and lagoon habitats was fair based on high-SST anomalies associated with MHW events in 2014–2016 and 2019, as well as low aragonite saturation in Tomales Bay. Salinity in Tomales Bay was affected by the level of discharge from Walker Creek and Lagunitas Creek but it remained above the threshold for oyster growth and survival. Aragonite saturation was seasonally low, resulting in corrosive conditions. Both aragonite saturation and salinity increased during the study period, while water discharge into Tomales Bay decreased. However, the available data were limited to Tomales Bay, and in some cases were incomplete, resulting in an undetermined trend. Data gaps for all indicators exist for Estero Americano, Estero de San Antonio, and Bolinas Lagoon.

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

Coastal and Offshore Region

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

Rationale: Microplastics were present in the sanctuary, but in lower abundance compared to more heavily developed coastal areas. Although discharges from U.S. Coast Guard vessels remained low, numerous illegal discharges into the sanctuary from cruise ships were documented during the study period. However, the volume of dredged material illegally discharged into the sanctuary decreased significantly. Vessel discharges and small oil spills were observed, but their impacts were not assessed or documented; no large spills occurred during the study period. Atmospheric emissions and illegal exhaust gas cleaning system discharges from vessels may result in harmful water quality impacts, but these have generally not been quantified in the sanctuary. It is unknown whether disruptions to natural sediment movement have affected turbidity.[13]

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good/fair and the trend was not changing. Ratings were based on few HAB observations, continued nonpoint source discharges from San Francisco Bay and Russian River, new coastal impaired water listings, decreased oil pollution, and decreased sediment spills from barges.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included microplastics, U.S. Coast Guard vessel discharges, cruise ship discharges, dredged material discharges, oil and other vessel discharges, emissions, and sediment transport (Table S.WQ.9.1).

[13] A status rating and associated confidence score were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

Table S.WQ.9.1. Summaries for the key indicators related to other stressors affecting water quality in the coastal and offshore region of GFNMS that were discussed during the May 19, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Microplastics	Sutton et al., 2019	Status: The abundance of microplastics in the sanctuary was lower than in San Francisco Bay and similar to the open ocean. Trend: No trend data were available.	S.WQ.9.1
USCG vessel discharges	ONMS, 2018b	Status: The amount of discharge from USCG vessels in the sanctuary was low. Trend: The number and type of ships and training activities and the amount of discharge was stable over the past several decades.	N/A
Cruise ship discharges	Blank Rome LLP, 2017	Status: Over 190 documented violations of discharge regulations by cruise ships from 2017–2019. Trend: Limited time series data on discharges precluded the assessment of a trend.	S.WQ.9.2; S.WQ.9.3
Dredged material discharges	Etrac, 2022	Status: Barges transiting GFNMS to dump dredged material at the SF-DODs offshore disposal site had minimal spills and leaks. Trend: The volume of dredged material discharged into the sanctuary decreased since 2010.	S.WQ.9.4
Oil and other vessel discharges	GFNMS, 2022d; USCG, 2022	Status: Small discharges of oil and other materials occurred as a result of medium-sized vessel groundings, but the impacts of these events is unknown. Trend: No trend data were available.	N/A
Emissions	National Centers for Environmental Information, 2023b; EPA, 2021b	Status: Atmospheric emissions and EGCS (scrubber) discharges from vessels in the sanctuary are a concern, but data on their impacts are lacking. Trend: No trend data were available.	S.WQ.9.5; S.WQ.9.6;
Fine sediment transport	Kordesch et al., 2019	Status: Disruptions to natural sediment movement may have affected turbidity. Trend: No trend data were available.	N/A
Data gaps	Gaps include trend data for microplastics, cruise ship discharges, EGCS (scrubber) discharges, other discharges from vessels, and sediment imbalances.		

Microplastics

Concerns about microplastics include their effects on water quality, organisms that consume them, and human health when they are present in seafood. They are found in nearly every environment on Earth (Thompson et al., 2004). Plastic debris of all sizes in the marine environment, including microplastics, contains organic contaminants, some added during manufacturing and others absorbed from surrounding seawater (Teuten et al., 2009). Particles may carry microorganisms, adsorbed chemicals, or other potentially hazardous materials (Danopoulos et al., 2020).

San Francisco Estuary Institute collected microplastics using manta trawls in three California national marine sanctuaries (GFNMS, CBNMS, MBNMS) and San Francisco Bay from 2017–2018 (Sutton et al., 2019). Microparticles (excluding fibers but including plastics) were found at all sites sampled in GFNMS during the wet and dry seasons; however, their abundance was much lower than in San Francisco Bay and slightly lower than MBNMS in the wet season, and was comparable to other open ocean marine settings (Figure S.WQ.9.1). Fibers were excluded because of logistical challenges in enumerating them and uncertainty about the representativeness of fiber samples collected using manta trawls (Sutton et al., 2019).

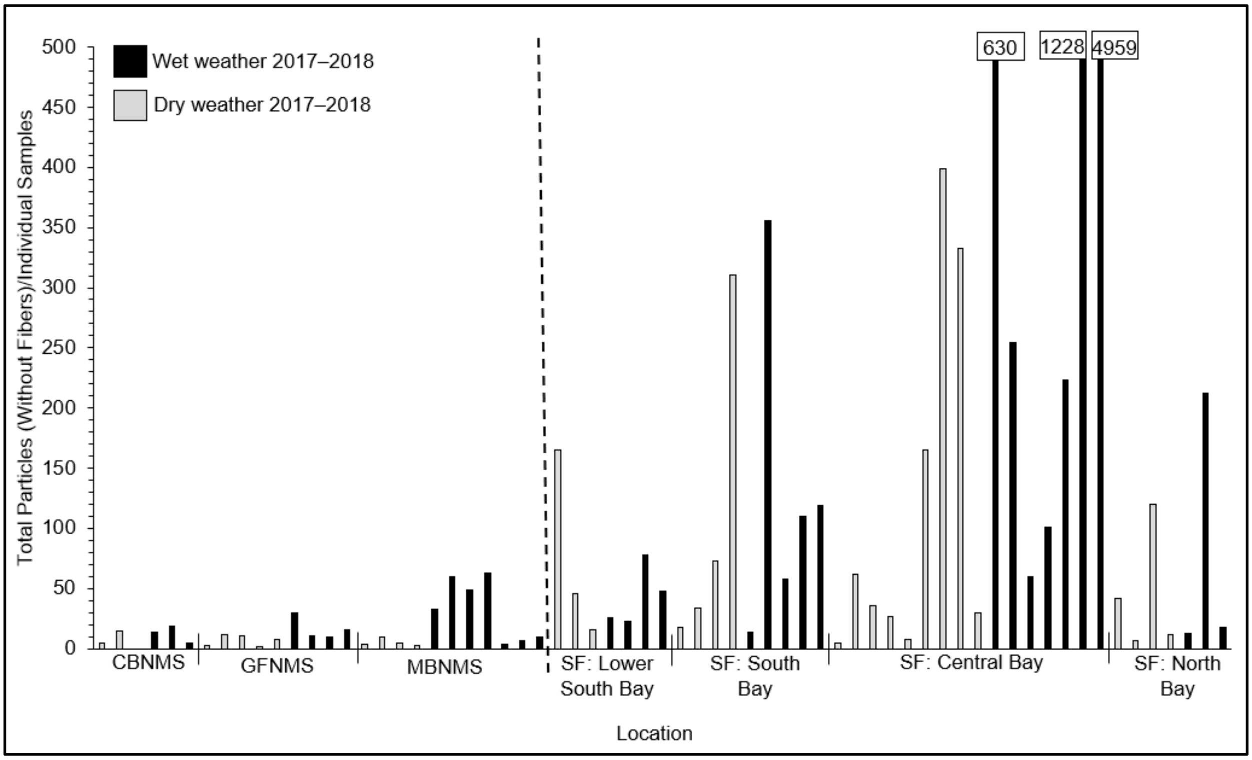


Figure S.WQ.9.1. Particles (excluding fibers) in individual samples from CBNMS, GFNMS, MBNMS, and San Francisco (SF) Bay in the dry and wet seasons, 2017–2018. Numbers in boxes indicate values that exceeded the axis maximum. Source: Sutton et al., 2019

U.S. Coast Guard Discharges

As part of its mission, USCG supports resource protection efforts by providing routine surveillance and enforcement of the National Marine Sanctuaries Act and other environmental laws and regulations (14 U.S.C. §§ 2; 14 U.S.C. §§ 89); supports resource protection in national marine sanctuaries and facilitates public and private uses, such as leading planning and response activities for oil spills and other incidents within its area of jurisdiction; and strives to minimize the loss of life, injury, and property damage or loss at sea through search and rescue missions (USCG, 2012).

USCG vessels and aircraft can discharge material and other matter as part of their operations within GFNMS federal waters (beyond three nautical miles of the shoreline). Materials discharged include ammunition and pyrotechnic materials used while conducting mission-critical training, as well as untreated wastewater (including blackwater and graywater) when on patrols. A total of three protector patrol boats, two buoy tenders, and three cutters use GFNMS waters for these activities. The amount of discharge from these activities each year was low, has occurred within GFNMS since its designation, and was determined, through a NOAA Final Environmental Assessment published in 2018, to not have a significant impact on water quality or sanctuary resources. The level of discharge was stable over the past several decades. No adverse impacts were documented on any sanctuary resources or uses as a result of USCG discharges of untreated vessel sewage, non-clean vessel graywater, or ammunition or pyrotechnic materials (ONMS, 2018b). Additionally, USCG must adhere to federal and state regulations that minimize impacts to coastal waters.

Cruise Ship Discharge

As discussed in Question 2, the high number of people on cruise ships creates a concentration of human waste, graywater, and trash, all of which pose risks to water quality. Illegal discharges by cruise ships are likely underreported due to a lack of oversight during transit in the U.S. Exclusive Economic Zone (e.g., *United States of America v. Princess Cruise Lines, Ltd., 2016*), but there is no evidence of any trends in reporting levels. However, between June 11, 2015 and April 11, 2017, a total of 190 discharges were reported to NOAA from five cruise ships operated by Princess Cruise Lines, Ltd. as part of a 2016 plea agreement. These discharges totaled 8,409,151 gallons of waste, including EGCS effluent; untreated and treated blackwater and graywater, including sewage sludge; and ground food waste (Blank Rome LLP, 2017; Figure S.WQ.9.2). An estimated 95% of the total discharge volume was released within GFNMS (Figure S.WQ.9.3). The largest ship of the five responsible for discharges into GFNMS, *Grand Princess*, has a capacity of 2,600 guests and 1,150 crew and was responsible for 103 of the 190 violations (Princess Cruise Lines, 2023).

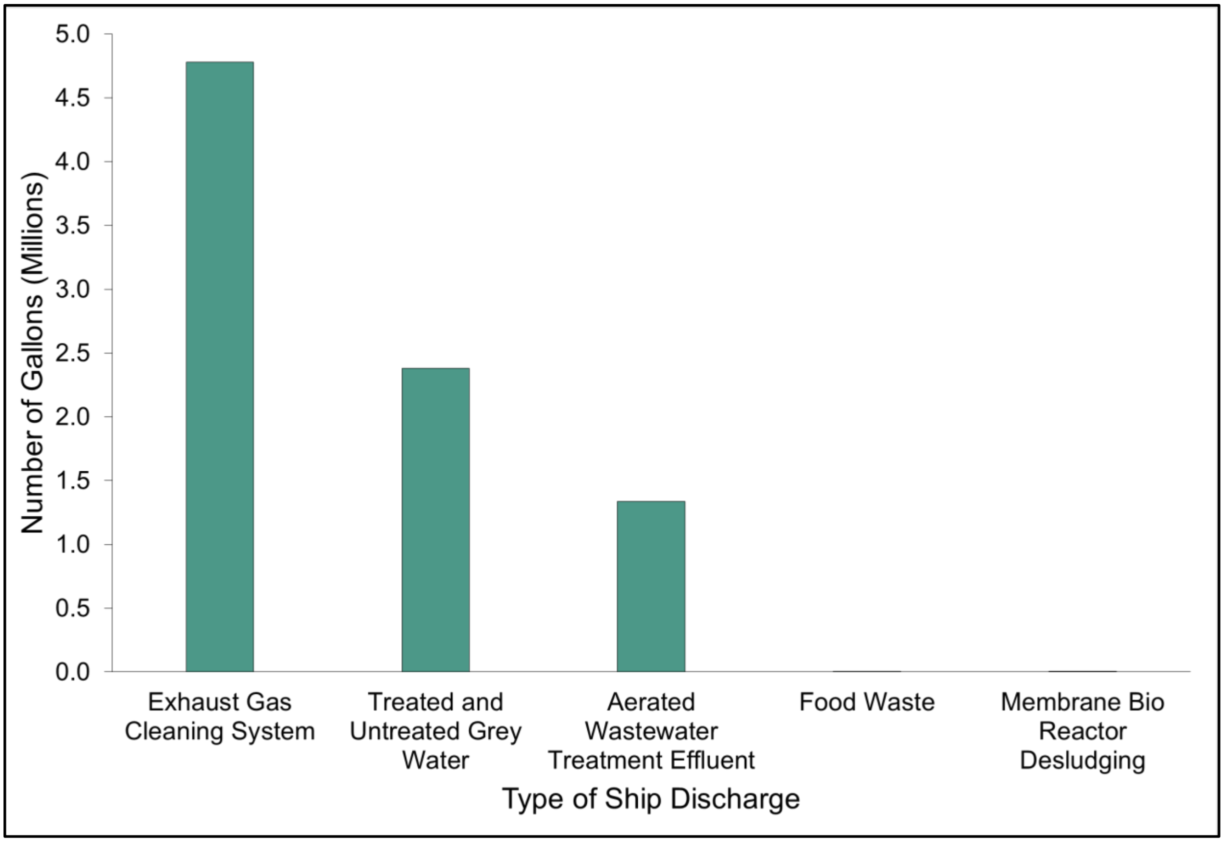


Figure S.WQ.9.2. Illegal waste stream discharges into GFNMS by type from five cruise ships operated by Princess Cruise Lines, Ltd. between 2015–2017. Food waste and membrane bio reactor desludging values are negligible (<7,000 gallons). Source: Blank Rome LLP, 2017

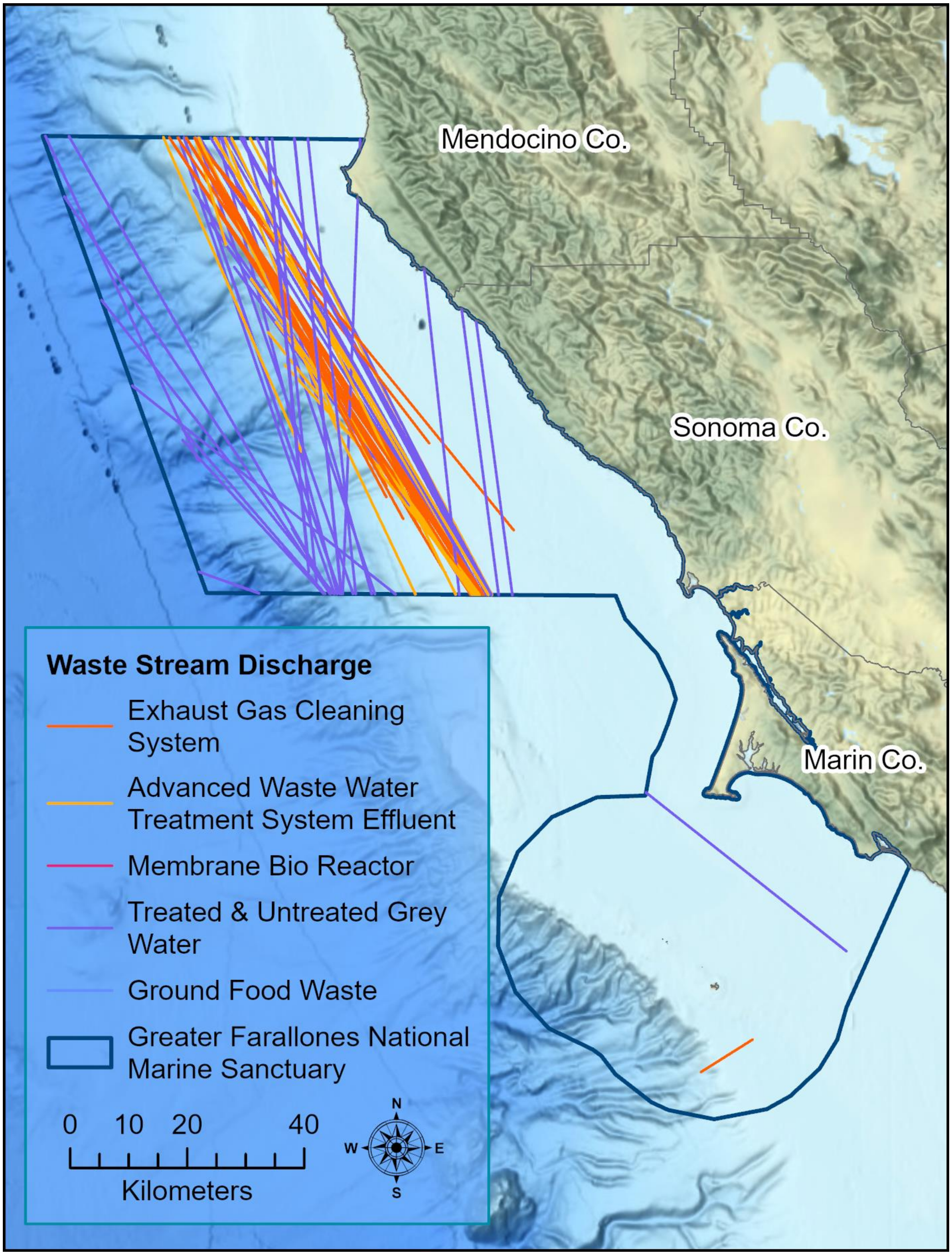


Figure S.WQ.9.3. Waste streams by type discharged by five cruise ships between 2015–2017 were estimated from the start and end points of each ship's transit, provided by the cruise ship companies. In some cases, the straight line connecting the start and end points artificially appears to show ship transits close to land, which did not occur. Image: NOAA; Source: Blank Rome LLP, 2017; Esri, 2020

Over half of the volume discharged originated from the use of EGCS (scrubbers; Figure S.WQ.9.1), which is prohibited in sanctuary waters (see Question 2). Scrubbers remove harmful substances from vessel exhausts; however, some of those substances are transferred to the water used to wash the exhaust. These may include pollutants (especially PAHs, which are toxic to marine life; Incardona et al., 2015), nutrients, and trace metals (EPA, 2011). Scrubber washwater can also alter water temperature, pH, oxygen levels, and turbidity below the sea surface (EPA, 2011).

Most discharge is treated or contained, but when released, discharges can have localized impacts. Nutrients and other harmful compounds in waste streams, some of which may remain even after treatment, can degrade water quality (EPA, 2008). Treated[14] and untreated blackwater and graywater have similar constituents but pose different levels of risk. These waste streams contain micropollutants, which are biological or chemical contaminants in trace quantities that can accumulate in the marine environment. Vessels, especially those that carry many passengers, such as cruise ships, are considered to be significant sources of micropollutants (Westhof et al., 2016). The illegal discharges that occurred between 2015–2017 within GFNMS included micropollutants that had the potential to impact water quality.

Dredge Material Discharges

Since 1999, a computerized recording system aboard dredge barges and scows has documented and notified the sanctuary of the location of accidental spills or premature dumping outside the SF-DODS disposal site (U.S. Army Corps of Engineers, 1998). During the reporting period for the previous condition report, the total volume of dredged material spills was estimated to be 69,695 cubic meters (91,158 cubic yards[15]). Between 2011 and 2016, there were no incidents of leaks or spills within GFNMS. Between 2017 and 2021, approximately 16.4 cubic meters (21.5 cubic yards) of dredged materials leaked into GFNMS, which represents a significant decrease compared to the previous condition report study period (Figure S.WQ.9.4).

[14] Treated sewage includes advanced wastewater treatment system and membrane bioreactor permeate discharges.

[15] One cubic yard is approximately the size of a standard home washing machine.

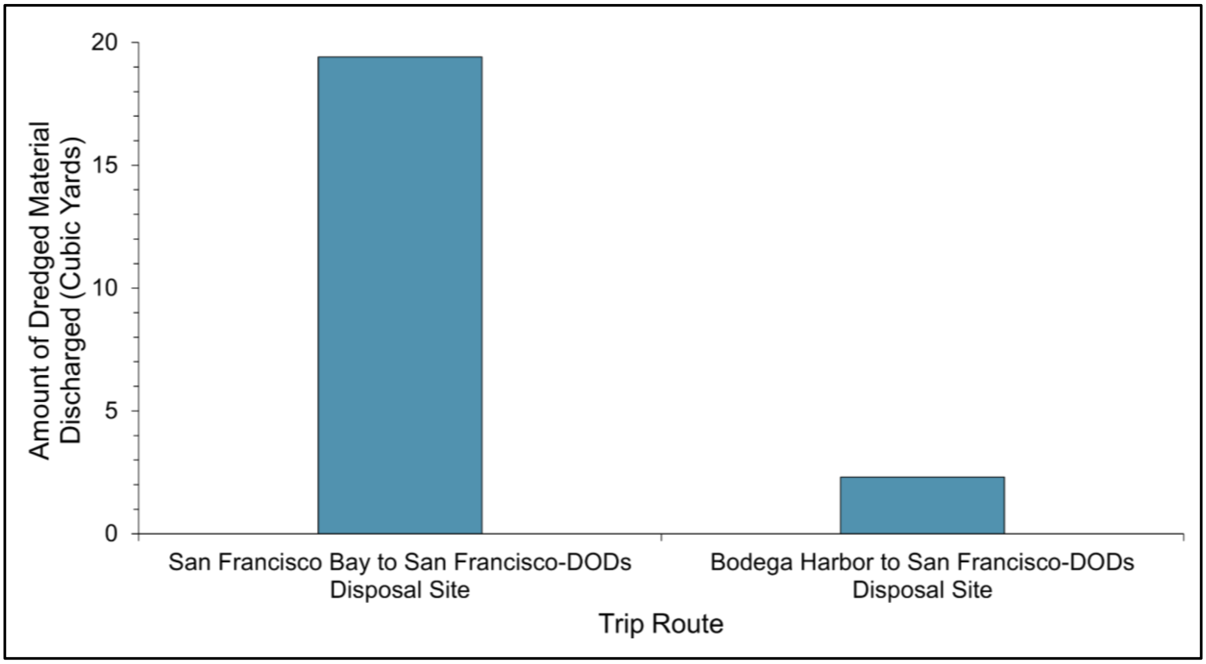


Figure S.WQ.9.4. Estimated dredged material discharged within GFNMS from leaking and spilling barges between 2017–2021. Calculations were based on the proportion of the trip that occurred in sanctuary waters (57.4% of the total reported amount lost along the route from San Francisco Bay to SF-DODS disposal site and 43.1% of the total reported amount lost along the route from Bodega Harbor to SF-DODS disposal site was within GFNMS). A consistent rate of loss over time was assumed. Source: Etrac, 2022

Oil and Other Discharges

Materials discharged or dumped from vessels, whether solid or liquid, can contain toxic chemicals, including asbestos, lead, PCBs, heavy metals, petroleum hydrocarbons, and petroleum metabolites. These substances can interfere with ecological and biological processes (Bryan, 1971; Ansari et al., 2004) and some, like PCBs, can bioaccumulate, adversely impacting the health of humans and wildlife (Beyer & Biziuk, 2009; Watanabe, 2001).

No major oil pollution events were reported during the study period. The amount of leaks and spills from small vessels are unknown. Although there have been no large vessel-based spills for this study period, small oil releases and discharges of other materials (e.g., polystyrene, plastic, solvents, paint, other cleaning products) occurred from 2010–2021 as a result of small to medium sized vessel groundings (see Question 2 for more information). The full extent of the impacts from these releases, as well as the types of materials released and trends, is not known.

Emissions

Greenhouse gas emissions impact global ocean temperatures and ocean chemistry. As a result of warming caused by greenhouse gas emissions and increasing greenhouse gas levels (Figure S.WQ.9.6), global ocean heat content anomalies (Figure S.WQ.9.5) have increased over time (National Centers for Environmental Information, 2023b; more information on this topic is provided in Question 8). Emissions from ships are deposited relatively close to the source vessel and become dissolved or suspended in the surface ocean, directly impacting the sanctuary. About 30% of carbon dioxide released into the atmosphere has been absorbed by the global ocean, resulting in a reduction in global mean surface ocean pH and a two-degree increase in global average surface temperature since the industrial revolution.

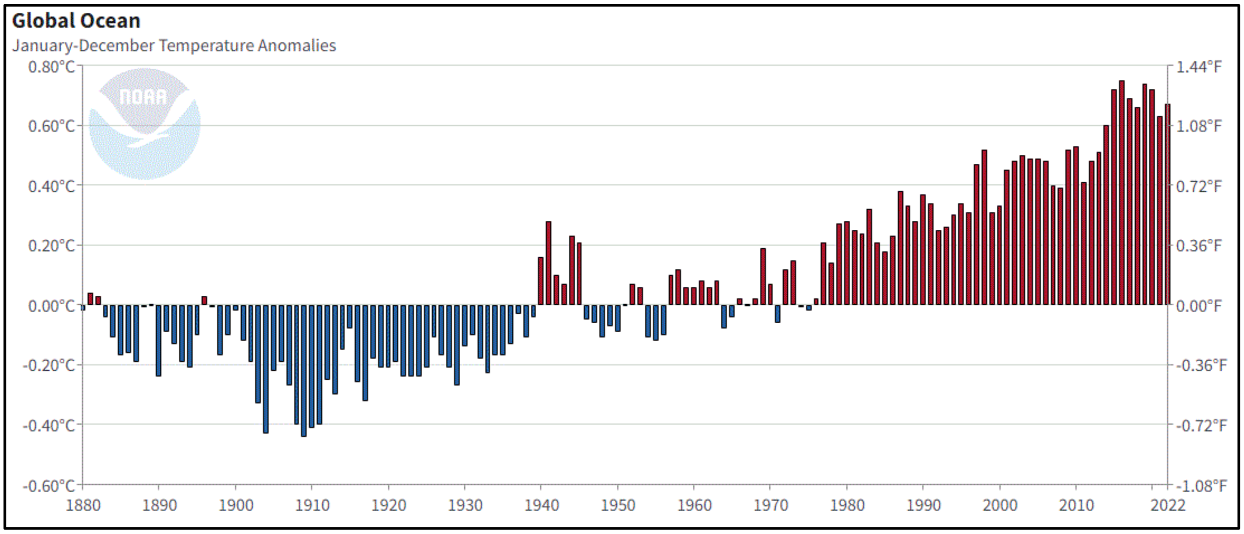


Figure S.WQ.9.5. Annual global ocean surface temperature anomalies, 1880–2022. Source: National Centers for Environmental Information, 2023b

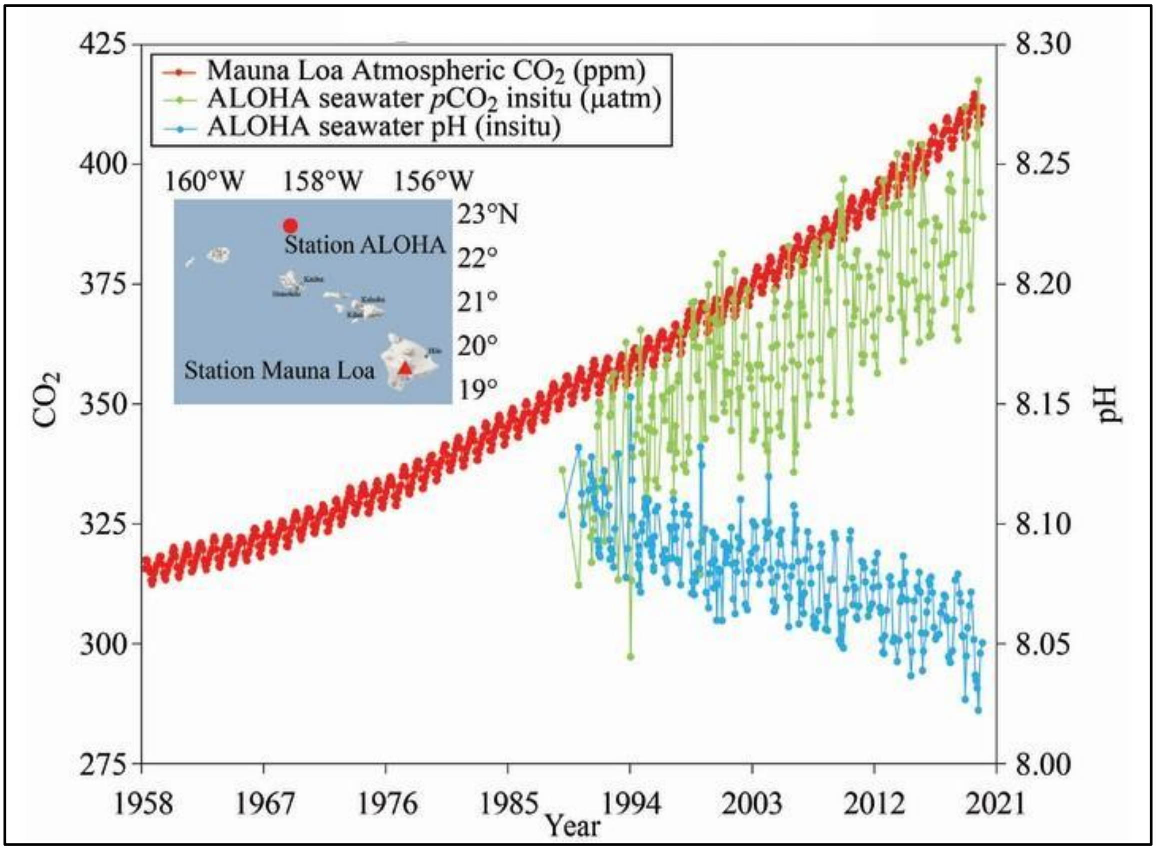


Figure S.WQ.9.6. Carbon dioxide and pH measurements in the north Pacific Ocean. Atmospheric data were collected at Station Mauna Loa and seawater data were collected at Station ALOHA (see inset). pH and pCO_2 were calculated at in situ temperature from dissolved inorganic carbon and total alkalinity. Source: Tans & Keeling, 2021; Adapted from Dore et al., 2009; Image: NOAA

Fine Sediment Transport

The transportation of fine sediment through the sanctuary impacts turbidity (suspended sediments). Suspended sediment can be harmful to eggs and larvae through burial or encasement of eggs in fine particles occupying interstitial spaces (Greater Atlantic Regional Fisheries Office, 2023). High suspended sediment levels can also cause a reduction in dissolved oxygen levels, which can have lethal and sub-lethal effects on fish species (Servizi & Martens, 1992). Deposited particles can indirectly impact biota as a vector for pollutants and contaminants and can directly impact biota by decreasing light penetration and suppressing primary production in algae and macrophytes (Noe et al., 2020).

Changes to fine sediment transport rates can occur through shoreline and upland development and human activities such as shoreline hardening, including seawalls and riprap (Grandpre et al., 2018). However, information was not available on specific changes to turbidity and sedimentation resulting from sediment imbalances within GFNMS, and there were no data to support the assessment of trends.

Conclusion

This question was rated good/fair based on moderate levels of known or suspected impacts from microplastic pollution, U.S. Coast Guard vessel discharges, dredged material discharges, and vessel oil spills. However, cruise ship discharges during the study period were high. A mixed trend was assigned to reflect the declining number of oil spills and unauthorized dredged material discharge incidents, as well as reported cases of illegal discharges by cruise ships. Furthermore, it is likely that most types of discharges are underreported, particularly those from the many small vessels using the sanctuary. Some point source discharges have declined because of the use of technology (i.e., dredge disposal barge monitoring). Trend data for microplastics, cruise ship discharges, other discharges from vessels, and sediment imbalances were unavailable for this assessment.

Estuarine and Lagoon Region

Status Description: Selected stressors have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Pathogens from human and animal waste were prevalent in Tomales Bay; however, management actions have been taken to address this issue. Microplastics were detected in Tomales Bay sediments and biota, suggesting they were also present in the water column. There have been measurable improvements in sediment transport and tidal prism in Bolinas Lagoon due to restoration activities. Trend data were unavailable for most indicators, and no data for Estero Americano or Estero de San Antonio were available.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair and the trend was undetermined. The rating was based on land use pressures that resulted in sedimentation, which in some cases led to the loss of eelgrass beds. Pollution from terrestrial sources resulted in the presence of mercury (covered in Question 2 in the current report) and fecal coliforms.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included sewage-related stressors, sources of pathogens, nonpoint source pollution, sediment and sediment transport, and microplastics (Table S.WQ.3.1).

Table S.WQ.9.2. Summaries for the key indicators related to other stressors affecting water quality in the estuarine and lagoon region of GFNMS that were discussed during the May 19, 2022 virtual status and trends workshop.

Indicator	Data Source/data visualization	Data Summary	Figures
Sewage-related stressors	CDPH, 2017, 2020, 2021a, 2021b; CSWRCB, 2022a; Ghodrati, 2022	Status: Human and animal waste enters Tomales Bay through a variety of sources. Wastewater treatment facilities did not impact water quality in the bay during the study period, and efforts to reduce waste discharge from boaters increased. However, fecal coliforms were measured in Tomales Bay during the study period, and shellfishery closures and beach advisories were issued due to fecal coliform contamination concerns. Trend: Trend was not assessed.	S.WQ.7.8; S.WQ.7.9

Indicator	Data Source/data visualization	Data Summary	Figures
Sediment and sediment transport	Marin County Parks and Open Space District, 2017	Status: Changes to sediment transport have impacted the hydrological function of Bolinas Lagoon. Trend: Restoration efforts in some areas of Bolinas Lagoon since 2010 have increased water flow, improving water quality.	N/A
Microplastics	Box & Cummins, 2019; Sutton et al., 2019	Status: Microparticles and microplastics were found in Tomales Bay sediment and fish, suggesting they are also likely present in Tomales Bay waters. Trend: No trend data were available.	N/A
Data gaps	Trend data were unavailable for most indicators. Data were unavailable or mostly unavailable for the esteros and Bolinas Lagoon, respectively. Information on sediment transport in the esteros and Tomales Bay was not available.		

Sewage-Related Stressors

A number of indicators presented earlier in this report (see Questions 2 and 7) were also considered in the evaluation of this question, including waterborne pathogens, beach water quality, and shellfishery closures. Briefly, Tomales Bay is considered an impaired water body (under Section 303(d) of the Clean Water Act) due to the presence of pathogens originating from human and animal waste. In addition to potential health risks from pathogens, human and animal waste can promote eutrophication and make ecosystems vulnerable to impacts from invasive species and harmful algal blooms (San Francisco Bay Regional Water Quality Control Board, 2005).

Human and animal waste may be introduced via runoff from agricultural or residential areas, failing septic systems or small wastewater treatment facilities, discharges from boaters and campers, and wildlife. Eight wastewater treatment facilities are present within the Tomales Bay watershed. Although none of these discharge directly into Tomales Bay, malfunctions may threaten water quality in the bay; however, no spills or discharges into the bay were reported during the study period (CDPH, 2021a), suggesting these facilities did not adversely impact water quality during the study period. The Marshall Community Wastewater System was completed in 2016 to address water quality issues associated with failing septic systems associated with 50 properties on the eastern shore of the bay (CDPH, 2021a; CSWRCB, 2022a). From July 2016 to June 2017, there were three effluent violations in which the fecal coliform seven-day mean exceeded the established threshold of 2.0 most probable number; however, the leach field was working properly during this time, and thus these violations did not affect Tomales Bay water quality (CDPH, 2017). Additionally, the installation of a waste receptacle station at Marin County's Miller Park Boat Launch is believed to have reduced the likelihood of waste discharge from boaters (see Question 2) and since 2020, new CDPH initiatives have aimed to increase monitoring and enforcement; improve public outreach; and develop new policy and regulatory initiatives to further reduce discharges from boaters (CDPH, 2021b).

Despite these improvements, pathogens associated with fecal contamination were measured in Tomales Bay during the study period. The following water quality indicators are presented in Question 7 of this report, but are summarized briefly here. Fecal coliform thresholds were exceeded in 131 water quality samples since 2010 at 16 sampling locations in tributaries of Tomales Bay that are monitored by the Regional Water Quality Control Board (Ghodrati, 2022). Rainfall-related closures of commercial shellfish operations, enacted to mitigate fecal coliform impacts to human health, occurred for 1,291 days from 2009 to 2021 (Figure S.WQ.7.8). Additionally, elevated levels of pathogenic bacteria associated with fecal contamination resulted in advisories for Tomales Bay Beaches annually throughout the study period (Figure S.WQ.7.9). Tomales Bay was also affected by infrequent outbreaks of norovirus, another human-waste-related pathogen, which led to shellfishery closures in 2018 and 2019 (CDPH, 2020, 2021b).

Sediment and Sediment Transport

Sediment levels and sediment transport are not measured in most estuaries and lagoons in GFNMS. However, studies from Bolinas Lagoon showed that since the early 19th century, human land uses have altered the shoreline and watershed, changing the proportion of sediment reaching the lagoon; threatening water quality by reducing wetland habitat, which filters water, and the exchange of lagoon and ocean water; and altering the rate at which natural processes shape the lagoon. The result was human-induced alteration of natural processes, which resulted in reduced tidal prism (the volume of water entering and exiting the lagoon during a tidal cycle) and changed the composition of plants, animals and habitats (Gulf of the Farallones National Marine Sanctuary, 2008). Since 2010, multiple actions, including culvert and road repairs surrounding Bolinas Lagoon and removal of invasive species, primarily at Kent Island (but also at other locations in and adjacent to the lagoon), which negatively affected hydrology, resulted in increased tidal prism in Bolinas Lagoon. A comparison of bathymetric data from 1998, 2012, and 2016 showed that the Bolinas Lagoon tidal prism increased from approximately 2.8 million cubic meters (3.7 million yd^3) in 1998 to 3 million cubic meters (4.0 million yd^3) in 2016 (Marin County Parks and Open Space District, 2017). These data also help scientists track shifts in habitat and sediment supply, which informs planning and prioritization of future restoration projects.

Microplastics

Sediment samples were collected at 18 sites in San Francisco Bay and two sites in Tomales Bay to assess baseline levels of microplastics in sediment and evaluate spatial distribution, including the influence of urban stormwater and wastewater discharges (Box & Cummins, 2019; Sutton et al., 2019). Tomales Bay sediment contained microparticles and microplastics, suggesting these are also present in Tomales Bay waters, but their abundance was among the lowest observed compared to areas within San Francisco Bay. Topsmelt and anchovies, both of which are prey species that could be indicators of water quality contaminants, were also sampled for microplastics in Tomales Bay (Box & Cummins, 2019; Sutton et al., 2019). Microparticles were found in both species, but at lower levels compared to San Francisco Bay sites.

Conclusion

This question was rated fair based mainly on the ongoing presence of pathogens, specifically fecal coliforms, at multiple locations in Tomales Bay. Several sources were identified as ongoing pathogen contributors, including boaters and campers, as well as nonpoint source pollution from land runoff. In addition, microplastics were present in Tomales Bay. Human land use has affected hydrology, threatening water quality in Bolinas Lagoon; however, improvements were made during the study period. The trend was undetermined because of analysis gaps and a lack of time series data available for several indicators. Additionally, most of the available data were only for Tomales Bay.

Status and Trends of Habitat (Questions 10–11)

The following sections assess the status and trends of key habitat indicators in GFNMS for the period from 2010–2022. We have noted where more recent data (e.g., 2023) became available during editing of this report.

Question 10 focuses on the integrity of major habitats within the sanctuary, including biologically structured (biogenic) and abiotically structured (physical) habitats. Physical habitats are abiotic structures (e.g., rocky reefs), while biogenic habitats (e.g., corals) 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 concentrations and variability of contaminants in major sanctuary habitats.

Because of the considerable differences in environmental pressures and responses between the coastal and offshore region and the estuarine and lagoon region, each question was assessed twice in order to represent these two environment types separately.

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

Coastal and Offshore Region

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

Rationale: There has been a significant loss of kelp canopy cover, stipe density, and understory algae and a proliferation of urchin barrens during the assessment period, resulting in a decline in habitat integrity. Sediment imbalances occurred along sandy beach habitat; however, shoreline armoring was stable during the study period. Structure-forming species within the rocky intertidal habitat were apparently stable in general. Healthy deep-sea coral and sponge habitats were documented in the sanctuary; however, sunken marine debris was also found at these sites.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, habitat integrity was addressed in two different questions, one focused on the abundance and distribution of major habitat types, and another focused on biologically structured habitat types. The status for both questions in the coastal and offshore region was good/fair and the trend was improving and undetermined, respectively. Although localized impacts from human population growth were of concern, these were potentially offset by reductions in trawling and improved management of dredged material disposal. Data gaps were present for some sanctuary habitats.

New Information in the 2010–2022 Condition Report

For this report, all major habitat types were assessed collectively. The area of the sanctuary more than doubled in size in 2015, adding deep-water habitats off the continental slope, including Arena Canyon, and surrounding pelagic habitat. Indicators used to evaluate this question included shoreline armoring, sandy beach habitat, rocky intertidal habitat, kelp canopy cover, kelp stipe density, understory kelp and algae density, deep-sea coral and sponge abundance, and deep-sea marine debris (Table S.H.10.1).

Table S.H.10.1. Summaries for the key indicators related to habitat integrity in the coastal and offshore region of GFNMS that were discussed during the June 9, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures and Tables
Shoreline armoring	California Coastal Commission, 2022	Status: A very small percentage of GFNMS coastal shoreline is armored. Trend: No new armoring has occurred in GFNMS (i.e., below mean high water) since 2010 and the trend was stable.	N/A
Sandy beach	Griggs, 2015; Lester et al., 2022; Hapke et al., 2009; Kordesch et al., 2019	Status: GFNMS has a significant length of sandy beach along its coastal shoreline. Trend: The majority of beaches in GFNMS are experiencing erosion that threatens beach and dune ecosystems. More data are needed to assess long-term trends at specific locations across the sanctuary.	N/A
Rocky intertidal	Multi-Agency Rocky Intertidal Network [MARINe], 2021	Status: Rocky intertidal sites in GFNMS span a variety of conditions, such as substrate type, wave energy, and exposure. Trend: There was some variability in recent trends for key species at three monitoring sites in GFNMS; however, several important habitat-forming species appeared to be generally stable. California mussel percent cover declined during the assessment period but appeared to be trending toward recovery at all sites. Acorn barnacles and dwarf/golden rockweed appeared to be stable, while turfweed algae and northern rockweed declined.	Figure S.H.10.1

Indicator	Source	Data Summary	Figures and Tables
Kelp forests	Freiwald, 2020; McPherson et al., 2021; California MPA Monitoring Data Portal, 2022; Bell et al., 2023	Status: Annual total kelp canopy area and kelp stipe density were high before 2014 and low after 2014. Annual understory percent cover was lower after 2014 than before 2013, with the level of decline dependent on species. Trend: Kelp canopy cover, kelp stipe density, and understory cover declined during the study period (2010–2022).	Figure S.H.10.2
Deep-sea corals and sponges	Etnoyer et al., 2014; Graiff et al. 2016, 2021	Status: Healthy coral and sponge colonies have been documented at several surveyed locations during four cruises since 2010. Trend: The trend was undetermined due to a lack of data for the study period (2010–2022).	Figure S.H.10.3; Table S.H.10.2
Deep-sea marine debris	Etnoyer et al., 2014; Graiff et al. 2016, 2021	Status: Deep-sea debris was documented on all ROV surveys conducted within GFNMS since 2010. Trend: The trend was undetermined due to a lack of data for the study period (2010–2022).	N/A
Data gaps	More monitoring plots are needed to fully assess trends for rocky intertidal habitat throughout the sanctuary. More data are needed to better assess the status and trends for sandy beach habitat. More data are needed on deep-sea coral and sponge habitat and sunken marine debris. Benthic habitat mapping is needed in areas where fishing occurs to help assess benthic habitat impacts. More data on anthropogenic noise impacts to the GFNMS soundscape are needed.		

Shoreline Armoring

Shoreline armoring can be an indicator of habitat integrity, as human-made structures can alter habitat in a variety of ways, including direct replacement; changing natural sediment dynamics and transport; hastening the loss of sandy beach seaward of and exacerbating erosion "downstream" of armored structures; blocking migration to certain habitats as sea level rises; and causing the loss of rocky intertidal habitats, upper beaches, and estuarine marsh habitats (Dugan et al., 2008; Grandpre et al., 2018; Von Holle et al., 2019). As of 2018, 13.9% of the entire state of California's coastline was armored, representing a 5.5-fold increase over 47 years (Griggs & Patsch, 2019) and reducing sand supply in the state by an average of 11% (Grandpre et al., 2018).

GFNMS regulations prohibit the placement of new structures below the mean high water line. However, armoring does occur adjacent to and above the mean high water line (i.e., outside the GFNMS boundary). Further, historic armoring exists below the mean high water line inside sanctuary boundaries at numerous locations. From the northern to southern boundary of GFNMS, there are 216 instances of armoring within the sanctuary, totaling 8,577.6 meters. This value excludes armoring locations within Point Reyes National Seashore, where the sanctuary boundary is 1/4 mile offshore; there are five additional instances of armoring within Point Reyes

National Seashore (outside GFNMS boundaries) totaling 102.3 meters. Of the instances of armoring within GFNMS boundaries, 125 of these (4,432.1 m) are within Tomales Bay. Marin County has 165 instances of armoring, Sonoma County has 50 instances of armoring, and Mendocino County has six instances of armoring. Types of armoring include revetments, seawalls, retaining walls, bulkheads, surface armoring, and other hardscaping. Since 2010, no new armoring has been constructed within GFNMS, and all maintenance of existing armoring has stayed within the existing footprints; thus, the trend was stable.

Sandy Beach Habitat

The majority of beaches in GFNMS are experiencing erosion that threatens beach and dune ecosystems. California coastlines have been retreating for decades (Griggs, 2015; Lester et al., 2022), with greater than 40% of California beaches chronically eroding in the long term (Hapke et al., 2009). Additionally, Northern California is experiencing the highest overall coastal cliff retreat rates (Hapke et al., 2009). Modeling based on long-term shoreline trends from satellite imagery estimates that, without interventions, 24–75% of California's beaches may be completely eroded by 2100 due to future sea level rise scenarios of one to three meters, respectively.

With worsening impacts from climate change and sea level rise, sandy beaches were identified as one of the most vulnerable habitats that may experience erosion and sand loss (Hutto et al., 2015). More shoreline change data are needed to better understand long-term trends, and more beaches need to be surveyed to fully assess the integrity of sandy beach habitat in the sanctuary. Additionally, more research is needed that considers a systems-based approach to work towards a broader understanding of natural sediment transport processes on a regional and watershed scale (Kordesch et al., 2019). More studies on specific sediment source/sink estimates would provide more reliable estimates of sand budgets and resulting understanding of accretion/erosion at a given coastline (Kordesch et al., 2019).

Rocky Intertidal

The health of key habitat-forming species in a region is a good indicator of rocky habitat integrity. Information on rocky intertidal communities is collected and shared through the MARINe program which monitors over 200 sites from Alaska to Mexico. Rocky intertidal sites in GFNMS span a variety of conditions, such as substrate type, wave energy, and exposure and results from one site may not be reflective of conditions throughout the sanctuary. Additionally, all key habitat-forming species are not monitored at every site. Sufficient long-term monitoring data on these species were available from three of the 12 MARINe monitoring sites in the sanctuary: Sea Ranch, Bodega Marine Life Refuge, and Bolinas Point (Figure S.H.10.1). California mussel (*Mytilus californianus*) declined after the 2014–2016 MHW but appeared to be recovering in Marin and Sonoma counties. See Question 13 and Figure S.LR.13.6 (Multi-Agency Rocky Intertidal Network [MARINe], 2022) for more information on this topic. Annual percent cover for acorn barnacles (*Chthamalus fissus*, *C. dalli*, *Balanus glandula*) and dwarf/golden rockweed (*Pelvetiopsis* spp.) was measured at two of the three sites, Sea Ranch and Bolinas Point, and varied recently but was generally stable during the study period. Annual percent cover of turfweed algae (*Endocladia muricata*) was monitored at two of the three sites and was stable at Sea Ranch but declined at Bodega Marine Life Refuge. Cover of northern rockweed (*Fucus* spp.) declined substantially at Bolinas Point and was very low in plots at Bodega Marine Life Refuge during the study period. Surfgrass (*Phyllospadix* spp.) abundance appeared stable but was only monitored at one site (MARINe, 2022). Rocky intertidal monitoring data were also collected at Southeast Farallon Island; however, there was an analysis gap for this data set. In general, more intertidal monitoring sites and data are needed to determine long-term trends for each of the habitat-forming species in GFNMS.

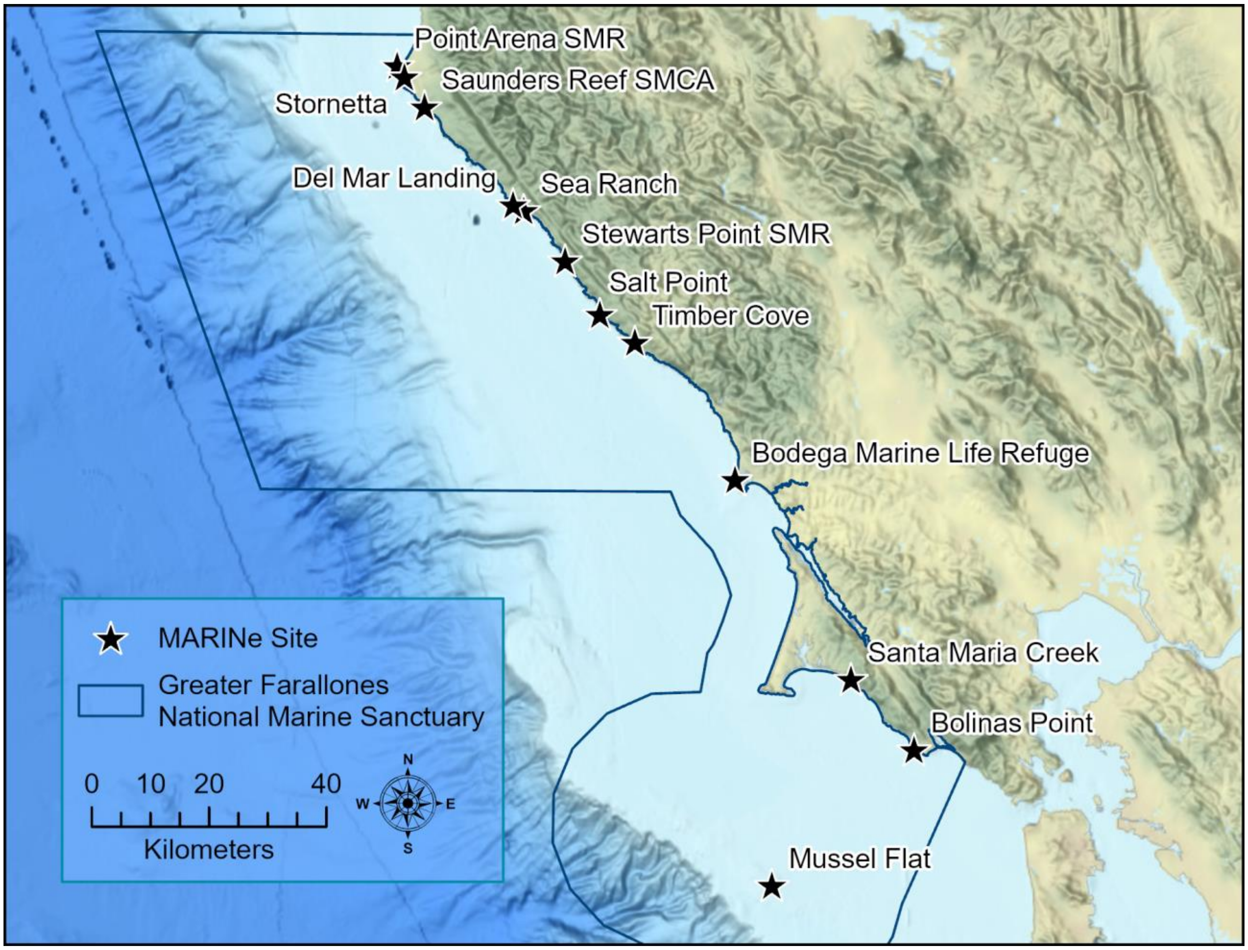


Figure S.H.10.1. Map of GFNMS indicating long-term monitoring and biodiversity survey locations conducted by the Multi-Agency Rocky Intertidal Network (MARINe), CDFW, and the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO). Not all core or target species are sampled at every location. Only locations where intertidal or subtidal data were used in this report are shown on this map. Image: NOAA; Source: MARINe, 2021; Esri, 2020

Kelp Forests

The nearshore rocky habitat along northern California is dominated by canopy-forming bull kelp (*Nereocystis luetkeana*), which forms dense underwater forests that marine organisms depend on for shelter and food (Springer et al., 2010; Hohman et al., 2019). An annual species, bull kelp exhibits strong spatial and temporal variability in distribution and abundance, and under ideal conditions can grow up to six centimeters per day (Springer et al., 2010). However, significant stressors on the ecosystem, such as the MHW of 2014–2016, can elicit a state shift from a kelp forest to an urchin-dominated state, subsequently impacting nearshore ecosystems and fisheries (Rogers-Bennett & Catton, 2019; McPherson et al., 2021). Urchin barrens in northern California are characterized by higher than average densities of purple sea urchin (*Strongylocentrotus purpuratus*), low biodiversity, and little to no macroalgae (Beas-Luna et al., 2020). Kelp forests may substantially contribute toward carbon sequestration and are thus a vitally important contributor to blue carbon (Hutto et al., 2021). Kelp forests may also mitigate the effects of ocean acidification (Pfister et al., 2019).

Long-term monitoring data on kelp canopy cover are collected at various sites throughout GFNMS (Bell et al., 2023). Greater than 90% of bull kelp forest habitat in northern California has been lost since 2014 due to compounding ecological stressors. Beginning in 2013, sea star wasting syndrome led to widespread mass mortality among 20 sea star species in northern California (and more generally the entire Eastern Pacific); some of these species are predators of urchins (Schultz et al., 2016; McPherson et al., 2021). A MHW in 2014–2016 (Di Lorenzo & Mantua, 2016; Bond et al., 2015; Gentemann et al., 2017; Elliott et al., 2022a), which overlapped with strong El Niño conditions (2015–2016), followed by another MHW in 2019 (see Figure S.WQ.8.3 and Figure S.WQ.8.4) contributed to the dieoff of kelp (Roger-Bennett & Catton, 2019; McPherson et al., 2021; Bell et al., 2023). The area and densities of bull kelp were greatly reduced and revealed widespread recruitment failure, resulting in the development of both habitat and food limitations for associated species within the ecosystem (Cavanaugh et al., 2019; Beas-Luna et al., 2020). In addition, purple urchin recruitment yielded populations that increased to greater than 60 times normal levels due to a lack of predation (Rogers-Bennett & Catton, 2019; Okamoto et al., 2020) and shifted behavior from passive feeding on algal detritus to active grazing on kelp and other marine algae, effectively outcompeting other herbivores such as abalone and red urchin. Following the decimation of “fleshy” benthic algae, purple urchins began grazing on the long-lived and slow-growing crustose coralline algae, thus creating large swathes of bare rock, which are unsuitable for post-larval settlement of abalone. Aerial surveys revealed that significant bull kelp canopy extent was lost and subtidal surveys confirmed a state shift to urchin-dominated conditions (McPherson et al., 2021). Recreational red abalone (*Haliotis rufescens*) and commercial red sea urchin fisheries in the region have collapsed, and deleterious cascading effects for other nearshore fisheries are expected in the coming years.

Kelp Canopy Cover

Since the extreme MHW of 2014–2016, greater than 90% of bull kelp, the primary kelp forest species in northern California, has been lost (McPherson et al., 2021; Roger-Bennett & Catton, 2019; Bell et al., 2023; Figure S.H.10.2). A slight increase in kelp canopy cover was observed in 2021, but there has been no significant recovery of kelp forests in GFNMS as of 2022 (Bell et al., 2023). Historical kelp persistence, or areas where kelp canopy occurred more frequently than surrounding areas prior to 2014, was assessed using remote sensing data such as Landsat and aerial plane-based surveys. From 2014–2022, kelp persistence was nearly nonexistent in the sanctuary due to extremely sparse growth (McPherson et al., 2021; Bell et al., 2023).

Kelp Stipe Density

Kelp stipe (the single stalk of each bull kelp) density data have been collected sporadically since 2008 by divers in GFNMS. PISCO collected data at multiple sites in 2010, 2011, and 2016–2019, as well as at Point Arena in 2021. Reef Check California monitoring data were available from

2007–2019 for four sites and 2011–2019 for two sites. Based on the limited data available, it appears most sites in GFNMS experienced high interannual variability until 2013, at which point a significant decline in kelp stipe density occurred (California MPA Monitoring Data Portal, 2022). Very little data exist after 2019; however, the 2021 Point Arena data show that stipe density remained low at that site. The decline in kelp stipe density was consistent with kelp canopy cover patterns. No significant increase or recovery of stipe density has been observed as of 2022.

Understory Kelp and Algal Density

Understory algal density for two dominant species, *Pterygophora californica* and Setchell's kelp (*Laminaria setchellii*), has declined since 2014, likely as a result of overgrazing by purple urchins, which increased in abundance over the same time period (California MPA Monitoring Data Portal, 2022). The density of erect coralline red algae has decreased, crustose red algae has increased, and fleshy red algal has varied since 2010. Thus, red algal groups had a mixed trend over the study period (California MPA Monitoring Data Portal, 2022; Freiwald et al., 2020).

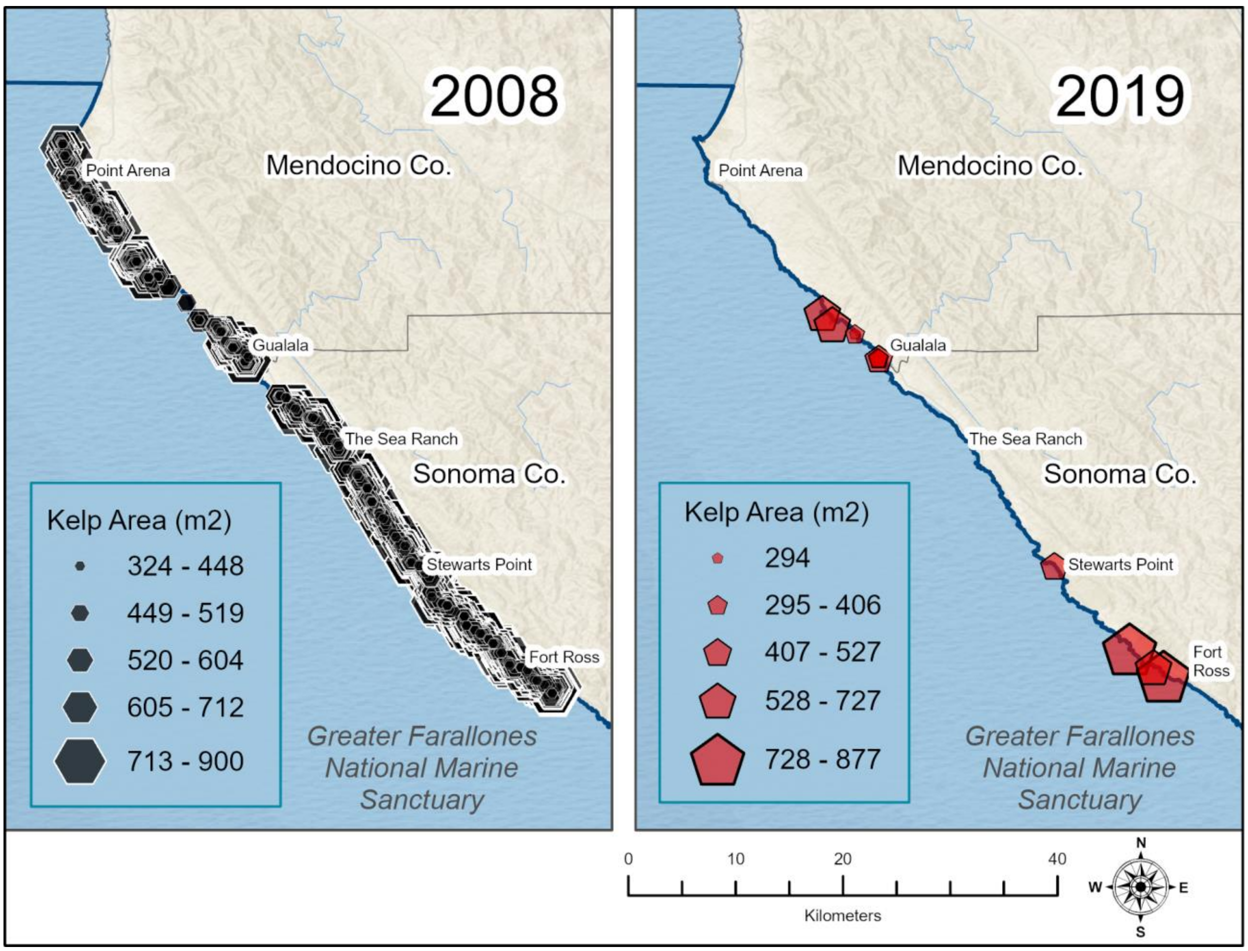


Figure S.H.10.2. Bull kelp canopy cover along the Sonoma Coast in 2008 and 2019. Image: NOAA; Source: Bell et al., 2023; Esri, 2016

Deep-Sea Corals and Sponges

Since 2010, four research cruises have used an ROV to visually ground-truth habitat types in GFNMS that were predicted from multibeam sonar data. However, the areas that have been visually surveyed in the deep sea (50 m or deeper as defined by NOAA's Deep Sea Coral Research and Technology Program) account for less than 1% of GFNMS seafloor (NOAA Deep Sea Coral Research and Technology Program, 2022). Of all the sites visually surveyed, Rittenburg Bank exhibited the highest density of sponges (Etnoyer et al., 2014; Table S.H.10.2). Additionally, many small corals and sponges were observed at the bank, suggesting recent recruitment, which can be an indication of a healthy benthic invertebrate community. A new species of gorgonian coral was also identified from samples collected during the survey at Rittenburg Bank (Etnoyer et al., 2014). The highest densities of large sponges were observed in areas of highest rugosity at the bank, which are also areas where trawling is not likely to occur. Since the early 2000s, there have been several mandated changes to the size of trawl roller gear and footropes that prevent the use of trawl gear in areas of high relief, which can damage the gear. Impacts of historic commercial fishing to GFNMS benthic habitat were evident, including the presence of derelict fishing gear, like lines and ropes tangled on the rocks at the Point Arena Biogenic Area South Essential Fish Habitat Conservation Area, which was established in 2005 and prohibits bottom-trawling, and a Rockfish Conservation Area (which is a depth-based, year-round closure area that prohibits fixed gear [hook and line], trawl gear, and traps at various depths) offshore off Point Arena, established in 2006 (Graiff et al., 2021). In general, data on the locations of corals and sponges across GFNMS is limited to locations that have been explored with an ROV, and more exploration is needed for baseline characterization of the habitat and species present in the offshore environment of GFNMS, especially in the northern area of the sanctuary added during the expansion in 2015.

Figure S.H.10.3. ROV survey locations: Point Arena Biogenic Area, The Football, Rittenburg Bank, Cochrane Bank, and the Farallon Escarpment. Image: NOAA; Source: Etnoyer et al., 2014; Graiff et al., 2016, 2021; Esri, 2020

Table S.H.10.2. Coral and sponge density from sites surveyed during the four NOAA deep-sea ROV cruises in GFNMS since 2010 (see Figure S.H.10.3 for a map of these locations). Source: Etnoyer et al., 2014; Graiff et al., 2016, 2021

Site (Cruise Year)	Area Surveyed (m^2)	Coral and Sponge Density (per 1,000 m^2)
Rittenburg Bank (2012)	14,561	60 corals; 184 sponges
Cochrane Bank (2012)	8,626	30 corals; 64 sponges
Farallon Escarpment (2012)	2,229	26 corals; 29 sponges
The Football (2016)	5,632	6 corals/sponges[a]
Point Arena South (2019)	15,914	0.01–17.9 corals; 0.01–0.43 sponges[b,c]
Southern Point Arena South (2019)	14,859	0.01–0.27 corals; 0.01–0.42 sponges[b,c]
Total	61,821	N/A

[a] Coral and sponge density for The Football was reported as a combined number.

[b] Coral and sponge density for Point Arena South and Southern Point Arena South was reported separately by genus or by transect and is thus presented here as a range.

[c] The unit of measurement for the reported coral and sponge densities is per 100 square meters (not 1,000 square meters).

Deep-Sea Marine Debris

Marine debris was also recorded during the four ROV survey cruises since 2010, and was found at all surveyed locations except the Farallon Escarpment; however, only a small fraction of the escarpment was surveyed. Debris was documented throughout most survey areas and was encountered at an average rate of one item per 1.06 kilometers. Marine debris was found in all benthic habitats on the bank, shelf, and deep canyons (Etnoyer et al., 2014; Graiff et al., 2016, 2021). The most prevalent debris type observed was derelict commercial fishing gear, including longlines, gill nets, and crab gear (pots and lines). Commercial fishing gear has been observed entangled on benthic structures and various rocky and mixed habitats in the sanctuary, which may include corals and sponges. Entanglement with fishing gear can damage coral-and-sponge-associated biological communities. Such gear can also be an entanglement hazard to other pelagic marine life if it extends into the water column.

Conclusion

This question was rated as fair primarily due to the severe loss of kelp canopy cover, stipe density, and understory algae during the assessment period, which decreased the habitat integrity for other kelp-forest-dependent species (such as abalone). Sandy beach habitat is present through GFNMS but sediment imbalances and/or erosion have occurred at some sites. Shoreline armoring did not change during the assessment period. There was some variability in recent trends for rocky intertidal habitat; however, many structure-forming species appeared to be stable. Visual surveys to confirm habitat type, characterize coral and sponge communities, and quantify marine debris have occurred in a very small percentage of the sanctuary's seafloor habitat. Sunken marine debris was found during each of the ROV surveys conducted in GFNMS during this assessment period. More data are needed to better assess status and trends for sandy beach habitat; long-term trends for rocky intertidal species across the sanctuary; and deep-sea coral and sponge habitat and sunken marine debris prevalence.

Estuarine and Lagoon Region

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

Rationale: Estuarine and lagoon habitats in GFNMS remained significantly degraded compared to historic levels. There was no evidence that marsh or mudflat habitat has worsened since the last assessment, and some restoration projects have been undertaken to improve the integrity of these habitats. Anecdotal evidence suggested that Olympia oysters were low compared to historic levels. Eelgrass extent varied with no clear trend in Estero Americano and Estero de San Antonio, but may have increased at Tomales Bay (although differences in methodology preclude the full assessment of a trend); eelgrass was not present in Bolinas Lagoon, consistent with earlier surveys. More data are needed to better understand any specific quantitative changes in mudflat, marsh, and eelgrass over time and to assess the status and trends of Olympia oyster populations in all estuaries, especially Tomales Bay.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair/poor and the trend was not changing. Substantial levels of habitat loss had occurred due to erosion, accretion, and habitat conversion (e.g., lost wetland area due to diking, mining, dredging, filling and reclamation); increased sedimentation due to logging, agriculture, and construction in floodplains; and reduced freshwater input due to dams and water extraction. Loss of eelgrass in Bolinas Lagoon occurred as a result of watershed issues that caused sedimentation and elevation of mudflats. Loss of native oyster beds in Tomales Bay also occurred due to sedimentation, roadside maintenance activities, anchoring, and mooring. The 2010 condition report generally lacked a quantitative assessment of estuarine and lagoon habitats.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included quantitative data on marsh and mudflat extent in all sanctuary estuaries; anecdotal information on Olympia oysters; and eelgrass extent in Tomales Bay, Estero Americano, and Estero de San Antonio.

Table S.H.10.3. Summaries for the key indicators related to habitat integrity in the estuarine and lagoon region of GFNMS that were discussed during the June 9, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures and Tables
Marsh and mudflat extent	Golden Gate National Parks Conservancy et al., 2021	Status: Mudflat and marsh habitats occur in all four GFNMS estuaries and are most prevalent in Tomales Bay and Bolinas Lagoon. Marsh habitat was severely reduced compared to historic levels. Trend: Although restoration projects may have resulted in improvements in these habitats in Bolinas Lagoon and Tomales Bay, marsh and mudflat extent was generally stable during the study period.	Table S.H.10.4
Olympia oysters	Wasson et al., 2015; Grosholz, 2022.	Status: Olympia oysters declined dramatically along the West Coast over the last century. Anecdotal data indicates low abundance of oysters in Tomales Bay compared to historic levels. Trend: No trend data were available within GFNMS during the study period.	N/A
Eelgrass	Svejkovsky, 2013; PSMFC, 2018; CDFW 2023b; Merkel & Associates, Inc., 2017b; Sherman & DeBruyckere, 2018	Status: Eelgrass was documented in three estuaries in GFNMS, and was most prevalent in Tomales Bay. Trend: Eelgrass habitat was stable overall. However, eelgrass extent may have increased slightly in Tomales Bay. There was substantial interannual variability in the total extent of eelgrass in both Estero Americano and Estero de San Antonio.	Table S.H.10.5; Figure S.H.10.4
Data gaps	More data are needed to better understand specific quantitative changes in mudflat, marsh, and eelgrass over time, as well as the status and trends of Olympia oyster populations in Tomales Bay.		

Marsh and Mudflat Extent

Estuarine habitats in GFNMS have experienced significant historic habitat degradation, and the amount of marsh habitat has been severely reduced from historic levels (ONMS, 2010). In 2020, the National Park Service's Golden Gate National Recreation Area completed an assessment of habitat types across Marin County, including GFNMS estuaries. Data were compiled mainly from aerial ortho imagery collected in 2018 and LiDAR data collected in 2019–2020. The Golden Gate National Recreation Area combined the sources to produce a fine scale mapping data layer and created an online viewer in 2020 (Golden Gate National Parks Conservancy et al., 2021). Table S.H.10.4 shows the total areal extent of each habitat type in the four estuaries. The largest habitat type in the estuaries was mudflat.

Table S.H.10.4. Extent of habitat types in the four estuaries within GFNMS boundaries (excluding channels). Source: Golden Gate National Parks Conservancy et al., 2021; GFNMS, 2018

Estuary	Marsh Extent (m^2)	Mudflat Extent (m^2)
Estero Americano and Estero de San Antonio	186,964.80	50,181.00
Tomales Bay	2,577,038.20	3,845,727.70
Bolinas Lagoon	793,993.23	3,037,975.10
Totals	3,557,996.20	6,933,883.80

More data are needed to determine the trend for marsh and mudflat habitats in the estuaries. Some activities since 2010 have likely improved habitat integrity in Bolinas Lagoon and Tomales Bay. In 2011, the Caltrans Culvert Replacement Project removed some structures and reconfigured culverts in Bolinas Lagoon, creating approximately a tenth of an acre of restored marsh and improving water quality and circulation. The Kent Island Restoration Project in Bolinas Lagoon also removed invasive vegetation from the island, allowing natural habitats to recover and likely causing a slight increase in marsh habitat and mudflats. In Tomales Bay, marsh restoration has occurred at the southern end of the bay at Giacomini Ranch since 2008, which has resulted in improved hydrology across 51 acres of marsh floodplain and new tidal channels being formed (Parsons & Ryan, 2015).

Olympia Oysters

The Olympia oyster (*Ostrea lurida*) is a habitat-forming species and the only oyster species native to the west coast of North America north of Baja California Sur, Mexico. The Olympia oyster population has declined significantly along the West Coast over the last century, but the historical extent of this species in GFNMS is not well documented; thus, status and trends cannot be determined. Anecdotal reports from Tomales Bay suggest Olympia oysters were once abundant enough to benefit the ecosystem by improving water quality through filter feeding and providing structure (i.e., a reef comprised of shells) to help buttress fragile shoreline habitat against waves, storm surge, or future sea level rise. It is unknown if Olympia oysters are providing these ecosystem services at their current abundance.

Eelgrass

Eelgrass was documented at three of the four estuarine habitats in the sanctuary: Estero Americano, Estero de San Antonio, and Tomales Bay (Table S.H.10.5). A survey in 1994 (Sherman & DeBruyckere, 2018) and anecdotal observations since then indicate eelgrass is absent in Bolinas Lagoon. Assessment and monitoring of the abundance and distribution of eelgrass are limited, are of eelgrass extent only, and do not include assessments to determine ecosystem functions, invertebrate interactions, or severity and persistence of eelgrass wasting disease. Further, substantial interannual variability in the total extent of eelgrass in each estuary may occur (CDFW, 2023b; Table S.H.10.5).

Table S.H.10.5. Amount of eelgrass in each estuary in select years from 2010 to 2018. Not all estuaries were assessed in the same year or using the same technique. Numbers reported are from estuary-wide surveys; surveys were conducted in Tomales Bay in other years for only a portion of the bay and were thus not included in this table. Source: Svejkovsky, 2013; PSMFC, 2018; CDFW 2023b; Merkel & Associates, Inc., 2017b; Sherman & DeBruyckere, 2018

Estuary	Amount of Eelgrass (m^2)	Year of Survey	Survey Performed By	Survey Technique
Estero Americano	22,298	2010	Ocean Imaging	Field survey GPS points analyzed with multi-spectral aerial imagery[a]
Estero Americano	16,779	2014	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero Americano	7,104	2016	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero Americano	13,120	2017	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero Americano	9,999	2018	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero de San Antonio	5,261	2010	Ocean Imaging	Multi-spectral aerial imagery
Estero de San Antonio	1,362	2016	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero de San Antonio	7,108	2017	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Estero de San Antonio	7,017	2018	CDFW	Field survey GPS points analyzed with multi-spectral aerial imagery
Tomales Bay	5,213,710	2013	CDFW	Multi-spectral aerial Imagery with accuracy assessment/ground truthing[b]
Tomales Bay	6,180,412.40	2017	Merkel & Associates, Inc.	Interferometric sidescan sonar and aerial imagery captured from uncrewed aerial systems (UAS)[c]

[a] This data collection method involved the notation of GPS waypoints from kayaks wherever eelgrass beds or meadows were encountered; detailed field notes were taken to supplement these points to capture information on density, orientation of the beds, whether they were distinct or continuous from a previously encountered bed, and other habitat features. Waypoints were then uploaded as GIS polygons in ArcMap and compared to National Agriculture Inventory Program's aerial imagery (the most recently available imagery for a given survey year).

[b] This data collection method involved the use of CDFW aerial imagery (photographs taken by a CDFW warden pilot in an airplane) captured on 6/29/10. The photos were georeferenced in a GIS system in 2013 and what appeared to be eelgrass habitat (beds/meadows, whether patchy, sparse, or dense) was delineated by creating a polygon in ArcMap; 234 random sampling points were assigned to the resulting features. CDFW staff then ground-truthed the draft data set by visiting each sampling point either by kayak or foot, sometimes via freediving or snorkeling, and verifying the presence or absence of eelgrass at each location. Field notes were also taken when appropriate. The final data set was produced by editing out the areas where eelgrass was determined to be absent during the ground-truthing effort.

[c] This data collection method involved a hybrid approach that leveraged the capabilities of vessel-mounted interferometric sidescan sonar and, where possible to fly, low-altitude color aerial imagery captured from UAS to detect eelgrass throughout its suitable depth range. Interferometric sidescan sonar surveys were conducted primarily during high tides within the deeper subtidal and extreme lower intertidal portions of the bay's channels and flats to capture both eelgrass and bathymetry data. At extreme low tides, color aerial imagery from low-altitude UAS was collected to assess intertidal and shallow subtidal

(i.e., less than 3–5 feet below mean lower low water) eelgrass distributed over intertidal flats. Synoptic ground-truthing was conducted during the field investigations, with eelgrass verified visually or using cameras and a single-beam fathometer in deeper waters.

Figure S.H.10.4 shows the maximum known extent of eelgrass in Tomales Bay based on data collected using different methods in 2013 and 2017 (PSMFC, 2018; Merkel & Associates, Inc., 2017b). These surveys may suggest an increase in eelgrass extent, although the difference in methodologies used complicates the assessment of a trend (Table S.H.10.5).

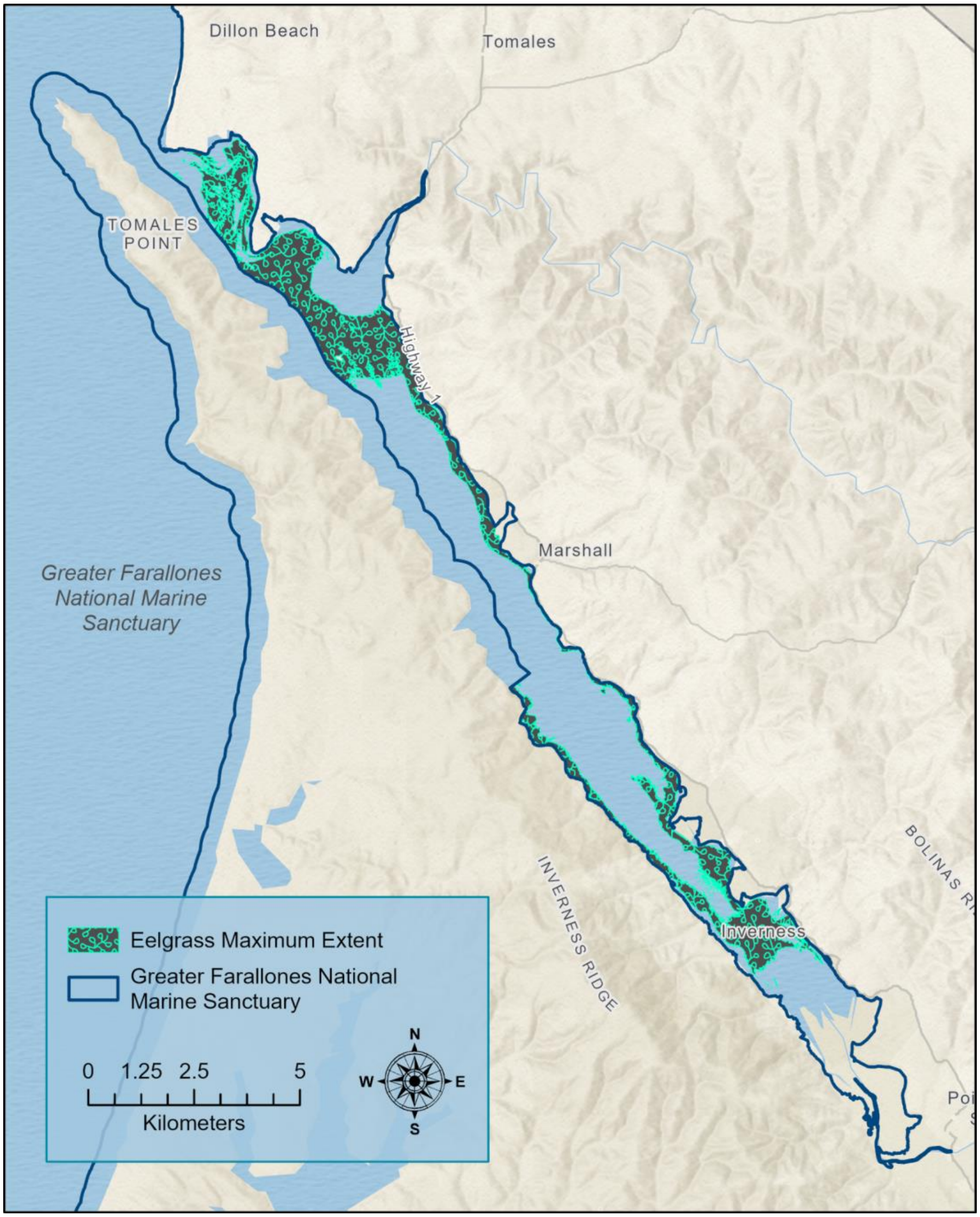


Figure S.H.10.4. Maximum extent of eelgrass beds in Tomales Bay. Image: NOAA; Source: PSMFC, 2018; Esri, 2016; Merkel & Associates, Inc., 2017b

Conclusion

This question was rated fair/poor and not changing. Estuarine and lagoon habitats remained significantly degraded compared to historic levels, but there was no evidence that marsh or mudflat habitat integrity had worsened since the last assessment. Restoration projects have improved the integrity of these habitats in Bolinas Lagoon and Tomales Bay. Olympia oysters have declined along the West Coast. Surveys of eelgrass extent in Tomales Bay suggest it may have increased during the study period. There was substantial interannual variability in the total extent of eelgrass in both Estero Americano and Estero de San Antonio. More data are needed to better understand any specific, quantitative changes in mudflat, marsh, and eelgrass habitat over time, as well as the status and trends of Olympia oyster populations in all estuaries, especially Tomales Bay.

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

Coastal and Offshore Region

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

Rationale: Mercury was present in sediments and levels increased. Levels of PAHs and DDT (and its derivatives) in Dungeness crab samples were below regulatory thresholds during the study period. Mercury in Dungeness crab exceeded the state limit in 2010 and PCBs in Dungeness crab exceeded the FDA limit in 2015, but both contaminants were low throughout the remainder of the study period. Mercury, PAH, PCB, and DDT levels in Dungeness crab were stable during the study period. Tarball pollution decreased, except for one isolated event in the winter of 2015–2016.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was undetermined and the trend was improving. Although data on contaminant concentrations were limited, those that were available suggested concentrations had decreased and were generally low, although some contaminants accumulated in sanctuary canyons. Concerns were present regarding bioaccumulation of contaminants at upper trophic levels, and elevated levels of legacy pollutants were detected in Steller sea lions.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included contaminant (mercury, PAHs, PCBs, and DDTs) concentrations in sediment and crabs, as well as tarballs and tar patties (Table S.H.11.1). The majority of data considered for this assessment were from two projects: (1) offshore sediment and biota monitoring sampling performed by the SFPUC Natural Resources and Lands Management Division, and (2) shoreline tarball and tar patty data collected as part of the Beach Watch project (see Box 2).

Table S.H.11.1. Summaries for the key indicators related to contaminants in the coastal and offshore region of GFNMS that were discussed during the May 19, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Contaminant levels in sediment and crabs	SFPUC, 2021	Status: Mercury concentrations in seafloor sediment samples were usually below the effects range median value of 0.71 ppm, the threshold for adverse effects in biota. In Dungeness crab tissues, mercury levels remained below regulatory limits in all years except 2010, PAHs were below alert levels but peaked in 2015, PCBs peaked in 2015 and exceeded FDA limits for food, and DDTs also peaked in 2015 but were below FDA limits for food. Trend: Mercury concentrations in sediment significantly increased in GFNMS. Mercury, PAHs, and PCBs in Dungeness crab tissues were stable during the study period. Levels of DDTs have decreased in Dungeness crab since 1997 and were stable during the study period.	S.WQ.7.5; S.H.11.1
Tarballs and tar patties	Lindquist and Roletto, 2022a; Office of Spill Prevention and Response, 2021	Status: The presence of tarballs and tar patties remained low since the lightering of SS *Jacob Luckenbach* in 2002, with an anomalous peak in 2016. Trend: Tarball deposition decreased on coastal beaches.	S.P.4.9
Data gaps	There is a lack of consistent sampling for legacy pollutants in some sanctuary locations and species, such as organic pollutants and trace metals in fish and mussels, and for pollutants discharged from leaking, grounded, and sunken vessels and aircraft.		

Contaminant Levels in Sediment and Crabs

SFPUC conducts annual monitoring of the nearshore and offshore areas of the Gulf of the Farallones region surrounding the Southwest Ocean Outfall, where treated sewer effluent is discharged. A subset of SFPUC monitoring sites are within GFNMS (see Figure S.WQ.7.4). Monitoring includes sampling of sediment and invertebrates to measure levels of legacy pollutants, including PAHs, PCBs, DDT (and its derivatives DDD and DDE; collectively referred to as DDTs here), and mercury. Data for these legacy pollutants were aggregated from 2010–2020 annual reports (SFPUC, 2021). In some cases, data for contaminants in the sediment were not readily available; therefore, benthic organisms were used as a proxy for sediment. Since 2010, mercury concentrations in seafloor sediment samples were usually below the effects range median value of 0.71 ppm (Long et al., 1995), the threshold beyond which adverse effects in biota are likely to occur. Levels of mercury in seafloor sediments significantly increased during the study period at sampling stations within GFNMS, which are closer to the mouth of San Francisco Bay than to the Southwest Ocean Outfall. However, mercury in Dungeness crab tissues has remained low during the study period with the exception of 2010, when some samples from the outfall site exceeded the state limit for contaminants in fish (Figure S.WQ.7.5). PAH levels in Dungeness crab have been well below alert levels set by the FDA since 2010. Peaks in PAH levels in 2015 coincided with higher-than-average tarball deposition on the adjacent sanctuary shoreline in 2015–2016 (SFPUC, 2021; Lindquist and Roletto, 2022a; Figure S.P.2.2). These tarballs, and potentially also associated PAHs, are thought to have originated from natural seeps (Office of Spill Prevention and Response, 2021). The highest levels of PCBs were found in Dungeness crab hepatopancreas. PCB levels in crab hepatopancreas also peaked in 2015 and were above FDA limit for food (200 µg/kg; SFPUC, 2021). Levels of DDTs have been decreasing in Dungeness crab since 1999. The highest levels of DDTs were also detected in Dungeness crab hepatopancreas and peaked in 2015, but were well below the FDA safety limit for food (5000 µg/kg; Figure S.H.11.1).

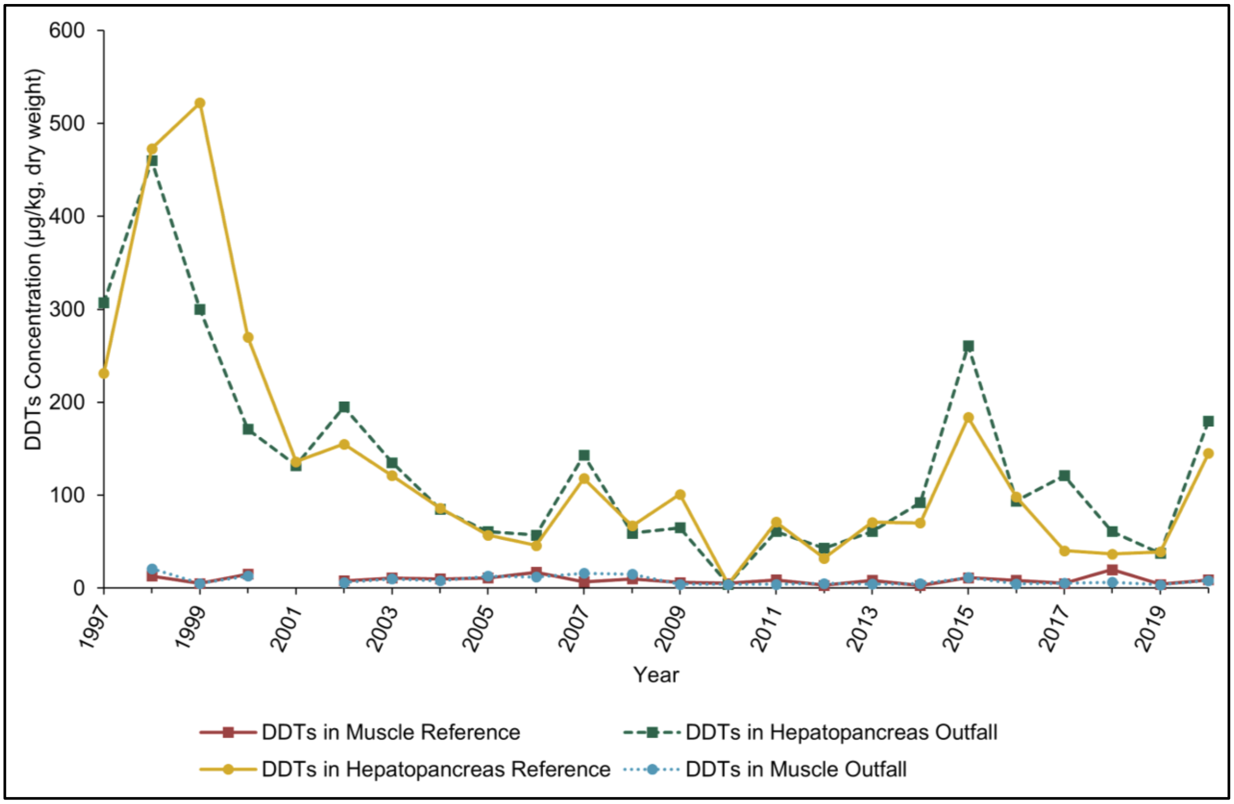


Figure S.H.11.1. Levels of DDTs in Dungeness crab hepatopancreas and muscle tissue from monitoring station 01, near the Southwest Ocean Outfall, and reference station 06, which is >4 km southeast of the outfall (Figure S.WQ.7.4). Levels are well below the FDA limit of 5000 µg/kg. Source: SFPUC, 2021

Tarballs and Tar Patties

In the 1990s and 2000s, oil pollution events were an ongoing management issue for GFNMS. Since the lightering of SS *Jacob Luckenbach* in 2002, the deposition rates of tarballs and tar patties (i.e., discrete accumulations of oil) have greatly decreased. From 2010–2021, low levels of tarballs and tar patties were encountered on sanctuary beaches (0–2.2 per km), except in the winter of 2015–2016 when over 10,000 tarballs were documented at one beach (Lindquist & Roletto, 2022a; Figure S.P.2.2). This deposition event correlated with the increased levels of PAHs, PCBs, and DDTs detected by SFPUC in 2015. For additional information regarding tarballs, see Questions 2 and 4 in this report.

Conclusion

This question was rated good/fair because no major chemical pollution was detected during the study period of the report. Although legacy pollutants are present, substantial tarball pollution was observed only in 2015–2016 and is thought to be from natural seeps. Contaminants were found in seafloor sediments and benthic biota, but generally did not exceed regulatory thresholds for concern and did not trigger advisories for consumption of benthic biota (with one exception for PCBs in 2015). The trend was mixed based on decreased oil pollution and DDTs, increased mercury in sediment, and stable levels of mercury, PAHs, and PCBs in crabs. Although PAHs, PCBs, and DDTs increased sharply in 2015, as did the deposition of tarballs and tar patties, this was a discrete event during the study period followed by a return to previous levels. There is a lack of consistent sampling for legacy pollutants in areas of the sanctuary and in species other than those measured by SFPUC, such as organic pollutants and trace metals in fish and mussels, and for pollutants discharged from leaking, grounded, and sunken vessels and aircraft.

Estuarine and Lagoon Region

Status Description: Selected contaminants have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: There is ongoing mercury contamination in sediments and biota in the Walker Creek Delta in Tomales Bay as a result of historic mining activities in the Walker Creek watershed. Mercury levels in sediment decreased following cleanup of a key mine site, but total maximum daily load was exceeded in Walker Creek in multiple years since the cleanup. Vessel and car sinkings have occurred in the sanctuary's estuaries, resulting in the release of fuel into sanctuary habitats, but the volume of contaminants released during these incidents is unknown. Tarballs, tar patties, and oiled wildlife were not observed on beaches in Tomales Bay or Bolinas Lagoon during the study period. There were little to no data on contaminants in Estero Americano, Estero de San Antonio, or Bolinas Lagoon.

Findings From the 2010 Condition Report

In 2010, both the status and trend for this question in the estuarine and lagoon region were rated undetermined. There was little information available to assess contaminants in sanctuary estuaries, however limited sampling showed low to moderate levels of contaminants in Tomales Bay mussels with no apparent trend.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included mercury levels in sediment and biota, as well as oil pollution (Table S.H.11.2). Data for legacy pollutants (PCB and DDT) in fish and invertebrates were not available for any of the sanctuary's estuaries or lagoons. The Regional Water Quality Control Board (RWQCB) report cards include mercury level data in Tomales Bay, including the Walker Creek delta.

Table S.H.11.2. Summaries for the key indicators related to contaminants in the estuarine and lagoon region of GFNMS that were discussed during the May 19, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Mercury in sediment and biota	CSWRCB, 2017, 2021a	Status: Mercury levels in surface sediment at Walker Creek Delta in Tomales Bay were lower after mine site remediation but still exceeded TMDL in some years. Safe levels of mercury were exceeded in one species for human consumption and a typical forage species consumed by birds. Trend: Although mercury in sediments decreased following the Gambonini Mine site cleanup in 1999–2000, there was no clear trend during the study period (2010–2022). There was also no clear trend in the available data on mercury levels in biota.	S.H.11.2; S.WQ.7.11
Tarballs and tar patties	Lindquist & Roletto, 2022a	Status: No data were available to assess pollution from vessel and vehicle incidents in Tomales Bay. No oil pollution was observed on beaches in Bolinas Lagoon or Tomales Bay. Trend: No trend data were available for pollution from vessel and vehicle incidents. There was no change in observations of tarballs and tar patties.	N/A
Data gaps	There is a data gap in monitoring and the understanding of biomagnification of mercury in the estuarine food web. There is a lack of data to quantify oil and other pollutants discharged from leaking, grounded, or sunken vessels and vehicles in estuaries. There is little to no monitoring of contaminants in Bolinas Lagoon, Estero Americano, or Estero de San Antonio.		

Mercury in Sediment and Biota

Historic mining activities in the Walker Creek watershed resulted in elevated mercury levels in Walker Creek and the Walker Creek Delta in Tomales Bay (see Question 2 in this report for more information). From 1999–2000, there was an emergency superfund cleanup of the Gambonini Mine site, the greatest source of mercury in the watershed, and a TMDL for mercury was established for Walker Creek in 2008 and Tomales Bay in 2012 (CSWRCB, 2021a). Monitoring of mercury in sediment and biota in Tomales Bay, particularly in the Walker Creek Delta and watershed, has been intermittent and inconsistent over the past 20 years. Monitoring increased following the Gambonini Mine cleanup, but gaps in data remain. Despite these gaps, available data show that mercury concentrations in sediment decreased at Walker Creek Delta in Tomales Bay; mercury load in surface sediment was 1.7 ppm in 2000 (before the cleanup was complete), and decreased to 0.94 ppm in 2009 and 0.52 ppm in 2018 (CSWRCB, 2019a). However, TMDL was still exceeded at Walker Creek in 2014, 2016, and 2017 (Figure S.H.11.2; CSWRCB, 2021a).

The maximum level of mercury allowable in food for human consumption is 0.22 ppm (CSWRCB, 2021a); for forage species consumed by birds, the maximum safe level is 0.05 ppm (San Francisco Bay Regional Water Quality Control Board, 2012). Data on mercury levels in invertebrates and fish were available for three time periods: 1998–2001, 2010, and 2019–2020. The levels of mercury in species consumed by humans were below the state's cautionary level, except for leopard sharks (Figure S.WQ.7.11; CSWRCB, 2021a). Levels of mercury in bird forage species varied, but exceeded 0.05 ppm in yellow shore crab, longjaw mudsucker, and threespine stickleback in both 2010 and 2019 (CSWRCB, 2021a).

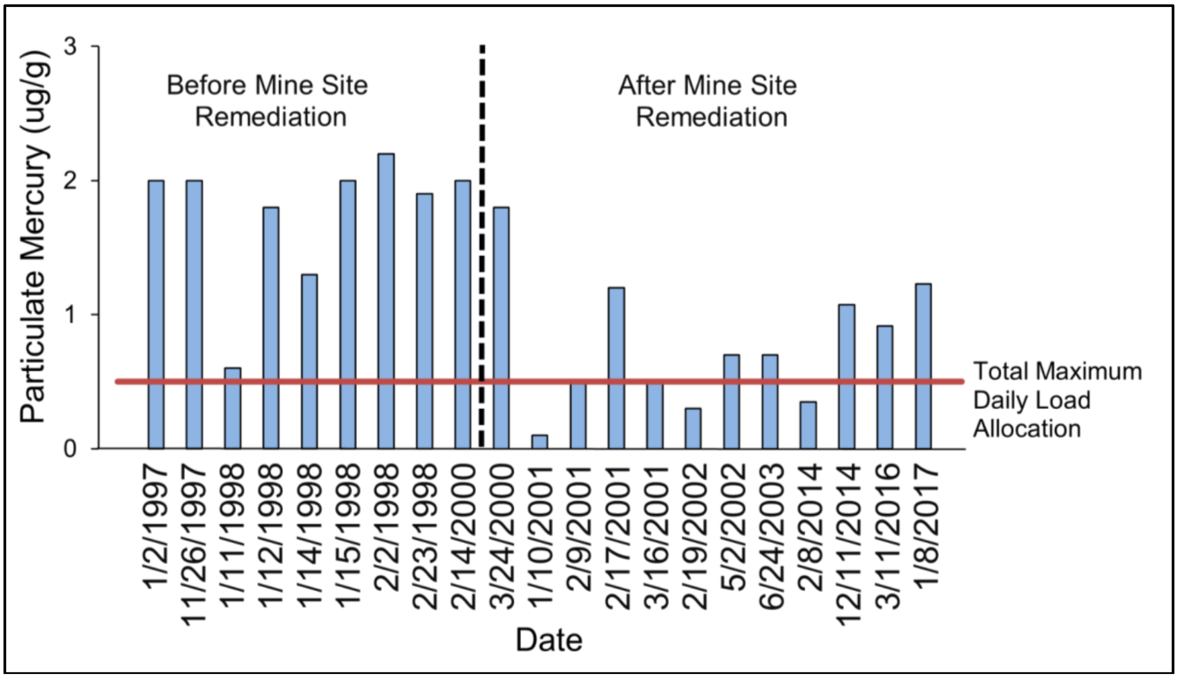


Figure S.H.11.2. Mercury concentration in sediment samples at Walker Creek before and after cleanup of the Gambonini Mine site. Source: CSWRCB, 2017

Oil Pollution

Although vessels and cars released fuel into Tomales Bay during the study period (see Question 2), any trends in associated contaminants from these incidents cannot be determined due to a lack of data. No oil pollution (tarballs, tar patties, or on wildlife) was documented in Bolinas Lagoon or Tomales Bay during the study period (Lindquist & Roletto, 2022a).

Conclusion

This question was rated fair based on ongoing mercury contamination in sediments and biota in Walker Creek and the Walker Creek Delta in Tomales Bay. Mercury levels in sediment were reduced following remediation of the Gambonini Mine site, but mercury TMDL was exceeded in the three most recent years sampled. Some fish species exceeded mercury levels for safe consumption by humans and birds. Although fuel was released into Tomales Bay following vessel and vehicle incidents, no data on the amount of associated petroleum pollution were available. However, oil pollution (tarballs, tar patties, or on wildlife) was not observed. The mixed trend reflects that although mercury levels in sediments decreased overall, mercury TMDL in sediment and biota was still exceeded in some years. New data are needed to understand biomagnification of mercury in the estuarine food web. Additionally, data are needed to quantify pollutants from leaking, grounded, or sunken vessels and vehicles in sanctuary estuaries. There is also a lack of data on contaminants in Estero Americano, Estero de San Antonio, and Bolinas Lagoon.

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

The following sections assess the status and trends of living marine resources in GFNMS for the period from 2010–2022. We have noted where more recent data (e.g., 2023) became available during editing of this report. The term "living marine resources" encompasses a range of organisms in GFNMS, including keystone, foundation, focal, and non-indigenous species. Each of the living marine resource questions focus on specific groups of species in GFNMS.

Question 12 evaluates changes to foundation species (those that create locally stable conditions for other species) and keystone species (those upon which a large number of other species in the ecosystem depend), which are critical to maintaining GFNMS's ecosystem structure, function, and stability over time.

Question 13 is centered around focal species that may not be abundant or key to GFNMS'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. Thus, these species are of particular interest from the perspective of sanctuary management.

Question 14 focuses on the impacts of non-indigenous species. Also called alien, exotic, non-native, or introduced species, these are animals or plants living outside their endemic geographical range. Given that GFNMS is outside the range of natural dispersal for these species, they are believed to have 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, is discussed. These species are of concern because they have the potential to impact GFNMS's ecosystem structure, function, and services, at which point they are considered invasive species.

Lastly, Question 15 addresses the status of native 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 species richness and diversity indices, and the abundance of species that influence the integrity of food webs and other aspects of ecosystem function. Non-indigenous species are not included in estimates of native biodiversity.

Because of the considerable differences in environmental pressures and responses between the coastal and offshore region and the estuarine and lagoon region, each question was assessed twice in order to represent these two environment types separately.

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

Coastal and Offshore Region

Status Description: The status of keystone and foundation species suggests severe degradation in some but not all attributes of ecological integrity.

Rationale: Bull kelp declined significantly in the sanctuary due to a series of events, including the 2014–2016 marine heatwave and a historic imbalance within the kelp forest ecosystem. Sea star wasting syndrome led to the loss of the predators of purple urchins, e.g., sunflower and giant sea stars, allowing the purple urchin population to increase dramatically. Purple urchins thus overgrazed kelp beds, resulting in a persistent loss of bull kelp. During the 2014–2016 marine heatwave, habitat compression also occurred, resulting in a redistribution of forage species from further offshore to closer inshore. During cooler water conditions and stronger upwelling periods, the proportion of krill to less nutritious gelatinous zooplankton was high. During warmer water conditions, the proportion of krill to gelatinous zooplankton was low.

Keystone species are organisms upon which a large number of other species in the ecosystem depend (Paine, 1969). Their contribution to ecosystem function is disproportionate to their abundance or biomass. They can be habitat creators (e.g., kelp, corals), predators that control food web structure (e.g., sea otters, certain sea stars), herbivores that regulate benthic recruitment (e.g., certain sea urchins), and species involved in critical symbiotic relationships (e.g., cleaning or cohabitating species). Foundation species are single species that create locally stable conditions for other species (Dayton, 1972). These are typically dominant biomass producers (e.g., mussels, hake, anchovy, krill) in an ecosystem and 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 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. This specific question was also not addressed in the 2010 report (see Appendix A); however, there were two questions that assessed the status and condition or health of "key species." In 2010, the status of key species in the coastal and offshore region was rated fair with an undetermined trend, and the condition or health of key species was rated good/fair with an improving trend. The ratings for the first question were based on the variable status of 49 key species and populations with varying states of integrity. The ratings for the second question were based on some indications of reduced health in gray whales and Steller sea lions, combined with reductions in oiling incidents for seabirds and marine mammals following the removal of oil from the SS *Jacob Luckenbach*.

New Information in the 2010–2022 Condition Report

Keystone species used to evaluate this question included bull kelp (*Nereocystis luetkeana*), purple urchins (*Strongylocentrotus purpuratus*), and kelp forest apex predators like sunflower sea stars (*Pycnopodi helianthoides*) and giant sea stars (*Pisaster giganteus*). Foundation species include krill (*Euphausia* sp., *Thysanoessa* sp., and other zooplankton), and northern anchovy (*Engraulis mordax*).

Table S.LR.12.1. Summaries for the key indicators related to keystone and foundation species in the coastal and offshore region of GFNMS that were discussed during the June 7, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Keystone species: Bull kelp, sea stars, and purple urchins	Bell et al., 2023; Rogers-Bennett & Catton, 2019; PISCO, 2022	Status: Annual kelp canopy area was at historic lows; in most locations canopy area was >90% less than historic average. Sunflower and giant sea star densities along the Sonoma and Mendocino county coast were nearly zero. Purple urchin density was high (>1,000 urchins m^{-2}) along the Sonoma and Mendocino county coast since 2013. Trend: Bull kelp declined severely during the 2014–2016 MHW and has generally not recovered since, with the exception of a slight increase in a few locations in 2021 and 2022. There was a dramatic decline in sea stars, which prey on purple urchins, since 2012–2014. Consequently, there was a dramatic increase in purple urchins 2014-2021.	S.LR.12.1; S.LR.12.2
Foundation species: Krill and anchovy	Elliott et al., 2022a; Santora et al., 2021b; NOAA, 2022d	Status: Krill were abundant in GFNMS and varied with oceanographic conditions. From 2010–2021, krill standardized CPUE anomalies were above or near average in 9 of 12 years. In recent years, anchovies were abundant forage species in GFNMS; from 2018–2022, anchovy abundance was well above average. Trend: Krill relative CPUE in the Gulf of the Farallones region decreased during the study period. Relative abundance of krill in relation to gelatinous zooplankton decreased during warm water years (2014–2016). Anchovy relative CPUE in the Gulf of the Farallones region increased during the study period.	S.LR.12.3; S.LR.12.4
Data gaps	There is a need for detailed data on the condition and density of krill across the shelf of the Gulf of the Farallones region. Kelp canopy cover data collected with consistent methods are needed so canopy cover can be compared across Marin, Sonoma, and Mendocino counties and among time periods.		

Keystone Species: Kelp, Sea Stars, and Purple Urchins

Since 2012, bull kelp in Sonoma and Mendocino counties has not reproduced or grown at the same rate as in previous years. For an explanation of the environmental influences impacting and limiting the regrowth of bull kelp in northern California, see Question 10. In summary, the extreme MHW of 2014–2016 exacerbated the decline of bull kelp; >90% of bull kelp has been lost and has not recovered (Rogers-Bennett & Catton, 2019; Bell et al., 2023; Figure S.LR.12.1; Figure S.H.10.2). Experts noted that there was a slight increase in a few locations in 2021 and 2022; however, sustained, widespread recovery has not occurred. Contributing to the suppression of kelp forest growth is the loss of urchin predators, particularly sunflower sea stars and giant sea stars. Prior to and during the MHW (2014–2016), there was a West-Coast-wide outbreak of sea star wasting syndrome (Konar et al., 2019), which resulted in the loss of several species of sea stars (see two examples in Figure S.LR.12.2). Densities of giant sea stars throughout northern California declined from an average peak density of nine per square meter in some areas to less than one per square meter (PISCO, 2022). These predators feed on purple urchins and have the capacity to control their populations. Purple urchins are kelp grazers along the Sonoma and Mendocino coast. The loss of their predators was most likely a driving factor of the increase in the purple urchin population in Sonoma and Mendocino counties, from an average of 23–35 urchins per square meter in 2010–2011 to >1,000 urchins per square meter in 2020 (no data were available for 2012–2015; PISCO, 2022; Figure S.LR.12.2). Since the MHW, purple urchins have overgrazed the kelp forests and understory algae of the sanctuary, leading to a historic imbalance in kelp forest ecosystem function and persistent loss of kelp beds (Rogers-Bennett & Catton, 2019).

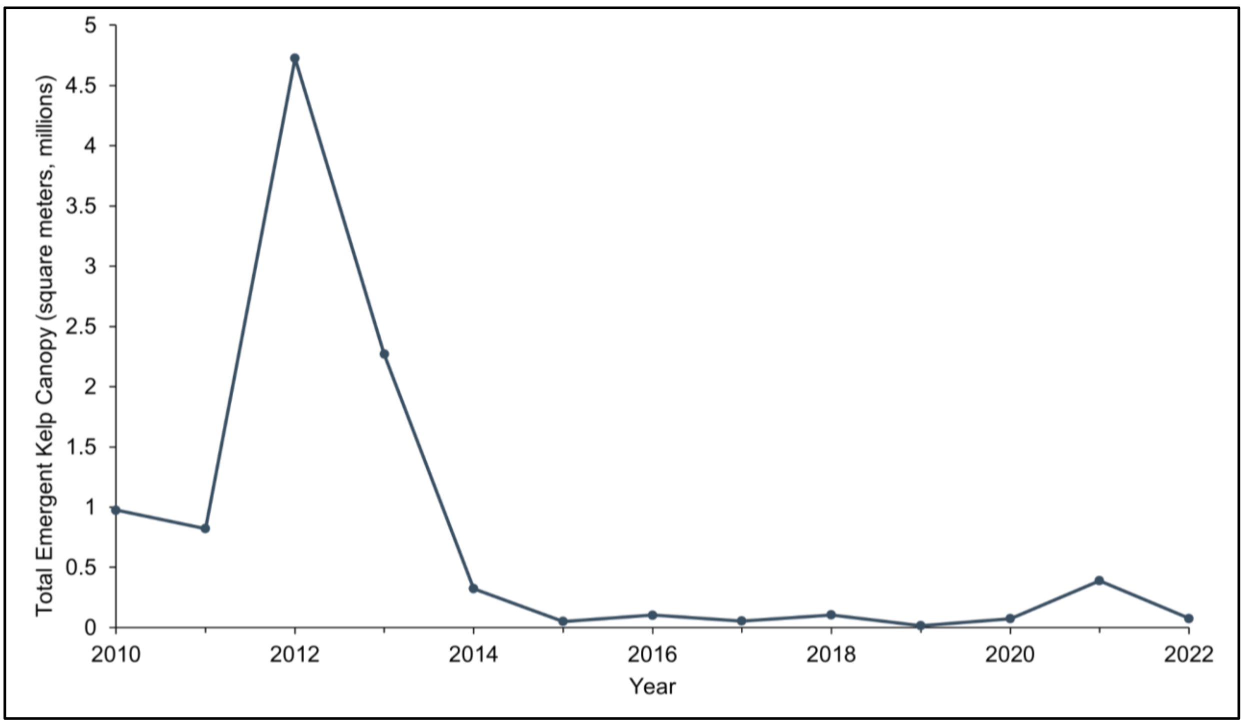


Figure S.LR.12.1. Total emergent kelp canopy in Sonoma and Mendocino counties in millions of square meters, 2010–2022. Source: Bell et al., 2023

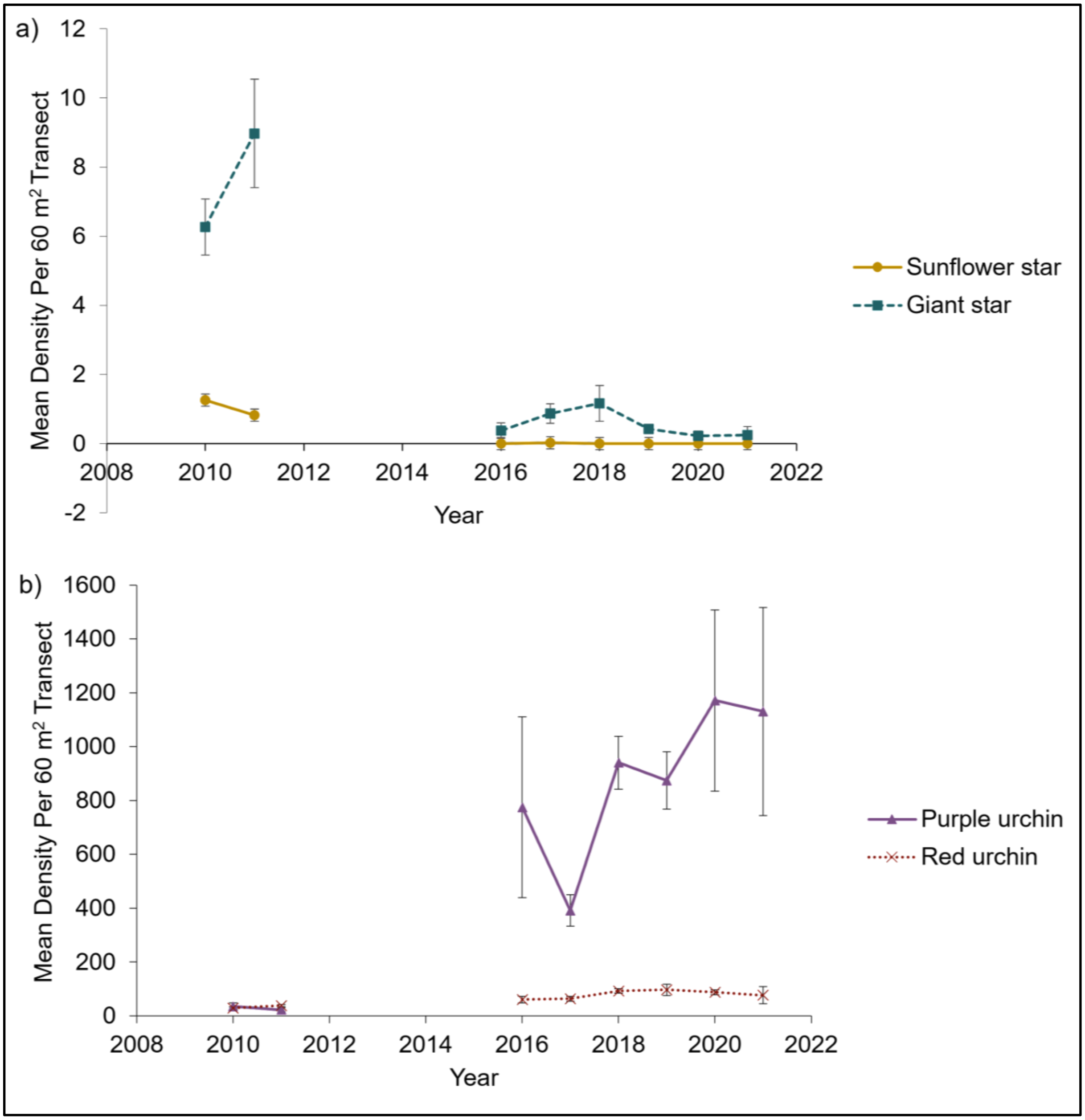


Figure S.LR.12.2. The average densities of sunflower sea stars and the giant sea stars (top graph) and purple and red urchins (*Mesocentrotus franciscanus*; bottom graph) at Point Arena, Salt Point, Stewart's Point, Del Mar Landing, Saunders Reef, Sea Ranch, Bodega Marine Life Refuge, and Bolinas Point monitoring sites in northern California (see Figure S.H.10.1 for a map of these locations). Note that sampling effort varied among locations and years. Although red urchins were not considered as an indicator species during the status and trend workshop, their density is provided here to highlight the substantial increase in purple urchin density relative to other native urchin species. Source: PISCO, 2022

Foundation Species: Krill and Anchovy

Krill samples were collected as part of Rockfish Recruitment Ecosystem Assessment Surveys from Point Reyes through Monterey Bay (see core sampling area in Santora et al., 2021b) during the spring upwelling months. These surveys showed an overall decline in relative abundance of krill species and an overall increase relative abundance of anchovies (measured as catch per unit effort [CPUE], an indirect measurement of relative abundance) though both were within one standard deviation of the long-term mean (NOAA, 2022d; Figure S.LR.12.3). In six out of 12 years (from 2010 through 2021), the relative abundance of krill was at or above average, with standardized anomalies[16] ranging from 0.94 to 1.39 relative to long-term average values. In three of those 12 years, krill CPUE was at or near average, with standardized anomalies ranging from 0.60 to -0.63 relative to long-term average values. In two of those 12 years, CPUE was well below average, with standardized anomalies ranging from -0.90 to -2.5 (NOAA, 2022d). From 2010–2017, anchovy CPUE was below average in the Gulf of the Farallones region, with standardized anomalies ranging from -0.81 to -1.01. From 2018 through 2021, anchovy abundance increased by several orders of magnitude (Kuriyama et al., 2022), with regional standardized anomalies ranging from 1.63 to 2.33 (NOAA, 2022d; Figure S.LR.12.3). In the Gulf of the Farallones region, krill and forage fish, such as anchovies, are important to the productivity and survival of locally breeding and migratory seabirds, marine mammals, and predatory fish species. The abundance of krill fluctuates annually and is greatly influenced by environmental conditions.

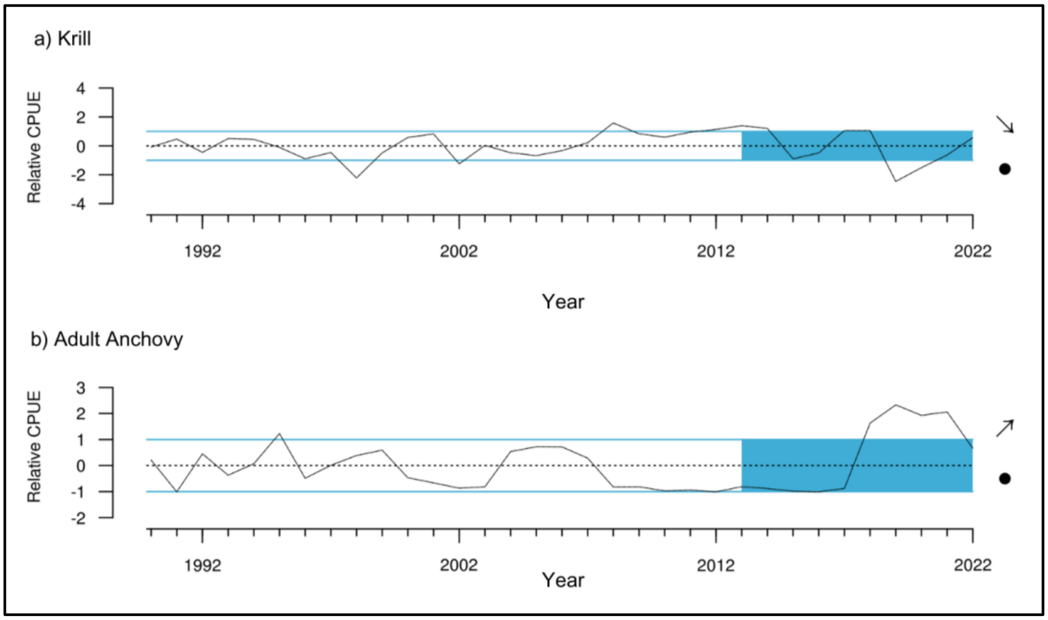


Figure S.LR.12.3. Relative long-term average CPUE of a) krill and b) adult anchovy in the Gulf of the Farallones region, 1990 through 2021. Blue shading indicates the years analyzed for trend, 2013–2022. The trend is indicated by the arrow to the right of each graph. The black dots indicate that the mean for 2013 through 2021 was within one standard deviation of the long-term mean (1990 through 2021). Source: NOAA, 2022d

[16] The National Marine Fisheries Service standardizes fishery survey catch rates to allow for trends to be expressed as either positive or negative anomalies from long-term average values (see Maunder & Punt, 2004).

MHWs and extended El Niño events can compress the typical distribution of krill and forage fish (see Pressures chapter). Habitat compression occurred during the 2014–2016 MHW, resulting in a redistribution of forage species, like krill and anchovy, from primarily being distributed along the shelf break (100–200 m depth) to being distributed from the shelf break through the Gulf of the Farallones shelf region, closer to shore (Santora et al., 2020, 2021a).

In addition to changes in spatial distribution, changes in species composition of zooplankton were observed. During warm water conditions, when upwelling was low and SST was warmer than average, the proportion of krill to gelatinous zooplankton (e.g., salps) was reduced within the Gulf of the Farallones region (Elliott et al., 2022a; Figure S.LR.12.4). During cooler water conditions and stronger upwelling periods (e.g., in 2009–2013 and 2017–2019), the proportion of krill increased, and gelatinous zooplankton increased during the 2014–2016 MHW (Figure S.LR.12.4). The proportion of krill to gelatinous zooplankton is significant because gelatinous zooplankton species, such as salps, are typically less nutritious than krill (Elliott et al., 2022a).

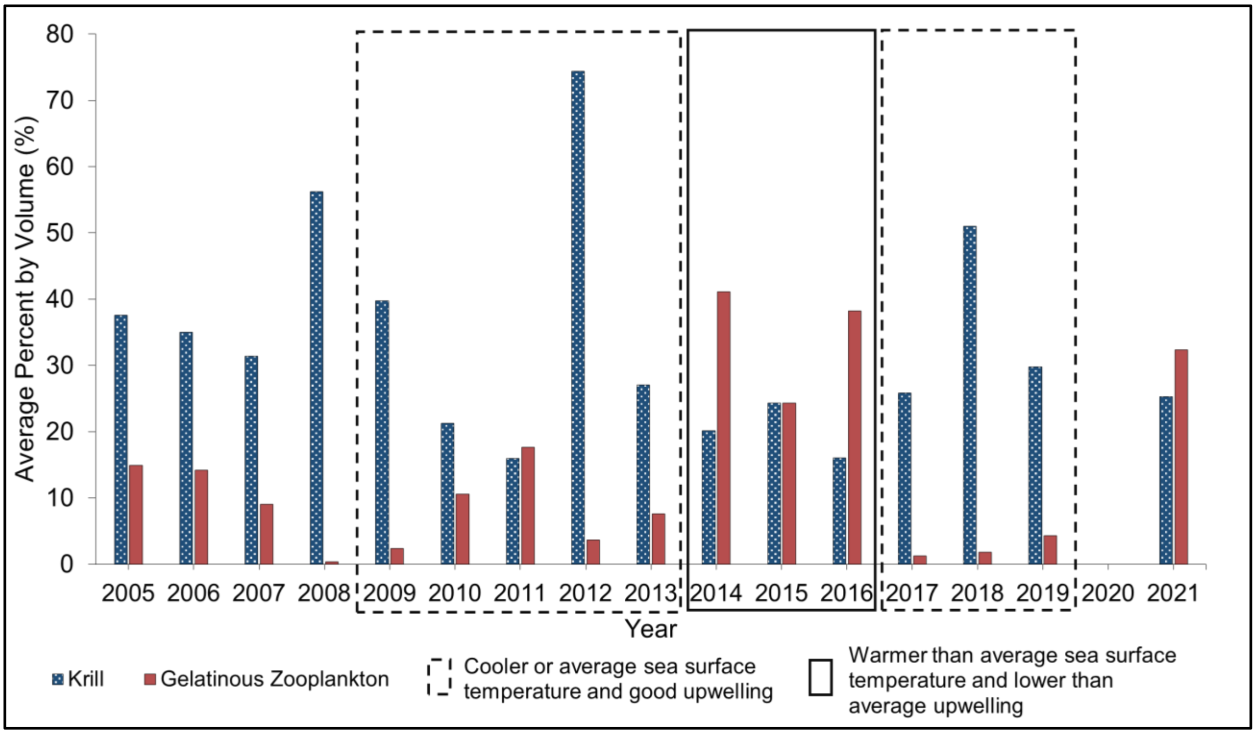


Figure S.LR.12.4. Average percent by volume of krill species and gelatinous zooplankton species from ACCESS midwater sampling (see Box 1) within the Gulf of the Farallones region, 2010–2021. Source: Elliott et al., 2022a

Conclusion

This question was rated fair/poor primarily due to the decimation and lack of recovery of bull kelp along the Sonoma and Mendocino coast during and since the 2014–2016 MHW. Bull kelp loss was linked to a sharp decline in sea stars driven by sea star wasting syndrome, which allowed purple urchins to increase dramatically and overgraze kelp and other algae. Krill and anchovy are abundant foundation species in GFNMS and vary with environmental conditions. Habitat compression during the 2014–2016 MHW changed the distribution of forage species, and anchovy CPUE increased during the study period. The trend for this question was mixed based on declines, increases, and variable trends among indicators. Bull kelp and sea stars declined in GFNMS, while throughout the Gulf of the Farallones region south to Monterey Bay, krill decreased and anchovy increased during the study period. The trend in species composition of krill and gelatinous zooplankton varied, with a higher proportion of krill in cooler years (2009–2013, 2017–2019) and a higher proportion of gelatinous zooplankton in warmer years (2014–2016). Detailed zooplankton data from the Gulf of the Farallones region are needed, including densities, distribution changes, nutritional value of copepods and gelatinous zooplankton, and comparison of samples collected by various projects in the region. Kelp canopy cover data collected using consistent methods are needed so canopy cover can be compared across Marin, Sonoma, and Mendocino counties, as well as across time periods.

Estuarine and Lagoon Region

Status Description: The status of keystone or foundation species suggests measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Eelgrass was documented in Tomales Bay, Estero Americano, and Estero de San Antonio. Anecdotal observations noted the absence of eelgrass in Bolinas Lagoon prior to and during the study period. There were dense eelgrass beds in Tomales Bay, which generally appeared to be healthy, although time series data were limited. Eelgrass wasting disease was present in Tomales Bay; its extent and impacts are unknown, but its presence is of concern.[17]

Findings From the 2010 Condition Report

This specific question was not addressed in the 2010 condition report (see Appendix A); however, there were two questions that assessed the status and condition or health of “key species.” In 2010, the status of key species in the estuarine and lagoon region was rated fair with a worsening trend, and the condition or health of key species was rated undetermined with an undetermined trend. Key species considered in 2010 included eelgrass, tidewater goby, and brant. Eelgrass had declined in some estuaries, particularly Bolinas Lagoon, where it was considered nearly extirpated; sedimentation, poor water quality, and physical disturbance negatively affected extant eelgrass in sanctuary lagoons. Although the abundance of endangered tidewater goby had declined throughout their range, they were apparently stable and locally abundant in some GFNMS estuaries. Brant populations increased gradually. Data on the health of key species were lacking for the majority of estuarine species; some fish were affected by high levels of mercury (covered in Question 7 and Question 11 in this report), and harbor seals were affected by disturbance in Bolinas Lagoon and Tomales Bay (covered in Question 4 in this report).

[17] A status rating and associated confidence score was not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

New Information in the 2010–2022 Condition Report

The sole foundation species used to evaluate this question was eelgrass (*Zostera marina*; Table S.LR.12.2).

Table S.LR.12.2. Summaries for the key indicators related to keystone and foundation species in the estuarine and lagoon region of GFNMS that were discussed during the June 7, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures and Tables
Eelgrass	Spratt, 1989; Svejkovsky, 2013; PSMFC, 2018; Merkel & Associates, Inc., 2017b; Sherman & DeBruyckere, 2018	Status: Eelgrass beds were documented in three of four estuaries in GFNMS. Anecdotal evidence suggested eelgrass beds in Tomales Bay were dense and healthy. Eelgrass wasting disease was documented but its prevalence and impacts were unknown. Trend: A lack of time series data precluded the assessment of a trend. Data from 2013 and 2017 suggested a possible increase in the extent of eelgrass in Tomales Bay, but comparison between survey years was complicated by differences in methodology.	Figure S.H.10.4; Table S.H.10.5
Data gaps	There is a need for consistent mapping to measure change in eelgrass extent, research and monitoring on the ecosystem functions of eelgrass habitat, and studies of the extent and impacts of eelgrass wasting disease.		

Eelgrass

Eelgrass is an important foundation species in GFNMS estuaries. Eelgrass is a supportive habitat, providing foraging areas as well as nurseries and shelter for many species of invertebrates, birds, and fish. Eelgrass rhizomes and roots help retain sediment, thus reducing erosion, dampening wave action, and sequestering carbon. For this study period, eelgrass was documented in three of the four estuarine habitats in the sanctuary: Estero Americano, Estero de San Antonio, and Tomales Bay (Figure S.H.10.5). The most recent survey that documented eelgrass in Bolinas Lagoon was in 1994 (Sherman & DeBruyckere, 2018). Since then, anecdotal observations of Bolinas Lagoon have indicated that eelgrass has been absent from the lagoon.

Quantification of eelgrass in the sanctuary has been limited to a small number of surveys conducted since the late 1980s by county and state agencies and contractors, as well as GFNMS (Spratt, 1989; Svejkovsky, 2013; PSMFC, 2018; Merkel & Associates, 2017; Sherman & DeBruyckere, 2018). Table S.H.10.5 lists surveys and acreage of eelgrass in the sanctuary's estuaries since 2010. Earlier surveys to map eelgrass beds used multispectral aerial imagery and more recent surveys used interferometric sidescan sonar, which is considered to be a more accurate method for quantifying submerged eelgrass.

Tomales Bay is recognized as one of the top five estuaries with prominent eelgrass beds along the West Coast (Sherman & DeBruyckere, 2018), and the eelgrass beds in Tomales Bay are considered to be dense and generally appear to be healthy (M. Ward/Marin County Open Space District, personal communication, June 7, 2022). The majority of the eelgrass in GFNMS occurs in the northern and southern portions of Tomales Bay, with over 6 km^2 of eelgrass covering these regions. In most areas where eelgrass occurs in Tomales Bay, its percent cover is well over 40%. Surveys in Tomales Bay in 2013 and 2017 suggested a possible increase in eelgrass area, but different methods were used, making a direct comparison difficult (see Question 10 for more information). In 2015, GFNMS implemented the Tomales Bay Mooring Program, which designated specific mooring zones in areas where no eelgrass is likely to grow. In recent years, GFNMS worked with the NOAA Office of Law Enforcement and the California State Lands Commission to remove moorings from eelgrass beds and relocate them. Both of these actions have likely contributed to recovery in those impacted areas.

Eelgrass wasting disease is caused by the marine protist *Labyrinthula zosterae*. Eelgrass wasting disease can have devastating effects on eelgrass beds, as it can result in lesions on eelgrass blades, thus reducing the ability to photosynthesize (Graham et al., 2021). Since approximately 2007, eelgrass wasting disease has been detected along the west coast of North America and has had effects ranging from limited to severe in eelgrass ecosystems (Merkel & Associates, Inc., 2017b). Studies have shown that temperatures above 27 °C may result in eelgrass wasting disease infections in some species of eelgrass (Brakel et al., 2019).

In 2015 and 2017, researchers observed the presence of eelgrass wasting disease on shed leaves that were floating (Merkel & Associates, Inc., 2017b). The extent of eelgrass wasting disease in Tomales Bay and the esteros is unknown, as are the impacts it may have on ecosystem function, including impacts to eelgrass community health and composition (e.g., fish and invertebrates). As rising temperatures may exacerbate the disease, this data gap is of increasing concern.

Conclusion

For this question, the status was rated fair based on the limited data indicating that eelgrass beds are present in three of the four estuaries in the sanctuary, Estero Americano, Estero de San Antonio, and Tomales Bay. There were no recent surveys in Bolinas Lagoon, but anecdotal observations indicated that eelgrass remained absent in Bolinas Lagoon during the study period. Although anecdotal evidence suggested there were dense eelgrass beds in Tomales Bay that appeared to be healthy and may be expanding, the presence of eelgrass wasting disease was of concern. Management actions to remove moorings from eelgrass beds in Tomales Bay may have promoted recovery in previously impacted areas. Assessment and monitoring of the abundance and distribution of eelgrass was limited, and surveys did not include assessments to determine ecosystem functions, invertebrate interactions, or severity of and persistence of eelgrass wasting disease. The trend was undetermined due to a lack of time series data. A comprehensive monitoring plan is needed to assess the effectiveness of management actions, impacts from climate change, and the severity of eelgrass wasting disease.

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

Coastal and Offshore Region

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

Rationale: The 2014–2016 marine heatwave greatly impacted the abundance and distribution of numerous species that are neither keystone nor foundation species, but are considered important to sanctuary management for other reasons (i.e., other focal species). However, some focal species remained stable or increased during the study period. Although the relative abundance of young-of-the-year rockfish was relatively high from 2013–2016, it declined overall in the Gulf of the Farallones and Monterey Bay region during the study period. The regional abundance of white sharks increased in Central California. Humpback whale populations increased gradually on the West Coast, and their densities in GFNMS varied with krill densities. Since the 2014–2016 marine heatwave, densities of whales and krill increased slightly. In some years, habitat compression was a key driver of the distribution of forage species; this shifted the distribution of some focal species from the shelf break to the shelf, closer to shore, including humpback whales and Cassin's auklets. Breeding populations of Brandt's cormorant, Cassin's auklet, and common murre increased during the study period. Encounter rates for shorebirds in the sanctuary were lower during the study period compared to historic values; encounter rates decreased for willets, although worldwide populations remained stable or increased, and encounter rates increased slightly for snowy plover. Sea palm and abalone densities declined during the 2014–2016 marine heatwave; sea palm showed signs of recovery, but abalone abundances remained very low.

This question targets species of particular interest from the perspective of GFNMS managers, local partners, and experts. These "focal species" 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 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. This specific question was also not included in the 2010 report (see Appendix A); however, this topic was addressed in a question focused on the status of "key species." In 2010, the status of key species in the coastal and offshore region was fair and the trend was undetermined. The rating was based on the status of 49 key species and populations that were in varying states of integrity. For example, some locally breeding seabird species like common murres and threatened baleen whale species were stable or increasing within the sanctuary after threats like oil pollution and whaling were abated. In contrast, Cassin's auklets and sooty shearwaters had declined, likely due to larger-scale changes in prey availability and productivity within the California Current Ecosystem.

New Information in the 2010–2022 Condition Report

Indicator species used to evaluate this question included juvenile rockfish, white shark, humpback whale, Brandt's cormorant, Cassin's auklet, common murre, snowy plover, willet, sea palm, California mussel, and red abalone (Table S.LR.13.1). These species are a subset of the 92 considered to be focal species by GFNMS managers; Appendix D provides information on each of these species and the criteria used to identify them as focal species. Briefly, the indicator species considered in this section include those that are important prey species or assemblages for birds and mammals (juvenile rockfish), those that are highly dependent on the sanctuary for foraging during their non-breeding season (white sharks, humpback whales, snowy plover, willet), those that rely on the sanctuary for both breeding and foraging (Brandt's cormorant, Cassin's auklet, common murre), and those that are important contributors to habitat integrity (sea palm, California mussel, red abalone). Some of the species considered are also federally listed as endangered or threatened (humpback whale, snowy plover).

Table S.LR.13.1. Summaries for the key indicators related to focal species in the coastal and offshore region of GFNMS that were discussed during the June 7, 2020 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Juvenile rockfish	NOAA, 2022d; PISCO, 2022	Status: The relative abundance of juvenile rockfish varied; during the study period, relative abundance offshore was highest during 2013–2016 and abundance in kelp forests was highest prior to 2016. Trend: Relative abundance of juvenile rockfish decreased overall during the study period. Juvenile rockfish abundance in kelp forests decreased since the 2014–2016 MHW.	S.LR.13.1
White shark	Kanive et al., 2021; Sanford et al., 2019; Tanaka et al., 2021	Status: White sharks were abundant seasonally in GFNMS. Trend: Estimated abundance of white sharks increased during the study period.	N/A
Humpback whale	Elliott et al., 2022a; Carretta et al., 2022	Status: Humpback whales were abundant in the sanctuary, particularly spring through fall. Their distribution within the sanctuary has shifted closer to shore since the 2014–2016 MHW as a result of habitat compression. Trend: Humpback whale abundance in GFNMS increased.	S.LR.13.2; S.LR.13.3

Indicator	Source	Data Summary	Figures
Seabirds: Brandt's cormorant, Cassin's auklet, and common murre	Johns et al., 2020a; Elliott et al., 2022b	Status: Breeding populations of Brandt's cormorants, Cassin's auklets, and common murres were abundant in GFNMS. Trend: Populations of Brandt's cormorant and Cassin's auklet increased and the common murre population was stable at the South Farallon Islands.	N/A
Shorebirds: Snowy plover and willet	Lau, 2020; Lindquist & Roletto, 2022b	Status: The number of nesting snowy plovers in Point Reyes National Seashore was low, estimated to be 39 adults in 2020. Encounter rates of willets were low. Trend: There has been a significant increase in the number of breeding snowy plovers in Point Reyes National Seashore, and an apparent slight increase in encounter rates of plovers throughout the sanctuary. Encounter rates of willet in the sanctuary decreased during the study period; however, regional willet populations were stable or increasing, suggesting a shift in distribution. Total shorebird encounter rates were apparently stable during the study period.	S.LR.13.4
Algae: Sea palm	MARINe, 2022; Raimondi & Smith, 2022	Status: Sea palm densities varied, with the most recent densities at moderate levels. Trend: Sea palm density has declined from a high of >86 per square meter in 2008 to nearly zero during the 2014–2016 MHW. Sea palm density increased gradually from 2016 to 2021 and was higher in state marine protected areas within and adjacent to GFNMS compared to unprotected areas.	S.LR.13.5
Invertebrates: California mussel and red abalone	MARINe, 2022; Rogers-Bennett et al., 2019; Rogers-Bennett & Catton, 2019	Status: Abundance of mussels at three sites in the sanctuary varied but was generally high and stable. Red abalone abundance was extremely low compared to historic levels. Trend: California mussel cover varied among sites; some declines occurred during the study period and generally corresponded with the 2014–2016 MHW, but more recent trends suggest recovery may be occurring. Red abalone declined substantially during the study period.	S.LR.13.6
Data gaps	Additional shorebird population data are needed, particularly for subspecies of willet, to adequately determine the extent to which shorebirds use the sanctuary as populations and ranges change. Information on trends would be enhanced by the addition of new monitoring locations within Marin and Sonoma counties to assess densities of juvenile rockfish in kelp beds, as well as mussels and sea palms.		

Juvenile Rockfish

Juvenile rockfish (*Sebastes* spp.), especially the shortbelly rockfish (*S. jordani*), are a primary forage taxa for many seabirds, piscivorous fishes (such as salmon and lingcod), and other predators. There was a peak in mean relative abundance (measured as relative CPUE) of juvenile rockfish in the Gulf of the Farallones and Monterey Bay regions from 2013–2016 (Figure S.LR.13.1). In 2016–2020, the mean relative abundance of juvenile rockfish declined in the Gulf of the Farallones and Monterey Bay regions (NOAA, 2022d), resulting in an overall declining trend for 2013–2022. Since the 2014–2016 MHW, juvenile rockfish within the kelp forests along Sonoma and Mendocino counties have also declined and remained suppressed (PISCO, 2022).

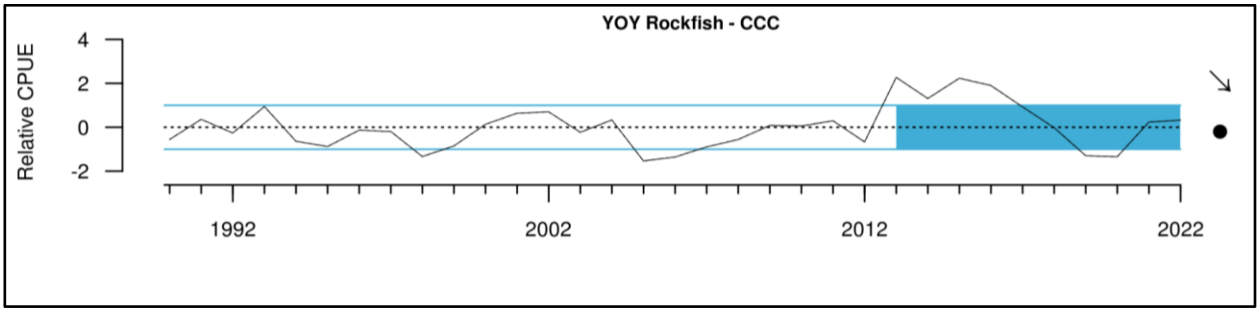


Figure S.LR.13.1. Mean relative CPUE of young of the year rockfish throughout the Gulf of the Farallones and Monterey Bay region, 1990 through 2021. Blue shading indicates the years analyzed for trend (2013 through 2021). The arrow indicates that there was a decreasing trend for the entirety of this period, and the black dot indicates that the mean for this period was within one standard deviation of the long-term mean. Source: NOAA, 2022d

White Sharks

White sharks (*Carcharodon carcharias*) have been an iconic species in the sanctuary since its designation, because the Farallon Islands are known as an aggregation location. Since 1994, state regulations have prohibited the take of white sharks, and in 2009, GFNMS established regulations to protect them from disturbance (i.e., approaching and attracting using chumming or decoys). From 2011–2018, the estimated overall abundance of white sharks in central California (i.e., the area bounded by Tomales Bay, the South Farallon Islands, and Año Nuevo Island) based on a mark-recapture model increased from a low estimate of 184 individuals in 2011 to a high estimate of 261 individuals in 2018; the estimated increasing trend was more consistent for mature individuals, while there was more uncertainty for sub-adults (Kanive et al., 2021). The estimated increase in white shark abundance was correlated with the reduction of take at the juvenile stage from fisheries throughout the U.S. waters and increased abundance of pinnipeds, their primary forage species in GFNMS (Kanive et al., 2021). Previously unobserved aggregations of juvenile white sharks (approximately one to three years old) began appearing in Monterey Bay along with other range-shifting taxa (Sanford et al., 2019) in 2014, coinciding with the onset of the MHW. Habitat modeling and preliminary observations indicated this new demographic partially extends into GFNMS waters (Tanaka et al., 2021).

Humpback Whales

The humpback whale (*Megaptera novaeangliae*) population in the Washington, Oregon, and California stock has been increasing at an annual rate of about 8% per year (Carretta et al., 2022). Humpback whales in GFNMS come primarily from the threatened Mexico Distinct Population Segment and endangered Central America Distinct Population Segment (Carretta et al., 2022). Their seasonality, abundance, and distribution within the sanctuary are influenced by ocean conditions and the presence of their forage species, such as krill and anchovy (Ingman et al., 2021; Santora et al., 2020; Gulland et al., 2022). Krill are more abundant in the sanctuary during times of cooler-than-average SSTs and higher-than-average upwelling indices (Schroeder et al., 2019; Santora et al., 2020, 2021b; Elliott et al. 2022a; Figure S.LR.12.3; Figure S.LR.12.4). Humpback whale densities are correlated with densities of krill in GFNMS, and both have been higher since 2015 (Figure S.LR.13.2; Elliott et al., 2022a). Humpback whales are distributed throughout the sanctuary, but forage primarily along the shelf break between 100–200 meters depth (Elliott et al., 2022a). Habitat compression during the 2014–2016 MHW resulted in the redistribution of forage species, and, as a result, humpback whales, closer to shore (Santora et al., 2020). In the period prior to the 2014–2016 MHW, only 5% of whales were observed nearshore. During the 2014–2016 marine heatwave, 9% of humpback whales were observed nearshore. In the years following the 2014–2016 MHW, 21% of observed humpback whales were observed nearshore (Elliott et al., 2022b; Figure S.LR.13.3). The movement of more whales closer to shore increases the co-occurrence of whales with large ships and commercial fishing traps (particularly Dungeness crab traps), making them more vulnerable to collisions with ships and entanglement in fishing gear (Figures S.P.4.2–S.P.4.4; Table S.P.4.2). The seasonality and timing of the arrival of most humpback whales in the Gulf of the Farallones region has shifted to an earlier arrival in the spring months (Ingman et al., 2021). On average, in comparison to 1993, humpback whales arrived 120 days earlier in 2016, increasing the number of days whales were present in the sanctuary during the commercial Dungeness crab fishery, November through June (Ingman et al., 2021). Humpback whales are particularly vulnerable to entanglement in the vertical lines and surface buoys of Dungeness crab traps (e.g., in 2015; Figures S.P.4.2–S.P.4.4; Table S.P.4.2; NOAA Fisheries, 2020a). Observations of dead whales reported to have been entangled in fishing gear occurred throughout northern California but were concentrated within the Gulf of the Farallones region.

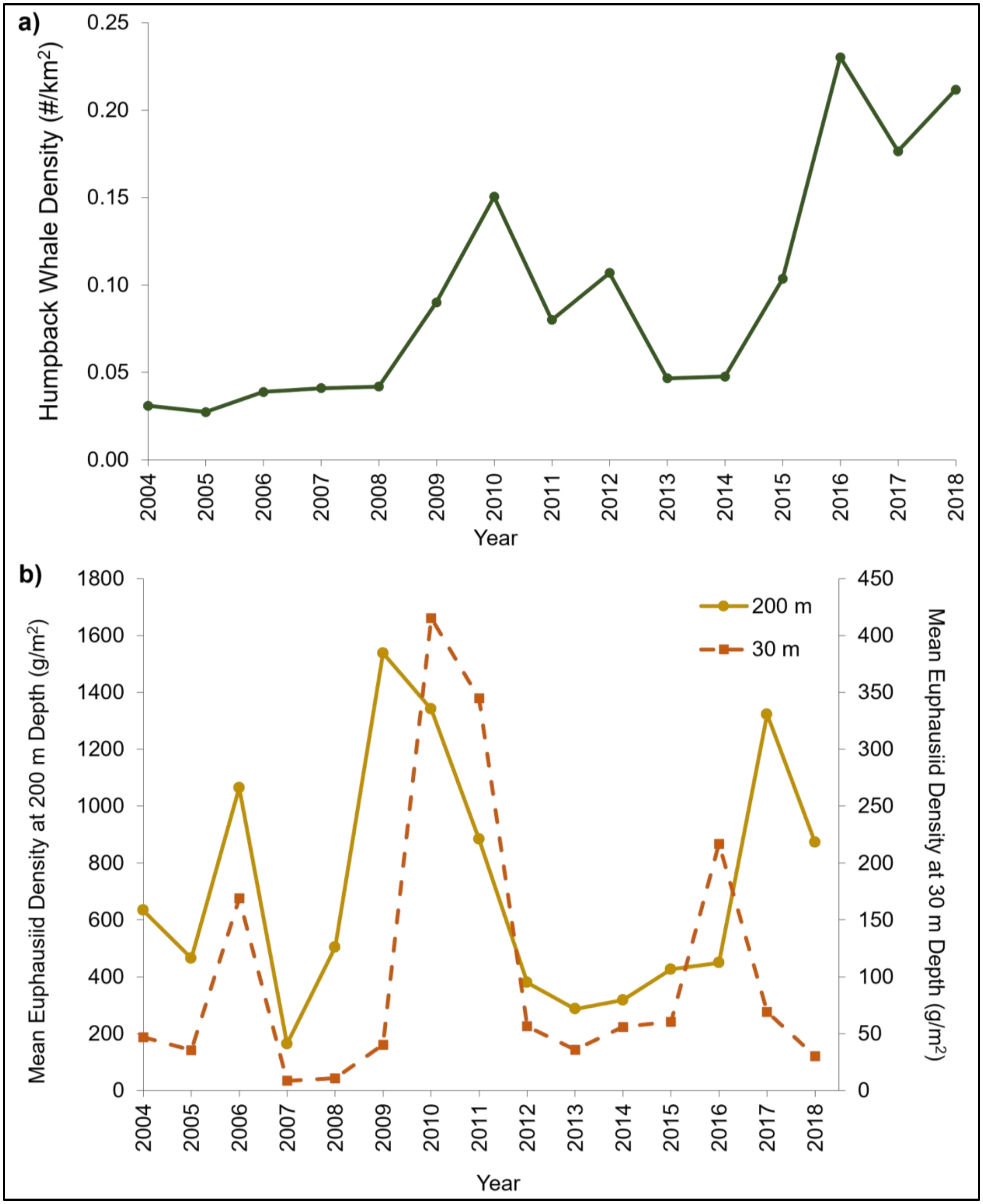


Figure S.LR.13.2. Density of (a) humpback whales and (b) krill within GFNMS, 2004–2018. Source: Elliott et al., 2022a

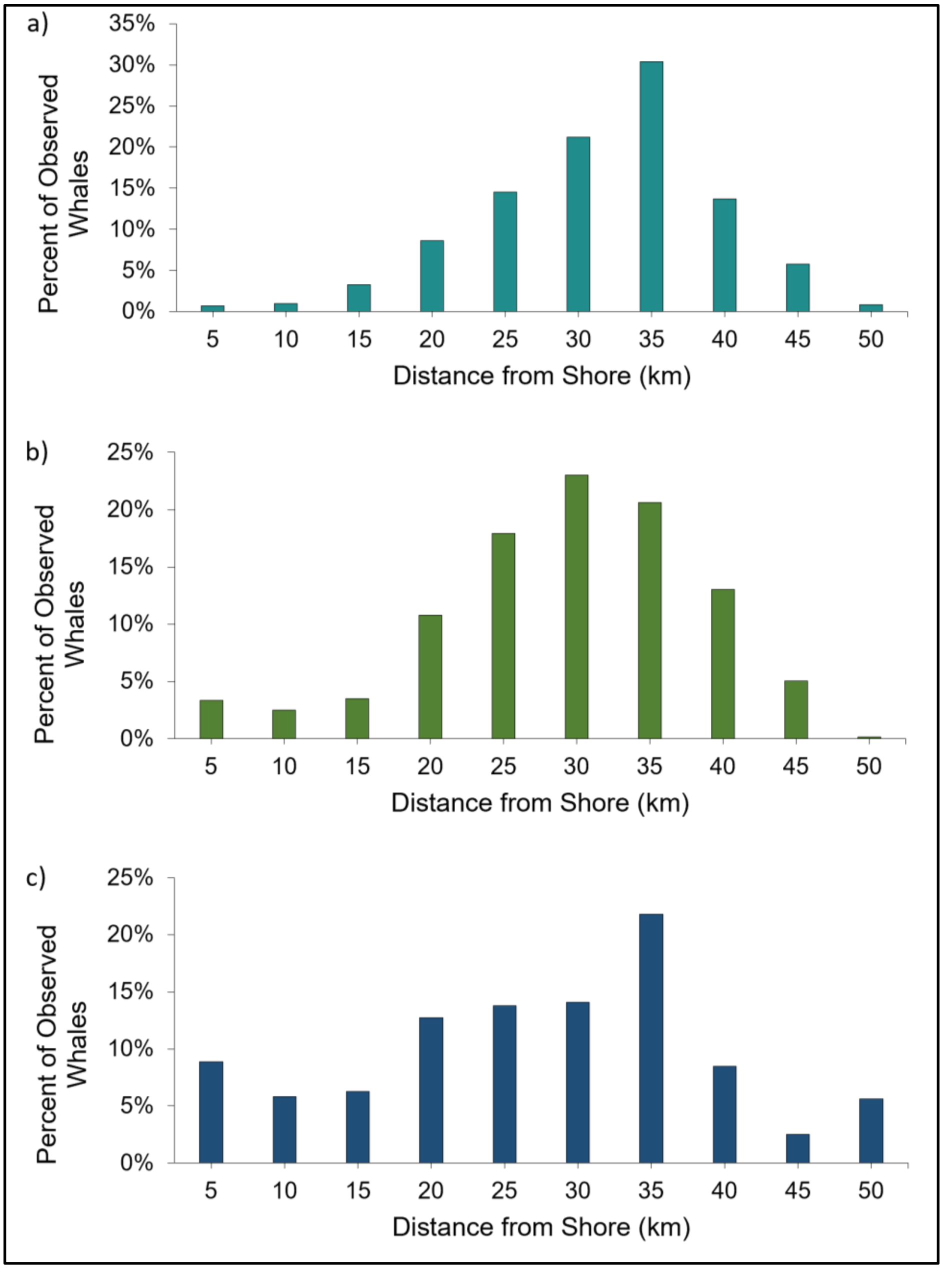


Figure S.LR.13.3. Humpback whale distance from shore observed during ACCESS research cruises in (a) 2010–2013, (b) 2014–2016, and (c) 2017–2019. Source: Elliott et al., 2022b

Seabirds: Brandt's Cormorants, Cassin's Auklets, and Common Murres

At the heart of the sanctuary are the South Farallon Islands, part of Farallon Islands National Wildlife Refuge, where over 365,000 birds breed, including 12 species of seabirds and one species of shorebird. Locally breeding seabirds are good indicators of sanctuary condition, as they respond quickly to environmental changes throughout the coastal and offshore regions of the sanctuary (Piatt et al., 2007). Three species of locally breeding seabirds, each occupying a different trophic niche, were selected for this assessment: Brandt's cormorant (*Urile penicillatus*; piscivorous), Cassin's auklet (*Ptychoramphus aleuticus*; planktivorous), and common murre (*Uria aalge*; primarily piscivorous but also forage on zooplankton).

The Brandt's cormorant breeding population on the South Farallon Islands was over 20,000 birds in 2007. A steep decline that coincided with unusual mortality events began in 2008 (Ainley et al., 2018), and the population of Brandt's cormorant on the islands was reduced to only 5,132 breeding birds by 2010. More recently, the breeding population has been slowly recovering and totaled approximately 10,408 breeding birds in 2021 (Spears et al., 2022). The Brandt's cormorant population size and breeding success on the South Farallon Islands is closely related to the abundance of juvenile rockfish and anchovy in the Gulf of the Farallones region (Ainley et al., 2018).

Similarly, the Cassin's auklet breeding population declined between 2005 and 2009, reaching an estimated low of 13,000 breeding birds in 2010. Cassin's auklet populations have been affected by threats including sea surface temperature anomalies, such as those associated with El Niño events (Johns et al., 2020b). Since 2010, the breeding population has gradually recovered, and the population was approximately 23,000 in 2021 (Spears et al., 2022).

The common murre breeding population has consistently increased since the mid-1990s following the elimination or reduction of threats including incidental fishing mortality, disturbance, oil pollution, and gillnetting (Spears et al., 2022; Capitolo, 2021). In 2000, the breeding population of common murres on the South Farallon Islands was approximately 60,000. By 2010, the population was 250,000. By 2021, the population had stabilized and was estimated to be approximately 300,000 breeding birds (Spears at al., 2022).

The seasonal distribution of Cassin's auklets mirrored the change in distribution that was observed in baleen whales during the 2014–2016 MHW (Hobday et al., 2016; Elliott et al., 2022a). Auklets and whales were more broadly distributed across the shelf during the 2014–2016 MHW, rather than where they are more typically concentrated along the shelf break, at the 100–200 m depth contours (Elliott et al., 2022a). Brandt's cormorants and common murres are typically distributed across the shelf in the Gulf of the Farallones region and did not appear to experience a similar shift to foraging further to the east (Elliott et al., 2022b; Johns et al., 2020a).

Point Reyes Headlands also hosts large colonies of Brandt's cormorants and common murres, where they have been monitored since 1996 (Scopel et al., 2023; Capitolo, 2021). Trends in cormorant and murre abundance have mirrored those observed at the South Farallon Islands. Elsewhere, common murres have been expanding and reestablishing their breeding colonies along the Sonoma Coast, which until recently held no breeding murres (Capitolo, 2021; Johns et al., 2020a).

Shorebirds: Willets and Snowy Plovers

In general, data from Beach Watch surveys indicated that encounter rates of shorebirds were lower during the study period (2010–2021) compared to earlier years (1995–2010), but were apparently stable during the study period (Lindquist & Roletto, 2022a, 2022b; Figure S.LR.13.4). Encounter rates for all shorebird taxa in the sanctuary ranged from 74 per kilometer in the 1990s to 21 per kilometer in 2021 (Figure S.LR.13.4). Even though encounter rates of willet (*Tringa semipalmata*) within the sanctuary have declined, many shorebird species are stable or increasing throughout their ranges, suggesting a shift in distribution rather than decline in total numbers (International Union for Conservation of Nature, 2022). For example, the encounter rate for willet in the sanctuary ranged from seven per kilometer in the 1990s to 0.8 per kilometer in 2021 (Figure S.LR.13.4), but the western and eastern North American populations were stable or increased in most of their breeding area (International Union for Conservation of Nature, 2022; Cornell Lab of Ornithology, 2022). Because the decline within the sanctuary was substantial, future regional population estimates of the western subspecies of willet are warranted.

Snowy plovers (*Charadrius nivosus*), which are federally listed as threatened, are present and breed in low but significantly increasing numbers (39 adults in 2020) within Point Reyes National Seashore, a regionally significant breeding area (Lau, 2020). Encounter rates of snowy plovers throughout the sanctuary have ranged from one to three individuals per kilometer. Since 2010, year-round encounter rates of snowy plover have slightly increased on sanctuary beaches (Lindquist & Roletto, 2022b).

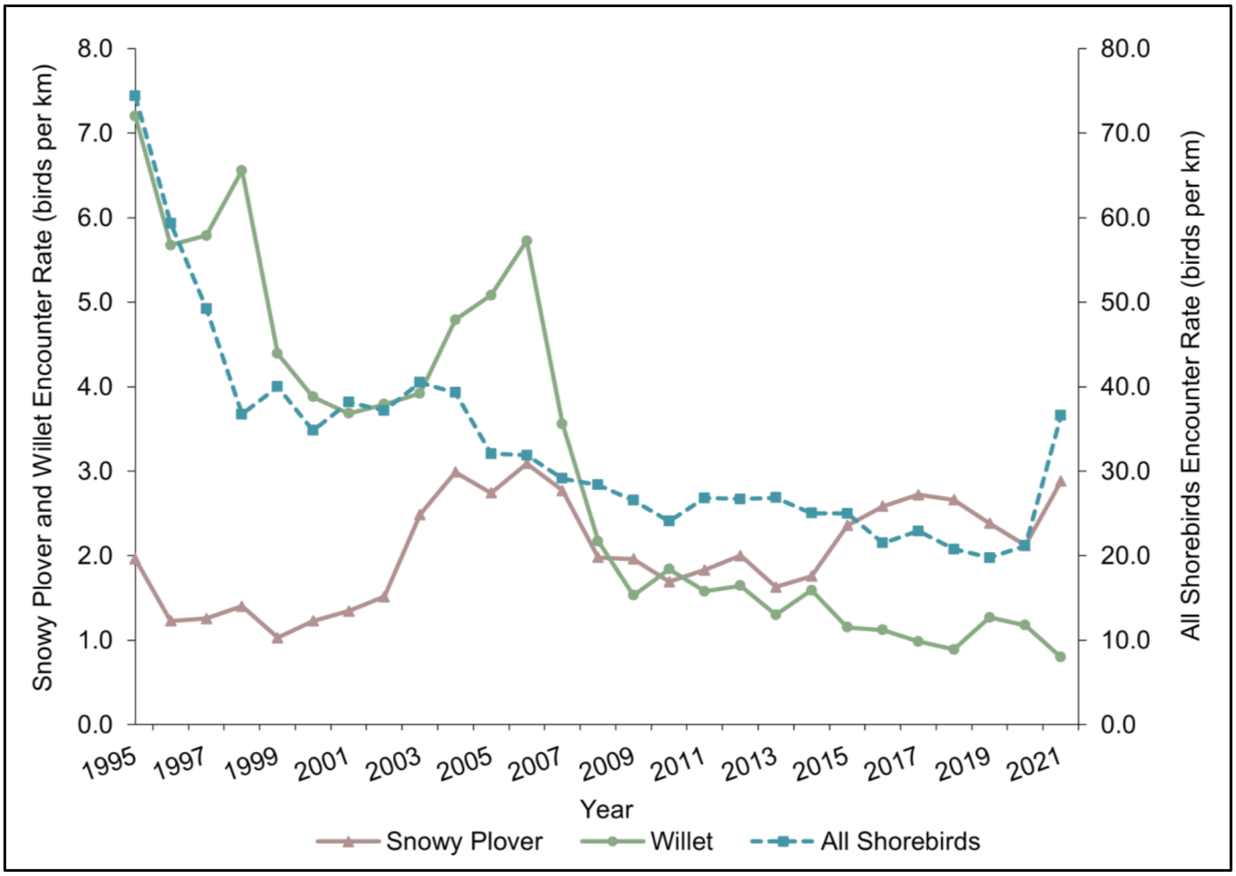


Figure S.LR.13.4. Annual encounter rates of snowy plover, willet, and all shorebirds in GFNMS, 1995–2021. Source: Lau, 2020; Lindquist & Roletto, 2022b

Algae: Sea Palm

Algae are important indicators of the health in the rocky intertidal habitat. Sea palm (*Postelsia palmaeformis*) was selected as an indicator species because it shows differential responses to natural and anthropogenic disturbances and it is a species of concern for the state. The density of sea palm at three intertidal locations in Sonoma and Marin counties (specific locations are not available due to the protected species status from the state) ranged from a high of >86 per square meter in 2008 to virtually zero in 2015 and 2016, during the 2014–2016 MHW (MARINe, 2022; Figure S.LR.13.5). It appears that sea palm is slowly recovering since the MHW. In 2021, researchers recorded an average seasonal density of 29.6 per square meter in Sonoma County and higher densities in the state's north-central marine protected areas (i.e., MPAs within and adjacent to GFNMS) compared to unprotected areas (Raimondi & Smith, 2022).

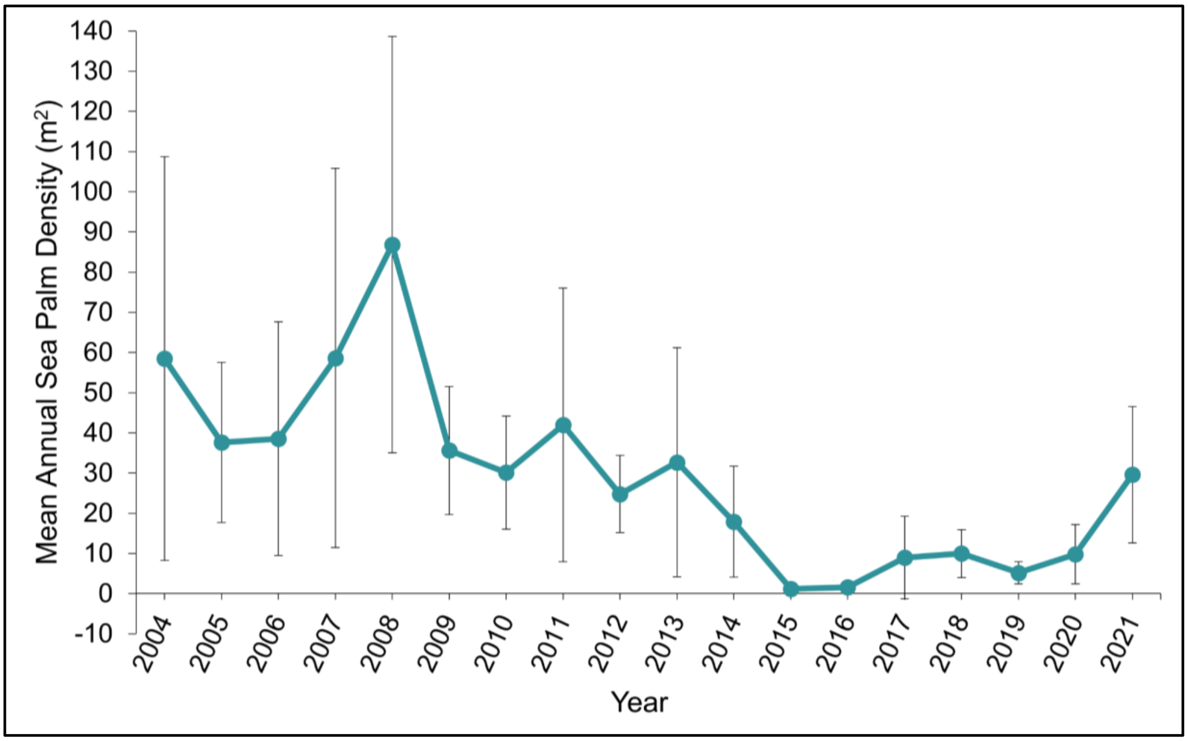


Figure S.LR.13.5. Mean annual densities of sea palm (*Postelsia palmaeformis*) measured at three sites in GFNMS, 2004–2021. Source: MARINe, 2022

Invertebrates: California Mussels and Red Abalone

The percent cover of California mussel (*Mytilus californianus*) at three sites in Marin and Sonoma counties ranged from a high of nearly 100% cover to a low of nearly 80% cover during the study period (Figure S.LR.13.6). At Bodega Marine Life Refuge, mussel cover declined during the 2014–2016 MHW. Mussel declines were also observed from 2016–2020 at Sea Ranch and Bolinas Point, but as of 2022, cover at all three sites appeared to be trending toward recovery (MARINe, 2022; see Figure S.H.10.1 for a map of survey locations).

The relative abundance of red abalone (*Haliotis rufescens*) in Marin, Sonoma, and Mendocino counties fluctuated during the study period. Prior to 2011, the population of red abalone was relatively stable and supported a recreational fishery. Due to significant population declines, the California Fish and Game Commission closed the recreational fishery in 2017. In 2011, the density of red abalone in Sonoma County was 0.5 per square meter (Rogers-Bennett et al., 2019). In 2011, a HAB caused by *Gonyaulax* spp. dinoflagellates caused a large mortality event among red abalone in Sonoma County. In 2012–2013, abalone density declined 30–35% to 0.35

per square meter (Rogers-Bennett et al., 2019), but were still considered to be relatively abundant; abalone density ranged from 0.24–1.01 per square meter in 2014 (Rogers-Bennett & Catton, 2019). The 2014–2016 MHW and sea star wasting syndrome disrupted the historic ecosystem balance between kelp, urchins, urchin predators (sea stars), and abalone in northern California kelp forests, resulting in a 43–96% decline among red abalone. In 2018, red abalone densities in northern California ranged from nearly zero at Caspar Cove, which is north of GFNMS, to nearly 0.2 per square meter at Timber Cove, within GFNMS. Densities of red abalone have decreased to the point that state fishery managers have predicted that it will take decades for the population to recover following increases in bull kelp (Rogers-Bennett & Catton, 2019).

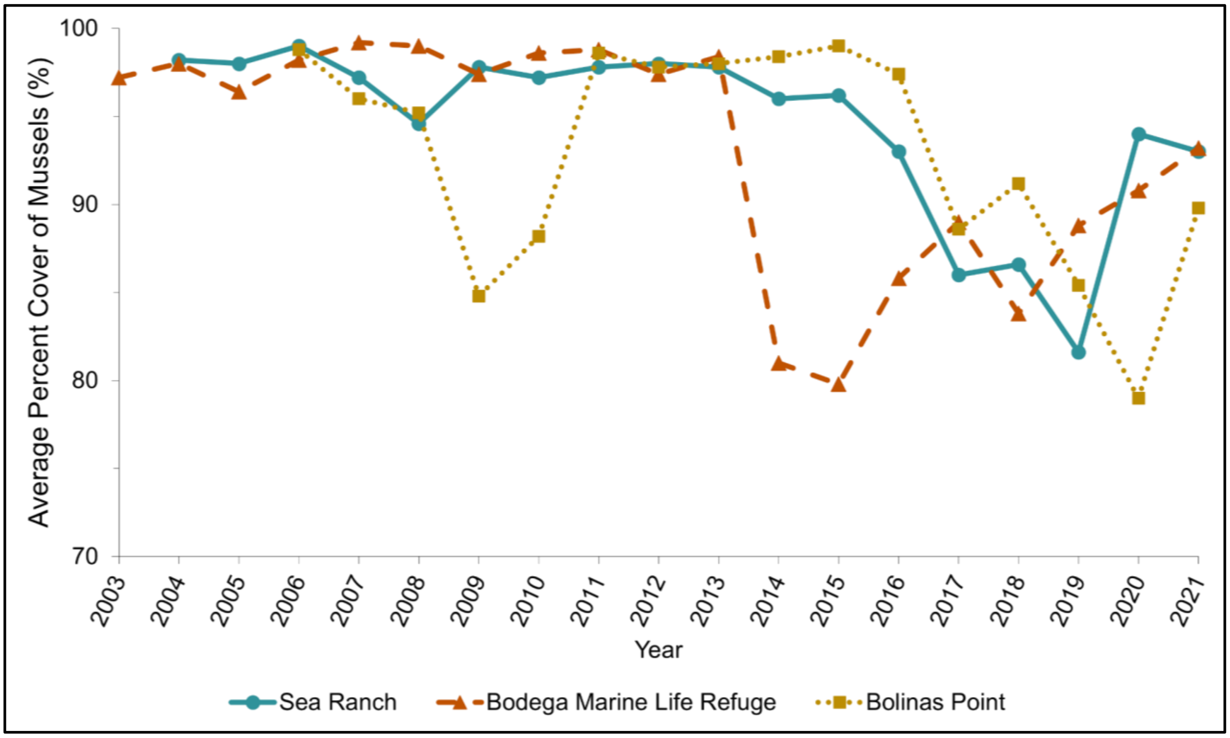


Figure S.LR.13.6. Percent cover of California mussel (*Mytilus californianus*) at three locations in GFNMS: Sea Ranch, Bodega Marine Life Refuge, and Bolinas Point. Note that the range for y-axis is 70–100%. Source: MARINe, 2022

Conclusion

This question was rated fair based mainly on impacts to species from the 2014–2016 MHW, such as severe declines in red abalone and sea palm, as well as the change in distribution of whales and Cassin's auklets from the shelf break to areas closer to shore. The trend was mixed, as some taxa declined, while others flourished and increased in abundance or appeared stable. Taxa that declined included juvenile rockfish, abalone, and sea palm. Encounter rates of willets in the sanctuary declined, but their coastwide populations appeared stable; snowy plover encounter rates appeared to increase slightly. Other species that increased during the study period included white sharks, humpback whales, Brandt's cormorants, and Cassin's auklets. Mussels and common murres appeared to be stable. Additional shorebird population data are needed for some species to adequately determine the extent to which shorebirds use the sanctuary as population expands and ranges change. Trend information could be enhanced with additional monitoring locations within Marin and Sonoma counties for densities of juvenile rockfish in kelp beds, mussels, and sea palm.

Estuarine and Lagoon Region

Status Description: Selected focal species are at substantially reduced levels, and prospects for recovery are uncertain.

Rationale: Anecdotal observations suggest that Olympia oysters, a native species, were present in Tomales Bay and Bolinas Lagoon, but no information on their abundance was available. Brant are thought to be declining throughout their range, but encounter rates for brant in the sanctuary fluctuated without a clear trend during the study period. Shorebird encounter rates during the study period were lower than in previous decades, but it is unknown whether this reflects the global decline in shorebird abundance or a range shift out of the sanctuary.

Findings From the 2010 the Condition Report

This specific question was not included in the 2010 report (see Appendix A); however, this topic was addressed in a question focused on the status of "key species." In 2010, the status of key species in the estuarine and lagoon region was fair and the trend was declining. Eelgrass had declined in some estuaries, particularly Bolinas Lagoon, where it was considered nearly extirpated; sedimentation, poor water quality, and physical disturbance negatively affected extant eelgrass in sanctuary lagoons. Although the abundance of endangered tidewater goby had declined throughout their range, they were apparently stable and locally abundant in some GFNMS estuaries. Brant populations increased gradually.

New Information in the 2010–2022 Condition Report

Indicator species used to evaluate this question included Olympia oysters, brant, and shorebirds as a group (Table S.LR.13.3). These species are a subset of the 92 considered to be focal species by GFNMS managers; Appendix D provides information on each of these species and the criteria used to identify them as focal species.

Table S.LR.13.2. Summaries for the key indicators related to other focal species in the estuarine and lagoon region of GFNMS that were discussed during the June 7, 2020 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Olympia oysters	Grosholz, 2022; Wasson et al., 2015	Status: Anecdotal data indicate that Olympia oysters were present in Tomales Bay and Bolinas Lagoon, but their abundance and density have not been assessed in recent years. Trend: Trends within the sanctuary during the study period were undetermined. There has been a long-term decline of native oysters along the West Coast.	N/A

Brant and shorebirds	Lindquist & Roletto, 2022b	Status: Encounter rates varied for brant (1–6.7 km^{-1}) and were low for all shorebirds (15–52 km^{-1}) compared to historic levels. Trend: A trend in brant encounter rate could not be determined given the high level of variability. Shorebird encounter rates declined during the study period.	S.LR.13.7; S.LR.13.8
Data gaps	No current data were available on the abundance or distribution of tidewater goby in sanctuary estuaries. Monitoring for Olympia oysters, and abundance and distribution information on other potential focal species (e.g., native and non-indigenous mud snails and oyster drills) are needed. A comparison of abundance and distribution within the sanctuary, foraging areas, and breeding areas are needed for shorebirds and brant.		

Olympia Oysters

Olympia oysters (*Ostrea lurida*) have greatly declined throughout the west coast of North America (Wasson et al., 2015; Grosholz, 2022). Data on the abundance and distribution of native oysters in the sanctuary's lagoon and estuaries are lacking. Minimal information on the presence of native oysters is available from researchers studying non-indigenous species in Tomales Bay (Kornbluth et al., 2022). Olympia oysters were present in Tomales Bay and Bolinas Lagoon; however, their population sizes during the study period were unknown (E.D. Grosholz/U.C. Davis, personal communication, May 24, 2022). The last study on Olympia oysters in Tomales Bay was conducted in 2006, and this work was described in the 2010 condition report (Kimbro & Grosholz, 2006; ONMS, 2010).

Brant and Shorebirds

The population of brant (*Branta bernicla*), a small sea goose, has been a concern to managers since sanctuary designation. Brant use the sanctuary's estuarine habitat to forage on eelgrass during their migration to and from their breeding areas in the arctic tundra. The North American population fluctuated over the past several decades and is now thought to be declining throughout its range (Sedinger et al., 2019). Encounter rates of brant in the sanctuary also fluctuated, with rates as high 6.7 birds per kilometer in 2014 to a low of one bird per kilometer in 2021 (Lindquist & Roletto, 2022b; Figure S.LR.13.7).

Worldwide populations of all shorebird species have declined over the past 20 years. For many species that breed in the arctic, populations declined by 70% (Munro, 2017). Encounter rates of all shorebird species in sanctuary estuaries also declined over the past two decades, from a peak encounter rate of 52 birds per kilometer in 1999 to a low of 15 birds per kilometer in 2020 (Lindquist & Roletto, 2022b; Figure S.LR.13.8). The reduced encounter rates for shorebirds compared to historic levels in GFNMS coastal and estuarine habitats may reflect a decline in shorebird populations or range shifts away from the sanctuary.

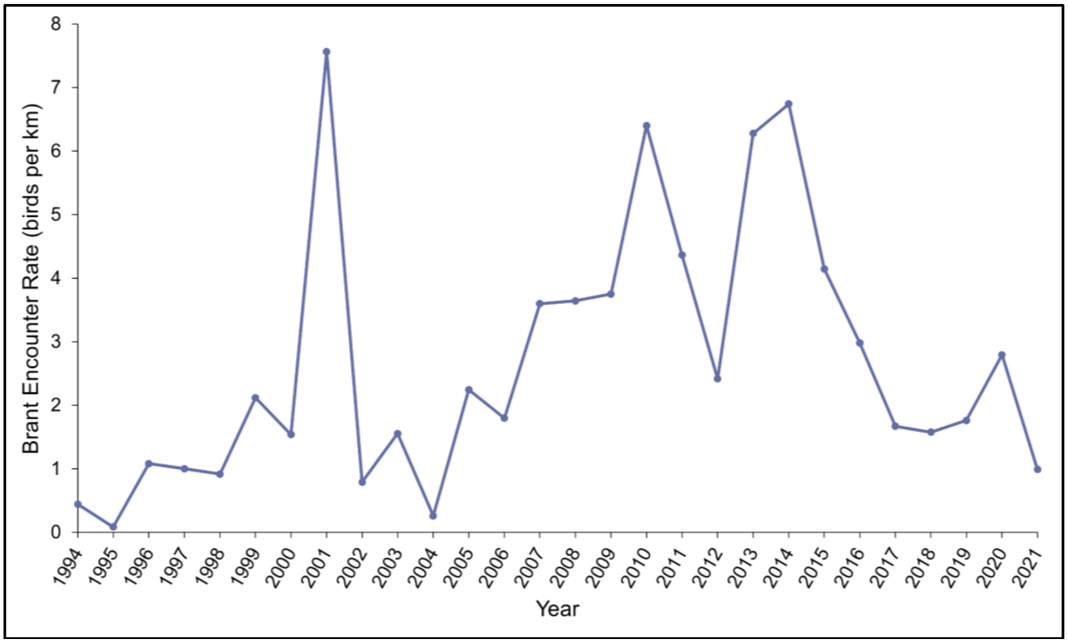


Figure S.LR.13.7. Encounter rates of brant in GFNMS, 1994–2021. Source: Lindquist & Roletto, 2022b

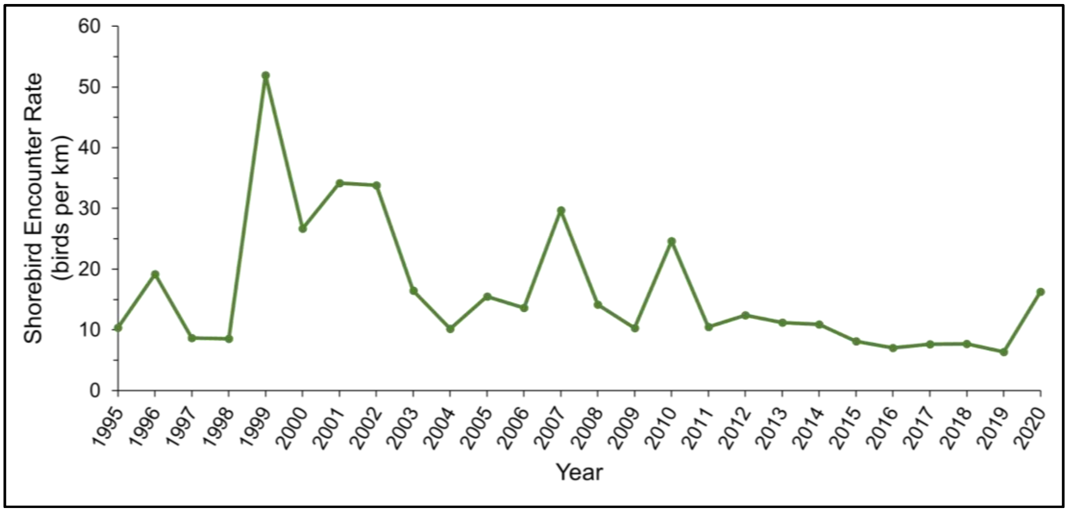


Figure S.LR.13.8. Encounter rates of shorebirds in estuarine habitat in GFNMS 1995–2020. Source: Lindquist & Roletto, 2022b

Conclusion

This question was rated fair/poor based on the anecdotally low abundance of native oysters, range-wide declines in and fluctuating encounter rates for brant, and low encounter rates for shorebirds compared to historic levels. The trend was undetermined based primarily on the lack of information on the density and distribution of native oysters; monitoring for native oysters is needed. Recent observations of shorebirds in the sanctuary were lower than in previous decades, but it is unknown whether this reflects worldwide population trends or a range shift out of the sanctuary. A comparison of abundance and distribution within the sanctuary, foraging areas, and breeding areas are needed for shorebirds and brant.

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

Coastal and Offshore Region

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: Non-indigenous species were present within the coastal and offshore region of GFNMS, and the number of non-indigenous species detected increased during the study period. However, available evidence suggests that the impacts of these species have been limited. Status and trend data, including abundance, density, and spatial distribution, were limited for most non-indigenous species of concern, and more long-term monitoring and systematic surveys are needed.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good and the trend was not changing. This rating reflected knowledge that non-indigenous species, such as *Codium fragile* ssp., were present in this region of the sanctuary but species of concern did not appear to be affecting ecosystem integrity. The report also identified the need for more monitoring.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included species richness and the presence of six non-indigenous species of concern: the alga *Caulacanthus okamurae*, the bryozoan *Watersipora* spp., the tunicate *Didemnum* spp., the alga *Codium fragile*, Japanese wireweed (*Sargassum muticum*), and wakame (*Undaria pinnatifida*).

Table S.LR.14.1. Summaries for the key indicators related to non-indigenous species in the coastal and offshore region of GFNMS that were discussed during the May 24, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures and Tables
Non-indigenous species richness	Fofonoff et al., 2018	Status: As of 2020, 84 non-indigenous species were established within the sanctuary. Of these, 22 species were found exclusively in the coastal and offshore region, and 19 were found in both the coastal and offshore and estuarine and lagoon regions. Trend: The overall number of non-indigenous species detected in the sanctuary increased; however, the rate of increase was lower during the study period compared to previous decades.	Figure S.LR.14.1; Table S.LR.14.2
Caulacanthus okamurae (algae)	Zabin et al., 2018; MARINe, 2021	Status: This species was first observed near Santa Maria Creek in 2014; it was observed at Bodega Marine Life Refuge in 2018, 2019, and 2020 and Santa Maria Creek in 2018 and 2021. Trend: No trend data were available.	Figure S.LR.14.2
Watersipora spp. (bryozoans) and *Didemnum* spp. (tunicates)	Mackie et al., 2012; MARINe, 2021; Zabin et al., 2018	Status: *Watersipora* and *Didemnum* spp. were first observed in the early 2000s. Both have had little to no known impact on the sanctuary. Trend: No trend data were available.	N/A
Codium fragile sspp. (algae)	MARINe, 2021	Status: This species was observed within the sanctuary during the study period at Mussel Flat (2017) and Santa Maria Creek (2010). Trend: No trend data were available.	Figure S.LR.14.2
Sargassum muticum (Japanese wireweed)	Freiwald, 2020; MARINe, 2021	Status: This species was recently observed within the sanctuary's coastal and offshore region for the first time in 2021; it was previously documented in the estuarine and lagoon region in 1973. Trend: No trend data were available.	N/A
Undaria pinnatifida (wakame)	Freiwald, 2020	Status: This species has not been observed within GFNMS, but is prevalent in nearby locations and can have substantial impacts on native species. Trend: No trend data were available.	N/A
Data gaps	Long-term monitoring data on density and geographic extent were limited for most non-indigenous species.		

Non-Indigenous Species Richness

While information is limited in the coastal and offshore region of GFNMS, non-indigenous species of concern are present and are known to have localized impacts. Non-indigenous species are documented in the coastal and offshore region of GFNMS primarily by MARINe at six long-term monitoring sites and through some targeted surveys. These data are for presence only, and do not indicate abundance or persistence (see MARINe [2021] for detailed methodology). As of 2020, 84 non-indigenous species have become established (reproducing) within the sanctuary (Fofonoff et al., 2018; Figure S.LR.14.1; Table S.LR.14.2) and 22 of those were found in the coastal and offshore habitat. Of the 22 species, three species (*Megasyllis nipponica*, *Perophora japonica*, and *Watersipora n.* spp. haplotype) were documented solely in the coastal and offshore habitat, while 19 species, representing nine taxonomic groups, were documented in both the coastal and offshore and estuarine and lagoon regions of the sanctuary (Fofonoff et al., 2018). The remainder (n = 62) were found in estuarine and lagoon habitat only, and are discussed further in the following section. The number of non-indigenous species within the sanctuary region has increased greatly over the last century, but the rate of increase slowed during the study period (Figure S.LR.14.1).

Overall, there have been fewer observations of non-indigenous species in the coastal and offshore region compared to the estuarine and lagoon region of GFNMS. This difference can be explained by a variety of potential factors. In the coastal and offshore region, higher energy, wave-swept habitats may hinder the establishment of some non-indigenous invertebrates, such as those that are transported from an estuarine habitat and are thus not well adapted to characteristics of the offshore environment (e.g., food availability, predation, temperature, etc.; Preisler et al., 2009; Ruiz et al.,1997; Zabin et al., 2018). Further, offshore areas are often too inaccessible or expensive to survey routinely, limiting the spatial and temporal coverage of monitoring efforts. In contrast, the lower-energy waters of estuarine and lagoon regions have been monitored more frequently over time due to an ease of access for surveys, as well as a known niche availability and presence of common vectors (e.g., shipping and aquaculture) for non-indigenous species of interest (Bailey et al., 2020; Preisler et al., 2009; Ruiz et al., 1997; Ruiz et al., 2009; Wasson et al., 2005; Zabin et al., 2018).

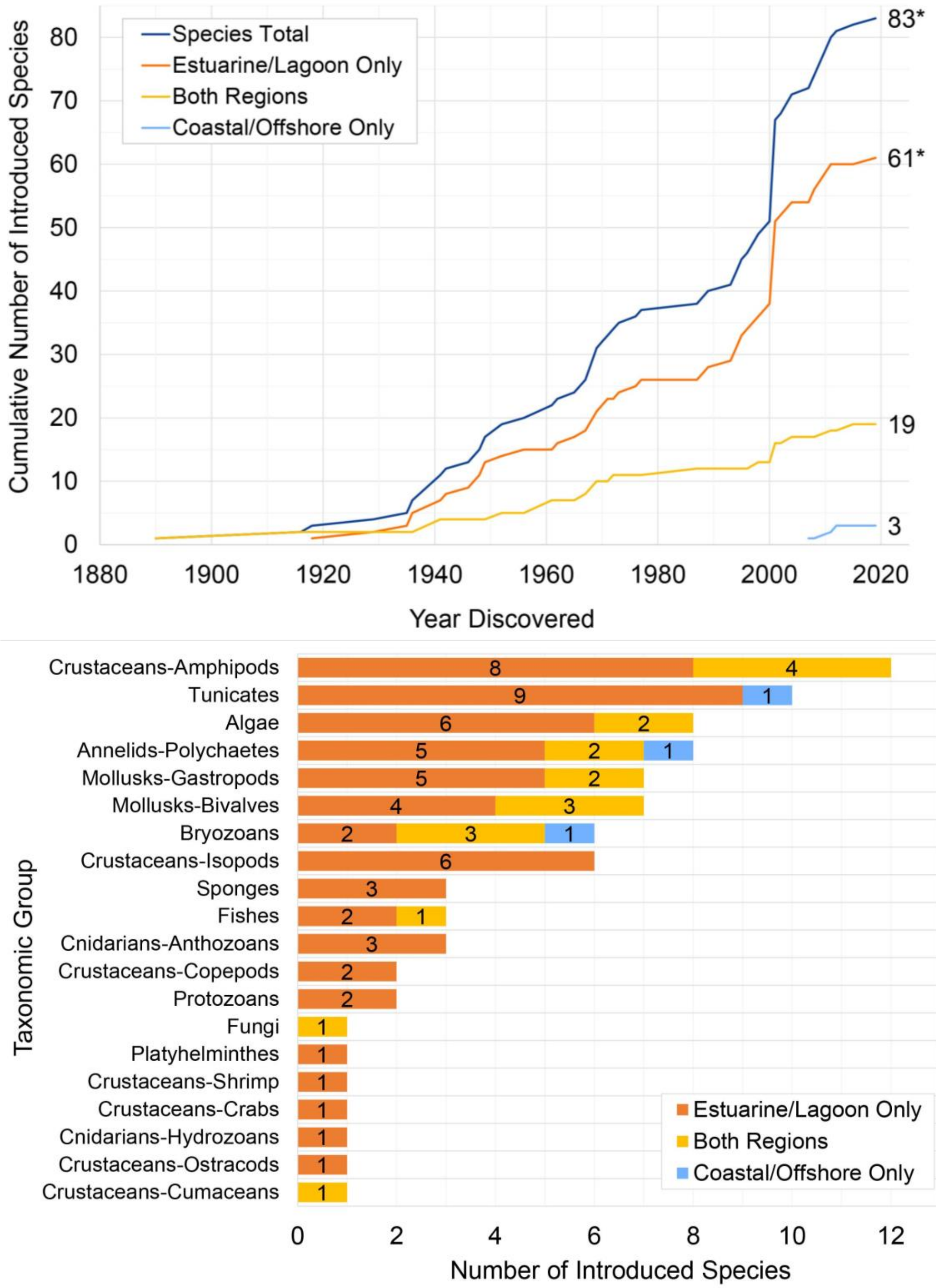


Figure S.LR.14.1. Cumulative non-indigenous species richness in GFNMS sanctuary-wide and by region, by year of first observation (top) and taxonomic group (bottom). The asterisk (*) indicates that one record within the estuarine and lagoon region had no year associated with the observation and was thus not included in the figure; the total number of non-indigenous species observed in GFNMS as of 2020 was 84. Survey records and effort were not equally distributed across sanctuary regions. Source: Fofonoff et al., 2018

Table S.LR.14.2. List of 84 established non-indigenous species in GFNMS from observations made since 1890. One asterisk (*) indicates that a given species was observed in both habitats, two asterisks (**) indicate that the species was observed in the coastal and offshore region only, and all others were observed in the estuarine and lagoon region only. Source: Fofonoff et al., 2018

Taxonomic Group	**Species**
Algae	*Agarophyton vermiculophyllum**
Algae	*Caulacanthus okamurae**
Algae	*Codium fragile* ssp. *fragile*
Algae	*Fucus spiralis*
Algae	*Gelidium vagum*
Algae	*Pyropia suborbiculata*
Algae	*Sargassum muticum*
Algae	*Ulva australis*
Annelids: Polychaetes	*Alitta succinea*
Annelids: Polychaetes	*Heteromastus filiformis* spp. complex
Annelids: Polychaetes	*Megasyllis nipponica***
Annelids: Polychaetes	*Neodexiospira brasiliensis*
Annelids: Polychaetes	*Polydora cornuta*
Annelids: Polychaetes	*Pseudopolydora* cf. *kempi**
Annelids: Polychaetes	*Pseudopolydora paucibranchiata**
Annelids: Polychaetes	*Streblospio benedicti*
Bryozoans	*Bugula neritina**
Bryozoans	*Bugulina stolonifera**
Bryozoans	*Cryptosula pallasiana*
Bryozoans	*Schizoporella japonica**
Bryozoans	*Watersipora n.* sp.**
Bryozoans	*Watersipora subatra*
Cnidarians: Anthozoans	*Diadumene franciscana*
Cnidarians: Anthozoans	*Diadumene lineata*
Cnidarians: Anthozoans	*Nematostella vectensis*
Cnidarians: Hydrozoans	*Climacocodon ikarii*
Crustaceans: Amphipods	*Ampelisca abdita*
Crustaceans: Amphipods	*Ampithoe valida*
Crustaceans: Amphipods	*Caprella mutica*
Crustaceans: Amphipods	*Corophium alienense*
Crustaceans: Amphipods	*Corophium heteroceratum*
Crustaceans: Amphipods	*Grandidierella japonica**
Crustaceans: Amphipods	*Incisocalliope derzhavini*

Taxonomic Group	**Species**
Crustaceans: Amphipods	*Jassa marmorata**
Crustaceans: Amphipods	*Monocorophium acherusicum**
Crustaceans: Amphipods	*Monocorophium insidiosum**
Crustaceans: Amphipods	*Monocorophium uenoi*
Crustaceans: Amphipods	*Paracorophium* sp.
Crustaceans: Copepods	*Mytilicola orientalis*
Crustaceans: Copepods	*Pseudodiaptomus marinus*
Crustaceans: Crabs	*Carcinus maenas*
Crustaceans: Cumaceans	*Nippoleucon hinumensis**
Crustaceans: Isopods	*Gnorimosphaeroma rayi*
Crustaceans: Isopods	*Iais californica*
Crustaceans: Isopods	*Limnoria quadripunctata*
Crustaceans: Isopods	*Niambia capensis*
Crustaceans: Isopods	*Pseudosphaeroma* sp. A
Crustaceans: Isopods	*Sphaeroma quoianum*
Crustaceans: Ostracods	*Spinileberis quadriaculeata*
Crustaceans: Shrimp	*Upogebia major*
Fishes	*Acanthogobius flavimanus*
Fishes	*Alosa sapidissima*
Fishes	*Morone saxatilis**
Fungi	*Claviceps purpurea* var. *spartinae**
Mollusks: Bivalves	*Arcuatula senhousia**
Mollusks: Bivalves	*Gemma gemma*
Mollusks: Bivalves	*Geukensia demissa*
Mollusks: Bivalves	*Mya arenaria**
Mollusks: Bivalves	*Mytilus galloprovincialis**
Mollusks: Bivalves	*Ruditapes philippinarum*
Mollusks: Bivalves	*Theora lubrica*
Mollusks: Bivalves	*Mya arenaria**
Mollusks: Gastropods	*Batillaria attramentaria**
Mollusks: Gastropods	*Haminoea japonica*
Mollusks: Gastropods	*Myosotella myosotis*
Mollusks: Gastropods	*Ocinebrellua inornatus*
Mollusks: Gastropods	*Philine auriformis**
Mollusks: Gastropods	*Philine orientalis*
Mollusks: Gastropods	*Urosalpinx cinerea*

Taxonomic Group	**Species**
Platyhelminthes	*Cercaria batillariae*
Protozoans	*Ancistrocoma pelseneeri*
Protozoans	*Trochammina hadai*
Sponges	*Cliona* sp.
Sponges	*Halichondria bowerbanki*
Sponges	*Hymeniacidon perlevis*
Tunicates	*Ascidia zara*
Tunicates	*Botrylloides violaceus*
Tunicates	*Botryllus schlosseri*
Tunicates	*Ciona robusta*
Tunicates	*Ciona savignyi*
Tunicates	*Didemnum vexillum*
Tunicates	*Diplosoma listerianum*
Tunicates	*Molgula manhattensis*
Tunicates	*Perophora japonica***
Tunicates	*Polyandrocarpa zorritensis*

Caulacanthus okamurae

The non-indigenous alga *Caulacanthus okamurae* was first observed in Tomales Bay in 2011 (Miller et al., 2011) and was observed for the first time in the coastal and offshore region of GFNMS in 2014 near Santa Maria Creek in Drakes Bay (Zabin et al., 2018). There has been an increase in the frequency of detection at the Santa Maria Creek (located in Point Reyes National Seashore; 2018, 2021) and Bodega Marine Life Refuge (2018–2020) MARINe long-term monitoring sites in recent years (MARINe, 2021; see Figure S.H.10.1 for a map of these sites). *C. okamurae* is known to displace some invertebrates (e.g., mussels, barnacles) in upper intertidal zone habitats where it has been observed (Figure S.LR.14.2). However, this species may increase habitat complexity and biodiversity in areas where such complexity is not often available, providing refuge, food, and other important ecological benefits to animals and algae in the upper intertidal zone (Smith et al., 2014; MARINe, 2021).

Watersipora and *Didemnum* spp.

The bryozoan *Watersipora* spp. and tunicate *Didemnum* spp. have been recorded in targeted coastal and offshore studies of GFNMS since the early 2000s (Mackie et al., 2012; Zabin et al., 2018; MARINe, 2021), and while they are present within the sanctuary and contribute to the increase in non-indigenous species composition and distribution, they have little to no known impact within this region of the sanctuary. *Didemnum* spp. are also found within the estuarine and lagoon region of GFNMS and their impacts in those habitats are discussed in the following section.

Codium fragile sspp.

Codium fragile sspp. (Figure S.LR.14.2) are an invasive green algae known to interfere with commercial fishing gear (by fouling gear surfaces) and aquaculture (by interfering with scallop movement or attaching to shellfish then floating away, taking the animal with it; Fofonoff et al., 2018), and overgrow bivalves and seagrass beds. *C. fragile* sspp. have been observed at MARINe long-term monitoring sites, including Mussel Flat in 2005 and 2017 and Santa Maria Creek in 2010 (MARINe, 2021), but their status and impact was unknown.

Sargassum muticum

Sargassum muticum is a non-indigenous species of concern at a number of locations on the West Coast—including San Francisco, the Channel Islands, and Washington—due to its potential negative impact to understory algae in kelp habitats (MARINe, 2021; ONMS, 2022b). *S. muticum* was previously observed in the estuarine region of the sanctuary in 1973, but was observed off the coast at Point Arena State Marine Reserve for the first time in 2021 (MARINe, 2021).

Figure S.LR.14.2. The invasive red algae *Caulacanthus okamurae* (left) and the green algae *Codium fragile* ssp. Photos (left to right): MARINe; S. Lonhart/NOAA

Undaria pinnatifida

Japanese kelp or wakame (*Undaria pinnatifida*) is a non-indigenous species that has not yet been observed within GFNMS, but was considered for the 2010–2022 assessment due to its prevalence and impact in nearby areas and the rapid rate at which it spreads to various habitats. It is listed as one of the world's 100 worst invasive alien species by the International Union for the Conservation of Nature (Global Invasive Species Database, 2022, 2023a). It is known to overgrow and compete with native algae species (particularly native kelp), and can attach to both natural (shells of abalone, bivalves, algae, etc.) and human-made (commercial fishing equipment, boat hulls, piers, etc.) hard surfaces in the marine environment (Lowe et al., 2000; De Poorter, 2009). Despite its absence within GFNMS, *U. pinnatifida* is present in nearby regions outside of the sanctuary, including San Francisco Bay, MBNMS, and Channel Islands National Marine Sanctuary (Miller & Engle, 2009; Hastings, 2020).

Conclusion

This question was rated good based on the known presence of 22 species in the coastal and offshore region of GFNMS. Although the known presence of non-indigenous species is not high enough to produce noticeable impacts, some algae species have the potential to become problematic. The number of non-indigenous species increased in the sanctuary over the long term, although the rate of increase was slower during the study period compared to the previous century. However, the trend for the study period was undetermined based on the lack of detailed time series data on non-indigenous species. More systematic and long-term surveys are needed, along with an increased focus on early detection in order to mitigate and/or prepare for potential negative impacts.

Estuarine and Lagoon Region

Status Description: Non-indigenous species have caused measurable but not severe degradation in some attributes of ecological integrity.

Rationale: Non-indigenous species remained present within the estuarine and lagoon region of GFNMS and caused measurable degradation at the local level. In particular, European green crabs in Tomales Bay and Bolinas Lagoon and non-native snails in Tomales Bay have had negative impacts on native species. The number of non-indigenous species in the sanctuary increased, but the rate of increase slowed during the study period compared to the last century. Some species, such as non-indigenous *Spartina* spp., declined, while others remained stable (European green crabs) or had variable or undetermined trends (snails). Data for most non-indigenous species were limited, and more long-term monitoring and systematic surveys are needed.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair/poor and the trend was undetermined. This rating was based on the high number of non-indigenous species in this region of the sanctuary (e.g., European green crab, Japanese mud snail, smooth cordgrass).

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included species richness and the presence of five non-indigenous species of concern: European green crab (*Carcinus maenas*), cordgrass (*Spartina* spp.), Japanese oyster drill (*Ocinebrellus inornatus*), Atlantic oyster drill(*Urosalpinx cinerea*), and Japanese mud snail (*Batillaria attramentaria*).

Table S.LR.14.3. Summaries for the key indicators related to non-indigenous species in the estuarine and lagoon region of GFNMS that were discussed during the May 24, 2022 virtual status and trends workshop.

Indicator	Sources	Data Summary	Figures
Species richness	Fofonoff et al., 2018	Status: As of 2020, 84 non-indigenous species were established within the sanctuary. Of these, 61 species were found exclusively in the estuarine and lagoon region, and 19 were found in both the coastal and offshore and estuarine and lagoon regions. Trend: The overall number of non-indigenous species detected in the sanctuary increased; however, the rate of increase was lower during the study period compared to previous decades.	S.LR.14.1
Carcinus maenas (European green crab)	Grosholz et al., 2021	Status: This species was present in the sanctuary. Trend: Not changing; no evidence of elevated recruitment in Tomales Bay and Bolinas Lagoon.	S.LR.14.4; S.LR.14.5
Non-indigenous *Spartina* spp. (cordgrass)	Rohmer & Kerr, 2021	Status: These species were present in the sanctuary. Trend: Improving; *Spartina* spp. of concern were mostly eradicated during the study period.	N/A
Ocinebrellus inornatus (Japanese oyster drill)	Rubinoff & Grosholz, 2022	Status: This species was present in the sanctuary. Trend: Abundance varied during the study period.	S.LR.14.6; S.LR.14.7
Urosalpinx cinerea (Atlantic oyster drill)	Rubinoff & Grosholz, 2022	Status: This species was present in the sanctuary. Trend: Abundance varied during the study period.	S.LR.14.6; S.LR.14.7
Batillaria attramentaria (Japanese mud snail)	Rubinoff & Grosholz, 2022	Status: This species was present in the sanctuary. Trend: A trend for the study period could not be determined, as data were limited to 2015–2019.	S.LR.14.6; S.LR.14.7
Data gaps	Data availability was limited for long-term monitoring, density, and geographic extent of most non-indigenous species.		

Species Richness

As of 2020, 84 established non-indigenous species from 20 different taxonomic groups were observed within GFNMS, and 81 of those were located in estuarine and lagoon habitats. Of those 81 species, 61 were found only in estuarine and lagoon habitats, and 19 were found in both estuarine and lagoon and coastal and offshore habitats (Fofonoff et al., 2018; Figure S.LR.14.1). Of the 61 species in estuarine and lagoon habitat, five were evaluated as data indicators for this question.

Non-indigenous species are monitored at four sites within the estuarine and lagoon region of GFNMS and two adjacent sites at Point Reyes National Seashore (Figure S.LR.14.3).

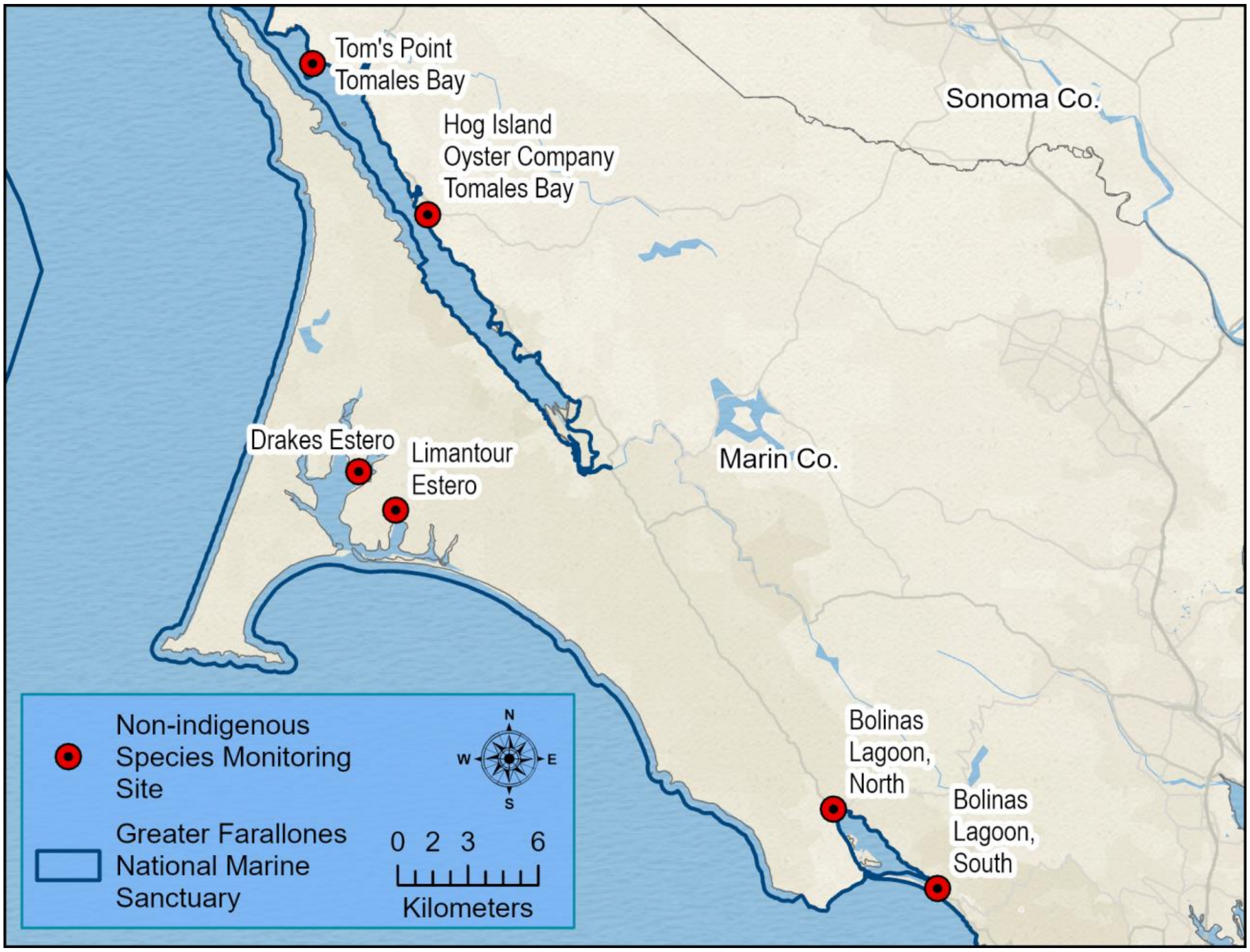


Figure S.LR.14.3. Map of non-indigenous species monitoring sites in the estuarine and lagoon region of GFNMS (Tomales Bay and Bolinas Lagoon) and adjacent sites at Point Reyes National Seashore (Drakes Estero and Limantour Estero). Image: NOAA; Source: Grosholz et al., 2021; Rohmer & Kerr, 2021; Rubinoff & Grosholz, 2022; Esri, 2016

European Green Crab

The European green crab (Figure S.LR.14.4), listed on IUCN's Global Invasive Species Database as one of the world's 100 worst invasive species (Global Invasive Species Database, 2022, 2023b), first became established in San Francisco in 1989–1990 and spread rapidly, gaining a foothold in shallow, warm estuaries and nearshore lagoon habitats throughout the west coast of the U.S. (Cohen et al., 1995; Jamieson et al., 1998; Grozholz et al., 2021). This species is notably present in Tomales Bay, Bolinas Lagoon, and nearby Bodega Harbor (outside GFNMS), where it impacts shorebirds and other native species by competing for food. The abundance of European green crabs in the sanctuary suggests they are unlikely to be eradicated, however they have not exhibited evidence of elevated recruitment (Figure S.LR.14.5). Furthermore, while European green crabs have been shown to negatively affect eelgrass in British Columbia (Howard et al. 2019), there has been no such impact observed in GFNMS, where eelgrass density is lower.

Figure S.LR.14.4. European green crab (*Carcinus maenas*). Photo: E. Grason/University of Washington

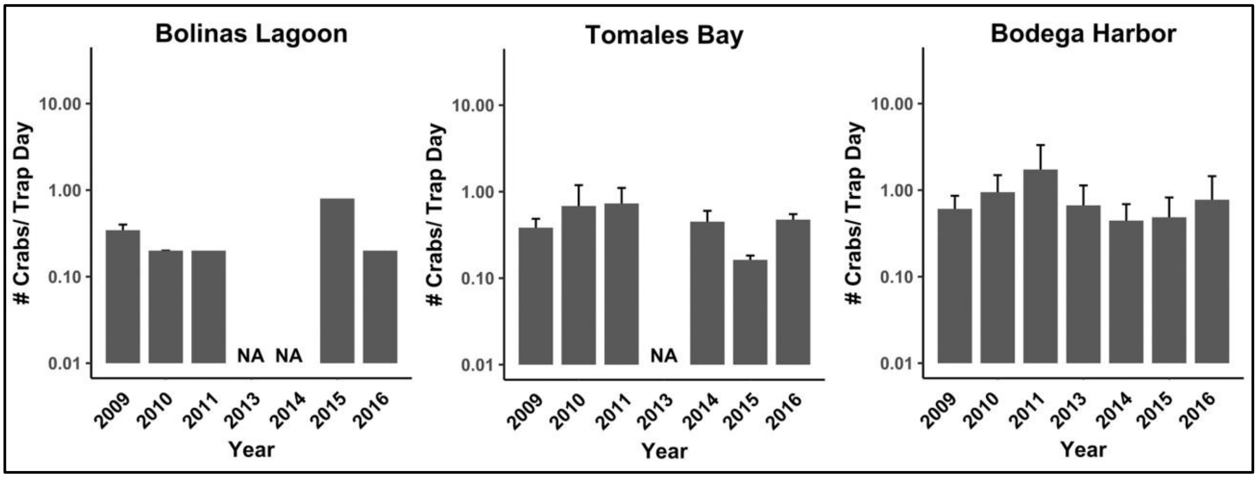


Figure S.LR.14.5. CPUE of European green crabs from 2009 to 2016 in Bolinas Lagoon, Tomales Bay, and Bodega Harbor (located outside the GFNMS boundary). Data were not collected in Bolinas Lagoon in 2013 and 2014 or in Tomales Bay in 2013. CPUE values represent the mean of 10 baited traps in each location over a three-day period, and error bars represent one standard error. Image: Modified from Grosholz et al., 2021 (Copyright 2021 National Academy of Sciences)

Cordgrass

The 2010 report identified cordgrass (*Spartina alterniflora*/hybrid and *S. densiflora*), a highly impactful invasive species, as a particular concern for GFNMS due to its interference with local taxa and ecosystem functions, including filling in mudflats and tidal flats, thus causing loss of habitat for some native species. However, the near eradication of these species is in large part due to the efforts of the San Francisco Estuary Invasive Spartina Project, a monitoring and treatment program that began collecting data, mapping the distribution of the introduced species, and treating them (using herbicide or manual removal) in 2000 (Rohmer & Kerr, 2021). This effort resulted in the near complete removal of *Spartina* spp. in GFNMS and surrounding estuarine habitats in 2018, which has considerably reduced concern for Tomales Bay, Drakes Estero, and Bolinas Lagoon (Rohmer & Kerr, 2021). For example, *S. densiflora* persisted in very low levels (0.02 m^2) in Tomales Bay in 2020.

Japanese Oyster Drill, Atlantic Oyster Drill, and Japanese Mud Snail

Japanese oyster drill (*Ocinebrellus inornatus*), Atlantic oyster drill (*Urosalpinx cinerea*), and Japanese mud snail (*Batillaria attramentaria*) are a group of non-indigenous species considered to have negative impacts on the sanctuary's estuary and lagoon habitats, and were also included in the status and trend rating for this assessment (Figure S.LR.14.6). The Japanese oyster drill was first observed in Tomales Bay in 1941 (Fofonoff et al., 2018), and the Atlantic oyster drill, initially recorded in San Francisco in 1890, was first observed in Tomales Bay in 1935 (Fofonoff et al., 2018). Both oyster drill species are known to severely impact commercial shellfisheries and reduce native oyster populations (Buhle & Ruesink, 2009; Kimbro et al., 2009; Fofonoff et al., 2018). The Japanese mud snail, a known competitor with native snails, was introduced along with the Pacific oyster (*Crassostrea gigas*) in the early 1900s in Washington, and was first collected in Bolinas Lagoon in 1955, Tomales Bay in 1973, and Drakes Estero in 1996 (Byers, 1999; Fofonoff et al., 2018). Data used for this assessment were from a study in Tomales Bay that was initiated to examine the effects of introduced species on native oysters and was then continued as a long-term monitoring effort (2009–2019; Rubinoff & Grosholz, 2022; Figure S.LR.14.7). Trends for the Japanese mud snail and Atlantic oyster drill varied from 2009–2019; however, after a sharp increase in abundance from 2012 to 2013, the Japanese oyster drill notably decreased in 2015 and has remained low since (Rubinoff & Grosholz, 2022). A lack of sampling in 2014 precludes a full understanding of this shift; however, the decrease in abundance may be linked to the 2014–2016 MHW (B. Rubinoff/Washington Sea Grant-University of Washington, personal communication, January 11, 2023), as water temperatures may have increased beyond the threshold for this species.

Figure S.LR.14.6. Clockwise from top left: Japanese mud snail (*Batillaria attramentaria*) at Point Reyes National Seashore; Atlantic oyster drill (*Urosalpinx cinerea*); Japanese oyster drill (*Ocinebrellus inornatus*); a Japanese oyster drill "drilling" into a *Batillaria* sp. snail. Photos: (top left) L. Zentall; (all others) E. Grason/University of Washington

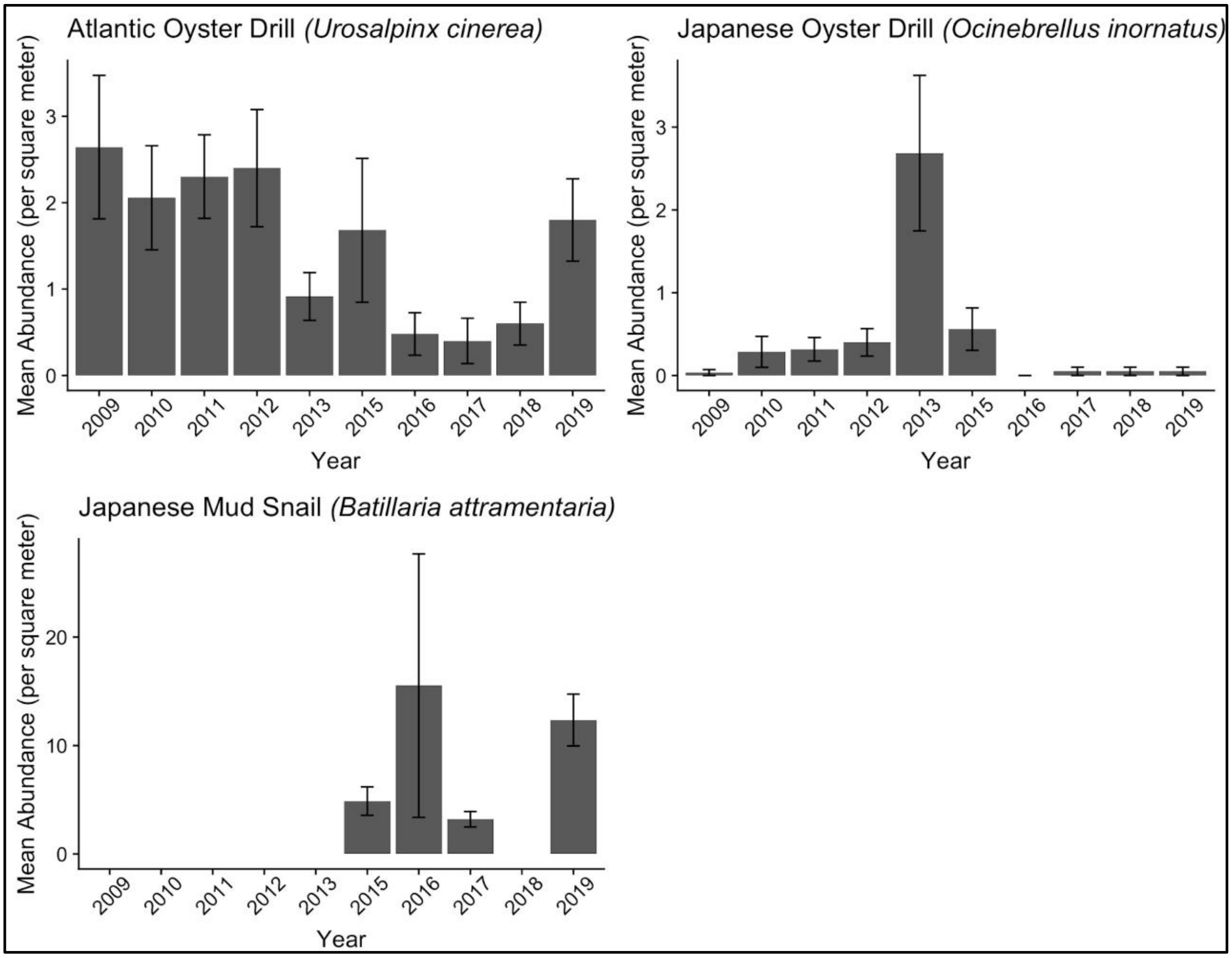


Figure S.LR.14.7. Mean abundance of the Atlantic oyster drill, Japanese oyster drill, and Japanese mud snail in Tomales Bay, 2009–2019. Note that data collection for the Japanese mud snail did not begin until 2015. Source: Rubinoff & Grosholz, 2022

Investigative studies on a variety of additional impactful invasive species, such as *Didemnum* spp., *Watersipora subtorquata*, *Molgula manhattensis*, *Arcuatula senhousia*, and others (Table S.LR.14.2) exist (e.g., Kimbro et al., 2009; Deck, 2010; Long & Grosholz, 2015; Rubinoff & Grosholtz, 2022); however, gaps in information on the density, abundance, or spatial distribution of these species in GFNMS prevent their incorporation into status and trend ratings.

Conclusion

This question was rated fair because some non-indigenous species had considerable impacts on attributes of ecological integrity at a local level. In particular, the continued presence of non-indigenous species such as the European green crab (*Carcinus maenas*) and Japanese mud snail (*Batillaria attramentaria*) within the sanctuary contributed to the fair rating, as both species can cause measurable impacts, but are restricted to specific locations. The improvement to fair, compared to the fair/poor rating in the 2010 report was attributed to the near eradication of non-indigenous *Spartina* spp. and the lack of severe impacts of non-indigenous species on ecological integrity. The trend was mixed based on the overall increase of non-indigenous species during the study period, combined with improvements in *Spartina* spp., no change in European green crabs, and variable or undetermined trends among non-indigenous snails in Tomales Bay. Although more evidence was available to support this rating compared to that of the coastal and offshore region, data availability was still limited due to the lack of long-term monitoring. Most of the available non-indigenous species data only provide species presence/absence information, precluding the assessment of trends in abundance, spatial distribution, or impacts.

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

Coastal and Offshore Region

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: Biodiversity was altered compared to near-pristine conditions, but was within the expected range of long-term natural variability. This is with the possible exception of range shifts and changes in species composition caused by the 2014–2016 marine heatwave, which, exacerbated by climate change, may have exceeded natural levels of variation. Benthic infauna species richness was high compared to areas near San Francisco Bay outflow areas. Rocky shore community stability was high. Kelp community indicators (fish, invertebrates, and understory species richness) varied. Forage fish species richness was high and remained stable over time. Groundfish species density was consistent with long-term means and was stable during the study period.

While the definition of biodiversity includes the full spectrum of species, communities, and genetic diversity, this report evaluates subsets of biodiversity. Specifically, status and trends were evaluated for functional groups of species and communities recognized as significant, such as kelp communities or forage fish assemblages. This practical approach enabled the application of monitoring information from a variety of sources to evaluate status and trends.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. In 2010, the status for this question in the coastal and offshore region was good/fair and the trend was not changing. The report considered rocky intertidal community structure and rockfish recruitment as important factors for tracking biodiversity in the sanctuary. It was noted that conditions were neither pristine nor significantly degraded, but long-term trends in physical oceanographic patterns were affecting species distributions and abundance.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question consisted of seven ecologically defined and measurable groups. The status of biodiversity within these distinct components of the ecosystem were analyzed as indicators of the biodiversity of the sanctuary.

The specific ecological groupings considered in this report include:

- Benthic infauna
- Rocky shore community
- Birds and mammals

- Kelp community
- Juvenile rockfish
- Forage fish
- Groundfish

In addition to the data reviewed below, subject matter experts considered additional factors, such as the 2014–2016 MHW. The effects of the MHW included species distribution shifts, which could affect the biodiversity of the sanctuary in both positive and negative ways. The MHW is described in further detail in the Pressures chapter.

Table S.LR.15.1. Summaries for the key indicators related to biodiversity in the coastal and offshore region of GFNMS that were discussed during the June 9, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Benthic infauna	SFPUC, 2021	Status: Benthic infauna species richness was high at five sites within GFNMS compared to surrounding areas. Trend: Species richness was stable at four sites and decreased at one site.	S.LR.15.1
Rocky shore community	MARINe, 2021	Status: Some shifts in community composition were detected at one out of four monitoring sites. Trend: Community diversity metrics were stable at three monitoring sites but more variable at a fourth site.	N/A
Birds and mammals	Lindquist & Roletto, 2022b	Status: Species richness was consistent with long-term levels. Trend: Species richness was stable.	S.LR.15.2
Kelp community	PISCO, 2022	Status: Kelp forest habitat was significantly reduced compared to historic levels, but kelp-associated species were present during the study period. Trend: Fish species richness decreased in kelp forest communities and was stable for invertebrate and understory kelp species.	S.LR.15.3
Juvenile rockfish	NOAA, 2022d	Please see Table S.LR.13.1 for a summary of juvenile rockfish abundance.	S.LR.13.1
Forage fish	Santora et al., 2021a	Status: Forage fish species richness was high. Trend: Forage fish species richness was stable.	N/A

Indicator	Source	Data Summary	Figures
Groundfish	NOAA Northwest Fisheries Science Center, 2021	Status: Mean species density and MTL were consistent with long-term means. Trend: Species density was stable on the shelf and decreased on the upper slope. MTL was stable in both regions.	S.LR.15.4; S.LR.15.5
Data gaps	Biodiversity indicators for juvenile rockfish were not available.		

Benthic Infauna

Benthic infauna abundance and species richness are tracked as one component of the Southwest Ocean Outfall Regional Monitoring Program, which is described in more detail in Question 7; Figure S.WQ.7.4 illustrates the location of survey sites. These data indicated that species richness was high at survey sites within the sanctuary (stations 32, 34, 35, 38, 39; Figure S.LR.15.1) compared to surrounding areas (not shown in the figure). There was a stable trend for species richness at most sites within the sanctuary, with the exception of station 32, where richness significantly declined from 2010–2020. No clear trends were found for total infauna abundance, diversity, or evenness.

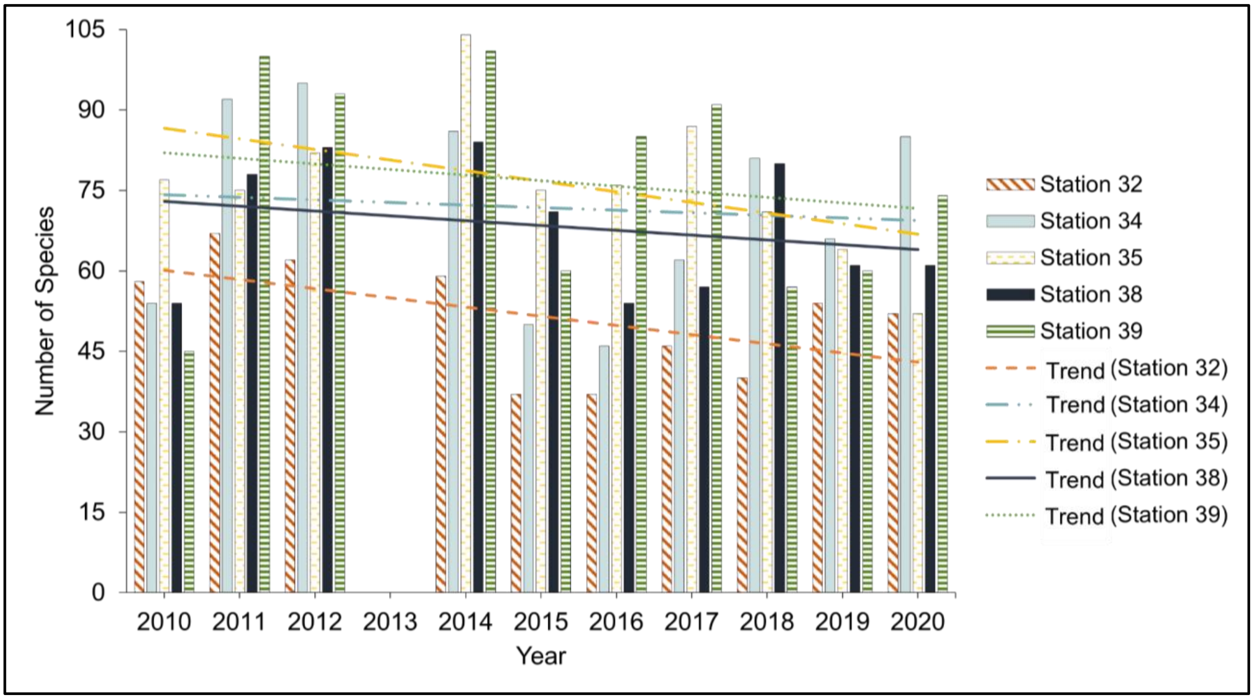


Figure S.LR.15.1. Species richness at survey sites (stations) within GFNMS monitored as part of the Southwest Ocean Outfall Regional Monitoring Program. Source: SFPUC, 2021

Rocky Shore Community

Information on rocky intertidal communities is collected and shared through MARINe, which monitors over 200 sites from Alaska to Mexico. This assessment focused on four monitoring sites within the sanctuary: Sea Ranch, Bodega Marine Life Refuge, Santa Maria Creek, and Bolinas Point (see Figure S.H.10.1 for a map of these sites). Santa Maria Creek is located within Point Reyes National Seashore, but was included in this analysis because its location surrounded by the sanctuary provides ecosystem context for the sites within the sanctuary. Community diversity metrics at Bodega Marine Life Refuge, Bolinas Point, and Santa Maria Creek were remarkably stable over time. However, communities were more variable at Sea Ranch, shifting from high cover of turfweed (*Endocladia muricata*), black pine (*Neorhodomela larix*), and acorn barnacles (*Chthamalus/Balanus* spp.) in earlier years (2004–2016) to higher cover of rockweed (*Pelvetiopsis limitata*) in more recent years (2017–2021).

Birds and Mammals

Marine mammals and birds are monitored by GFNMS through the Beach Watch program (see Box 2). Bird and mammal species richness was stable on outer coast beaches during the study period, with the exception of an apparent decrease in bird species richness in 2020; however, this observation may be attributable to reduced survey effort that year due to the COVID-19 pandemic (Figure S.LR.15.2).

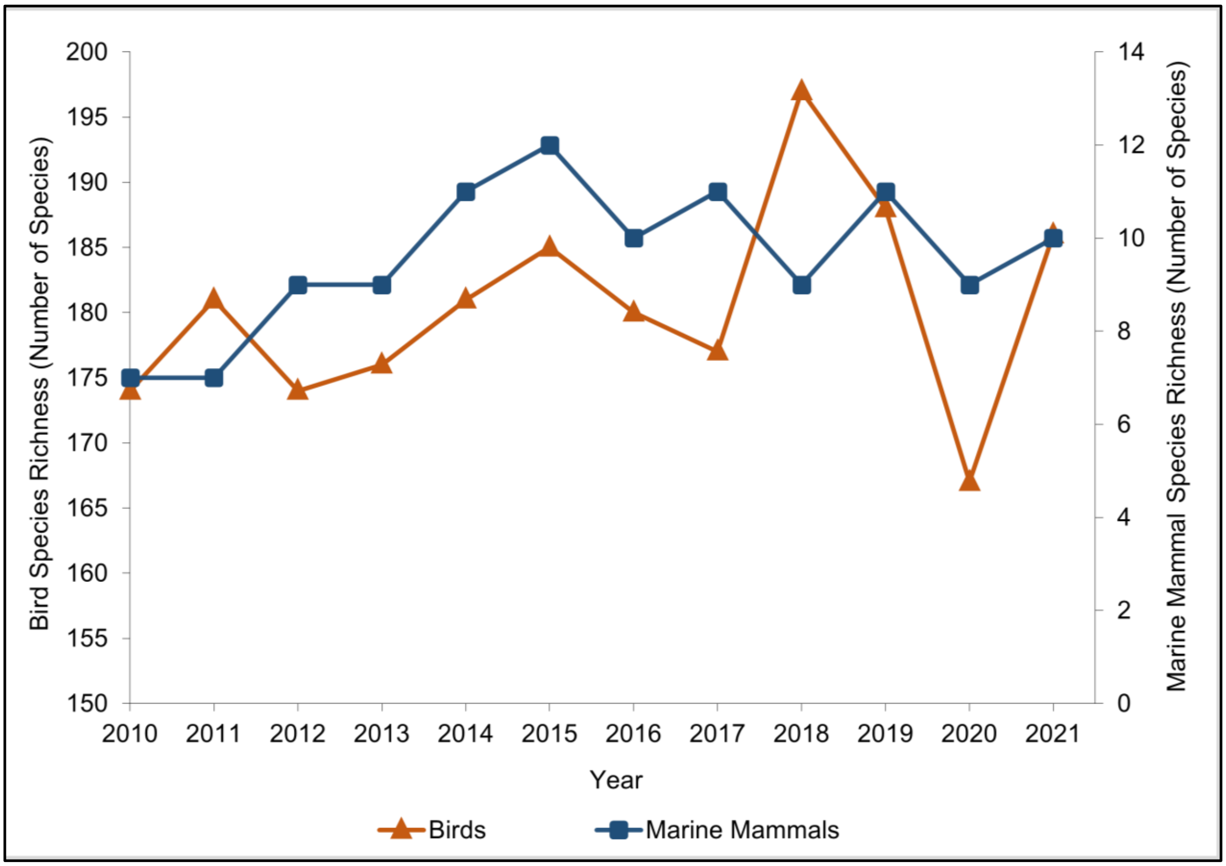
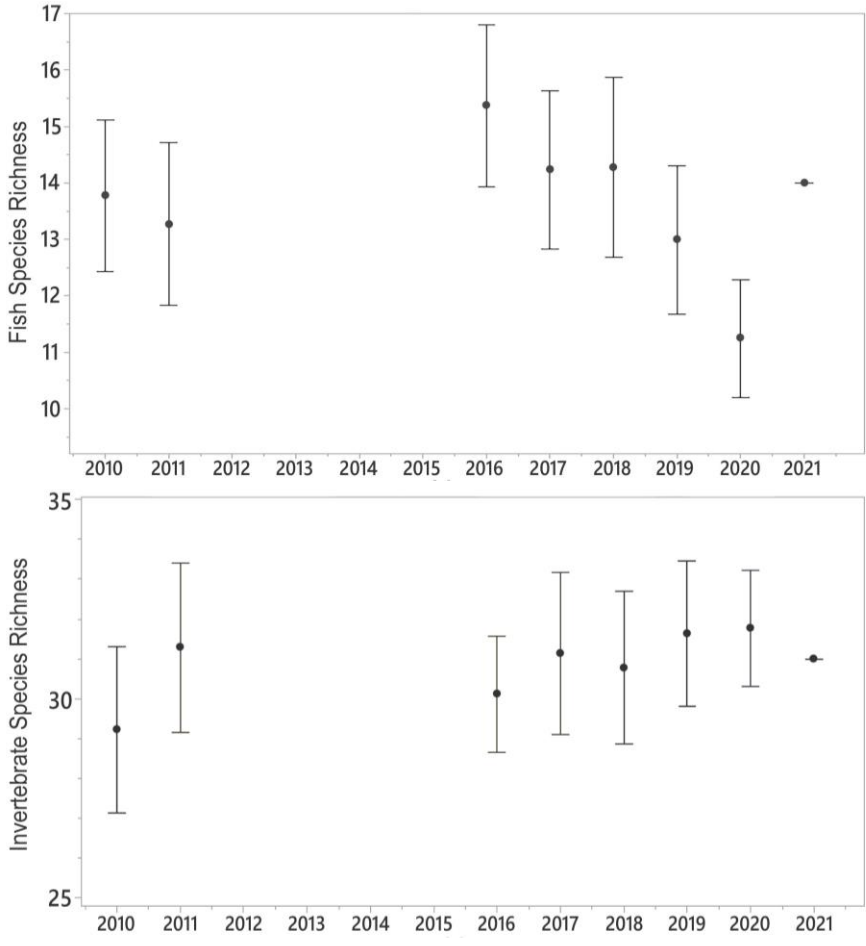


Figure S.LR.15.2. Bird and mammal species richness (number of species) observed during Beach Watch surveys. Lower bird species richness likely resulted from reduced survey effort. Source: Lindquist & Roletto, 2022b

Kelp Community

PISCO, a long-term scientific program led by scientists from four partnering universities, conducts kelp forest community monitoring. Question 10 discusses the widespread declines in kelp forest habitat during the study period, while information on kelp fish biodiversity, invertebrate species biodiversity, and understory kelp species biodiversity are evaluated here. No data were available for 2012–2015. From 2016–2020, at the end of and following the 2014–2016 MHW, experts noted an apparent consistent decline in kelp forest fish species richness followed by a slight increase in 2021 (Figure S.LR.15.3). This trend was not detected for invertebrate or understory kelp species (Figure S.LR.15.3), resulting in a mixed trend for this indicator.



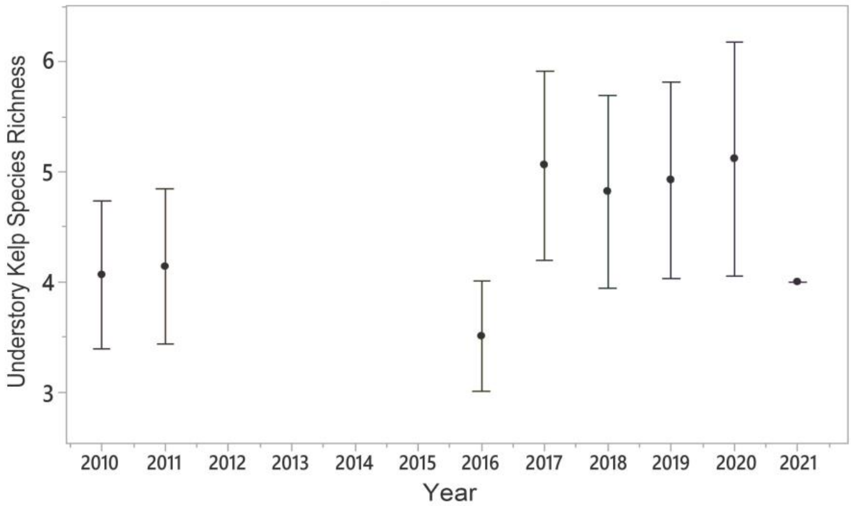


Figure S.LR.15.3. Estimated fish (top), invertebrate (middle), and understory kelp (bottom) species richness across sites within the kelp community of the sanctuary. Data were standardized to 2021 sample size to avoid sampling effort bias and included sites from Point Arena State Marine Reserve, Saunders Reef State Marine Conservation Area, Stewarts Point State Marine Reserve, and reference areas. Because the numbers of transects conducted varied among years and sites, a resampling approach was used to estimate species richness for the region as a whole. Image: Adapted from PISCO, 2022

Juvenile Rockfish

Rockfish are important for their role in the food web and as recreational and commercial fisheries, but biodiversity indicators were not available for this species group. Please see Question 13 for a discussion of juvenile rockfish abundance.

Forage Fish

The Fisheries Ecology Division of NOAA's Southwest Fisheries Science Center has conducted the Rockfish Recruitment Ecosystem Assessment Survey since 1983. This survey includes mid-water trawl surveys; conductivity, temperature, and depth surveys; acoustic surveys of the water column; visual surveys of mammals and seabirds; and plankton surveys. For a more complete description of how all of these components can be used together to track biodiversity, see Santora et al. (2021a). Forage fish species richness was assessed using midwater trawl data from the Rockfish Recruitment Ecosystem Assessment Survey core study region, which includes GFNMS. Forage fish species richness was high and remained stable throughout the study period. In contrast, total species richness from mid-water trawl surveys (for all taxa, not just forage fish) decreased (Santora et al., 2021a).

Groundfish

NOAA's National Marine Fisheries Service conducts the West Coast Groundfish Bottom Trawl Survey to collect fishery-independent data for use in stock assessments and groundfish management. "Groundfish" refers to more than 90 different types of groundfish, flatfish, rockfish, sharks, and skates off the U.S. west coast; these species live primarily on or near the seafloor. West Coast Groundfish Bottom Trawl Survey data sets (NOAA Northwest Fisheries Science Center, 2021) from the continental shelf (55–200 m) and upper slope (201–400 m) within the sanctuary were obtained and analyzed by the California Current Integrated

Ecosystem Assessment team based on the approaches used in Harvey et al. (2021). The number of species per trawl provides a measure of species density (Figure S.LR.15.4). From 2016–2021, species density was stable on the continental shelf, but decreased on the upper slope by more than one standard deviation of the long-term mean.

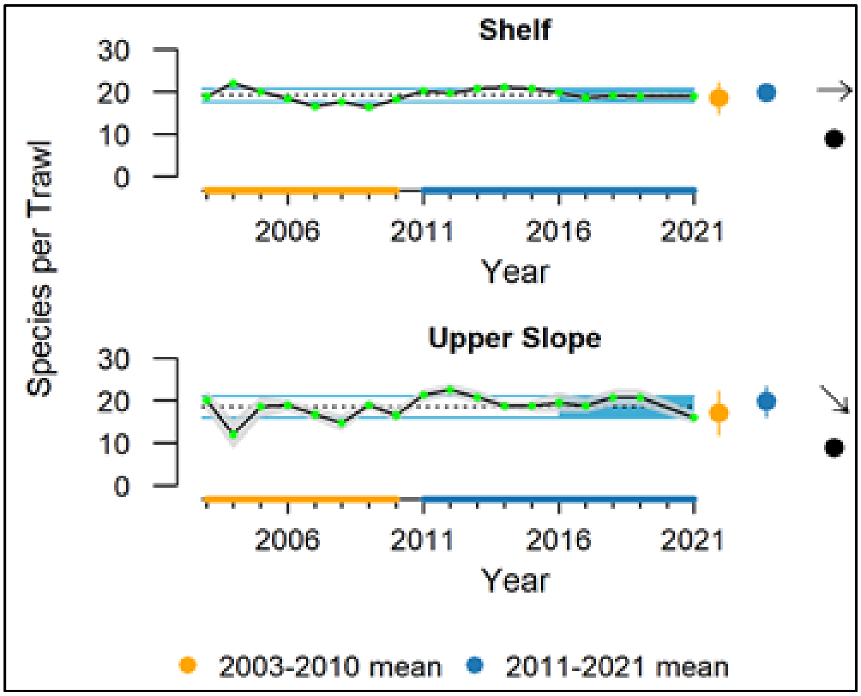


Figure S.LR.15.4. Groundfish species density (number of species per trawl) within GFNMS. Data are shown relative to the mean (black dotted horizontal line) and one standard deviation (solid blue lines) of the full time series (2003–2021). Points to the right of the figure indicate the mean ± 95% confidence interval for the time periods, indicated by the corresponding color along the x-axis. The arrows to the right indicate that the trend during the evaluation period (shaded blue) was stable (→) on the shelf and decreased (↘) on the upper slope by more than one standard deviation of the full time series. The symbol at the lower right (•) indicates that the recent mean was within one standard deviation of the long-term mean on both the shelf and upper slope. The gray envelope indicates observation error, defined as ± one standard error. Image: NOAA Northwest Fisheries Science Center, 2021

Mean trophic level (MTL) was also considered as a biodiversity indicator. MTL provides information on community structure, which is an important component of biodiversity. Changes in MTL indicate changes in the trophic structure of a given assemblage. MTL ranged from 3.64–3.88 on the shelf and 3.52–3.73 on the upper slope. Despite some variation, mean MTL on both the shelf and the upper slope was stable from 2016–2021 and was within one standard deviation of the long-term mean[18] (2003–2021; Figure S.LR.15.5).

[18] MTL data were not presented at the expert workshop; however, they are used here in place of CPUE, as MTL is considered to have greater relevance for evaluating biodiversity status and trends.

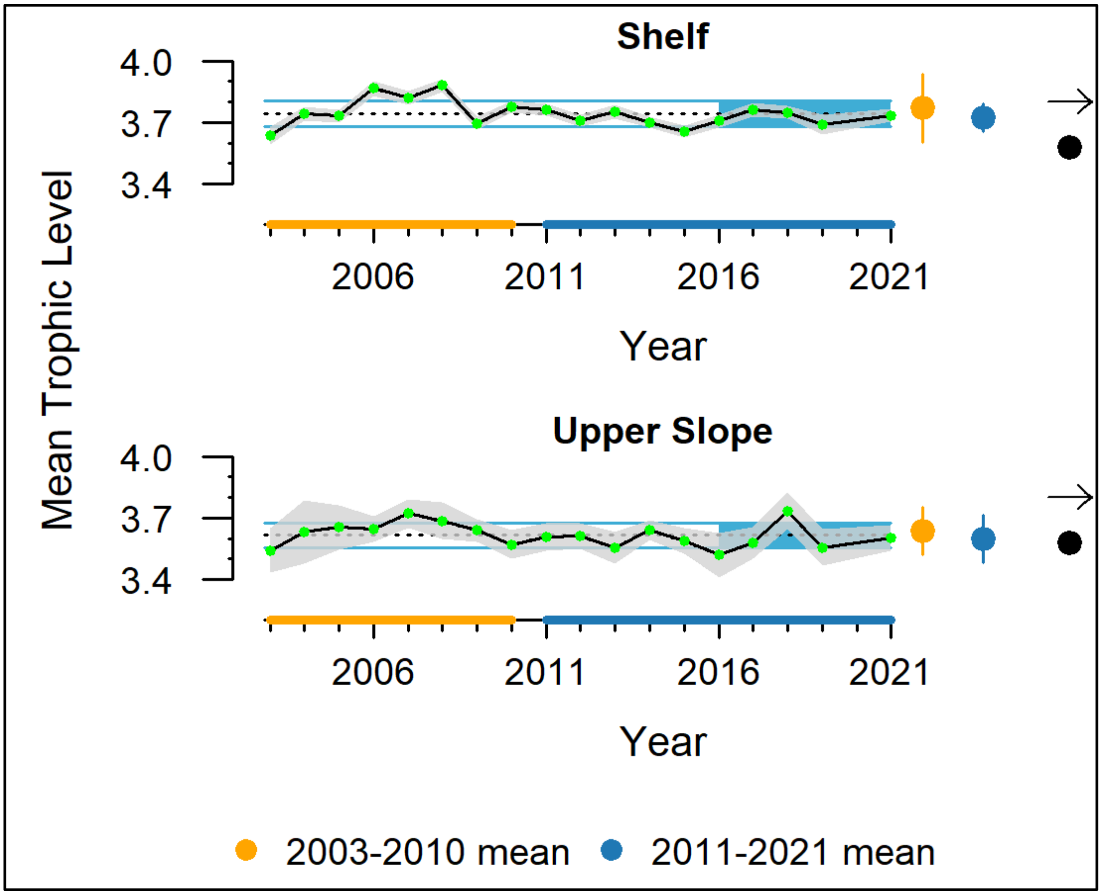


Figure S.LR.15.5. Groundfish MTL within GFNMS. Data are shown relative to the mean (black dotted horizontal line) and one standard deviation (solid blue lines) of the full time series (2003–2021). Points to the right of the figure indicate the mean ± 95% confidence interval for the time periods, indicated by the corresponding color along the x-axis. The arrows to the right indicate that the trend during the evaluation period (shaded blue) was stable (→) on both the shelf and the upper slope. The symbol at the lower right (•) indicates that the recent mean was within one standard deviation of the long-term mean on both the shelf and upper slope. The gray envelope indicates observation error, defined as ± one standard error. Image: NOAA Northwest Fisheries Science Center, 2021

Conclusion

This question was rated good/fair because most indicators were within the expected range of long-term natural variation despite some suspected biodiversity loss. The trend over the study period was mixed based on the variety of responses observed in the ecological groups evaluated. Benthic infaunal diversity was high compared to the surrounding area and was generally stable, but declined at one site. The rocky intertidal community was also stable at most sites, although some changes were observed at one site. Marine mammal and bird species richness was also apparently stable. Although there were widespread declines in kelp abundance, trends in kelp forest species composition were mixed; kelp forest fish species richness decreased from 2016–2021, while invertebrate and understory kelp species richness remained stable. Forage fish species richness was high with a stable trend. From 2016–2021, groundfish species density was stable on the continental shelf and decreased on the upper slope; however, MTL was stable in both regions.

Estuarine and Lagoon Region

Status Description: N/A

Rationale: At the time of the assessment, there were no known comprehensive surveys of biodiversity in GFNMS estuaries. There was no apparent change in shorebird and marine mammal species richness during the study period, but these data were not sufficient to assess biodiversity for the entirety of the estuarine and lagoon region of the sanctuary.

Findings From the 2010 Condition Report

In 2010, the status for this question in the estuarine and lagoon region was fair/poor and the trend was worsening. These ratings were based on loss of eelgrass habitat, particularly in Tomales Bay.

New Information in the 2010–2022 Condition Report

Indicators used to evaluate this question included shorebirds and marine mammals (Table S.LR.15.2).

Table S.LR.15.2. Summaries for the key indicators related to biodiversity in the estuarine and lagoon region of GFNMS that were discussed during the June 9, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Shorebirds and marine mammals	Lindquist & Roletto, 2022b	Status: Undetermined due to limited study sites and variable survey effort. Trend: Seabird species richness was apparently stable and marine mammal species richness varied with no clear trend in Tomales Bay and Bolinas Lagoon.	S.LR.15.6
Data gaps	There are currently no surveys that address biodiversity in GFNMS estuaries. Monitoring of eelgrass, fish, invertebrate, and benthic infaunal communities is necessary to assess this question.		

Shorebirds and Marine Mammals

Bi-monthly, effort-based shoreline surveys of shorebird and marine mammal species occurred at three locations in Tomales Bay and Bolinas Lagoon as part of the Beach Watch program (see Box 2). Shorebird species richness was stable during the study period at these study sites. Species richness of marine mammals was more variable over time with no clear trend at the study sites. The dip in 2020 for both groups was likely a result of reduced survey effort due to the COVID-19 pandemic.

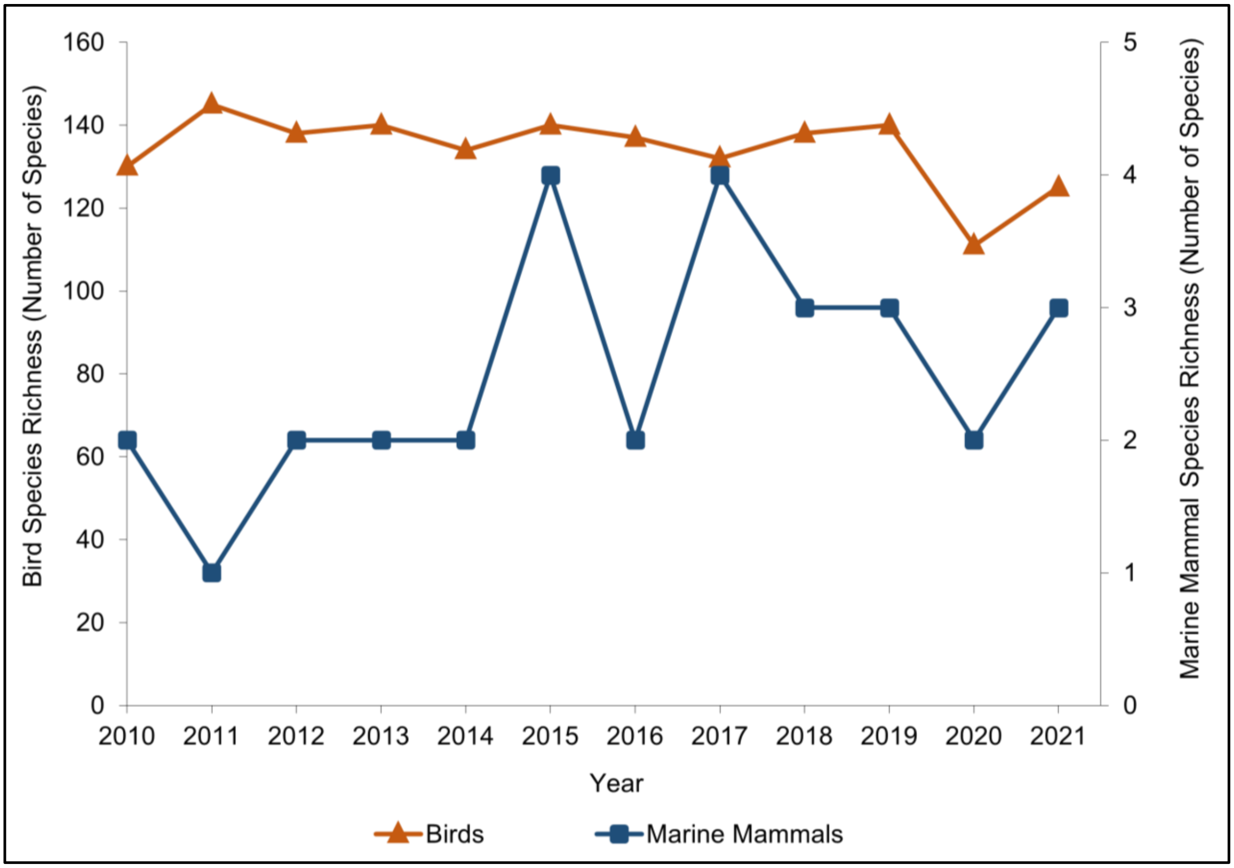


Figure S.LR.15.6. Species richness for shorebirds and marine mammals. Source: Lindquist & Roletto, 2022b

Conclusion

While some evidence was available, it was not sufficient to make a determination on the status and trend of biodiversity in the estuarine and lagoon region of GFNMS. The only relevant data available were for seabird and marine mammal species richness. Seabird species richness was stable and marine mammal species varied without a clear trend. Other indicators were identified as important for assessing biodiversity in GFNMS estuaries. These included eelgrass communities, wintering shorebirds, fish, and invertebrates. However, no biodiversity data for these indicators was available at the time of the assessment.

Status and Trends of Maritime Heritage Resources (Question 16)

The following section addresses the condition of maritime heritage resources and properties 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 describes shipwreck (archaeological/historical) resources. Question 16 assesses the integrity of known, tangible 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.

Because of considerable differences in environmental pressures and responses between the coastal and offshore region and the estuarine and lagoon region, this question was assessed twice in order to represent these two environment types separately.

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

Coastal and Offshore Region

Status Description: 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.

Rationale: Historic sites, properties, and artifacts associated with shipwrecks and doghole ports are known to exist within GFNMS boundaries. The 2015 expansion of the sanctuary increased the number of maritime heritage resources within its boundaries. Summary findings of condition could be made for 13 of the 33 known shipwrecks; all 13 showed structural degradation. Some impacts to condition were due to physical processes, while others related to human interactions, although the latter did not appear to be significant. Two shipwrecks showed signs of fishing gear entanglement; however, neither trawling nor looting was known to have impacted any shipwrecks during the rating period. Twenty-four historic doghole port sites have been documented in or adjacent to GFNMS. No other maritime heritage properties were documented within sanctuary boundaries, though more are likely present. Expert confidence in the trend assessment was low because of limited evidence due to a lack of systematic site assessment and monitoring data.

Findings From the 2010 Condition Report

A direct comparison of status and trends to the 2010 condition report is not possible because the sanctuary expanded in 2015, during the time period for this assessment. The expansion added new coastal and offshore areas and habitats that were not assessed in the 2010 condition report. Note also that the wording of this question has changed slightly since the 2010 report (see Appendix A). In 2010, both the status and trend were undetermined because little was known about the existence or condition of shipwreck resources in the sanctuary, and there was a need for archaeological surveys and monitoring. Only shipwrecks and their condition were discussed in the 2010 report. At that time, of 180 records of losses of historic shipwrecks and aircraft, 31 shipwreck sites were known. One shipwreck in the region, the steamship *Jacob Luckenbach*, was assessed.

New Information in the 2010–2022 Condition Report

Four indicators of known, tangible maritime heritage resources were selected and assessed: shipwrecks, aircraft, doghole ports, and other maritime heritage properties (inclusive of locations and resources; Table S.MHR.16.1). Only shipwrecks and doghole ports have been documented to be within GFNMS; however, future analysis of records from the California Office of Historic Preservation's California Historical Resources Information System (CHRIS) and other sources could indicate the presence of other types of maritime heritage resources (prehistoric or historic).

Table S.MHR.16.1. Summaries for the key indicators related to the condition of maritime heritage resources in the coastal and offshore region of GFNMS that were discussed during the July 6, 2022 virtual workshop.

Indicator	Source	Data Summary	Figures and Tables
Shipwrecks	R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022; Delgado & Haller, 1989; ONMS & California State Parks, 2021; Delgado et al., 2020	Status: 33 shipwrecks are known in the coastal and offshore region, with 16 documented by federal, state, and private partners. Loss records indicate others may be present. Findings about the condition of 13 of the 16 documented shipwrecks indicate all have experienced physical degradation. Trend: No trend data were available.	Figure S.MHR.16.1; Figure S.MHR.16.2; Table S.MHR.16.2
Aircraft	R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022	Status: There are no documented historic aircraft in the coastal and offshore region, although loss records indicate some may be present. Trend: No trend data were available.	N/A

Indicator	Source	Data Summary	Figures and Tables
Doghole ports	R. Schwemmer/NOAA, personal communication, March 8, 2022; Marx & Jaffke, 2021; D. Jaffke/Far Western Anthropological Research Group, Inc., personal communication, August 11, 2022; ONMS & California State Parks, 2021	Status: 24 doghole port sites were documented in or adjacent to GFNMS in the coastal and offshore region. Remnants (submerged artifacts/features) have been located at three sites. Trend: No trend data were available.	Figure S.MHR.16.3; Figure S.MHR.16.4; Figure S.MHR.16.5
Other maritime heritage properties	H. Van Tilburg/NOAA, personal communication, June 16, 2022; California Office of Historic Preservation, 2022; Terrell, 2007; ICF International et al., 2013	Status: Of 70 sites or features returned by a CHRIS database search for GFNMS, 20 may be in the coastal and offshore region of the sanctuary. Trend: No trend data were available.	N/A
Data gaps	There is a gap in shipwreck assessments; climate change may increase shipwreck degradation due various factors, including swells and storms, but no data were available on these effects. There is a gap in doghole port assessments; no data were available on climate change effects to doghole ports. There is a gap in obtaining and examining CHRIS site-level documentation and reports to determine if there is additional data on presence and condition of doghole port properties or resources associated with such properties. Other maritime heritage properties are not known to be, but may be, present; there is a gap in obtaining and examining site-level documentation and reports from CHRIS and other sources to determine if data exist that could verify the presence and condition of other maritime heritage properties.		

Shipwrecks

As of June 2022, historical documents indicated there were 408 losses of historic ships and aircraft throughout GFNMS (both coastal/offshore and estuarine/lagoon regions), with 87 shipwrecks recorded as rescued or salvaged (some partial remains or cargo items could still be on site). In the coastal and offshore region, there are 33 known, documented shipwreck locations (Figure S.MHR.16.1). A few reported as known within the sanctuary in 2010 were not included in this updated list of 33 known shipwrecks, as it was determined that they are outside sanctuary boundaries; for example, the cargo steamer SS *Hartwood*, the cargo steamer SS *Munleon*, and the steam-schooner SS *Pomo* (R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022). Others were removed from the list of known shipwrecks as their location is inexact or unverified; for example, the galleon *San Augustin*, the oldest known West Coast shipwreck, which sank in 1595 in Drake's Bay (Terrell, 2007) at an unknown location within the bay (P. Engel/National Park Service, personal communication, February 25, 2022).

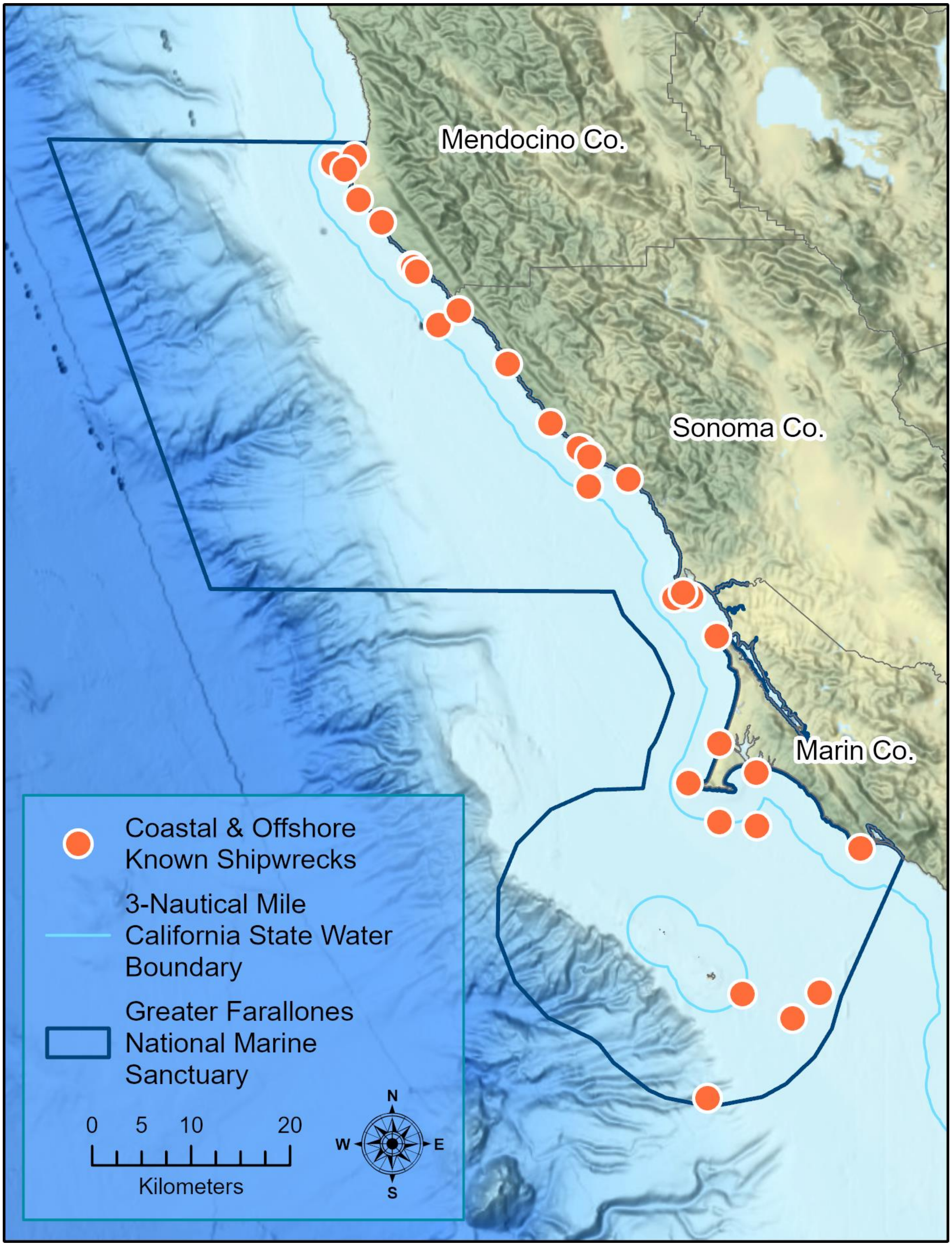


Figure S.MHR.16.1. Known historic shipwrecks in the coastal and offshore region of GFNMS. Image: NOAA; Source: R. Schwemmer/NOAA personal communication, March 8, 2022; Schwemmer, 2022; Delgado & Haller, 1989; Delgado et al., 2020; Esri, 2020

Of the 33 known shipwrecks in this region, 17 were located by the sport diving community with high reliability but have not been formally documented, and 16 were documented by federal, state, or private sector partners. Summary findings about the condition of 13 shipwrecks are available, including what structure remains and if any human impacts are known (Table S.MHR.16.2). All of the 13 shipwrecks have experienced physical degradation. In some cases, wooden hulls or structures are largely missing, some metal hulls are complete, and others have collapsed or are collapsing. Impacts to maritime heritage resource condition can occur due to both natural processes and human impacts. Variables that may influence resource condition include: the year of loss and submergence; ship materials (wood, iron, steel); artifact material; depth at site location; oceanographic factors; cause of loss; and human activities. Some variables relate to physical and natural processes, with metal materials usually more durable than wooden materials; others relate to human interactions, including full or partial salvage, looting, and deposition of lost fishing gear. Trawling is not known to have impacted any shipwrecks during the rating period. Some human impacts on some wrecks have been observed or via anecdotal evidence are thought to have occurred (D. Jaffke/Far Western Anthropological Research Group, Inc., personal communication, March 1, 2023), but workshop participants felt they were not significant for the rating period, nor for the whole suite of maritime heritage resources.

Table S.MHR.16.2. Summary of the condition of 13 shipwreck sites in the coastal and offshore region of GFNMS, in descending order of year lost. Asterisks (*) indicate that a given shipwreck is listed on the National Register of Historic Places.

Name	**Year Lost**	**Location Lost (Coastal or Offshore)**	**Site Condition**
Tank vessel *Puerto Rican* (stern)	1984	Offshore	Stern section (steel) covered in fishing gear
SS Jacob Luckenbach	1953	Offshore	Steel hull degradation and separation; looting occurred in the past
SS *Dorothy Wintermote*	1938	Offshore	Steel hull collapsed; no known human impacts
*Norlina**	1926	Coastal	Scattered steel remains—structural and machinery; some past salvage
Isaac Reed	1924	Offshore	Extreme wooden hull degradation; no known human impacts
USS *Conestoga**	1921	Offshore	Lower steel hull complete, upper wooden structure missing; no known human impacts
SS *Klamath*	1921	Coastal	No wooden hull structure recorded, artifact distribution; looting occurred in the past
SS *Ituna*	1920	Offshore	Lower iron hull degradation and collapsing; no known human impacts.

Name	Year Lost	Location Lost (Coastal or Offshore)	Site Condition
SS *Selja*	1910	Offshore	Steel hull inverted; signs of fishing gear
SS *Pomona**	1908	Coastal	Steel hull degradation; looting occurred in the past
J. Eppinger	1898	Coastal	No wooden hull structure recorded, artifact distribution; looting occurred in the past
SS *Whitelaw*	1893	Coastal	No wooden hull structure recorded, artifact distribution; looting occurred in the past
Joseph S. Spinney	1892	Coastal	No wooden hull structure recorded, artifact distribution; looting occurred in the past

Surveys were done on some of the sites during the study period. Most were done by ROV and documented using video. The United States Ship (USS) *Conestoga*, which is on the National Register of Historic Places (ONMS, 2022c), was surveyed by ROV in 2014 and 2015. The SS *Ituna* was surveyed by ROV in 2015 and 2016; the cause of degradation of this resource has not been determined. *Isaac Reed* was surveyed by ROV in 2015. The stern of the TV *Puerto Rican* was surveyed by ROV in 2021. The SS *Pomona*, which is on the National Register of Historic Places (NPS, 2008), was surveyed in 2016 and 2017 as part of the Sonoma Doghole Ports Project by magnetometer, snorkel, and scuba diver visual surveys, as were other wreck sites, including *Norlina*, which was subsequently added to the National Register of Historic Places (D. Marx/independent contractor, personal communication, October 7, 2022; NPS, 2022b), the SS *Klamath*, and *Joseph S. Spinney* (ONMS & California State Parks, 2021; Marx & Jaffke, 2021).

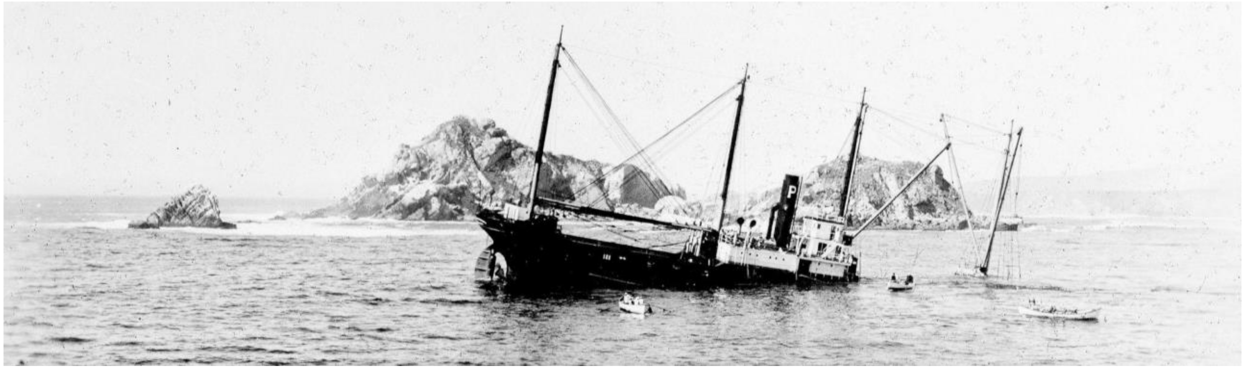


Figure S.MHR.16.2. The SS *Dorothy Wintermote*, lost in 1938. Photo: San Francisco Maritime National Historic Park

Aircraft

There are loss records in the coastal and offshore region for historic aircraft, but no locations have been discovered (R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022), and thus no surveys or assessments of condition have been done.

Doghole Ports

After the 2015 expansion, doghole port sites in the coastal waters of Sonoma County and southern Mendocino County were included within the sanctuary (Figure S.MHR.16.3). Records indicate there are 24 sites within sanctuary boundaries[19] (R. Schwemmer/NOAA, personal communication, March 8, 2022; California Department of Parks and Recreation, 2021; Marx & Jaffke, 2021); three of these locations are approximate and based on historical records (D. Jaffke/Far Western Anthropological Research Group, Inc., personal communication, August 11, 2022). Surveys were conducted at the 14 Sonoma County sites by federal and state partners to document both underwater and terrestrial remnants of the ports (along with shipwrecks) for the Sonoma Doghole Ports project. A few port remnants were documented by magnetometer, snorkel, and scuba diver visual surveys at three sites within the sanctuary (ONMS & California State Parks, 2021; Marx & Jaffke, 2021). Substantial archaeological evidence of maritime commerce at the ports, including trough chutes, were recorded (Figure S.MHR.16.4). Anchors and heavy chains, no longer *in situ*, were documented nearby on land, along with other artifacts (Figure S.MHR.16.5; ONMS & California State Parks, 2021; Marx & Jaffke, 2021). Subsequent documentation of doghole ports by nonprofit partners indicated there are 10 sites in Mendocino County that are within the sanctuary (Marx & Jaffke, 2021); these have not been surveyed.

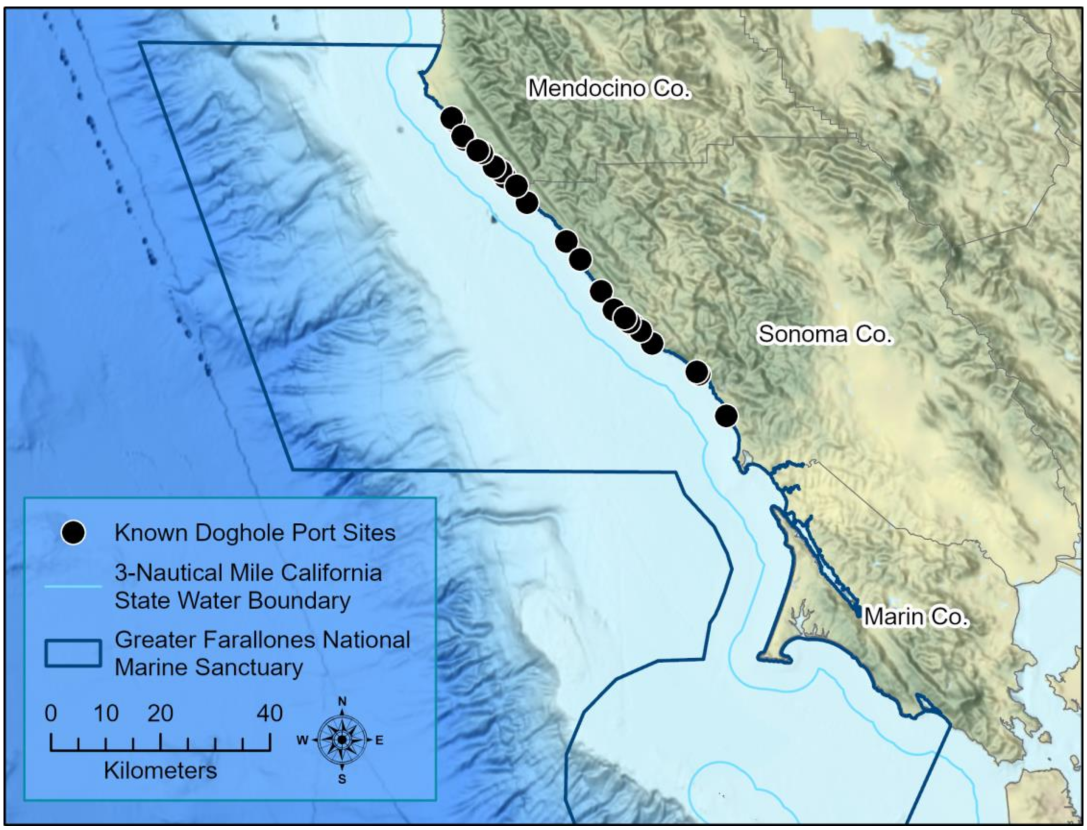


Figure S.MHR.16.3. Doghole port sites in the coastal and offshore region of GFNMS. Image: NOAA; Source: R. Schwemmer/NOAA personal communication, March 8, 2022; ONMS & California State Parks, 2021; Marx & Jaffke, 2021; Esri, 2020

[19] Sanctuary boundaries do not include Arena Cove. The ocean portion of Arena Cove, though geographically close, is east of and adjacent to sanctuary boundaries.

Figure S.MHR.16.4. Trough chutes at Stewart's Point Landing, a doghole port, and an unknown schooner loading tanbark. Photo: San Francisco Maritime National Historical Park SAFR 21374

Figure S.MHR.16.5. Mooring hardware; a section of stud link chain pile at a doghole port site within the sanctuary. Photo: NOAA and California Department of Parks and Recreation

In 2021, the National Park Service accepted a Northern California Doghole Ports Maritime Cultural Landscape Multiple Property Submission[20] of 57 doghole ports[21] for consideration for listing on the National Register of Historic Places and listed the Salt Point Landing Historical and Archaeological District (D. Marx/independent contractor, personal communication, April 17, 2022; NPS, 2022c). Fort Ross Landing Historical and Archaeological District was subsequently listed in April 2023 (NPS, 2022d). A National Register of Historic Places listing recognizes resources of community, state, and national significance as worthy of preservation. Federal, tribal, state, and local laws establish important rules for historic preservation. Workshop experts indicated they were not aware of condition changes at doghole port sites from looting port remnants during the report timeframe.

Other Maritime Heritage Properties

Similar to the findings in the 2010 condition report, other archaeological sites and resources not associated with historic shipwrecks, aircraft, or doghole ports may be present in this region. These could include prehistoric or historic areas of human activity (e.g., habitation sites and artifacts), remnants of historic vessel landings or wharves, or other maritime heritage properties. The 2010 condition report referenced the potential for exposure of submerged cultural material associated with Indigenous terrestrial sites in the nearshore environment as a result of coastal land erosion (Terrell, 2007; ICF International et al., 2013).

Twenty of 70 archaeological sites returned in a CHRIS database search may be within, or have elements within, the coastal and offshore region of GFNMS (H. Van Tilburg/NOAA, personal communication, June 16, 2022); however, the extent to which they are adjacent to and/or extend into the sanctuary has not yet been determined. Taking a landscape approach to understanding the history of the sanctuary and its associated communities could also yield information about sanctuary maritime heritage resources and their condition. Gaining more understanding of this topic by examining site-level documentation and reports in CHRIS and other sources would inform this question, but represents an analysis gap for the present report.

Conclusion

This question was rated good/fair based on existing assessments for 33 shipwrecks and 24 doghole port sites. Neither looting nor trawl damage are thought to have occurred within the rating period. The tangible presence of aircraft or other maritime heritage properties was unknown. However, more information was gained about the presence of maritime heritage resources and their condition since the 2010 condition report, and the expansion of the sanctuary resulted in the inclusion of a number of additional shipwrecks and doghole ports within its boundaries. The trend was not changing based on a lack of evidence of significant

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[20] A multiple property submission covers a grouping of individual properties characterized by common physical and/or associative attributes, tied to a historic context. The cover form contains much of the context for evaluation, which does not have to be repeated in individual nominations submitted as part of the group. It facilitates evaluations of significance for related resources, enabling easier assessment of National Register of Historic Preservation eligibility for individual properties.

[21] Only 24 of the 57 ports sites included in the multiple property submission (for which the cover documentation was approved in April 2022) are within GFNMS. The others, in Mendocino County, are outside the sanctuary's boundaries.

changes. However, there was a lack of quantitative data for many of the resources that would have enabled tracking condition changes, and limited qualitative data were available, with one expert noting no significant changes in resource conditions were observed over many years of scuba diving in the region. The lack of resources for regular monitoring was a factor in the lack of condition data. As a general statement, when changes in maritime heritage resources are observed, it is unclear in most cases if the observed deterioration is from natural processes or human activities, though in the coastal and offshore region of GFNMS, it is likely such changes are mainly from natural causes.

There is only a small amount of information known about the maritime heritage resources within the sanctuary; there are data gaps for each indicator, and much of the information that is available is qualitative and not quantitative. Data gaps exist due to a lack of comprehensive, standardized baseline site assessments for many of the resources as well as a lack of monitoring data from periodic, standardized subsequent assessments of the resources' condition in the field. One need is to review and assess the information on potential prehistoric and historic locations and features (e.g., geographic coordinate data) listed in CHRIS and examine associated site-level documentation. This would need to be coordinated with similar efforts in the estuarine and lagoon region.

Estuarine and Lagoon Region

Status Description: Known maritime heritage resources appear to reflect little or no unexpected natural or human disturbance.

Rationale: The one known resource, the shipwreck *Oxford*, located in Tomales Bay, is buried by mud, which makes both natural and anthropogenic deterioration less likely. Expert confidence was low in determining a trend because the assessment was based on one site and a single survey. Aircraft, doghole ports, and other maritime heritage resources were investigated as data indicators but no known resources were identified.

Findings From the 2010 Condition Report

In 2010, the status and trend ratings for known maritime heritage resources in the estuarine and lagoon region were undetermined because archaeological surveys to investigate vessel losses and monitoring had not been conducted. Seven records of losses of historic shipwrecks, all in Tomales Bay, were mentioned in the report, but no sites were known or assessed.

New Information in the 2010–2022 Condition Report

Four indicators of known, tangible maritime heritage were used to evaluate this question: shipwrecks (the only indicator discussed in the 2010 report), aircraft, doghole ports, and other maritime heritage properties (inclusive of locations and resources; Table S.MHR.16.3).

Table S.MHR.16.3. Summaries for the key indicators related to the condition of maritime heritage resources in the estuarine and lagoon region of GFNMS that were discussed during the July 6, 2022 virtual workshop.

Indicator	Source	Data Summary	Figures and Tables
Shipwrecks	R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022; Delgado & Haller, 1989; Delgado et al., 2020	Status: One shipwreck, *Oxford*, is known and documented within the estuarine and lagoon region. A hydraulic probe survey was conducted to determine the location of the wreck, but it was not fully assessed. Loss records indicate additional shipwrecks could be present. Trend: No trend data were available.	Figure S.MHR.16.6; Figure S.MHR.16.7; Table S.MHR.16.4
Aircraft and doghole ports	R. Schwemmer/NOAA, March 8, 2022; Schwemmer, 2022	Status: There are no documented historic aircraft or doghole ports in the estuarine and lagoon region of GFNMS. Trend: No trend data were available.	N/A
Other maritime heritage properties	H. Van Tilburg/NOAA, personal communication, June 16, 2022; California Office of Historic Preservation, 2022	Status: Ten archaeological sites returned by CHRIS database search (after terrestrial sites were excluded) may be within, or have elements within, the estuarine and lagoon region of GFNMS. However, it is undetermined whether these properties extend into or are adjacent to the sanctuary. Trend: No trend data were available.	N/A
Data gaps	There were gaps in assessments of all resource types, as well as analysis gaps for CHRIS site reports pertaining to doghole ports and other maritime heritage properties.		

Shipwrecks

There are 408 records of losses of historic ships and aircraft within all of GFNMS (both regions), with 87 shipwrecks recorded as rescued or salvaged (some partial remains or cargo items could still be on site). In the estuarine and lagoon region of GFNMS, there is one documented shipwreck, *Oxford* (R. Schwemmer/NOAA, personal communication, March 8, 2022, March 10, 2022; Schwemmer, 2022; Delgado & Haller, 1989; Figure S.MHR.16.6). It was located in Tomales Bay by a team led by NOAA archaeologists.

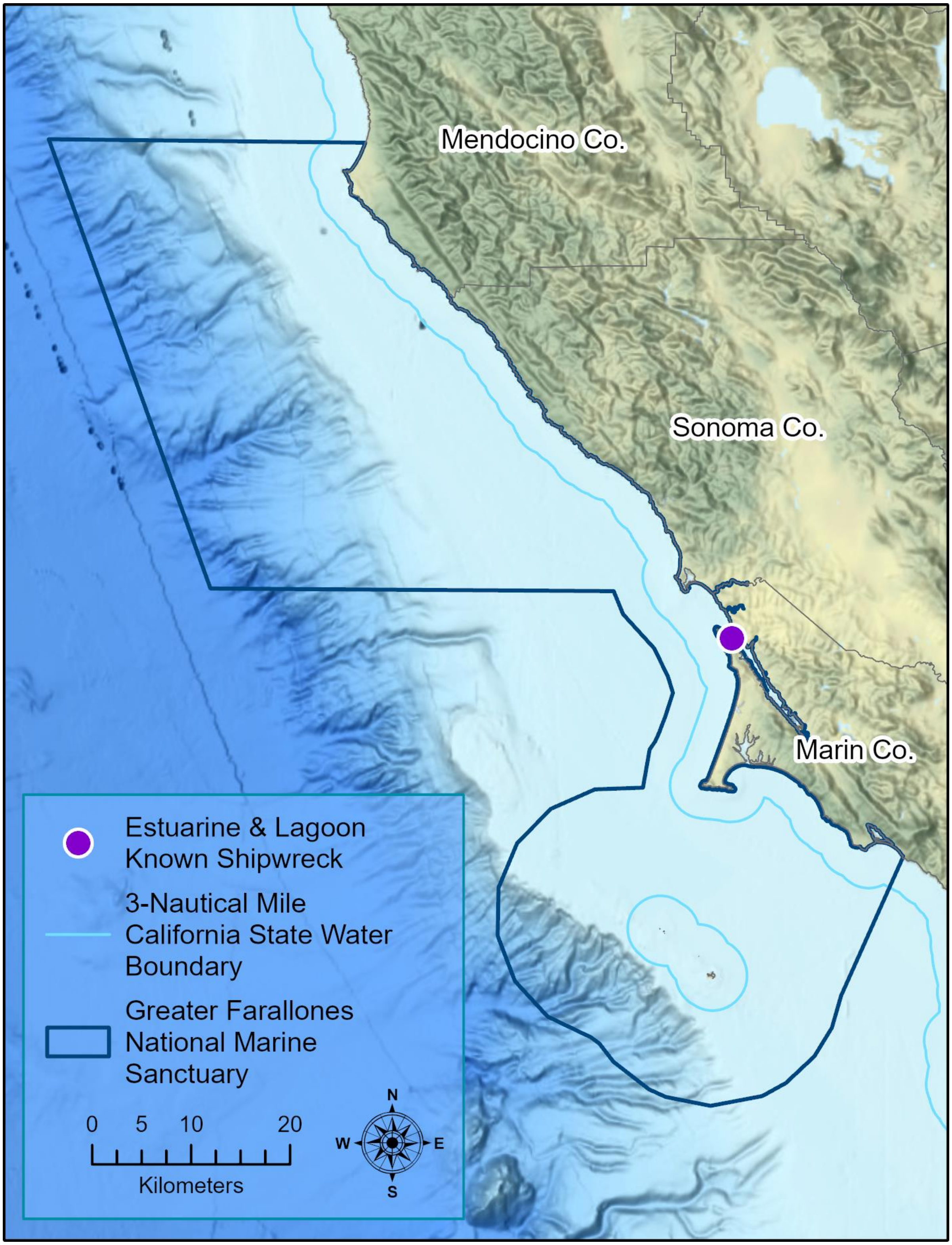

Figure S.MHR.16.6. The location of the known historic shipwreck in the estuarine and lagoon region of GFNMS. Image: NOAA; Source: R. Schwemmer/NOAA personal communication, March 8, 2022; Schwemmer, 2022; Delgado & Haller, 1989; Delgado et al., 2020; Esri, 2020

The only survey of the wreck of *Oxford* (Table S.MHR.16.4) was a hydraulic probe survey to determine its location in 2014 (Figure S.MHR.16.7).

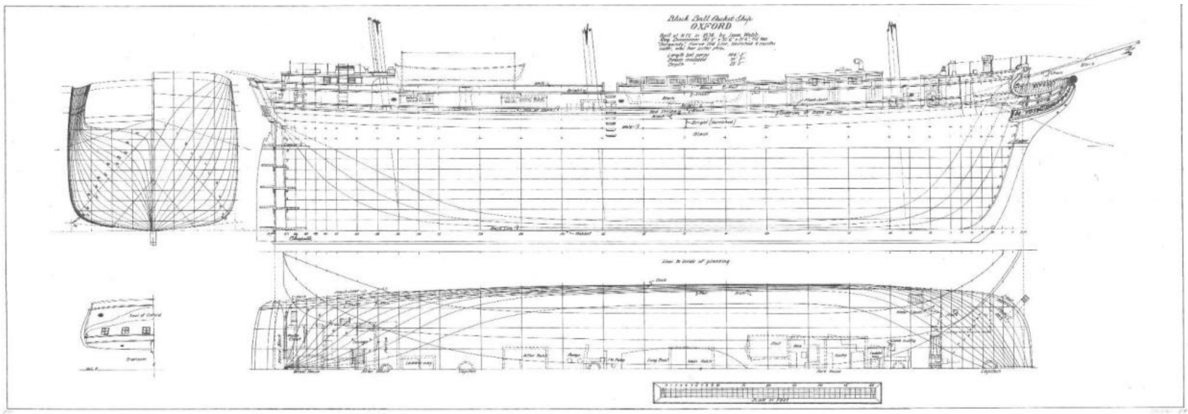

Figure S.MHR.16.7. Ship plans of *Oxford*. Image: Smithsonian Institution

Delgado et al. (2020) reported a "crunchy" mass buried under a mud and sand shoal. Human impacts on the wreck are not known, other than those due to the research activity (J. Delgado/NOAA, personal communication, February 6, 2015) that determined the wreck's location; hydraulic probing resulted in 20 or fewer probe holes and probable introduction of some oxygen (see Question 5). This could have had an effect on the wreck's condition, but the nature and extent of that effect is undetermined. Workshop experts indicated that the fact that the structure is buried by mud makes both natural and anthropogenic deterioration less likely.

Table S.MHR.16.4. Summary of condition of one shipwreck site in the estuarine and lagoon region of GFNMS.

Name	Year Lost	Location Lost (Estuarine or Lagoon)	Site Condition
Oxford	1852	Estuarine	"Crunchy" mass buried under a mud and sand shoal; no known human impacts beyond possible survey probe holes and temporary introduction of oxygen

Aircraft and Doghole Ports

No historic aircraft or doghole ports have been documented within the estuarine and lagoon region of GFNMS (R. Schwemmer/NOAA, personal communication, March 8, 2022; Schwemmer, 2022).

Other Maritime Heritage Properties

Experts believe there may be other archaeological sites and resources in this region that are not associated with historic shipwrecks, aircraft, or doghole ports. These could include prehistoric or historic areas of human activity (e.g., habitation sites and artifacts) and remnants of historic vessel landings or wharves. Ten of 70 archaeological sites returned in a CHRIS database search may be within the estuarine and lagoon region of GFNMS, specifically in Tomales Bay (H. Van Tilburg/NOAA, personal communication, June 16, 2022; California Office of Historic

Preservation, 2022). The extent to which these properties are adjacent to and/or extend into the sanctuary is not yet determined and is an identified analysis gap. Gaining more understanding of this topic by examining geographic coordinates of sites listed in the CHRIS and by looking at any site-level documentation and reports, as well as integrating information by taking a landscape approach, are identified as data and analysis needs that would inform this question.

Conclusion

This question was rated good based on the condition of the one known shipwreck in this region, *Oxford*. Little information is available on its condition, but because it is submerged underwater in mud, its status is presumed to be good. Other shipwrecks may exist within the region based on loss records, but the presence of tangible remains have not been ascertained. Three other indicators were investigated (aircraft, doghole ports, and other maritime heritage properties) but no other maritime heritage resources have been verified to be within the sanctuary. The trend was not changing based on the presumed stable condition of *Oxford*, other than potentially negligible adverse effects caused by the hydraulic probe survey used to determine its presence. It is not likely to be subjected to natural deterioration or be adversely affected by human activities, though further field research could disturb the resource. There is a need to review and assess available information on potential prehistoric and historic locations and features (e.g., geographic coordinate data) listed in CHRIS and examine associated site-level documentation. This would need to be coordinated with similar efforts in the coastal and offshore region.

Status and Trends of Ecosystem Services

This section summarizes the status and trends of ecosystem services. Virtual expert workshops were convened by GFNMS staff on various dates from June–July, 2022 (see Appendix B and Appendix C) to discuss ecosystem services. It is important to note that, in general, the assessments of the status and trends of key indicators in GFNMS are for the period from 2009–2022. During the virtual workshops, indicators for each topic were presented, accompanied by data sets ONMS compiled prior to the meeting. Attendees were then asked to review the indicators and data sets, identify data gaps or misrepresentations, and suggest any additional data sets that may be relevant. Once all data sets 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 methods used to develop this report.

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. Workshop discussions and ratings were based on data available at the time (e.g., through summer 2022). However, in some instances, newly available data were reevaluated and/or incorporated 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 to support a rating, but were not presented or discussed during the workshop, are noted in the text.

In contrast to the pressures and resources questions, which were assessed separately for the coastal and offshore and estuarine and lagoon regions of GFNMS, the status and trend of each ecosystem service were assessed once for the entirety of the sanctuary.

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 national marine 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 or 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 Status and Trends of Sanctuary 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 GFNMS, eight of the 13 final ecosystem services were rated during virtual workshops held in June and July of 2022: Science, education, heritage, sense of place, consumptive recreation, non-consumptive recreation, commercial harvest, and coastal protection. The other five 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 recreational use, 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.

Cultural Services (Non-Material Benefits)

Science

The capacity to acquire and contribute information and knowledge

Good/Fair

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

Rationale: Long-term scientific data on resources in the sanctuary have been collected for over 30 years, and some projects have grown over time. Data on the sanctuary have been disseminated through online data portals, publications, reports, and GFNMS-supported symposia. However, staffing and funding levels have not been adequate to fully support science activities and data collection in all areas of the sanctuary. Accessing some areas of the sanctuary was also challenging due to weather, the presence of white sharks (which limits diving operations), and limited vessel capabilities.

Understanding the health of the sanctuary through exploration, characterization, research, and monitoring has been one of the highest priorities for sanctuary management since 1981. Science activities at GFNMS support the goal of maintaining a healthy and resilient sanctuary by assessing the effectiveness of sanctuary management actions and regulations. These activities include the collection of data to provide a baseline from which to measure the positive and negative impacts of management decisions, environmental influences, anthropogenic pressures, as well as to detect anomalous changes in species seasonality, abundance, and distribution. Sanctuary science projects have also forecasted near-term and long-term effects of physical, chemical, and biological processes and ecological interactions on the health of the sanctuary. The science program at GFNMS has promoted the sanctuary as a premier site for research, monitoring, and habitat characterization. Science findings have been integrated into sanctuary management actions (i.e., adaptive management actions). The science program at GFNMS has also offered community-based scientists the opportunity to learn about the sanctuary and to actively collect data essential for management, resulting in increased stewardship and protection of the sanctuary.

Indicators used to evaluate the science ecosystem service in GFNMS included research permits issued each year; the number of partnerships that rely on sanctuary data and provide in-kind and financial support for GFNMS science projects; the number of exploration, characterization, and monitoring projects; the level of funding from the site's budget and funds from outside sources and partnerships; community-based science projects; publications; and the challenges that limit the capacity of GFNMS to acquire and share data and information (Table ES.S.1).

Table ES.S.1. Summaries for the key indicators related to science in GFNMS that were discussed during the June 10, 2022 virtual workshop.

Indicator	Source	Data Summary	Figures and Tables
Research permits	ONMS, 2022a	Status: There were 157 active research permits in the sanctuary from 2010–2021. Trend: The number of permits increased slightly.	Table ES.S.2
Science funding	Internal data	Status: GFNMS budget funds for science projects has averaged $400,000 per year, with a peak of $536,000 in 2021, which was primarily due to combining the GFNMS and CBNMS budgets. Trend: Science funding levels have remained relatively stable and increased in 2021 when the GFNMS and CBNMS budgets were combined.	Figure ES.S.1
Partnerships	Internal data	Status: GFNMS partners with at least 34 federal, state, and county government; academic; and research organizations on science projects, including data sharing, in-kind support, and vessel support. Trend: No trend data were available.	Figure ES.S.2
Research cruises, monitoring, and expeditions	Internal data	Status: During the study period, GFNMS led or participated in 13 seafloor exploration and research cruises; 33 pelagic surveys; and over 16,000 shoreline surveys. In 2015, when the sanctuary expanded, 15 additional sandy beach monitoring sites and two rocky intertidal sites were added to the GFNMS monitoring projects. Trend: The number of seafloor exploration cruises and shoreline monitoring surveys increased since 2010. The number of pelagic cruises remained stable, except during the pandemic.	Table ES.S.3
Community-based science	Lindquist & Roletto, 2022a; Long-term Monitoring Program and Experiential Training for Students [LiMPETS], 2022	Status: Volunteers were engaged in eight science shoreline survey projects; the majority of volunteer hours (84%) were for Beach Watch, and ranged from 6,324 hours in 2011 to 12,240 hours in 2018. Trend: There was an apparent increase in the total number of volunteer science projects from 2010 to 2019, but hours decreased in 2020 as a result of the COVID-19 pandemic.	Figure ES.S.3
Publications	Internal data	Status: At least 222 publications were produced from GFNMS-supported science projects during the study period. Trend: The number of publications was stable during this study period.	Table ES.S.4

Indicator	Source	Data Summary	Figures and Tables
Limitations and challenges	Internal data	Status: Limitations that affected science during the study period include staffing and funding, weather, inability to mobilize opportunistically, and a lack of suitable anchorages. Trend: No trend data were available.	N/A

Research Permits

GFNMS issues research permits for science projects that benefit management but would otherwise violate sanctuary regulations. For example, permits are issued for low overflights that may disturb wildlife, but yield status and trend data on seabird populations. Permit special conditions allow staff to provide strict requirements on the type of aircraft and number of passes over a particular colony, which minimizes or eliminates the likelihood of disturbance. Other projects that would otherwise violate sanctuary regulations, such as those that disturb the seabed, discharge human-made objects into the sanctuary, or disturb seabirds, marine mammals, or white sharks, provide vital data on habitats and health of species while minimizing negative impacts. From 2010–2021, GFNMS had 157 active research permits (Table ES.S.2; ONMS, 2022a). Since the sanctuary expansion in 2015, the number of new research permits increased slightly, but most existing permits were expanded to include new areas protected in Sonoma and Mendocino counties.

Table ES.S.2. From 2010–2021, GFNMS issued 157 permits for research activities that included activities that otherwise would have violated sanctuary regulations. Source: ONMS, 2022a

Year	Active Research Permits	Types of Research
2010	11	Benthic invertebrate assessments, benthic fish surveys, climate impacts on estuarine invertebrates, rocky intertidal habitat surveys, invertebrate assessments in sandy shore habitats, non-indigenous species impacts, white shark tagging, water quality buoy deployment
2011	9	Acoustic monitoring of southern resident killer whales, non-indigenous species impacts, white shark tagging, water quality buoy deployment
2012	8	Habitat assessment using wave glider and expendable bathythermograph (XBT), ocean acidification impacts to eelgrass, seabird aerial surveys, white shark tagging
2013	8	Benthic fish assessment, climate impacts to estuarine marsh, habitat assessment using XBTs, intertidal habitat assessment, white shark tag-receiver moorings, whale tagging
2014	20	Marine mammal aerial surveys, maritime heritage, non-indigenous species impacts, ocean acidification impacts to eelgrass, white shark tag-receiver moorings, water quality buoy deployment
2015	6	Benthic fish assessment, maritime heritage surveys, white shark tag-receiver moorings, water quality buoy deployment

Year	Active Research Permits	Types of Research
2016	17	Acoustic assessments of marine mammals, aerial surveys and tagging marine mammals, benthic fish assessment, intertidal habitat assessment, invertebrate assessment, maritime heritage mapping including XBTs deployment, seabird attractants, white shark tag-receiver moorings, water quality buoy deployment, waterfowl aerial surveys
2017	10	Acoustic assessments of marine mammals, benthic fish assessment, invertebrates biodiversity assessment, climate impacts on eelgrass, crab gear assessment, eelgrass assessment, intertidal and subtidal habitat assessments, intertidal surveys of marsh habitat, mapping including XBTs deployment, marine mammal assessments, non-indigenous species impacts, seabird aerial surveys, white shark tag-receiver moorings, waterfowl aerial surveys
2018	10	Clamming impacts using UAS, crab gear assessment, estuarine eelgrass assessment using UAS, intertidal and subtidal habitat assessments, mapping including XBTs deployment, water quality buoy deployment, water quality wave glider
2019	32	Aerial surveys and tagging of marine mammals and turtles, benthic fish assessment, benthic habitat assessment, benthic invertebrate assessment, climate impacts to eelgrass, contaminant assessment, crab gear assessment, intertidal and subtidal habitat assessments, UAS assessment of kelp canopy, larval fish and invertebrate assessment, mapping including XBTs deployment, maritime heritage surveys, non-indigenous species impacts to seagrass, white shark tag-receiver moorings, water quality buoy deployment
2020	11	Crab gear assessment, intertidal habitat assessment, UAS assessment of kelp canopy, larval fish and invertebrate assessment, white shark tag-receiver moorings, water quality buoy deployment
2021	15	Acoustic monitoring of marine mammals, aerial surveys and tagging of marine mammals and turtles, benthic fish assessment, benthic habitat assessment, eelgrass assessment, intertidal and subtidal habitat assessments, invertebrate assessment on sandy shores, kelp assessment and seeding research, UAS assessment of kelp canopy, water quality assessment using wave glider

Science Funding

Funding for science projects was limited and has not kept pace with inflation or been sufficient to expand projects to include new areas of the sanctuary added during the 2015 expansion (Figure ES.S.1). Therefore, GFNMS has relied on strong partnerships to help support and fund science projects of highest priority to sanctuary management. GFNMS science programs also provided in-kind support to many other natural resource management agencies. GFNMS budget funds for science projects has averaged $400,000 per year, with a peak of $536,000 in 2021, which was primarily due to combining the GFNMS and CBNMS budgets.

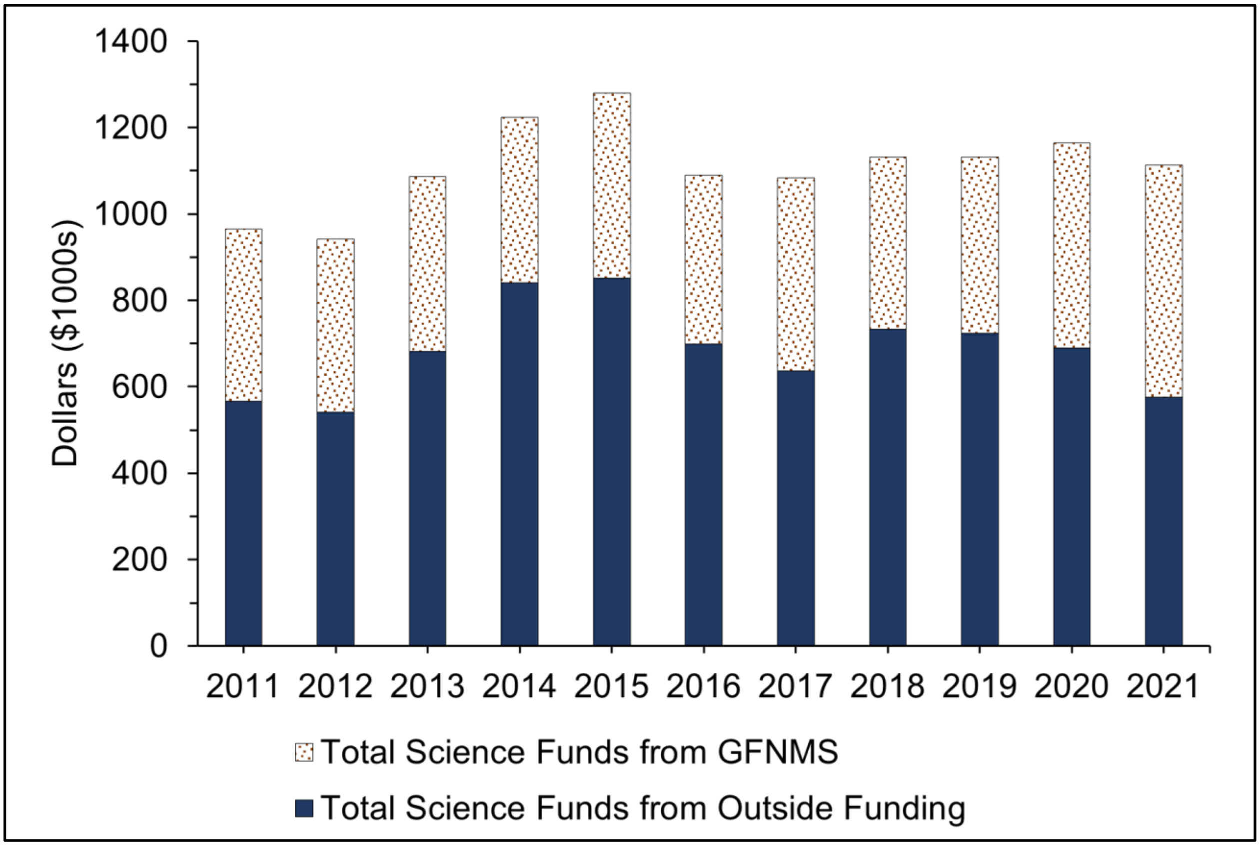

Figure ES.S.1. Funds for science projects in the sanctuary led by GFNMS and partners, including in-kind funding (e.g., staff, office space, amenities) and outside funding (i.e., funds not coming from the GFNMS budget) that support GFNMS science projects. This figure does not account for funding for external projects that do not partner with GFNMS. Source: NOAA

Partnerships

GFNMS partners provide more than half of the funds used to support sanctuary science projects (Figure ES.S.1), either through grants used to support GFNMS-led projects or through in-kind funding supporting science volunteers, analysis, and publishing data. From 2010–2021, GFNMS worked with at least 34 partners from federal, state, and county governments and academic and research institutions (Figure ES.S.2). GFNMS's strong partnerships also promote sanctuary awareness and expand stewardship and knowledge about sanctuary resources. GFNMS provided funding for five projects with a science component; 12 partners provided funding for science projects; 29 partners provided in-kind funding in the form of data and in-kind support (e.g., staffing, analyses, writing reports and papers); and 28 partners used GFNMS science data for natural and cultural resource management, violation detection, outreach, interns, and students. GFNMS supported at least 28 partners through in-kind support from science staff and provided vessel support to eight partners.

Figure ES.S.2. Logos for non-NOAA GFNMS science partners. Source: NOAA

Research Cruises, Monitoring, and Expeditions

Exploration, characterization, and monitoring are at the heart of the GFNMS science program. The number of seafloor exploration cruises and shoreline monitoring surveys has increased since 2010, particularly since the expansion of the sanctuary in 2015. The number of pelagic cruises remained stable, except during the pandemic. In 2015, when the sanctuary expanded, 15 additional sandy beach monitoring sites and two rocky intertidal sites were added to the GFNMS monitoring projects. From 2010–2021, GFNMS worked with NOAA's National Marine Fisheries Service and National Centers for Coastal and Ocean Science to support 13 exploration and research cruises to map and characterize sanctuary seafloor habitats (i.e., quantification of biota and confirming substrate type). Along with staff from CBNMS and Point Blue Conservation Science, GFNMS co-led 33 pelagic surveys as part of the ACCESS project (see Box 1) to quantify abundance and distribution of birds, mammals, zooplankton, marine debris, and drift algae (Elliott et al., 2022b). Also, in partnership with the Greater Farallones Association, GFNMS conducted over 16,000 shoreline surveys to quantify coastal birds, mammals, human activities, and marine debris, and to quantify invertebrate and algae species in sandy beach and rocky intertidal habitats (Table ES.S.3). Most of the shoreline surveys were performed by well-trained volunteers as part of the Beach Watch project (see Box 2; Lindquist & Roletto, 2022a).

Table ES.S.3. Number and type of cruises and surveys led or co-led by GFNMS science staff and partners, 2010–2021. Source: NOAA

Year	GFNMS-Led and Co-Led Seafloor Cruises	Partner-Led Seafloor Cruises	GFNMS-Led and Co-Led Pelagic Cruises	GFNMS-Led and Co-Led Coastal and Estuarine Surveys	Partner-Led Coastal and Estuarine Surveys
2010	1		3	1,275	32
2011			3	1,275	32
2012	1		3	1,274	50
2013			3	1,274	50
2014		1	3	1,638	50
2015			3	1,639	50
2016	1		3	1,638	50
2017		1	3	1,639	50
2018	2	1	3	1,638	34
2019	1	2	3	1,638	38
2020	1			320	
2021	1		3	1,638	38
TOTAL	8	5	33	16,886	474

Community-Based Science

Community-based scientists (i.e., volunteers) contributed a significant amount of sampling effort along the coast of the sanctuary. Eight science projects used volunteers for shoreline surveys that collected data on various metrics, including: human activities; the abundance and distribution of birds, mammals, invertebrates, and algae; oil pollution; and if the mouth of a stream or lagoon was open or closed to the ocean (Figure ES.S.3). The majority (84%) of volunteer hours were contributed to the Beach Watch project and ranged from 6,324 hours in 2011 to 12,240 hours in 2018 (Lindquist & Roletto, 2022a; Figure ES.S.3). Annual sampling hours on the Beach Watch project fluctuated due to levels of funding obtained by the Greater Farallones Association for recruitment and training of new volunteers. The Greater Farallones Association also obtained non-NOAA funding in 2014, just prior to the sanctuary expansion, to recruit and train more volunteers to survey beaches in the expansion area. The Greater Farallones Association also provided funds and staffing for the Long-term Monitoring Program and Experiential Training for Students (LiMPETS) project, which trains students to collect ecological monitoring data on sandy beaches and rocky shores along the sanctuary's coast (LiMPETS, 2022). In 2015, LiMPETS added seasonally dependent surveys at one sandy beach (for a total of six beaches monitored) and two rocky intertidal beaches (for a total of five beaches monitored). LiMPETS sampling occurs four times per year at each site. Due to the COVID-19 pandemic, sampling by all volunteers was limited in 2020–2021. Prior to the pandemic, there had been an apparent increase in the total number of volunteer hours contributed to sanctuary science projects (Figure ES.S.3).

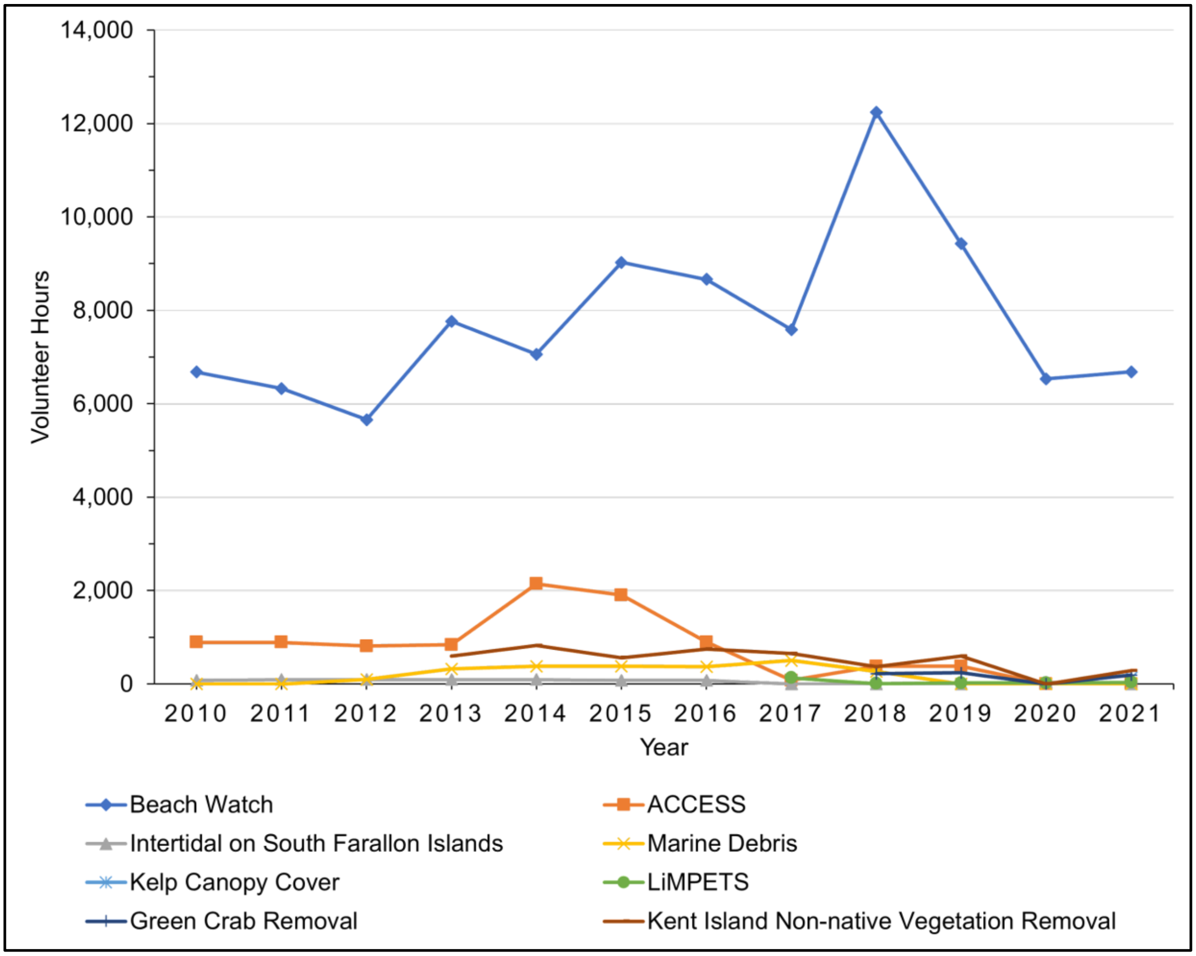

Figure ES.S.3. Volunteer hours for sanctuary science monitoring and restoration projects from 2010–2021.

Publications

At least 222 publications have been produced from science projects supported by GFNMS. Publications included abstracts produced for conferences and symposia, peer-reviewed papers in journals, reports in the ONMS Conservation Science Series, book chapters, and technical reports produced after major events, incidents, or research cruises (Table ES.S.4). The number of abstracts produced in a given year was dependent on the number of conferences and symposia that were held that year and available funding. On average, one to two dissertations or theses and one or two peer-reviewed papers were completed each year of the study period using data from sanctuary science projects, suggesting a stable trend.

Table ES.S.4. Publications produced from 2010–2021, including abstracts for various conferences and symposia, peer-reviewed papers in journals, reports in the ONMS Conservation Science Series, chapters in books, and technical reports based on data collected for GFNMS science projects.

Type of Publication	Number of Publications
Peer-reviewed papers	59
Technical reports	54
Dissertations and theses	10
Abstracts, presentations, and posters	95
Cruise reports	2
Books and chapters	2
Total	222

GFNMS supported the “Beyond the Golden Gate Research Symposium” in 2016 and 2022. In both years, this symposium provided a venue for regional researchers, students, and science educators to collaborate and exchange information about their projects with each other, educators, and members of the public. Symposium topics were relevant to marine resource management, such as climate change impacts and indicators, restoration and mitigation activities, defining and identifying ecological hotspots, oceanographic patterns, the integration of biological and physical observations, habitat characterization, and the importance of long-term monitoring of marine and estuarine habitats and species. The goal of the symposium was to increase understanding and protection of regional marine and estuarine ecosystems and to support and guide wise management of the environment. Each year of the symposium resulted in published proceedings that included 40–60 abstracts summarizing current research and monitoring projects.

Sanctuary data are available through several online data portals, including those of partners, such as the Greater Farallones Association, the Central and Northern California Ocean Observing System, NOAA’s Deep Sea Coral Research and Technology Program, the Southwest Environmental Response Management Application, the Federal Geographic Data Committee, and NOAA’s National Centers for Environmental Information.

Limitations and Challenges

Science in GFNMS was affected by significant limitations and funding challenges, particularly following the sanctuary expansion in 2015. Weather and sea state conditions limited the ability to access northern and offshore areas of the sanctuary due to the size of its primary research vessel, the RV *Fulmar* (67 feet). The RV *Fulmar* is too large to safely anchor overnight in harbors or doghole ports north of Bodega Head and is too small to access the offshore and northern portions of the sanctuary during the rough seas that often occur November through April. The home port of the RV *Fulmar* is more than 80 miles from the southern sampling locations in the sanctuary. Since no crew have been housed near the San Francisco Bay or Bodega Bay ports, GFNMS has not had the opportunity to mobilize a cruise during an opportunistic weather window of good sea state and safe conditions. Weather and the high number of white sharks limited the ability to safely conduct scuba research dives in June through September. Prior to 2022, funding was limited to one full-time research position, and science projects were thus limited to the highest-priority habitats, such as pelagic, rocky shores, and sandy shores. Limited funding has also placed a higher burden on GFNMS partners, who provide a significant amount of staffing and funding for sanctuary science projects.

Conclusion

This ecosystem service was rated good/fair and improving based primarily on the abundance of data collected, partnerships, and publications. Data have been collected by researchers in the sanctuary for over 30 years. Partnerships were numerous and provided more than half of the science staff and funding for research and monitoring projects in the sanctuary. Many data sets have been made publicly available and staff have supported data accessibility. There were numerous opportunities for the dissemination of scientific information through GFNMS-supported symposia and publications. Some limitations exist, such as a lack of access to larger vessels that can operate in rougher sea conditions. Although staffing and funding levels have not increased at the rate of inflation or with the expansion of the sanctuary, some science projects have expanded. Well-trained volunteers and strong partnerships have allowed the sanctuary science program to grow and support the sanctuary's resource protection, education, and outreach goals.

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: The quality, diversity, and reach of education programs provided or supported by GFNMS were considered excellent by experts. Programs reached a wide range of socioeconomic status levels, geographies, and ages. Educational partnerships were strong and could be expanded to reach more target audiences with additional financial support. The diversity of programs offered and the number of participants and collaborators were robust. The number of people served by various education programs was stable or increased during the study period. The lack of increased participation for some programs was determined to reflect limited staff capacity rather than reduced ecosystem function or a lack of desire for programs among the community. Staff capacity did not meet the community demand for intellectual enrichment during the study period.

GFNMS fosters intellectual enrichment by engaging the public in both informal and formal programs that increase ocean literacy and better prepare participants to make informed decisions that affect the marine environment. Informal education was defined as public programs, while formal education was defined as programs for students and teachers. The following narrative addresses indicators relevant to both types of programs (Table ES.E.1; Table ES.E.3).

Informal Education

Informal education occurs outside of a school or university setting. GFNMS staff worked with strategic partners to develop and deliver a wide variety of programs to engage the public in ocean and coastal science and recreation. Programs imparted messages about the sanctuary and the value of marine protected areas. Programs with fees had scholarships available.

Table ES.E.1. Summaries for the key indicators related to GFNMS informal education that were discussed during the June 15, 2022 virtual workshop. These data are from GFNMS and were recorded in NOAA's annual education accomplishments database. External exhibit visitorship numbers were provided by partner institutions and organizations and reference total visitorship.

Indicator	Data Summary (2011–2021)
Exhibits about GFNMS	Seven exhibits at GFNMS and partner institutions were viewed by over 28 million visitors, based on partner reporting. Six of the seven exhibits have been updated or refreshed, indicating partners also valued the stories the exhibits impart.
Docents, volunteers, and interns	Docents, volunteers, and interns provided 20,623 service hours, valued at $588,580. Volunteer support greatly increased program capacity and reach, and volunteers gained knowledge, experience, and skills.
Get Into Your Sanctuary series	3,787 individuals participated in a monthly exploration series focused on sanctuary habitats and wildlife.
Art and Science Lecture Series	6,759 adults participated in the Sanctuary Art and Science Lecture Series, which included renowned scientists that shared the latest research on sanctuary marine life while participants created ocean-themed art and participated in social learning activities.
Family workshops	5,635 families with children aged 4–10 years explored special topics by participating in two-hour workshops at the Pier Classroom on the GFNMS campus in San Francisco.
Summer camps	2,180 youth participated in week-long camps that included field trips to sanctuary habitats and marine science activities.
Sharktoberfest	This annual event with over a dozen education, research, and conservation partners attracted 10,248 people to celebrate the annual return of white sharks to the sanctuary.
Naturalist training	768 naturalists were trained for partner organizations and the Sanctuary Naturalist Course program trained 43 GFNMS naturalists.
Outreach: Social media, partner events, and lectures	68,726 people participated in virtual and in-person lectures to community organizations and engaged with GFNMS staff at community events. There was steady growth in the numbers of followers for the GFNMS Facebook and Twitter accounts.

Exhibits About GFNMS

Seven exhibits in four California counties featured GFNMS, including an exhibit at the GFNMS visitor center (Table ES.E.2). These exhibits brought sanctuary places, stories, and marine life to people through aquaria, touch tanks, murals, dioramas, mounted specimens, life-size marine life models, interactive learning stations (Figure ES.E.1), sound, film, photography, and maps. Over 28 million visitors experienced these exhibits from 2011–2021. Five of the six partner exhibits have been updated and refreshed, indicating that GFNMS partners also valued the sense of place and stories imparted by the exhibits.

Table ES.E.2. Information on the seven exhibits that feature GFNMS.

Institution or Organization	Year Exhibit Opened Followed by Year(s) Refreshed	Location by County	Visitorship 2011–2021
Aquarium of the Bay	2007	San Francisco	6,323,089
University of California, Davis' Bodega Marine Lab	1998, 2008	Sonoma	48,443
California Academy of Sciences	2008, 2014, 2017	San Francisco	16,224,518
GFNMS Visitor Center	1998, 2006, 2017	San Francisco	171,004
Pigeon Point Light Station (California State Parks)	2004, 2016	San Mateo	1,186,187
Point Reyes National Seashore	2007, 2016, 2022	Marin	3,562,824
Randall Museum	2010, 2016	San Francisco	775,000
Total	**--**	**--**	**28,291,065**

Figure ES.E.1. Students on a field trip at the GFNMS Visitor Center. Photo: Justin Holl/NOAA

Docents, Volunteers, and Interns

Docents and volunteers have supported the GFNMS Visitor Center and public and partner programs. Their support greatly increased program capacity and reach. In turn, volunteers and interns gained experience, skills, and knowledge about the sanctuary. From 2011–2021, a total of 20,623 hours of volunteer service were provided, and these were valued at $588,580 (based on a volunteer rate of $28.54/hour as of April 2021).

Get Into Your Sanctuary Series

GFNMS staff hosted a Get Into Your Sanctuary exploration series for the public to discover their national marine sanctuary on foot, by boat, or paddling. From 2011–2021, a total of 3,787 individuals experienced this monthly exploration series that combined recreation and education to share information about sanctuary habitats and wildlife, including topics such as spring gray whale migrations or winter elephant seal mating.

> *"Thank you SO much for the experience of a lifetime. Everything, from the light, the air, the sound and sight of the waves, the birds, the islands, the whales, felt profound. The crew and naturalists were extraordinary. Guests kept busy sighting whales on every side of the [boat]!" –Alice, Get Into Your Sanctuary exploration series participant, 2017*

Art and Science Lecture Series

The Art and Science Lecture Series was a bi-annual series for adults to learn from renowned scientists about sanctuary habitats and wildlife, create ocean-themed art, and participate in social learning activities. From 2011–2021, 6,759 adults participated in the series, with more participants each year, including during the COVID-19 pandemic when the series went virtual.

> *"Laurence Doyle's presentation last year was perhaps the most enthralling—and yes, mind bending—talks I've ever heard!" –Bill Brick, an Art and Science Lecture Series participant*

Family Workshops

GFNMS offered two-hour family workshops from 2011 through 2021, and 5,635 families with children ages 4–10 explored special topics (e.g., crabs in the sanctuary) in the Pier Classroom on the GFNMS campus in San Francisco. Before the COVID-19 pandemic, participation was increasing. A subset of family workshops were evaluated by an external consultant in 2018 and 2019. Figure ES.E.2 illustrates key results from this evaluation.

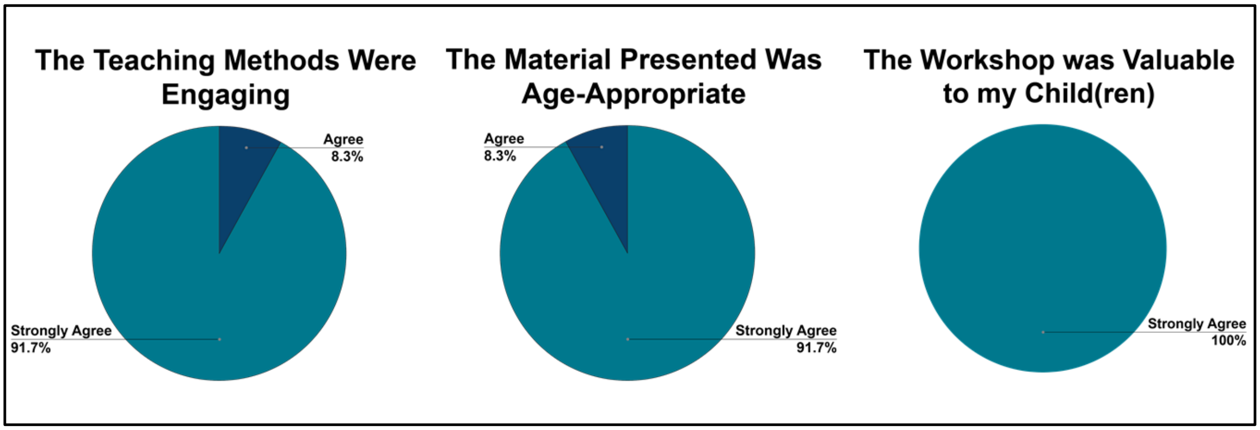

Figure ES.E.2. Select results from an evaluation of family workshop programs in 2018 and 2019. Source: Phukan, 2018

Summer Camps

Week-long camps for youth included field trips to sanctuary habitats, ocean science activities, kayaking, and exploring, all in a fun-filled environment. From 2011–2021, 2,180 campers participated in the program. The summer camp roster fills every year with a wait list nearly equal to the participant list, indicating that participation could double if staff capacity was increased to meet the demand. Outcomes of pre and post surveys for the camp showed that 96% of students had an increased understanding of marine life on the last day of camp compared to the first day of camp. Numerous students and parents have reported that these were the best summer camps they've ever experienced.

Sharktoberfest

Sharktoberfest was an annual event GFNMS coordinated with over a dozen education, research, and conservation partners. The event was co-hosted by Shark Stewards and the Greater Farallones Association to celebrate the return of white sharks to the sanctuary each year. A total of 10,248 people of all ages participated in the event from 2011–2021. Twelve partners have been involved in the program since its inception, including during the COVID-19 pandemic when the program was virtual. Prior to the pandemic, participation steadily increased. During the first year of the pandemic, when the program was launched virtually, participation doubled; however, by the second year of the pandemic, when the program was still offered virtually, participation dropped significantly (Figure ES.E.3.). Many in-person programs that became virtual during the pandemic had the same trend in participation, which seemed to indicate burnout on virtual programs during the pandemic.

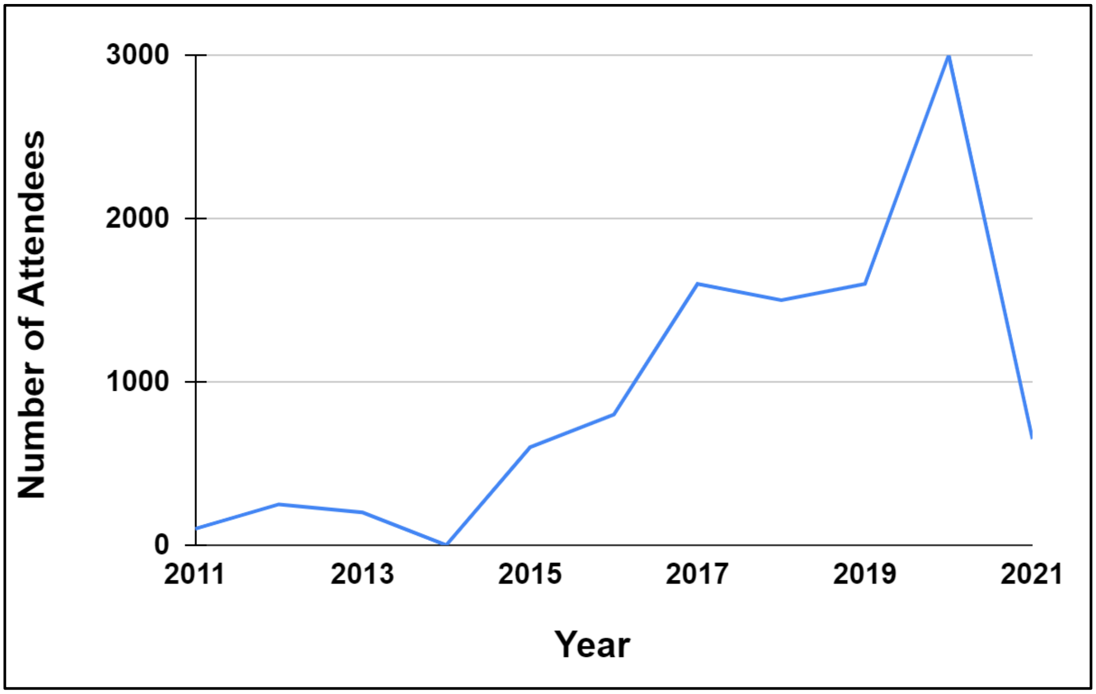

Figure ES.E.3. Sharktoberfest attendance from 2011–2021. The event was canceled in 2013 due to a government shutdown, and programs were offered virtually in 2020 and 2021 due to the COVID-19 pandemic. Source: GFNMS, 2022g

Naturalist Training

GFNMS staff provided naturalist training for partner organizations. The training included natural history, sanctuary messaging, and the latest science. GFNMS offered these training sessions to whale watching organizations and docent programs at local parks, such as Fitzgerald Marine Reserve. These classes trained 768 naturalists, who in turn amplified sanctuary messaging to thousands of people recreating in the sanctuary. In addition, in 2020, the sanctuary launched a new, more comprehensive 22-hour naturalist course designed to train GFNMS volunteer naturalists. This sanctuary volunteer naturalist course trained 43 adults. A participant from the first sanctuary naturalist course said:

> *"This class was incredibly well thought out. Great balance of exercises and playful exploration with very rich material. I couldn't wait to get here every week, and then I couldn't wait to tell other people what I learned. " –Audrey*

Outreach: Social Media, Partner Events, and Lectures

The numbers of GFNMS Facebook and Twitter followers grew steadily from 2015–2021 and 2016–2021, respectively (Figure ES.E.4; Figure ES.E.5).

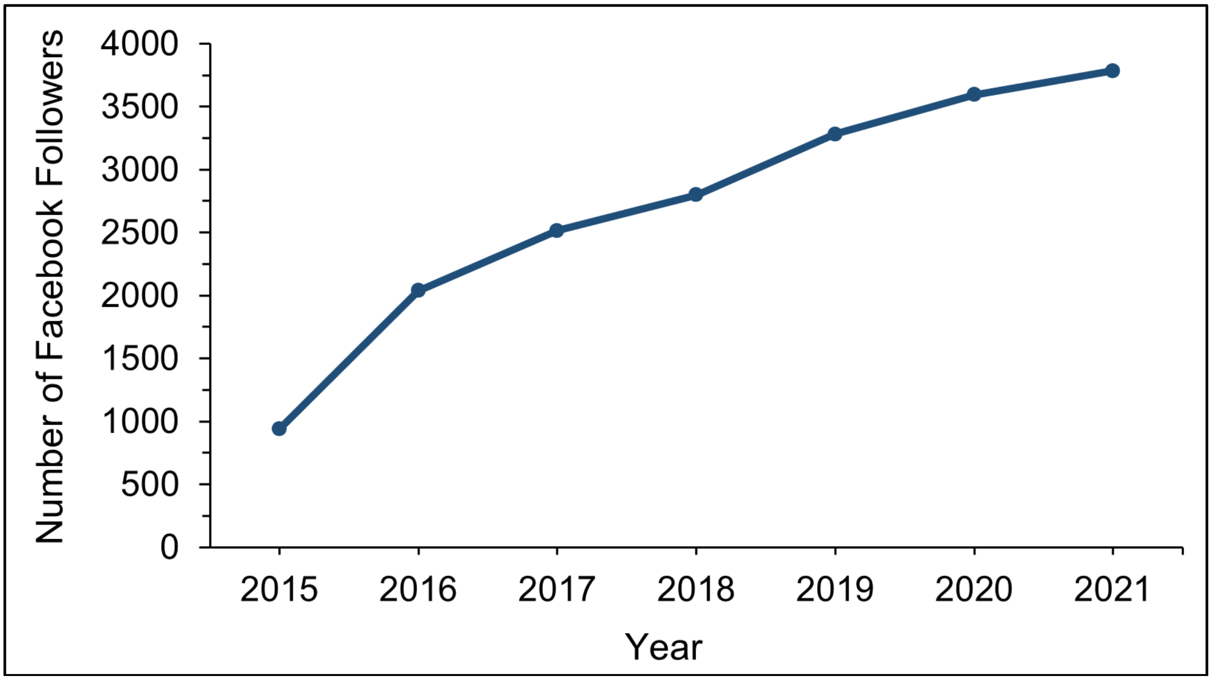

Figure ES.E.4. GFNMS Facebook account followers, 2015–2021. Source: Facebook, 2022

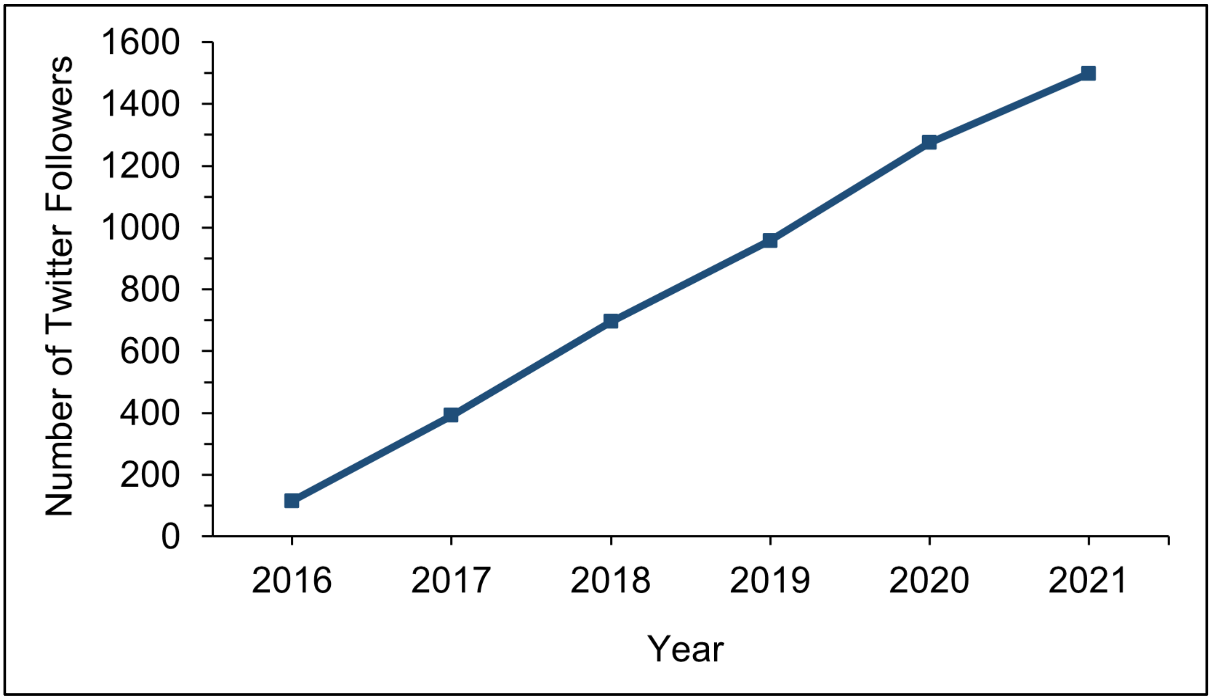

Figure ES.E.5. GFNMS Twitter account followers, 2016–2021. Source: Twitter, 2022

GFNMS staff provided lectures to multiple organizations, such as the American Cetacean Society, yacht clubs, and rotary clubs. From 2011–2021, 2,041 people participated in sanctuary lectures. In addition, GFNMS staff participated in partner educational programs such as Ocean Exploration Trust's *Nautilus* Live, California Academy of Sciences Nightlife events, and the San Francisco Zoological Gardens World Ocean Day. From 2011–2021, 68,726 people participated in virtual and in-person sanctuary talks and engaged with GFNMS staff at exhibit booths at community events.

Formal Education

GFNMS staff worked with strategic partners to develop and deliver a wide variety of programs for K–16 students and teachers to increase ocean literacy. Scholarships were available for programs with fees.

Table ES.E.3. Summaries for the key indicators related to GFNMS formal education that were discussed during the June 15, 2022 virtual workshop. These data are from GFNMS and were recorded in NOAA's annual education accomplishments database.

Indicator	Data Summary
GFNMS Visitor Center field trips	18,990 K–16 students participated in 90-minute interactive and grade-specific field trips that correlated to state standards and included indoor and outdoor components.
Farallones virtual school programs	5,609 K–16 students participated in interactive, multimedia programs on multiple marine topics. Programs were 90 minutes long, grade specific, and correlated to state standards.
Teacher workshops	1,300 K–16 educators received professional development on multiple topics that included grade specific standards-based curriculum and resources.
At Your School Programs	32,457 K–12 students had ocean science delivered to their classrooms. The 60-minute, interactive, grade specific programs correlated to state standards.
Fisherman in the Classroom	5,543 7^{th}–12^{th} grade students experienced an interdisciplinary 90-minute program co-taught by a commercial fisher and GFNMS staff.
LiMPETS	20,014 6^{th} grade to university students participated in rocky shore and sandy beach intertidal monitoring.
Oceans After School	4,359 3^{rd}–5^{th} grade students participated in 8–10 two-hour sessions of hands-on marine science learning after school.

GFNMS Visitor Center Field Trips

Programs at the GFNMS Visitor Center, delivered by sanctuary educators to serve kindergarten to university students, were 90 minutes long, interactive, and grade specific; correlated to state standards; and included indoor and outdoor components. From 2011–2021, 18,990 students participated in visitor center field trips. Post-trip evaluations showed that 100% of students believed that national marine sanctuaries protect the ocean. From 2015–2021, 44% of the students served were from families that are low income (as indicated by participation in the state's free and reduced-price meal program.)

Figure ES.E.6. Students observe seabird behaviors at Crissy Beach in San Francisco. Photo: J. Holl/NOAA

Farallones Virtual School Programs

During the COVID-19 pandemic, new interactive, virtual multimedia programs on marine topics were developed for kindergarten to university students. The virtual programs were launched for the fiscal year 2021 school year (fall of 2020 through spring of 2021) and had 5,609 students, 38% of which were from families that are low income (as indicated by participation in the state's free and reduced-price meal program). The programs were 90 minutes long, grade specific, and correlated to state standards. A participating teacher provided this feedback:

> *"Most of my students, who are English language learners, have not developed the skill of asking questions. This awesome program was so interesting for my students that during the questioning part of the presentation, many students raised their hands because they wanted to know more about the animals. This was such a positive*

experience, especially for my shy students, who wanted to get their questions answered!" –Gordon Lau Elementary School teacher

Teacher Workshops

From 2011–2021, a total of 1,300 kindergarten to university teachers participated in workshops on climate change, ocean acidification, deep-sea corals, and training for teachers in the LiMPETS program. Workshops included the latest science information, grade-specific classroom activities, and necessary resources (Figure ES.E.7). Outcomes of post-workshop surveys in 2019 showed:

- 100% of teachers believed that people are changing the climate;
- 100% of teachers believed that people need the ocean; and
- 100% of teachers knew how climate change has impacted the ocean.

Pre-workshop survey results varied considerably.

Figure ES.E.7. Teachers discuss plankton collected from net tows projected on the screen. Photo: J. Holl/NOAA

At Your School Program

GFNMS delivered At Your School ocean science programs to kindergarten through 12th grade classrooms. The programs included immersive activities, artifacts, specimens, models, visuals, and presentations from GFNMS staff. Programs were 60 minutes long, interactive, grade specific, and correlated to state standards. From 2011–2021, a total of 32,457 students participated, and from 2015–2021, 41% were from families that are low income (as indicated by participation in the state's free and reduced-price meal program).

A program evaluation consultant assessed the program on leatherback turtles for 5th grade students. An excerpt of the evaluation report stated:

"100% of the teachers surveyed said:

- The program was valuable to my students
- The teaching methods were effective
- The pace of the program was suitable
- The material presented was age-appropriate
- That they would recommend the program
- The program was 'very good' (the highest rating)" (Phukan, 2018).

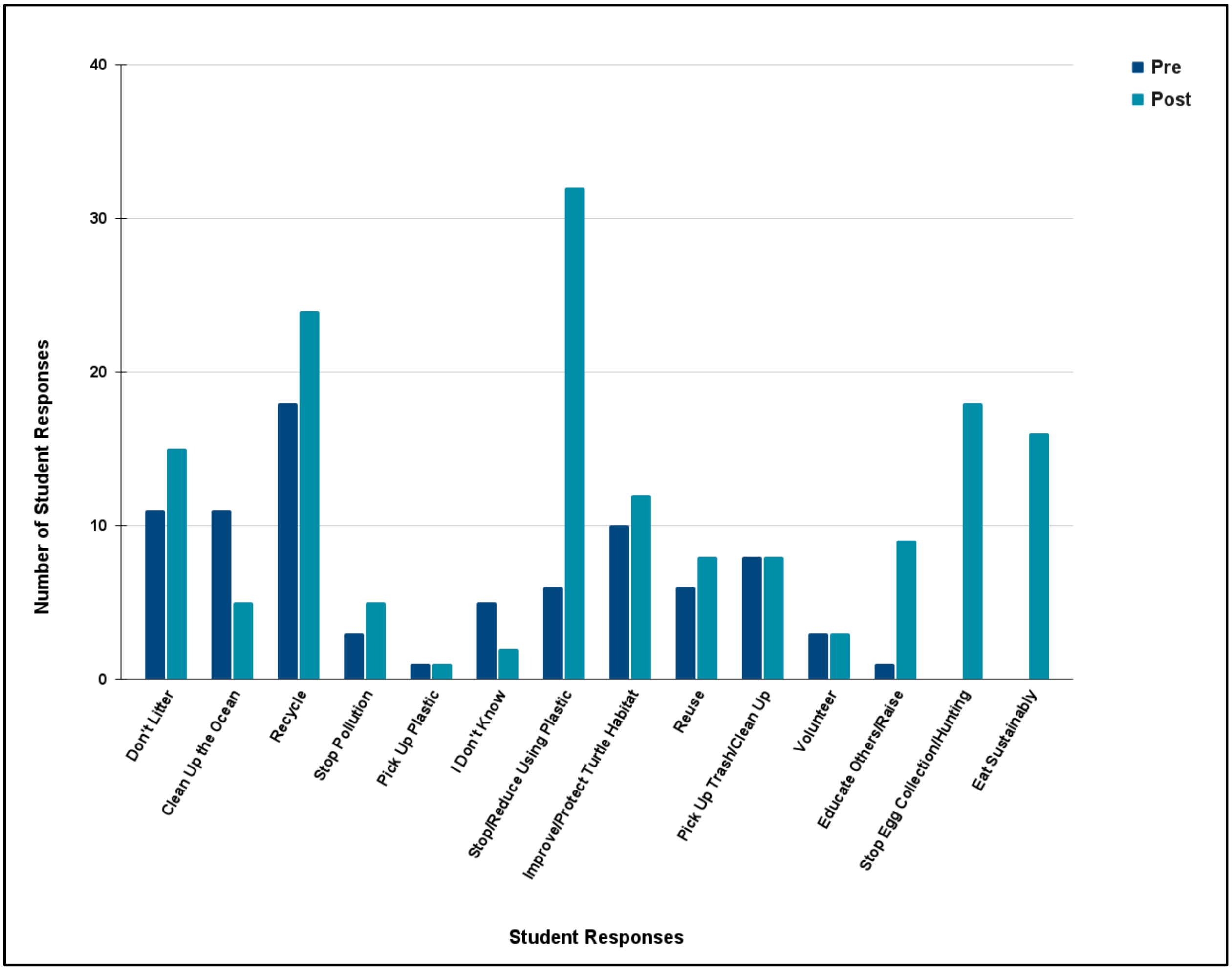

Figure ES.E.8. Student responses to the question "What can you do to help protect the leatherback turtle?" before (pre) and after (post) a program on leatherback turtles for 5th grade students. Source: Phukan, 2018

Fisherman in the Classroom

GFNMS staff, along with commercial fishers, co-taught an interdisciplinary 90-minute program that included subjects such as climate change, economics, oceanography, and sustainable fisheries (Figure ES.E.9). From 2011–2021, 5,543 7th–12th grade students participated in the program, and from 2015–2021, 42% of the students served were from families that are low income (as indicated by participation in the state's free and reduced-price meal program.)

Evaluations from a sample of 43 teachers indicated that following student participation in the program 92% of their students understood national marine sanctuaries protect ocean habitats and 96% of their students understood we obtain food from the ocean.

Figure ES.E.9. A fisherman shows students how a Dungeness crab trap works. Photo: M. McIntosh/NOAA

LiMPETS

LiMPETS is a rocky shore and sandy beach intertidal monitoring and education program for 6th grade–university students, educators, and volunteer groups. From 2011–2021, 20,014 students participated in the program, and from 2015–2021, 28% of students served were from families that are low income (as indicated by participation in the state's free and reduced-price meal program).

From 2018–2021, 75% of students who participated in LiMPETS experienced an improvement in their knowledge about the ocean and the importance of scientific monitoring. Additionally, 100% of teachers who participated in a LiMPETS program agreed or strongly agreed that they developed a deeper understanding of the “practice” of science, gained more confidence in facilitating students in the “practice” of science, and had a positive experience through their participation in the program.

Oceans After School

Oceans After School programs were delivered to 3rd–5th grade students enrolled in after school programs with either their school or local recreation centers. From 2011–2021, 8–10 two-hour sessions of experiential marine science instruction were delivered to 4,359 students. From 2015–2021, 57% of the students served were from families that are low income (as indicated by participation in the state’s free and reduced-price meal program). A staff member from one of the sites served by the program said:

> *“I have never participated in a program with children that was this engaging. Each and every week I could tell that the students were actually learning and happy to learn. The experiments were also very fun for the kids, and out of all the programs we run, they were most excited to participate in Oceans [After School].” –Staff member, Booker T. Washington Community Service Center*

Partnerships

GFNMS education and outreach partners help extend the reach of the sanctuary to high priority audiences (Figure ES.E.10). GFNMS’s strong partnerships promote sanctuary awareness and expand stewardship and knowledge about sanctuary resources. Sanctuary education and outreach events can be very resource intensive and partner support is essential to accomplishing GFNMS goals and objectives.

Figure ES.E.10. Logos of primary non-NOAA sanctuary education partners GFNMS worked with to produce education programming during the study period.

Conclusion

This ecosystem service was rated good/fair and improving based on responses from program participants, the diversity of offerings, and the geographic and socioeconomic reach of the education and outreach program at GFNMS, which was considered excellent by the condition report workshop expert panelists. The programs increased the ocean literacy of participants in both school and public programs. The investment of time and resources in forging strong partnerships with multiple education organizations was recognized as an effective strategy to ensure sustained education engagement in multiple communities. However, the demand for sanctuary programs exceeded the capacity of GFNMS staff and funding, limiting the ability to reach new audiences and fully engage the diverse communities of the San Francisco Bay Area on ocean conservation topics. The numbers of people served by GFNMS programs were stable or increasing; stable numbers of people served were linked to limited staff capacity rather than reduced ecosystem function or a lack of community desire for programs. Closing the gap between the capacity to deliver education programs and the unmet demand would increase the opportunity for GFNMS to use sanctuary education and outreach programs and visitor centers to highlight the value of sanctuaries and other marine protected areas as strategies to manage climate impacts and other threats.

Heritage

Recognition of historical and heritage legacy and cultural practices

Status Description: The capacity to provide the ecosystem service has remained unaffected or has been restored.

Rationale: There has been a gradually increasing amount of recognition of the importance of heritage by GFNMS staff, community members, and some government agencies. The expansion of the sanctuary in 2015 approximately doubled its size, thus associating with it a broader set of communities and additional aspects of maritime heritage (inclusive of historical and heritage legacy and cultural practices). The ecosystem service of heritage was already well supported prior to 2010 through events, stories, and management of historic places by various agencies. New partnerships, events, and exhibits on heritage were initiated by various groups and agencies, including GFNMS staff. With the 2015 expansion of the sanctuary, new connections have been made with communities adjacent to the northern area of the sanctuary, including coastal Indigenous communities. There is a need to include more experts, particularly from Indigenous communities, in future assessments of this ecosystem service.

National marine sanctuaries are iconic and have long been recognized, used, and valued by the communities that are near them as well as those in more distant communities. Shared history and heritage creates the unique cultural character of many present-day coastal communities, and can also be an important part of the modern economy. Recognition of the past through exhibits, artifacts, records, stories, songs, and chants provides a link to the history of these areas and a way to better understand the maritime and cultural heritage within the environment itself. This ecosystem service category defines benefits from resources primarily attached to historical and heritage legacy and culture. Tangible and intangible aspects of heritage blend together to contribute to the history and legacy of the sanctuary. ONMS and its partners have made efforts to document, describe, and protect for future generations the historic and potentially historic sites within the sanctuary (see Question 16), and these efforts have been increasing since the sanctuary expanded in 2015.

The heritage of the GFNMS region is long, varied, and complex, with a number of historical shifts in resource use patterns. As such, the five selected indicators are intended to serve as a gauge for the heritage ecosystem service, rather than a comprehensive list (Table ES.H.1). However, other ecosystem services may also include information on efforts to promote heritage (e.g., Education) or the influence heritage may have (e.g., Sense of Place).

Table ES.H.1. Summaries for key indicators related to heritage in GFNMS that were discussed during the July 6, 2022 virtual workshop.

Indicator	Data Summary	Figures and Tables
Heritage-related community events	Status: Events were held throughout the study period. Trend: Trends were not assessed.	Table ES.H.2
Iconic heritage locations	Status: Iconic maritime heritage locations associated with the sanctuary include Fort Ross, Point Reyes, the Northern California Doghole Ports Maritime Cultural Landscape (includes multiple sites), and locales with heritage place names. Trend: Trends were not assessed.	Figure E.S.H.1
Iconic ships and shipwrecks	Status: Iconic shipwrecks include the SS Pomona, the USS Conestoga, and iconic ships include lumber schooners/steam schooners. Trend: Trends were not assessed.	Figure E.S.H.2
Heritage museum outreach	Status: Outreach through museums and exhibits occurred, among other places, at San Francisco Maritime National Historical Park, Point Arena Lighthouse and Museum, Point Reyes National Seashore Lighthouse Visitor Center, and Bear Valley Visitor Center. Trend: Trends were not assessed.	Figure E.S.H.3
Indigenous heritage	Status: Indigenous heritage is strongly recognized and represented in the sanctuary community, and three tribes are known to have heritage connections to the sanctuary. Trend: Trends were not assessed.	Figure E.S.H.4
Data gaps	There is a need to identify additional place names for iconic heritage locations, to identify the location of additional shipwrecks and assess shipwreck records, and review publications describing tribal histories and learn more directly from Indigenous tribes and nations.	

The GFNMS region has a long history that is relevant to the heritage service. Some of the earliest travelers through and inhabitants of this coastal area, the ancestors of the modern day Pomo and Miwok peoples, would have used the natural resources of the sea and coasts. European contact with Indigenous people in this area began with Sir Francis Drake of England in 1579. This and subsequent settlement changed the earlier ways of life and traditional sea and land uses. People from many countries, including Spain, Russia, and China, came (with more arriving as visitors or new residents), comprising groups such as settlers, traders, loggers, farmers, ranchers, and fishers. Recognition and celebration of heritage is shaped by present-day communities, and this region continues to attract people with diverse interests and backgrounds, including small business owners, marine transportation owners, recreational enthusiasts, scientists, educators, homeland security and military branches, and more (ONMS, 2014a, 2014b). Descendants of the first peoples and groups who arrived later continue to live in the area today.

Heritage-Related Community Events

Many heritage-related public community events in the region focus on commercial fishing and fish, general heritage, and Indigenous heritage, and demonstrate to attendees the enduring maritime connections the community has with the expansive ocean area encompassed by GFNMS. Examples of events held between 2010–2022 adjacent to or in locations near the sanctuary are provided in Table ES.H.2. These events have been held by various organizers in the community regularly since 2010, with some exceptions, and the number of events held annually generally increased prior to the COVID-19 pandemic, at which time a number were delayed or canceled due to health concerns.

Table ES.H.2. Examples of heritage-related public community events held between 2010–2022 adjacent to or in locations near the sanctuary, listed geographically from south to north.

Event Name	Inaugural Year	Source
Sausalito Herring Festival	2013	Sausalito Community Boating Center, 2022a, 2022b; R. Gorum/Sausalito Community Boating Center, personal communication, February 4, 2022
Big Time Festival at Kule Loklo	1980	National Park Service, 2022e, 2022f; MarinArts, 2018; P. Engel/National Park Service, personal communication, February 25, 2022; C. Arreglo/National Park Service, personal communication, April 27, 2022
Bodega Bay Fisherman's Festival	1973[22]	Bodega Bay Fisherman's Festival, 2022
Fort Ross Festival	More than five decades ago	Fort Ross Conservancy, 2022a; S. Sweedler/Fort Ross Conservancy, personal communication, February 22, 2022
Fort Ross Harvest Festival	2011	Fort Ross Conservancy, 2022b; S. Sweedler/Fort Ross Conservancy, personal communication, February 22, 2022
Alaska Native Day	2015	Fort Ross Conservancy, 2022c, 2022d; S. Sweedler/Fort Ross Conservancy, personal communication, February 23, 2022; L. Peters/University of California Davis, personal communication, March 2, 2022
Metini Day	2013[23]	Fort Ross Conservancy, 2022c; Shinal, 2017; Scully, 2013; S. Sweedler/Fort Ross Conservancy, personal communication, February 23 and March 2, 2022

[22] 1973 was the first year of this festival with this name; its origin was as a celebration of the start of the salmon fishing season and the annual Blessing of the Fleet in previous decades.
[23] In 2013, this event was called Big Time at Metini.

Event Name	Inaugural Year	Source
Sonoma Mendocino Coast Whale and Jazz Festival	2002	Gualala Arts, 2022; K. Stillman/Gualala Arts, personal communication, February 17 and 18, 2022
Point Arena Harbor and Seafood Festival	1999	City of Point Arena, 2019; Point Arena Merchants Association, 2022; P. Anderson/City of Point Arena, personal communication, March 2, 2022
Acorn Festival	2016[24]	McLaughlin, 2016; Smith, 2017, 2018; SmallTownPapers, Inc., 2019

As a result of the 2015 expansion, additional coastal communities now border the sanctuary from north of Bodega Bay in Sonoma County to Manchester Beach in the southern part of the Mendocino County coast, resulting in the inclusion of additional maritime-heritage-related events in the overall data set.

Iconic Heritage Locations

Iconic heritage locations within the sanctuary or in the communities near it are significant because of their importance and connections to maritime history and for some, their continued use today, including for cultural purposes or recreation (e.g., beachgoing, scuba diving). Several of the most iconic are described below.

Fort Ross State Historic Park has an active visitor center with exhibits and historic structures. The park also hosts cultural events that provide information about a thriving Russian-American Company settlement from 1812 to 1841, where the first shipbuilding in California was done (California Department of Parks and Recreation, 2022). A doghole port was located at Fort Ross (ONMS & California State Parks, 2021), so the historical significance of the site includes maritime connections with what is now GFNMS as well as northern states, including Alaska; Alaska Native and Indigenous peoples; and early North Pacific sailing routes.

Point Reyes National Seashore also has multiple connections with maritime heritage and the nearby ocean waters of GFNMS,[25] as it includes coastal Indigenous villages, Sir Francis Drake's presumed landing site (NPS, 2022g), the location of an early lifesaving station at Ten Mile Beach in Point Reyes, the still-present Lifeboat Station and Lifeboat on Drake's Bay (Figure ES.H.1; NPS, 2020). The Point Reyes Lighthouse, Lighthouse Visitor Center, and Bear Valley Visitor Center all have heritage information and maritime exhibits (NPS, 2022h). The two visitor centers present information on national marine sanctuaries (GFNMS, 2022h).

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[24] The last traditional festival prior to 2016 was held circa 100 years earlier.

[25] The GFNMS boundary is mostly ¼ mile from the shoreline in the portion of the sanctuary adjacent to Point Reyes National Seashore, but follows the mean high water line in a small portion of Tomales Bay (see 15 C.F.R. part 922, subpart H).

Figure ES.H.1. The Historic Point Reyes Lifeboat Station's Boathouse in 2013. Photo: R. Schwemmer/NOAA

Twenty-four doghole ports in the sanctuary along the Sonoma and southern Mendocino coasts were once centers of maritime activity and trade, and there are opportunities to read about them and view artifacts in parks and other locations at or near the former ports as well as on the GFNMS website. All are important historical sites that have the potential to be officially recognized for their national significance; they were included in a broader National Register of Historic Places Northern California Doghole Ports Maritime Cultural Landscape Multiple Property Listing accepted by the National Park Service in 2021 (Marx & Jaffke, 2021). One doghole port, Salt Point Landing Historical and Archaeological District, was recognized and listed in the National Register of Historic Places in 2022 (D. Marx, personal communication, April 17, 2022; NPS, 2022i).

Place names that reflect history, including tragic events, can also reflect the maritime heritage of the region. For example, Windermere Point and Franconia Bay are named after the wrecks of *Windermere* and *Franconia*, respectively. A data gap was identified regarding the need to determine additional iconic place names, including any Indigenous place names, associated with the sanctuary's maritime heritage.

The number of iconic maritime heritage locations associated with the sanctuary increased due to the 2015 sanctuary expansion.

Iconic Ships and Shipwrecks

Historic ships and shipwrecks sometimes gain enough popularity to serve as iconic features, in addition to being archaeological properties. An example of an iconic ship in San Francisco is *C. A. Thayer*, a lumber schooner that once operated in GFNMS and is afloat at San Francisco

Maritime National Historical Park. The wooden-hulled, three-masted schooner was built in Northern California in 1895 and was the last commercial sailing vessel in operation on the West Coast. It is typical of the ships that visited doghole ports, and it also traveled far beyond the California coast carrying cargoes to and from other West Coast states and foreign ports (NPS, 2015). West Coast coastal steamships ("steam schooners") are also associated with the area and have a recognized history and heritage. Examples within the sanctuary of iconic shipwrecks are the wrecks of the SS *Pomona* and the USS *Conestoga* (Figure ES.H.2). These are both listed on the National Register of Historic Places. The SS *Pomona* struck rocks in 1908 while steaming north in heavy seas, then hit wash rocks in Fort Ross Cove (Fort Ross Conservancy, 2022e). Artifacts from this wreck are displayed at Fort Ross State Historic Park Visitor Center, and it is visited by scuba divers (GFNMS, 2022i, 2022j). The USS *Conestoga*, a U.S. Navy tug, was lost at sea with 56 sailors in 1921. Its location was one of the top unsolved maritime mysteries in U.S. naval history until the wreck was discovered in 2009, and its identity was confirmed in 2015 (ONMS, 2022c). The number of iconic ships and shipwrecks in the sanctuary increased due to the 2015 sanctuary expansion.

Figure ES.H.2. Modern painting of the USS *Conestoga* on its final voyage pounding through large waves during a gale off Southeast Farallon Island in March 1921. Image: D. Frka; Source: Naval History Heritage Command, 2022

Heritage Museum Outreach

Heritage museum outreach is a broad term that encompasses maritime heritage exhibits and other information at regional museums and other venues. In addition to the sanctuary visitor center and partner exhibits, almost every national, state, and regional park in the counties neighboring the sanctuary provides heritage information associated with the area (Figure ES.H.3). The number of heritage museums and exhibits neighboring the sanctuary increased due to the sanctuary expansion in 2015.

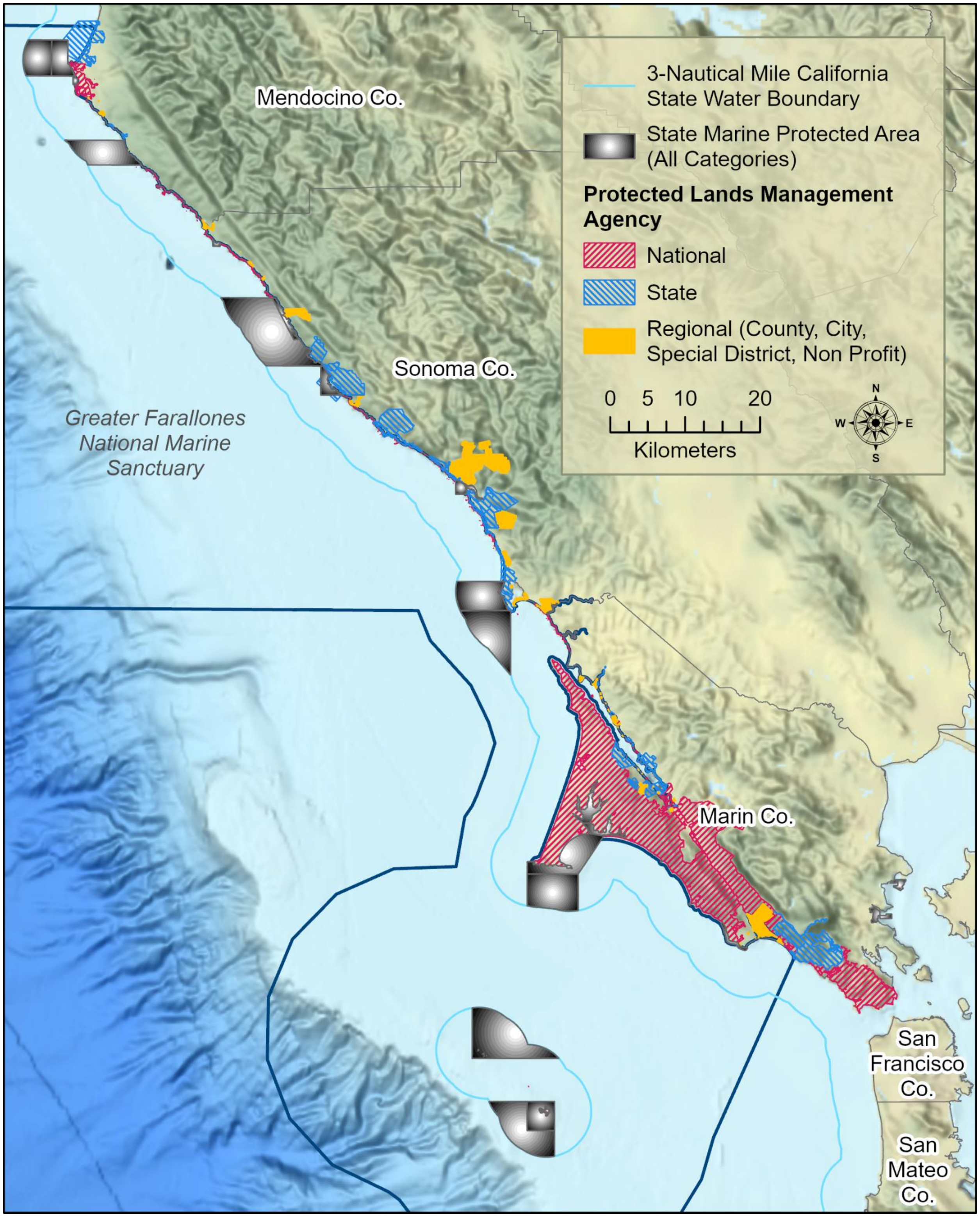

Figure ES.H.3. Coastal parks in the counties adjacent to and marine protected areas in the sanctuary. Image: NOAA; Source: California Protected Areas Database, 2021; CDFW, 2023c; Esri, 2020

San Francisco Maritime National Historical Park, Point Reyes National Seashore, and Point Arena Light Station and Lighthouse (owned by Point Arena Lighthouse Keepers, Inc.) are examples of places with museums or visitor centers where people may learn about regional heritage. The heritage exhibits and events at San Francisco Maritime National Historical Park cover California's seafaring past. The park also has information on local tribes, regional shipwrecks, cargo shipping, whaling, coastal navigation, and sea shanty singing. Prior to the COVID-19 pandemic, the park offered ranger tours and received four million visitors per year. The San Francisco Maritime National Park Association supports public programming, and over the decade prior to 2022, its membership increased 400% (B. Ho/NPS, personal communication, January 12–31, 2022; D. Plumtree/San Francisco Maritime National Park Association, personal communication, April 1, 2022). Visitation was also high at Point Reyes National Seashore's Lighthouse Visitor Center and Bear Valley Visitor Center. Between 2009–2020, over three million people visited the centers (Moore, 2022). The Point Arena Lighthouse complex includes a museum and lodging and offers an interactive experience in the exchange between history, science, and natural beauty. By many accounts, public interest in maritime heritage has been steadily increasing.

Indigenous Heritage

Indigenous heritage[26] is intrinsic to the coastal region bordering GFNMS. Thousands of years prior to first contact with Europeans, the ancestors of the Pomo and Miwok peoples inhabited the area. Later, Alaska Native peoples were brought to the region by Russian fur traders and their descendants remain. The three local coastal tribes with GFNMS heritage connections are: the Federated Indians of Graton Rancheria, comprised of Coast Miwok and Southern Pomo (Federated Indians of Graton Rancheria, 2022); the Kashia Band of Pomo Indians of Stewarts Point Rancheria (Kashia Band of Pomo Indians, 2022); and the Manchester Band of Pomo Indians of the Manchester Rancheria (Manchester-Point Arena Band of Pomo Indians, 2022). Multiple tribes, with a complex history of travel and trade relationships, are located throughout California (California Native American Heritage Commission, 2022).

Indigenous peoples have used and continue to use a wide variety of marine resources for food or other purposes, including fish, shellfish, kelp, and salt (NPS, 2022j; California Indian Museum and Cultural Center, 2022; California Marine Sanctuary Foundation, 2022). Local public festivals celebrate Indigenous traditional cultures, and events promote culture, religion, and/or education at places close to GFNMS, including public lands, tribal lands, or areas representative of traditionally used places (e.g., Kule Loklo at Point Reyes National Seashore; Figure ES.H.4).

[26] The heritage of Indigenous tribes and nations described in this report relies on publicly available and published sources. This summary information is acknowledged as often partial and incomplete, and not intended to speak for or on behalf of the tribes or Indigenous communities or peoples regarding their varied histories and past and current traditions and values.

Figure ES.H.4. Kule Loklo, a recreated village at Point Reyes National Seashore. Photo: National Park Service

As part of a 2015 event celebrating the expansion of Cordell Bank and Greater Farallones national marine sanctuaries, Kashia elders shared a name for the GFNMS ocean waters along the coastline, “Ahqa Pilili walli,” which translates to “place of churning waters.” This event was attended by local tribal members and tribal elders, along with other groups, officials, and GFNMS staff.

Data and assessment gaps were identified, including the need for collaborative publications describing tribal histories and the need to learn more directly from the Indigenous tribes and nations connected to GFNMS.

Conclusion

This ecosystem service was rated good based on the rich heritage in the region that includes tribal and Indigenous connections and heritage, maritime trade and transit history, shipwrecks and artifacts, and the abundant opportunities to connect to GFNMS maritime heritage through heritage-related community events, iconic heritage locations, iconic ships and shipwrecks, and heritage museum outreach. The complex and broad topic of GFNMS heritage was well represented and recognized within GFNMS and in the region during the study period. While trends were not assessed by indicator, the overall trend for this ecosystem service was assessed for the time frame covered by this condition report as improving, partly due to the inclusion of additional historic and potentially historic sites within the sanctuary and ONMS efforts with partners to document, describe, and protect these sites for future generations. Other factors that supported an improving trend included increased opportunities for people to attend public heritage festivals and rising public interest in learning about heritage at museums and visitor centers. Recognition of tribal and Indigenous heritage has been strong for a long time in this region. That recognition has increased among GFNMS staff, particularly since the expansion of the sanctuary in 2015, and has also increased among the community at large. More information, collaboration, and partnerships are needed regarding iconic heritage locations, locations and assessment of shipwrecks, and Indigenous heritage. GFNMS heritage partnerships could be considered for inclusion in future condition reports as a new indicator to better inform this question.

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: Many communities have deep connections to the sanctuary and recognize its unique power as a place that sustains, nurtures, and inspires. These connections to the sanctuary have been reflected in a variety of exhibits, film, photography, books, and businesses, as well as in long-term commitments to supporting sanctuary conservation. Experts stated that although environmental conditions were highly variable and increasingly unpredictable due to climate change, the aesthetic attraction of the sanctuary remained uncompromised, and it continued to offer inspiration for individuals and communities. Additionally, experts noted an increase in coastal recreation activities during the COVID-19 pandemic, as well as an increase in community awareness of the sanctuary since its expansion in 2015.

Sense of place is the aesthetic and spiritual attraction and level of recognition and appreciation that humans derive from a location. The indicators below provide insight into the extent to which sense of place affects people of the community and the broader public.

Designations Form a Foundation for Sense of Place

Special designations in and around the sanctuary are important and can indicate the area's level of regional, state, national, and international significance. In 1981, Gulf of the Farallones National Marine Sanctuary was designated to protect the largest assemblage of breeding seabirds in the contiguous United States as well as to protect large concentrations of marine mammals that use the sanctuary's productive waters. In 1988, the UNESCO Man and the Biosphere Programme established the Golden Gate Biosphere Reserve, which includes the sanctuary along with Point Reyes National Seashore and Golden Gate Recreation Area. Bolinas Lagoon and Tomales Bay were recognized under the Ramsar Convention as Wetlands of International Importance in 1998 and 2002, respectively. The state of California established a series of marine reserves and marine conservation areas that included state waters of the sanctuary under the state's Marine Life Protection Act of 1999. Also, the state designated Areas of Special Biological Significance within the sanctuary that are monitored and maintained for water quality by the State Water Resources Control Board. The North-Central Coast set of marine reserves and conservation areas, extending from Pigeon Point north to Point Arena, was created in 2009, and includes 21 marine protected areas covering 153 square miles. About 11% of these are fully protected as reserves, and six special closure areas exist to protect sensitive seabird breeding and marine mammal haul-out sites. In 2015, recognizing one of the most biologically important ecosystems in the world, the federal government expanded the sanctuary to encompass the nutrient-rich upwelling zone off of Point Arena that flows south into the original sanctuary area. As part of this expansion, the sanctuary was renamed Greater Farallones National Marine Sanctuary. GFNMS lies adjacent to diverse and complex urban and rural communities.

Place Identity and Place Attachment

The discussion of factors that influence a sense of place is personal, nuanced, generational, and complex. Although there may be tangible places or measurements discussed here, quantifying place identity is highly subjective. Place identity and the related concept of place attachment are crucial descriptors of the connection between peoples and the ecosystem. Place identity, a component of personal identity, is defined as a process by which people describe themselves as belonging to a specific place (Hernández et al., 2007). Identification between self, family, community, and place develops over the long term and can run very deep, particularly where lineage is place based, with genealogy going back many generations. Place identity is often expressed in reciprocal human-ecosystem relationships. This reciprocal relationship emphasizes that people are inseparable from the ecosystem, a common belief among Indigenous cultures; people derive benefits from the ecosystem (ecosystem services) and also contribute to the maintenance or enhancement of the ecosystem (services to ecosystems). Also inherent in a sense of place is an intrinsic stewardship value, in which individuals recognize their role in caring for resources, not simply due to the reciprocal dynamic but also because of love of a place.

Place attachment is defined as a connection to a location that may develop and change over time, reflected in aesthetic attraction (e.g., books, film, artwork), architecture, therapeutic rejuvenation, and even national iconic symbols (Hernández et al., 2007). At both the personal and societal level, place attachment may evolve into place identity; however, the timeframe over which this may occur is highly variable. To address this complexity, sense of place indicators were discussed by a diverse group of stakeholders with deep connections to the sanctuary. The st included: a commercial fisherwoman, a surfer, a naturalist, a diver, a conservationist, a boat captain, a GFNMS staff member, and an artist.

The indicators for rating sense of place at GFNMS included measures associated with exhibits, film, photography, books, direct experiences in the sanctuary, people who recreate and/or make a livelihood in the sanctuary, and people who engage with the sanctuary mission. The sense of place created by these measures is central to the mission of protecting the sanctuary.

Table ES.SP.1. Summaries for key indicators related to sense of place in GFNMS that were discussed during the June 15, 2022 virtual workshop.

Indicator	Data Summary	Figures
Exhibits	Six exhibit partnerships as well as the GFNMS Visitor Center featured the nature and identity of the sanctuary and shared its sense of place with 28 million visitors from 2011–2021. Five of the six partner exhibits have been updated and refreshed, indicating partners valued the sense of place and stories the exhibits impart.	ES.SP.1
Film, video, and photography	Films about the sanctuary, including Sanctuary in the Sea, Beach Watch, and Cool Water Haven have been produced. Additionally, over fifteen videos on various topics such as shark research, kelp monitoring, deep sea coral, shipwrecks, were created. The annual Get In Your Sanctuary photo contest also helps share GFNMS sense of place.	N/A

Indicator	Data Summary	Figures
Sanctuary explorations	The Get Into Your Sanctuary exploration series encouraged the public to discover GFNMS on foot, by boat, or through paddling. Telepresence programs broadcasted sanctuary research in real time.	ES.SP.2
Books inspired by experiences in GFNMS	Several books have been created about experiences in GFNMS, including widely acclaimed bestseller, Devil's Teeth by Susan Casey.	N/A
Sanctuary-inspired restaurants	During the study period, Devil's Teeth Baking Company and Farallon Restaurant used imagery associated with iconic GFNMS places and species as part of their businesses.	N/A
People with a deep connection to the sanctuary	Multiple groups of people have deep experiences being in the sanctuary, and through those experiences have unique memories and appreciation that they have shared with others. Some volunteers and staff have served GFNMS for 20+ years.	ES.SP.3

Exhibits

Seven exhibits in four California counties, including the GFNMS Visitor Center, feature the nature and identity of GFNMS. The exhibits bring sanctuary places and marine life to people through a variety of media and approaches (Figure ES.SP.1; see the section on Education for additional examples). More than 28 million visitors experienced exhibits featuring GFNMS 2011–2021. Six of the seven exhibits have been updated and refreshed since they opened, indicating ongoing value by GFNMS and its partners for the sense of place and stories the exhibits impart (see Table ES.E.2).

Figure ES.SP.1. Visitors peer into a 100-gallon, three-story high tank featuring habitats and marine life found in GFNMS at the California Academy of Sciences Steinhart Aquarium. Photo: California Academy of Sciences

Film, Video, and Photography

Many films and videos have been created about GFNMS and shown at film festivals, such as the International Ocean Film Festival and Point Arena Film Festival. Some of the films were screened regularly as part of partner exhibits at highly visited institutions such as Aquarium of the Bay and California Academy of Sciences. Tens of thousands of people have watched the following films about GFNMS: *Sanctuary in the Sea*, *Beach Watch*, *Cool Water Haven*, and *Blue Serengeti*. The film *Beach Watch*, produced by GFNMS staff, was entered into the International Ocean Film Festival in 2018 and won an award. *Sanctuary in the Sea* has over 10,000 views online and *Cool Water Haven* plays daily in the Dive Into Your National Marine Sanctuaries exhibit at Aquarium of the Bay, which was visited by 6,323,089 people from 2011–2021. In addition, over 15 videos on various topics such as shark research, kelp monitoring, deep-sea coral, and shipwrecks, aired on the GFNMS and/or ONMS websites. Many of these videos have been used in sanctuary programs such as lecture series and school programs. ONMS hosts an annual Get Into Your Sanctuary photo contest, and GFNMS has been the subject of several winning photos.

Sanctuary Explorations

Connecting physically to a place can increase a sense of place. GFNMS staff hosted a Get Into Your Sanctuary exploration series for the public to discover their marine sanctuary on foot, by boat, or paddling (Figure ES.SP.2). From 2011–2021, a total of 3,787 adults and families experienced the monthly exploration series to discover special sanctuary habitats and seasonal events, such as spring gray whale migrations, coastal wildflower blooms, kayaking trips to experience bioluminescence in Tomales Bay, or winter elephant seal mating.

> *“I will carry the memory of this trip in my heart.” –Carol, Tomales Bay Kayak, 2017*

> *"The paddle we did was an amazing experience. Words fail. I settled on magical as my word to describe the paddle.” –David, Bioluminescence Kayak, 2017*

Figure ES.SP.2. Kayaking in a sanctuary estuary. Photo: K. McLaughlin

GFNMS staff delivered sanctuary-focused programming at partner outreach events and lectures. Outreach programs included telepresence that broadcasted research occurring in the sanctuary live and highly engaging talks with stunning visuals. Between 2011–2021, 68,726 people participated in partner events, such as *Nautilus* Live, and 2,041 people participated in GFNMS staff lectures at partner institutions such as the San Francisco Zoological Gardens.

Books Inspired by Experiences in GFNMS

Many books have been created about experiences in GFNMS. These books have been geared toward multiple audiences, including children, naturalists, wildlife enthusiasts, history buffs, and birders. Here is a sampling of some of the books that depict natural history in the sanctuary:

- *Devil's Teeth* by Susan Casey, a New York Times bestseller
- *Neighborhood Sharks: Hunting with the Great Whites of California's Farallon Islands* by Katherine Roy, an illustrated children's book
- *The Farallon Islands: Sentinels of the Golden Gate* by Peter White, a history book with 80 archival photographs, maps and drawings.
- *Ocean Birds of the Nearshore Pacific* by Rich Stallcup, a guide for birders that includes bird field marks and behaviors
- *The Intertidal Wilderness: A Photographic Journey through Pacific Coast Tidepools* by Anne Wertheim Rosenfeld and Robert T. Paine, a photographic book for seashore explorers
- *The Whale that Lit the World* by Josh Churchman, a book about experiences fishing in the Gulf of the Farallones and at Cordell Bank for many decades

Sanctuary-Inspired Restaurants

Devil's Teeth Baking Company, which has three locations in San Francisco, uses the iconic Farallon Islands and white sharks in their branding and products. Farallon Restaurant was a renowned restaurant in San Francisco for 23 years; unfortunately, it closed during the COVID-19 pandemic. The restaurant's furnishings included jelly sculptures, urchin test lights, and other sea life decor inspired by GFNMS.

People With a Deep Connection to the Sanctuary

Multiple groups of people have had meaningful experiences visiting or working in the sanctuary itself, over a long period of time. Through these experiences, these people have created unique memories and developed a deep appreciation of the place. This includes scientists, divers, naturalists, birders, commercial and recreational fishers, surfers, artists, filmmakers, volunteers, and GFNMS staff.

Two GFNMS staff members have over 20 years of service and five others have over 15 years of service. Fifteen Beach Watch program volunteers have over 25 years of service and 45 have over 20 years of service (Figure ES.SP.3). From 2011–2021, Beach Watch and education and outreach program volunteers contributed 114,265 hours of service. Sanctuary Advisory Council and Greater Farallones Association board members contributed 29,071 hours of service from 2011–2021.

Figure ES.SP.3. Volunteers work on a Beach Watch survey. Photo: D. Devlin/NOAA and Greater Farallones Association

The sense of place experts who participated in the workshop all engage deeply with the sanctuary through their livelihood, a lifetime passion for recreation, and/or a lifelong commitment to conservation. To further explore and provide insight into the concept of sense of place, these experts were asked two questions:

1. What would you miss if you couldn't be in the sanctuary?
2. Why do you care about Greater Farallones National Marine Sanctuary?

Here is a sample of expert responses:

- "Everything about the sanctuary, it is our food source."
- "Observing seasonal patterns."
- "Recreating and observing others recreating."
- "The feeling of cold water and extraordinary wildlife experiences."
- "My buffer to a busy and challenging world."
- "Getting in the water as a reset."
- "A challenging place to sail, which brings satisfaction and pride."
- "The sanctuary is important for nourishment of individuals, food security, incomes in our fleet—all contribute to deeper health of coastal communities."

Conclusion

This ecosystem service was rated good/fair based on the strong connections that people have made and the many opportunities that have been available for people to establish a sense of place with the sanctuary. These include exhibits, films, books, and excursions. A strong sense of place was also evident in the deep engagement of longtime volunteers and staff. Although trends were not captured in the indicators reviewed in this section, experts pointed to a number of overarching factors that drove their selection of an improving trend. These factors included increased community awareness since the 2015 sanctuary expansion and increased human recreational activities on sanctuary shores during the COVID-19 pandemic. Experts also noted, however, that emerging threats to the health of GFNMS, primarily climate change, threatened sense of place by negatively impacting fisheries, livelihoods, and coastal communities, as well as favorite diving, beach combing, and tidepooling locations. Degradation of the sanctuary environment is detrimental to a strong, positive sense of place.

Consumptive Recreation

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

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

Rationale: Though data were limited, there is evidence that commercial passenger fishing vessel fishing activity and shoreline angling have increased over the past decade. The number of recreationally harvested rockfish (unspecified species) and Dungeness crab also increased, while other species varied without a clear trend. Although the Chinook salmon ocean fishery was reopened following statewide closures just prior to the study period, some stocks that inhabit the sanctuary were listed as endangered or threatened, and progress toward recovery has been mixed. Additionally, the sport abalone fishery has been compromised by multiple stressors and has been closed since 2017.

Consumptive recreation includes recreational activities that result in the removal of or damage to natural and cultural resources. In GFNMS, this activity is primarily recreational fishing, either from private or rental vessels, commercial passenger fishing vessels (CPFVs), or from shore. Diving for abalone is another culturally and economically significant recreational activity within the sanctuary and broader region (Reid et al., 2016). NOAA Fisheries and CDFW manage recreational fishing activities; recreational fisheries are not managed by GFNMS.

Table ES.CR.1. Summaries for the key indicators related to consumptive recreation in GFNMS that were discussed during the July 7, 2022 virtual workshop.

Indicator	Source	Data Summary	Figures and Tables
Species kept by CPFV anglers	CDFW, 2020c	Status: Unspecified rockfish was the most frequently kept species caught, followed by Dungeness crab, blue rockfish, lingcod, black rockfish, Chinook salmon, and several other rockfish species. Trend: The number of unspecified rockfish and Dungeness crab kept by anglers increased significantly from 2010–2020; other species varied without trend.	Table ES.CR.2; Figure ES.CR.1; Figure ES.CR.2
Shore-Based Fishing	Lindquist & Roletto, 2022a	Status: The available data do not indicate an overall level of activity. Trend: Shore-based recreational fishing increased at survey sites during the study period.	N/A

Indicator	Source	Data Summary	Figures and Tables
Recreational private/rental trips	PSMFC, 2022b	Status: The available data do not indicate an overall level of effort in sanctuary. Trend: Private/rental vessel fishing trips varied without trend in a subset of California counties that included the GFNMS study area.	N/A
CPFVs	CDFW, 2020C	Status: GFNMS continues to be an area used by CPFVs. Trend: CPFV angler-days increased significantly during the study period, likely reflecting resumed activity in the for-hire salmon sector.	Figure ES.CR.2
Chinook salmon	NOAA Fisheries, 2020c	Status: Peaks in the number of Chinook salmon retained reflected a rebuilding of the ocean fishery following statewide closures in 2008 and 2009 and a substantially shortened season in 2010. Trend: Chinook salmon stocks that seasonally inhabit the sanctuary are listed as either endangered, threatened, or species of concern, and progress toward recovery has varied by stock. CPFV angler-days increased significantly during the study period, likely reflecting resumed activity in the for-hire salmon sector.	N/A
Red abalone	CDFW, 2015a; Sanctuary Integrated Monitoring Network, 2021	Status: The red abalone fishery closed in 2017 and will remain closed at least until 2026. Trend: Red abalone harvest at locations within GFNMS declined from 2010–2015.	Figure ES.CR.3
Data gaps	Data on private and rental vessel fishing effort specifically within the sanctuary were not available. There was also a lack of information about how the recreational take of groundfish has influenced the recovery of groundfish populations.		

Recreational fishing may occur from private boats, rental boats, or CPFVs. A private boat belongs to an individual, not for rent and not with paying passengers. A rental boat is rented by an individual, without crew or a guide. A CPFV may fall into one of two categories: a charter boat, which operates under charter for a specified price, time, etc.; or a party boat, which provides fishing space and privilege for a fee per recreational fisher (Leeworthy & Schwarzmann, 2015).

Species Kept by Commercial Passenger Fishing Vessel Anglers

The top ten most kept species based on CPFV logbook data are shown in Table ES.CR.2. From 2015 to 2019, the most commonly retained catch was unspecified rockfish, with an annual average of 86,800 kept fish. Dungeness crab was the second most commonly retained species, with nearly 70,600 kept each year. Over 48,000 blue rockfish were kept by CPFV anglers each year. Other common species kept by CPFVs included lingcod, black rockfish, Chinook salmon, canary rockfish, widow rockfish, copper rockfish, and yellowtail rockfish.

Table ES.CR.2. Top ten most kept species by CPFV anglers (five-year average, 2015–2019). Source: CDFW, 2020c

Species	Average Number Kept	Rank
Unspecified rockfish	86,802	1
Dungeness crab	70,596	2
Blue rockfish	48,227	3
Lingcod	16,473	4
Black rockfish	14,242	5
Chinook salmon	13,021	6
Canary rockfish	9,883	7
Widow rockfish	8,712	8
Copper rockfish	6,300	9
Yellowtail rockfish	2,445	10

Figure ES.CR.1 shows trends in the numbers of each species retained by CPFV anglers from 2010 to 2020 for the top six most frequently kept species. The top ranked species was unspecified rockfish, and there was a statistically significant increase in the number kept by CPFV anglers from 2010 to 2020 (generalized linear model (GLM); coefficient = 2715, $p = 0.02$; CDFW, 2020c). The number of Dungeness crab, the second most kept species, also increased significantly (GLM; coefficient = 8915, $p < 0.01$; CDFW, 2020c). The low level of Dungeness crab catch in 2015 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). Although there was no formal stock assessment for Dungeness crab, the stock appeared to be healthy, as commercial landings have fluctuated around a stable long-term mean for around 40 years (CDFW, 2023a; Ocean Protection Council, 2013a). The number of blue rockfish, the third ranked species kept by CPFV anglers, increased gradually through 2019, then declined in 2020 due to the COVID-19 pandemic and associated decline in for-hire vessel activity (CDFW, 2020c). An assessment of the blue and deacon rockfish complex off California was conducted in 2017; results were consistent with the 2007 blue rockfish assessment and indicated that the population had increased to target levels of unfished spawning output by 2017 (Dick et al., 2017). Lingcod, the fourth ranked species, increased from under 3,000 fish to a peak of over 25,000 fish retained in 2015, then declined in subsequent years (CDFW, 2020c). According to the PFMC, the West Coast lingcod stock was successfully rebuilt as of 2005, following historical declines in the stock (PFMC, 2020b; see the report section on Commercial Harvest for more information on lingcod trends). The number of black rockfish retained peaked in 2013 and 2014 with over 60,000 landed in both years (CDFW, 2020c).

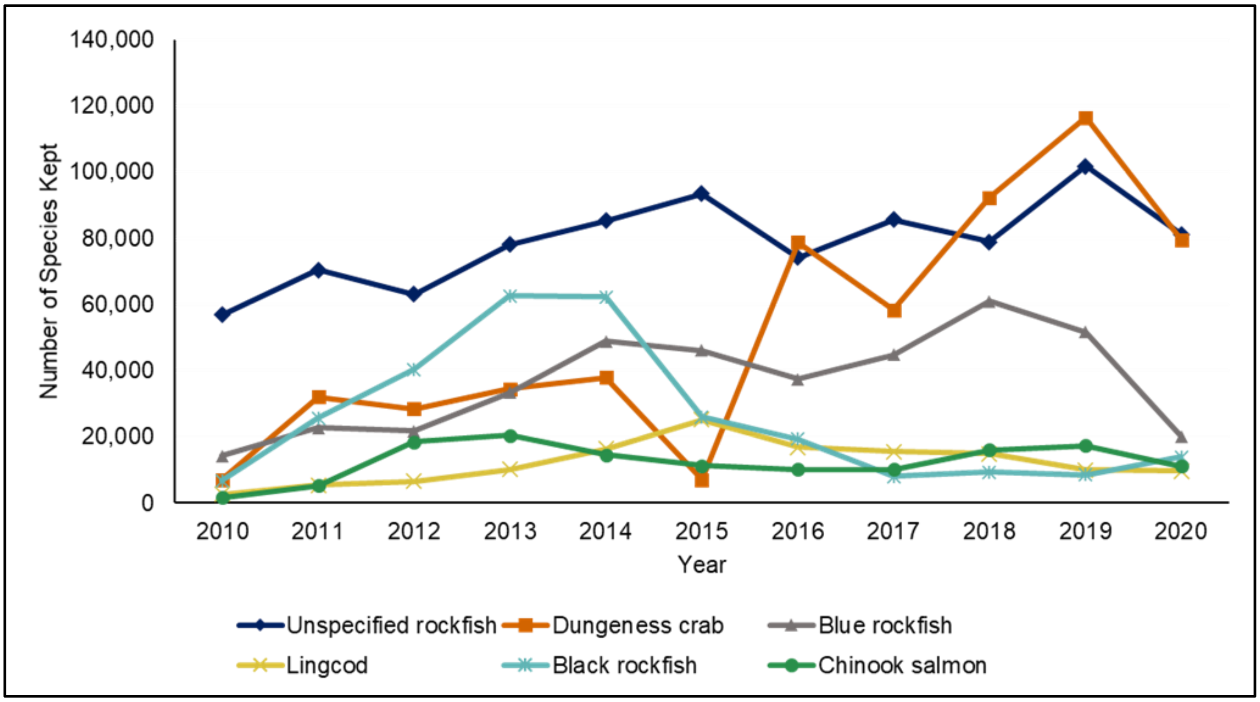

Figure ES.CR.1. Annual number of the top 6 most kept species retained by CPFV anglers from 2010 to 2020. Source: CDFW, 2020c; Image: J. Eynon/National Marine Sanctuary Foundation

Shore-Based Fishing

Beach Watch monitoring data indicate how levels of human activities have changed over time along sanctuary beaches. Beach Watch surveyors recorded counts of activities per kilometer along roughly 51 kilometers of GFNMS beaches (Lindquist & Roletto, 2022a; see Box 2).[27] Methods for recording consumptive recreation activities on Beach Watch surveys changed in 2014. Thus, in order to analyze trends for 2010–2022, all consumptive recreation activities were grouped into one activity type, a general "fishing" category, encompassing clam digging, hand collection of biota, consumptive diving, and shore-based fishing with hooks, traps, nets, and spears. There were statistically significant increases in fishing across all sets of survey sites analyzed, including beaches sampled since 1993 (GLM; coefficient = 0.032, p-value < 0.01) and sampling sites added in 2014 (GLM; coefficient = 0.024, p-value < 0.01; Lindquist & Roletto, 2022a). There was also a statistically significant increase in hook-and-line fishing from shore from 2010 to 2022 (GLM; coefficient = 0.03, p-value < 0.01; Lindquist & Roletto, 2022a). Notably, during the study period, a new method of crab trapping was popularized; this method consists of a rod and reel with a small trap attached to the line (Lindquist & Roletto, 2022a).

[27] Twelve new Beach Watch sampling sites were added in 2014, totaling almost 19 km. The beaches added in 2014 are more remote (i.e., less frequently used) than the original beaches, surveyed since 1993. To avoid obscuring trends in the analysis of activity rates (by adding more survey kilometers with less use observed), the two groups of sites were analyzed separately.

This crabbing method is not always distinguishable from hook-and-line fishing and may have been enumerated as such on surveys (K. Lindquist/Greater Farallones Association, personal communication, July 5, 2022). The method also may have opened up new areas to crabbing that were not previously viable.

Recreational Private/Rental Trips

Data on the number of private and rental vessel fishing trips in two California Recreational Fisheries Survey districts were assessed as a proxy for private and rental vessel effort in the sanctuary. California Recreational Fisheries Survey districts 4 and 5 comprise the following counties: Mendocino, Sonoma, Marin, Napa, Solano, Contra Costa, Alameda, Santa Clara, San Mateo, and San Francisco.[28] The number of private and rental vessel trips from those 10 counties varied without trend from 2010 to 2021 (PSMFC, 2022b).

Commercial Passenger Fishing Vessels

Figure ES.CR.2 shows trends in CPFV effort, in angler-days,[29] in the sanctuary from 2010 to 2019. Effort in the sanctuary increased significantly by over 1,600 angler-days per year over the 10 years analyzed (GLM; coefficient = 1,618, p-value = 0.03; CDFW, 2020c).

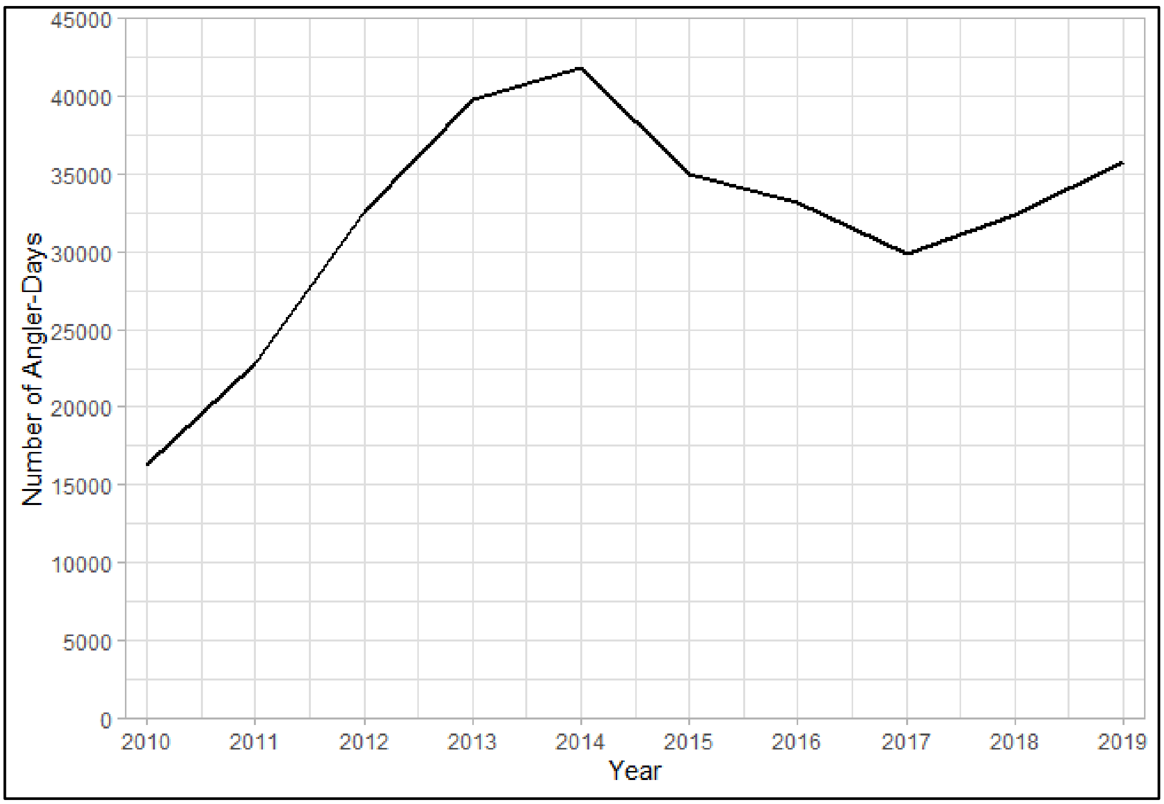

Figure ES.CR.2. Annual number of CPFV angler-days in GFNMS from 2010 to 2019. Source: CDFW, 2020c; Image: J. Eynon/National Marine Sanctuary Foundation

[28] Of these ten counties, six—Contra Costa, Marin, Mendocino, San Francisco, Solano, and Sonoma—are considered to be within the GFNMS study area (Leeworthy & Schwarzmann, 2015).

[29] An angler-day is defined as one person fishing for any part of one day.

Chinook Salmon

Similar to the commercial fishery, the recreational salmon fishery was severely curtailed in 2008, 2009, and 2010, so much of the increase in the early years was likely a result of the for-hire salmon sector resuming activity. CPFV effort peaked in 2014, declined in 2015 (at which time there were health advisories for Dungeness crab), continued to decline through 2017, then increased again in 2018 and 2019. On average from 2015–2019, there were over 33,000 angler-days per year in the sanctuary and about 76 CPFVs reporting catch (CDFW, 2020c).

The trend in the number of Chinook salmon retained reflected a rebuilding of the ocean fishery after a statewide closure in 2008 and 2009 and an eight-day season in 2010 (CDFW, 2020c; ONMS, 2011). The peaks in 2012–2013 and 2018–2019 track harvest trends in the commercial fishery as well as the 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 (PFMC, 2020c). Chinook salmon stocks that seasonally inhabit the sanctuary (California Coastal, Central Valley spring-run, Central Valley fall and late-fall, and Sacramento River winter-run) are listed as either endangered, threatened, or species of concern, and stocks have shown mixed progress toward recovery (CDFW, 2022c; National Marine Fisheries Service [NMFS], 2016a, 2016b; NOAA Fisheries, 2020c).

Red Abalone

Red abalone stocks in Northern California declined dramatically following the 2014–2016 MHW, which resulted in population shifts, reductions in nutrients and productivity, and changes to kelp forest ecosystems (Rogers-Bennett et al., 2021). In response, the recreational red abalone fishery was closed in 2017 and will remain closed until 2026 (CDFW, 2022d). The impacts of the closure are substantial; a study by Reid at al. (2016) estimated that, as of 2013, approximately 31,000 fishers in Northern California derived between $26.8 million and $51.2 million (in 2021 dollars) of recreational value per year from the fishery. Beginning in 2000, recreational harvesters were required to record their red abalone catch and effort, including date and location of harvest (CDFW, 2015a). Even before the 2017 closure, there was a clear decline in sport abalone catch from reporting locations within GFNMS (Figure ES.CR.3). The five-year average catch in GFNMS from 2005–2009 was nearly 150,000 abalone per year.

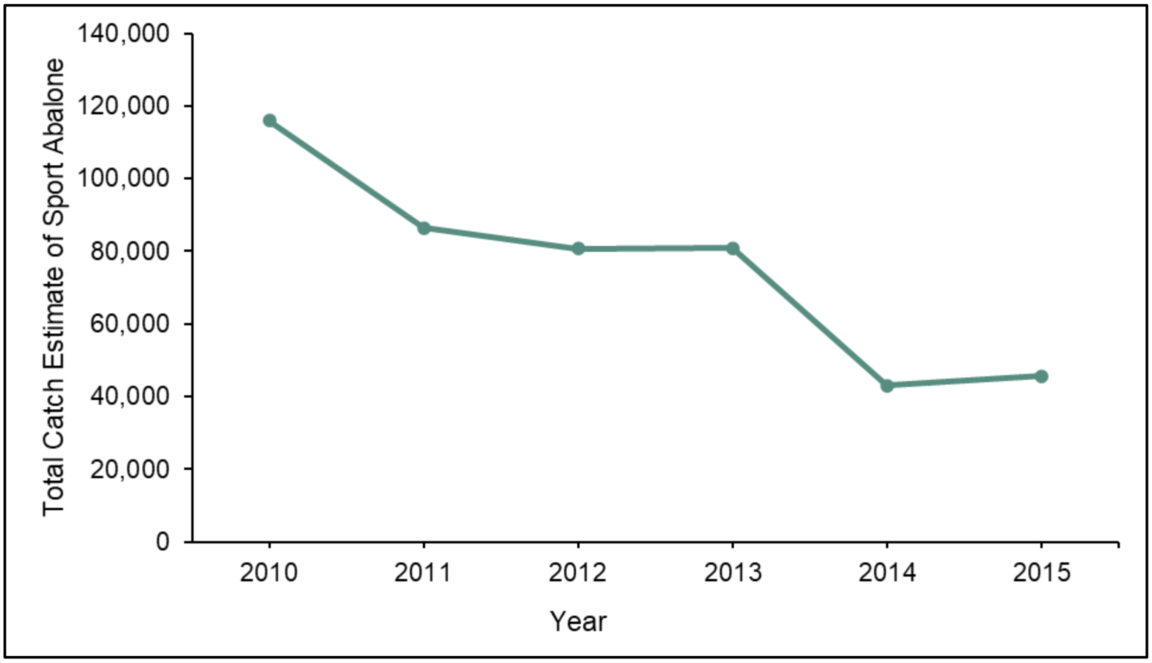

Figure ES.CR.3. Red abalone catch from reporting locations within GFNMS, 2010–2015. Source: CDFW, 2015a; Image: J. Eynon/National Marine Sanctuary Foundation

Conclusion

This ecosystem service was rated fair based on reduced fishing opportunities for salmon, Dungeness crab, and red abalone due to listings of species as endangered or threatened, health advisories, and closures. The 2014–2016 MHW severely impacted populations of red abalone, a culturally significant species in the region. Private and rental fishing trips from within and near the sanctuary varied without trend, while CPFV effort and shore-based fishing increased. The number of unspecified rockfish and Dungeness crab kept by CPFV anglers also increased. The opposing trends, in addition to a lack of information about recreational take of groundfish, which influences the recovery of groundfish stocks and may allow for increased catch and effort for several recreational targets, resulted in an undetermined trend.

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: Many types of recreational activities take place in the sanctuary, and its capacity to provide non-consumptive recreation opportunities appeared to be robust. Common activities included wildlife viewing, surfing, and other board sports, which increased during the study period, as well as kayaking, tidepooling, and beachgoing, which varied without trend. The decline of kelp likely contributed to a decrease in scuba diving in the northern portion of the sanctuary, although more information is needed to fully assess patterns in this activity. Data on recreational boating in the sanctuary were limited, and available data did not suggest a clear pattern during the study period. Effects of the COVID-19 pandemic were apparent for multiple indicators.

Recreational activities that do not result in the intentional removal of or damage to natural and heritage resources are considered non-consumptive. The sanctuary contains estuarine, beach, nearshore, and offshore environments, presenting a variety of opportunities for recreation. Non-consumptive recreational activities that occur in or adjacent to GFNMS include wildlife viewing, especially marine mammal and bird watching, sailing and boating, diving, surfing and boogie boarding, tidepooling, paddling, swimming, and beachgoing (GFNMS, 2022k).

Table ES.NCR.1. Summaries for the key indicators related to non-consumptive recreation in GFNMS that were discussed during the July 7, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Wildlife viewing	A. Jaramillo/Alvaro's Adventures and M.J. Schramm/NOAA, personal communication, July 7, 2022; eBird, 2021	Status: Viewing of wildlife, including whales, seabirds, and sharks, occurred regularly in the sanctuary. The number of eBird reports was highest in 2020, at 45,000. Trend: Wildlife viewing increased during the study period, as smaller charter vessels entered the industry. One expert also noted increased public interest in pelagic birding trips. The number of eBird users and reported sightings increased during the study period.	ES.NCR.1

Indicator	Source	Data Summary	Figures
Shoreline use	Lindquist & Roletto, 2022a	Status: Recreational activities, including tidepooling, kayaking, surfing, other board sports, wildlife viewing, and beachgoing, occurred on GFNMS beaches. Trend: Significant increases in surfing, other board sports, and shore-based wildlife viewing were documented during the study period. All other activities varied without trend.	N/A
Recreational boating	NOAA Office for Coastal Management, 2022a	Status: Recreational boating was concentrated around San Francisco Bay, Bodega Bay, Point Reyes, and Point Arena. Trend: Distance traveled by recreational boats peaked in 2018, then declined in 2019 and 2020 (based on data for 2016–2020).	N/A

Wildlife Viewing

GFNMS provides unique opportunities for wildlife viewing throughout the year. Between December and February, wintering seabirds are present in the open ocean, and the California gray whale migration peaks in mid-January (GFNMS, 2022l). The upwelling season in March–August creates opportunities to view humpback whales, blue whales, sharks, and seabirds (GFNMS, 2022l). Species like ocean sunfish (*Mola mola*), dolphins, porpoise, sea turtles, and sharks can be seen in September through November (GFNMS, 2022l). Additionally, the density of blue and humpback whales is high in GFNMS, and these species are commonly spotted (Carretta et al., 2022; Becker et al., 2020; Elliott et al., 2022a).

There are at least four tour operators specializing in whale or seabird watching who regularly make trips to GFNMS. Two other tour operators specialize in shark diving or viewing in GFNMS and the surrounding region (ONMS, 2023b). These operations are based in San Francisco, Marin County, and Half Moon Bay; some operate their own vessels, while others charter fishing vessels to run tours. In addition to these more established operators, multiple experts noted an increase in the number of small charter vessels conducting wildlife tours (A. Jaramillo/Alvaro's Adventures and M.J. Schramm/NOAA, personal communication, July 7, 2022). Small vessels were able to engage in "pop-up" whale watching as whale populations moved closer to shore in response to warmer ocean conditions (Santora et al., 2020). One expert noted that the younger generation of charter fishing captains have shown greater interest in diversifying their businesses by "moonlighting" as wildlife tour operators (A. Jaramillo/tour operator, personal communication, June 30, 2022). In addition to pandemic-related disruptions, experts cited rising overhead as a challenge, especially higher fuel prices, which have caused some operators to raise their rates (A. Jaramillo/tour operator, personal communication, July 7, 2022). Another challenge was the growing difficulty of chartering fishing vessels to operate tours, driven by an apparent decline in the size of the party boat fleet (A. Jaramillo/tour operator, personal communication, June 30, 2022).

With over 160 bird species and more than 400,000 breeding seabirds (McChesney et al., 2013), the sanctuary provides excellent opportunities for birdwatching. Cassin's auklets, black-footed albatrosses, sooty shearwaters, and pink-footed shearwaters are common in GFNMS (Elliott et al., 2022a). One popular birding app, eBird, allows users to record information about bird sightings. From 2010 to 2020, the five most common species recorded on eBird in GFNMS were, in order of frequency: western gulls, common murres, California gulls, Brandt's cormorants, and brown pelicans (eBird, 2021). Two other frequently recorded pelagic species were pelagic cormorants and sooty shearwaters (eBird, 2021). Key species of interest on pelagic trips include tufted puffins on or near Southeast Farallon Island, as well as pelagic shearwaters, albatrosses, storm-petrels, alcids, skuas, and jaegers. For information on population trends for these species, see Johns and Warzybok (2019). The annual number of reported sightings in the sanctuary grew steadily from around 15,000 reports in 2010 to over 45,000 in 2020 (eBird, 2021). That increase was due in part to a growing number of app users; the annual number of eBird observers in GFNMS rose from over 100 in 2010 to a peak of nearly 500 users in 2019 (eBird, 2021). In 2020, the annual number of eBird users in the sanctuary declined from the previous year, likely due to the added challenges of accessing the sanctuary during the COVID-19 pandemic, while the average number of reports per user increased (eBird, 2021). One expert reported an increase in the number of people interested in going on for-hire pelagic birding trips during the study period (A. Jaramillo/tour operator, personal communication, July 7, 2022).

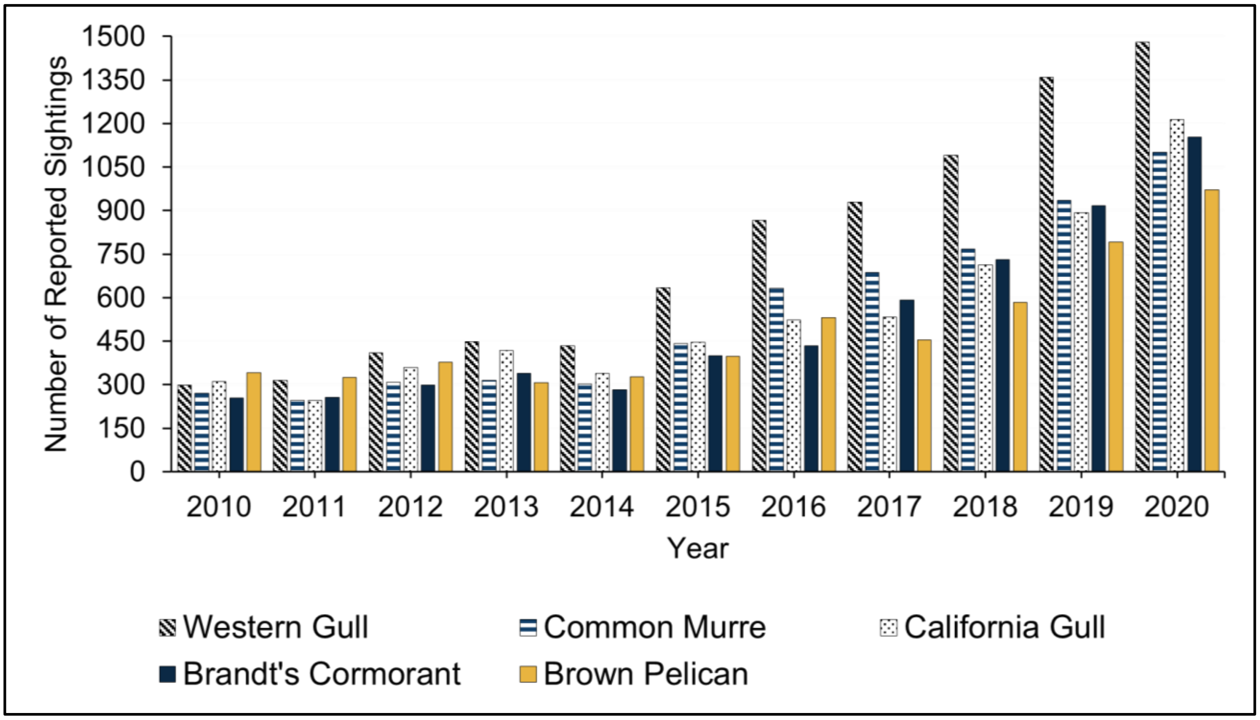

Figure ES.NCR.1. Reported sightings of the top five seabird species in GFNMS as logged on eBird, 2010–2020. Source: eBird, 2021; Image: J. Eynon/National Marine Sanctuary Foundation

Shoreline Use

Beach Watch monitoring data indicate how participation in recreational activities has changed over time along sanctuary beaches. Beach Watch surveyors record counts of human activities along roughly 51 kilometers of GFNMS beaches.[30] Among the non-consumptive recreational activities enumerated are tidepooling, kayaking, surfing, board sports (excluding surfing), wildlife viewing (both rocky shoreline and sandy shoreline), and a general category for "person on beach." Over the period from 2010 to 2020, there was a statistically significant trend in the encounter rate (counts per km) for only three of these activities (Lindquist & Roletto, 2022a). At a 95% confidence level, there was a significant increase in the rate of surfing[31] over the decade (seasonal Mann-Kendall test; coefficient = 0.05 encounters/km/year, p-value = 0.03). This increase may have been driven by surfing at one site, Miwok Beach, which was sparsely used until the COVID-19 pandemic (K. Lindquist/Greater Farallones Association, personal communication, July 5). The rate of board sports (excluding surfing) also increased significantly from 2010 to 2020 (seasonal Mann-Kendall test; coefficient = 0.03, p-value < 0.01), which coincided with the growing popularity of stand-up paddle boarding during that period (K. Lindquist, personal communication, July 5, 2022). There was also an increase in wildlife viewing on rocky shorelines (seasonal Mann-Kendall test; coefficient = 0.04 encounters/km/year, p-value < 0.01; K. Lindquist/Greater Farallones Association, personal communication, July 7, 2022). The encounter rates for all other listed non-consumptive recreational activities varied without trend during the study period (Lindquist & Roletto, 2022a). Although jet skiing and shore-based scuba diving are enumerated in Beach Watch surveys, there were too few observations in the survey data to analyze their trends. Information on scuba diving is a notable data gap for this ecosystem service. Anecdotally, diving has been negatively impacted by the loss of kelp forests, especially in the northern part of the sanctuary.

Recreational Boating

AIS data from 2016–2020 provide some indication of trends in recreational boating in the sanctuary as well as where boating activity is concentrated. But because AIS is not required on recreational vessels, it cannot be used to determine specific levels of recreational boating activity. The total distance traveled by pleasure craft and sailing vessels carrying AIS in the sanctuary increased from around 1,800 nautical miles in 2016 to nearly 2,500 nautical miles in 2018 (NOAA Office for Coastal Management, 2022a). However, this may reflect an increase in the number of vessels carrying AIS rather than a true increase in distance traveled through the sanctuary. Following the peak in 2018, the distance traveled fell to just over 1,200 nautical miles in 2019 then a low of around 900 nautical miles in 2020 (NOAA Office for Coastal Management, 2022a). Recreational boating was largely concentrated around the mouth of San Francisco Bay, Point Reyes, Bodega Bay, and Point Arena.

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[30] Twelve new Beach Watch sampling sites were added in 2014, totaling almost 19 km. The beaches added in 2014 are more remote (i.e., less frequently used) than the original beaches, surveyed since 1993. To avoid obscuring trends in the analysis of activity rates (by adding more survey kilometers with less use observed), the two groups of sites were analyzed separately.

[31] Though surfing increased significantly at survey sites added in 2014, no trend was detected at sites surveyed since 1993.

Conclusion

This ecosystem service was rated good/fair because, despite disruptions due to the COVID-19 pandemic and response, there was continued engagement across all categories of non-consumptive recreation. The productive ocean ecosystem in GFNMS supported wildlife viewing businesses, particularly opportunities to see whales and seabirds. Surfing, other board sports, paddle boarding, kayaking, and tidepooling were all common activities observed on the GFNMS shoreline. The trend was mixed, as some activities, such as charter- and shore-based wildlife viewing, surfing, and other board sports, increased, while other shore-based activities and distance traveled by pleasure craft and sailing vessels equipped with AIS varied with no apparent trend (however, these data did not allow for a complete understanding of recreational boating trends in the sanctuary). Additionally, anecdotal data suggested a decrease in scuba diving as a result of kelp forest loss; however, more data are needed to fully assess patterns in this activity.

Provisioning Services (Material Benefits)

Commercial Harvest

The capacity to support commercial market demands for seafood products

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

Rationale: Although certain high-value fisheries, including Dungeness crab and Chinook salmon, have been impacted by management interventions and environmental pressures, stock assessments and catch trends indicated satisfactory performance across most key fisheries in the sanctuary. Despite some challenges, there appeared to be continued participation across a variety of fisheries. Shellfish aquaculture in Tomales Bay also contributed to commercial harvest in the sanctuary.

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 GFNMS, commercially targeted species include Dungeness crab, Chinook salmon, market squid, and several species of groundfish, among others.

Table ES.CH.1. Summaries for the key indicators related to commercial harvest in GFNMS that were discussed during the July 7, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Target species: Dungeness crab	CDFW, 2020a; Richerson et al., 2020	Status: Dungeness crab was the most valuable species by harvest revenue in GFNMS from 2015–2019. The fishery was affected by closures due to domoic acid and whale entanglement risk. Estimated Dungeness crab abundance during the study period was higher compared to past decades. Trend: There is no clear trend.	ES.CH.1
Target species: Chinook salmon	CDFW, 2020a	Status: Chinook salmon was the second most valuable species by harvest revenue in GFNMS from 2015–2019. Harvest rebounded following closures in 2008 and 2009 and a substantially shortened season in 2010. Trend: Pounds landed and harvest revenue varied from 2010–2020, peaking in 2012 and 2013, respectively.	ES.CH.2
Target species: Market squid	CDFW, 2020a	Status: Market squid harvest was the third most valuable species by harvest revenue in GFNMS from 2015–2019; however, harvest was episodic and low in most years. Trend: Harvest varied from 2010–2020, peaking in 2014 and 2015.	N/A

Indicator	Source	Data Summary	Figures
Target species: California halibut	CDFW, 2020a	Status: California halibut was the fourth most valuable fishery by harvest revenue in GFNMS from 2015–2019. Trend: There was no statistically significant trend in harvest from 2010–2020. Peaks in harvest occurred in 2014 and 2015.	N/A
Target species: Sablefish	CDFW, 2020a	Status: Sablefish was the fifth most valuable fishery by harvest revenue in GFNMS from 2015–2019. Trend: There was no statistically significant trend in harvest from 2010–2020. Catch peaked in 2011 and was lowest in 2014.	N/A
Target species: Sole	CDFW, 2020a	Status: Petrale and Dover sole were the seventh and ninth most valuable fisheries by harvest revenue in GFNMS from 2015–2019, respectively. Trend: Petrale sole catch increased from 2010–2019, while Dover sole catch decreased during the same time period.	N/A
Target species: Lingcod	CDFW, 2020a; Johnson et al., 2021	Status: Lingcod was the 10th most valuable fishery by harvest revenue in GFNMS from 2015–2019. Trend: Lingcod catch increased from 2010–2019.	N/A
Target species: Hagfish and coonstriped shrimp	CDFW, 2020a	Status: Hagfish and coonstriped shrimp were the sixth and eighth most valuable fisheries by harvest revenue in GFNMS from 2015–2019, respectively. Trend: Hagfish catch increased from 2010–2019. Coonstriped shrimp catch varied during the same time period, peaking in 2017.	N/A
Commercial gears	CDFW, 2020a	Status: The top five gear types by harvest revenue were pots/traps, troll, trawl, other seine/dip nets, and longlines. Trend: There were no statistically significant trends in pounds harvested for any of the top 10 gear types by harvest revenue.	N/A
Aquaculture	CDFW, 2020b	Status: As of 2018, less than a third of the total acreage leased for aquaculture in Tomales Bay was actively farmed; however, aquaculture in Tomales Bay accounted for 43% of oyster production and 6% of mussel production in California. Trend: No trend data were available.	N/A
Data gaps	There was a lack of information on the level of satisfaction (either by the general public or by those employed in the seafood sector) with how well sanctuary resources support seafood production and livelihoods.		

Target Species

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, and revenue values are provided in 2020 U.S. dollars. The top ten species harvested from GFNMS were Dungeness crab, Chinook salmon, sablefish, petrale sole, Dover sole, longspine thornyhead, market squid, shortspine thornyhead, chilipepper rockfish, and hagfish (CDFW, 2020a). Collectively, these 10 species accounted for over 96% of the catch value from the sanctuary and over 90% of the weight landed from the sanctuary. These species inhabit an array of target depths and locations, from shallow/nearshore species (e.g., California halibut and Dungeness crab) to pelagic species (e.g., market squid) to deep-water species (e.g., sablefish). Fishers employ a variety of gear types, including pots/traps, troll gear, trawls, seines, longlines, and hook and line (CDFW, 2020a).

Table ES.CH.2. Top 10 species captured in GFNMS by harvest revenue (five-year average, 2015–2019). Revenue and average price per pound are in 2020 U.S. dollars. Source: CDFW, 2020a

Species Name	Harvest Revenue	Pounds Landed	Average Price per Pound	Revenue Rank	Pounds Rank
Dungeness crab	$9,924,777	3,245,162	$3.06	1	1
Chinook salmon	$1,769,327	263,818	$6.71	2	3
Market squid	$448,480	1,557,449	$0.29	3	2
California halibut	$345,091	71,363	$4.84	4	11
Sablefish	$341,942	154,272	$2.22	5	6
Hagfish	$161,668	238,234	$0.67	6	4
Petrale sole	$104,114	89,769	$1.16	7	10
Coonstriped shrimp	$88,026	18,776	$4.69	8	17
Dover sole	$79,489	194,230	$0.41	9	5
Lingcod	$78,814	45,484	$1.73	10	13

Chilipepper rockfish, bocaccio, and longspine thornyhead did not rank in the top 10 species by harvest revenue but were in the top 10 species in terms of pounds landed (7th, 8th, and 9th, respectively). These and other rockfish species are considered iconic fishery species in the region. Following high levels of catch of groundfish species, including rockfish, in the 1980s, there were declines in the 1990s; however, all West Coast groundfish stocks are no longer overfished or experiencing overfishing, with the exception of yelloweye and California quillback rockfish[32] (NOAA Fisheries, 2023b). The following sections describe each of the top 10 species by harvest revenue.

Dungeness Crab

From 2015–2019, the Dungeness crab fishery accounted for nearly 72% of harvest revenue from GFNMS (CDFW, 2020a). Dungeness crab catch varied without a clear trend over the past decade. Since at least the 1970s, researchers have documented a cyclic fluctuation in abundance and catch (Botsford et al., 1982), now believed to be caused by favorable oceanographic conditions for larval recruitment (Shanks & Roegner, 2007). The first thorough population estimate of West Coast Dungeness crab stocks showed a rapid increase in pre-fishing season abundance in Central California during the past decade (2007-2016), following a long period of low abundance (Richerson et al., 2020). The Central California abundance estimates over the last two decades were nearly five times higher than the estimates from 1970 to 2000, despite a high rate of exploitation over that time (Richerson et al., 2020).

The Dungeness crab fishery has been subject to several management actions in recent years. During the 2015–2016 season, the fishery start was delayed from November to March as elevated levels of domoic acid, a neurotoxin associated with HABs, triggered health advisories (California Ocean Science Trust, 2016; Figure ES.CH.1). The fishery was also subject to delays and closures in the "2019-2020" and 2021-2022 seasons due to elevated risk of whale entanglement in the trap gear configurations used by the fleet (see Question 4 in this report for more information; CDFW, 2019b, 2020d, 2021a, 2021b). Although delays and closures are disruptive to seafood markets, impacts on the overall level of harvest may be limited given the derby nature of the fishery and the fleet's ability to harvest a majority of the resource in a short time (D. Ogg/commercial fisherman, personal communication, July 7, 2022). That said, condensed seasons also have the potential to affect safety at sea by encouraging risk-taking behaviors such as fishing in poor weather and operating under fatigue (Pfeiffer et al., 2022; Petursdottir et al., 2001).

[32] NOAA Fisheries notified the Pacific Fishery Management Council that the quillback rockfish stock off the coast of California was overfished on December 14, 2023 (NOAA Fisheries, 2023c), which falls outside the 2010–2022 study period for this report. The overfished status of quillback rockfish was not considered as part of the status and trends assessment for this question.

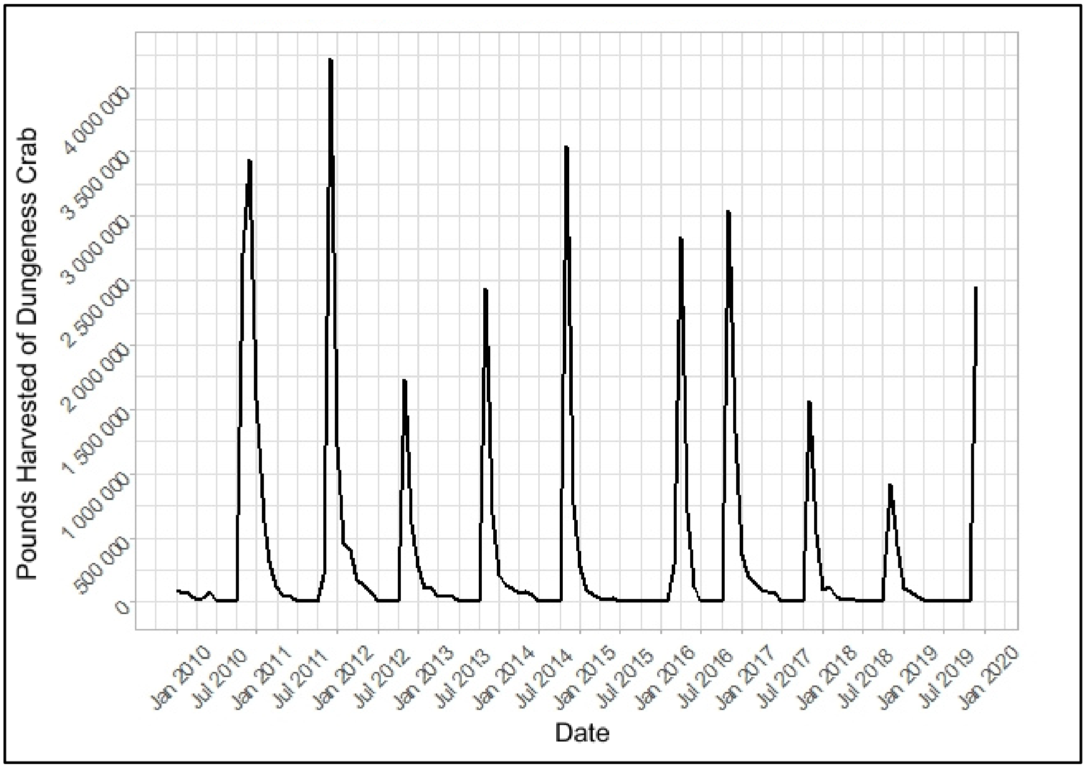

Figure ES.CH.1. Monthly harvest of Dungeness crab, in pounds, from 2010–2020. Source: CDFW, 2020a; Image: J. Eynon/National Marine Sanctuary Foundation

Chinook Salmon

The next most valuable fishery in the sanctuary, accounting for nearly 13% of catch value, was Chinook salmon. Several distinct populations of Chinook salmon may inhabit the sanctuary for part of their life cycles, including California Coastal, Central Valley spring-run, Central Valley fall and late-fall, and Sacramento River fall-run and winter-run salmon (ONMS, 2014b). These populations are all listed as either endangered, threatened, or species of concern, and stocks have shown mixed progress toward recovery (CDFW, 2022c; NMFS, 2016a, 2016b; NOAA Fisheries, 2020c). In 2008 and 2009, for the first time in state history, PFMC closed the commercial salmon fishery entirely in response to the collapse of the Sacramento River fall-run Chinook salmon population (PFMC, 2009). The collapse was attributed to environmental conditions that resulted in poor performance of the 2004 and 2005 broods of Sacramento River fall-run Chinook salmon, on top of long-term degradation of freshwater and estuarine environments (Lindley et al., 2009). In 2010, the commercial season was severely shortened again, and less than 2,500 pounds were landed in the sanctuary (CDFW, 2020a). Chinook salmon catch increased through 2012, as vessels reentered the fishery, then declined to fairly low levels again in 2016–2018 (CDFW, 2020a; Figure ES.CH.2). Landings rebounded in 2019, possibly due to high flow conditions in 2017 (PFMC, 2019). Overall, commercial harvest tracks closely with the Sacramento Index, a metric that represents 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 (PFMC, 2020c; CDFW, 2022e).

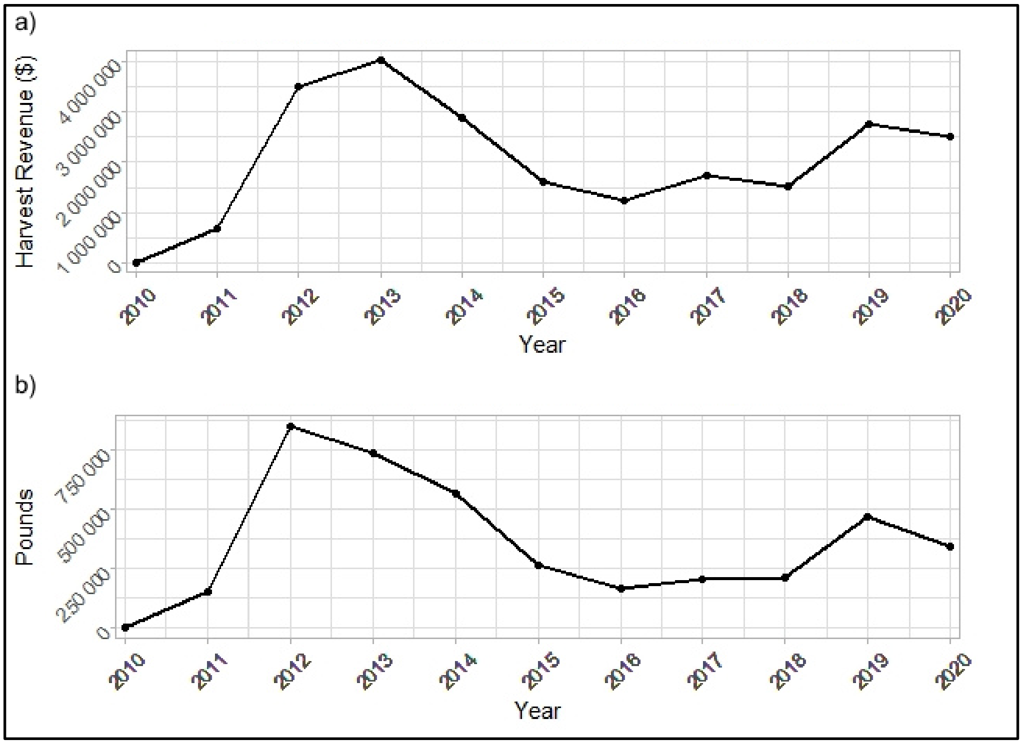

Figure ES.CH.2. Chinook salmon a) harvest revenue and b) pounds landed from GFNMS, 2010–2020. Source: CDFW, 2020a; Image: J. Eynon/National Marine Sanctuary Foundation

Market Squid

Of the species harvested in GFNMS from 2015–2019, market squid ranks third in terms of harvest revenue and second in terms of pounds landed (CDFW, 2020a). Market squid harvest in the sanctuary was episodic and associated with environmental conditions in the California Current Ecosystem (Suca et al., 2022). Most of the fishing activity in the region was concentrated near Monterey Bay in MBNMS (CDFW, 2022f). The squid are caught using drum seines or purse seines. Harvest in GFNMS was near zero from 2010 to 2013 and jumped to over 6 million pounds in 2014 and 2015 before declining to over 1.5 million pounds in 2016 (CDFW, 2020a). Catch in the following four years remained near zero, except for a slight increase in landings (less than 1 million pounds) in 2020 (CDFW, 2020a). The majority of market squid catch was landed in Princeton-Half Moon Bay or San Francisco, suggesting those fleets may have shifted effort north in 2014–2016 in response to changing distribution of squid.

California Halibut

The Dungeness crab, Chinook salmon, and market squid fisheries account for roughly 88% of harvest revenue in the sanctuary. Of the remaining top ten species, five are part of the groundfish complex, which, with the exception of California halibut, is managed by PFMC. The groundfish complex includes California halibut, sablefish, petrale sole, Dover sole, and lingcod. Over 85% of California halibut catch in GFNMS is harvested by trawl, with some catch by hook and line (CDFW, 2020a). There was no statistically significant trend in California halibut catch from 2010 to 2020 (CDFW, 2020a). Catch peaked in 2014 and 2015 at over 100,000 pounds (CDFW, 2020a). As of a 2011 stock assessment by the state, the California halibut population in

Central California was estimated to be well above the biomass associated with maximum sustainable yield, and overfishing was not occurring (CDFW, 2011a).

Sablefish

From 2015 to 2019, 46% of sablefish caught in the sanctuary was harvested by trawl, 40% by set longline, and 12% by fish trap (CDFW, 2020a). Sablefish catch varied without a statistically significant trend over the decade beginning in 2010. Harvest revenue peaked in 2011 at over $780,000 (> 246,000 pounds; CDFW, 2020a). In the same year, the National Marine Fisheries Service implemented a catch share program for the fishery in response to an assessment indicating that the stock had declined to biomass levels in the "precautionary zone" (Ocean Protection Council, 2013b). Sablefish landings decreased to a low of under 85,000 pounds in 2013 and have since hovered around 160,000 pounds per year (CDFW, 2020a).

Sole

Both petrale sole and Dover sole are harvested almost entirely by trawl in GFNMS (CDFW, 2020a). There were statistically significant but opposite trends in harvest for the two species; petrale sole catch increased from 2010 to 2019 (Mann-Kendall test; tau = 0.511, p-value = 0.049) and dover sole catch decreased over the same period (Mann-Kendall test; tau = -0.689, p-value < 0.01). Differences in depth distribution and fishery value may affect effort and harvest levels. As of 2019, petrale sole populations were above spawning biomass targets set by fishery managers (Wetzel, 2019). Dover sole populations were also well above biomass targets, and overfishing was not occurring (PFMC, 2021).

Lingcod

Lingcod in the sanctuary are caught by trawl (61% by weight), hook and line (24%), and long line (12%; CDFW, 2020a). There was a statistically significant increase in lingcod catch from 2010 to 2019 (Mann-Kendall test; tau = 0.733, p-value < 0.01) driven by a large, sustained jump in landings between 2017 and 2018 (CDFW, 2020a). Spawning biomass trended upward during the study period due to a period of high recruitment that ended in 2013 (Johnson et al., 2021). The most recent estimated biomass of lingcod was below, but close to, the management target of 40% unfished biomass with uncertainty spanning above and below the targets (Johnson et al., 2021).

Coonstriped Shrimp and Hagfish

The remaining two species among the top-valued species in GFNMS were coonstriped shrimp and hagfish. Both are trap-based fisheries with relatively few participants (between 0–4 vessels per year for coonstriped shrimp and between 1–4 vessels per year for hagfish from 2010–2019). Despite the small number of participants, the hagfish fishery ranks 4th in terms of pounds landed from the sanctuary. The fishery developed in response to demand from South Korean buyers (CDFW, 2015b). There was a statistically significant increase in hagfish catch from 2010 to 2019 (Mann-Kendall test; tau = 0.556, p-value = 0.03). Coonstriped shrimp ranks 17th in terms of pounds landed, but its high price per pound ($4.69/lb on average from 2015–2019) makes it a top-value fishery in GFNMS (CDFW, 2020a). Around 25,000 pounds of coonstriped shrimp were harvested in 2012 and 2013, followed by a larger peak in harvest in 2016 and 2017 (nearly 31,000 and 54,000 pounds, respectively; CDFW, 2020a). Outside of those four years, landings from GFNMS were below 10,000 pounds (and near zero in 2011 and 2014). Most vessels that target coonstriped shrimp or hagfish also target Dungeness crab (CDFW, 2020a). From 2015–2019, vessels that reported catching hagfish generated an annual average of 57.5% of their revenue from hagfish alone, with much of their remaining revenue coming from Dungeness crab and, to a lesser extent, red rock crab (CDFW, 2020a). From 2016–2018, vessels that caught coonstriped shrimp received an annual average of 16.9% of their revenue from the species, with remaining revenue coming primarily from Dungeness crab, followed by sablefish, Chinook salmon, and some rockfish (CDFW, 2020a). No coonstriped shrimp catch was reported in 2015 or 2019 (CDFW, 2020a).

Commercial Gears

Table ES.CH.3 shows average harvest revenue and pounds landed by gear type, along with the average and standard deviation of the annual number of vessels reporting catch using each gear category. The gears used to target Dungeness crab and Chinook salmon (traps and troll gear) accounted for a high proportion of harvest revenue and number of vessels. There were no statistically significant trends in pounds harvested for any of the listed gear types. In 2010, as the commercial salmon season was severely shortened for the third consecutive year, there were only 205 vessels reporting catch from the sanctuary (CDFW, 2020a). The number of vessels increased to 510 in 2014, then fluctuated between 300 and 400 from 2015 to 2020 (CDFW, 2020a). Fishery dynamics are complex and include port infrastructure, cost of operations, and fishing capacity, which drives the concentration of fishing activity in certain geographic areas (Harvey et al., 2019).

Table ES.CH.3. Top gear types by harvest revenue (2015–2019) with the average and standard deviation in the number of vessels using each gear. Source: CDFW, 2020a

Rank	Gear Type	Harvest Revenue (annual average)	Pounds Landed (annual average)	Average Number of Vessels	Standard Deviation of Average Number of Vessels
1	Pots/traps	$ 10,285,944	3,542,086	167.8	31.5
2	Troll	$ 1,754,485	263,817	201.6	29.2
3	Trawl	$ 839,564	892,940	8.0	1.6
4	Other seine/dip nets	$ 308,970	1,011,746	4.8	4
5	Longlines	$ 277,289	96,502	19.8	3.2
6	Hook/line	$ 156,259	34,790	61.8	9.8
7	Purse seine	$ 144,361	557,064	3.8	3.4
8	Hookah/diving	$ 50,085	51,693	4.0	3.1

Rank	Gear Type	Harvest Revenue (annual average)	Pounds Landed (annual average)	Average Number of Vessels	Standard Deviation of Average Number of Vessels
9	Set gill net	$ 1,647	9,873	0.6	1.3
10	All other	$ 1,551	389	0.4	0.5

Aquaculture

In addition to commercial fishing activities, aquaculture also takes place in the sanctuary. A number of aquaculture operations in Tomales Bay grow shellfish, including Pacific, Kumamoto, eastern, and European flat oysters; Manila clams; and Mediterranean, California sea, and bay mussels (CDFW, 2020b). Growers employ multiple shellfish culture methods, including bags on groundline, rack-and-bag, rack-and-tray, intertidal longlines, stakes and wires, rafts, floating longlines, and in-ground culture with net cover systems. The greatest number of state bottom water leases in California are located in Tomales Bay, with a total of 12 leases operated by seven different businesses (CDFW, 2020b). Of the 520 acres leased in the bay, only 152 acres are currently used (CDFW, 2020b). In 2018, aquaculture in Tomales Bay accounted for 43% of oyster production and 6% of mussel production in the state (CDFW, 2020b). Mussel production in 2018 totaled 5.22 metric tons and generated $34,545 in revenue (CDFW, 2020b). No production estimates for oysters were available. Also in 2018, Tomales Bay was the only location in the state with reported clam production, generating a half ton of clams and $5,120 in revenue (CDFW, 2020b). There was limited information on trends in shellfish production in Tomales Bay.

Conclusion

This ecosystem service was rated good/fair based on the abundant and diverse fisheries in the region. Regional catch trends for two of the highest-value species in the sanctuary—Dungeness crab and market squid—were cyclical and appeared to be driven by environmental variability. Climate-driven changes to the California Current Ecosystem (e.g., HABs) drove some fluctuations in harvest and disrupted seafood markets. Recent shifts in Dungeness crab seasons appear to have had a limited impact on the overall level of harvest, but may have had negative impacts on the fishery (e.g., potential effects on safety at sea). Chinook salmon populations have been depleted due to ongoing anthropogenic pressures; stocks have shown mixed progress toward recovery and harvest was variable during the study period. The trend in commercial harvest was mixed. Despite some fishery closures and shortened seasons during the study period, there was continued participation across a number of fisheries in the sanctuary, and stock assessments indicated that most target species had stable or increasing populations. Though substantial data exist on catch levels, a significant gap in this assessment is a lack of information on demand for seafood, which would serve as a benchmark for whether the level of commercial harvest is satisfactory. There was also a lack of information on the level of satisfaction (either by the general public or by those employed in the seafood sector) with how well sanctuary resources support seafood production and livelihoods.

Regulating Services (Buffers to Change)

Coastal Protection

Flow regulation that protects habitats, property, coastlines, and other features

Status Description: The capacity to provide the ecosystem service is compromised, and substantial new or enhanced management is required to restore it.

Rationale: Significant external (e.g., dams and culverts) and some internal built infrastructure (shoreline armoring) has disrupted the supply of sediment in numerous areas along the already naturally eroding coastline of GFNMS. The effects have likely been far ranging, and are being exacerbated by changes in climate that directly affect sediment delivery to coastal ecosystems. The extent of these influences is not fully understood, but it is clear that substantial management would be needed to restore natural control of sediment delivery and movement, as the entirety of the GFNMS coast is actively erosive. There was a lack of information on changes in shoreline hardening and habitat condition during the study period.

Coastal protection is defined as the flow regulation that protects habitats, property, coastlines, and other features. Saltmarsh, eelgrass beds, and sandy beaches and dunes near GFNMS protect coastlines by dissipating wave energy, resulting in smaller, less destructive waves reaching the coast and inshore areas. These natural buffers also help protect against erosion, which can threaten coastal properties and resources. It is important to note that coastal protection was evaluated based on the ability of natural features (not built infrastructure) to provide protection. However, built infrastructure was considered to the extent that it impacts protection offered by natural features, such as barrier beaches. Where possible, estimates of the economic value of natural habitats for coastal protection were provided. However, these estimates varied greatly depending on local characteristics, and information specific to the sanctuary was limited.

Table ES.CP.1. Summaries for the key indicators related to coastal protection in GFNMS that were discussed during the July 5, 2022 virtual status and trends workshop.

Indicator	Source	Data Summary	Figures
Flooding	NOAA Office for Coastal Management, 2022b; NOAA, 2022e	Status: Properties adjacent to estuarine areas are within flood zones. There was an annual average of 1.4 flood days, as measured at Point Reyes. Trend: The number of high tide flood days varied without trend from 2010–2022.	N/A
Saltmarsh and eelgrass beds	Golden Gate National Parks Conservancy et al., 2021; Merkel & Associates, Inc., 2017a; PSMFC, 2018	Status: Both saltmarsh and eelgrass beds have been shown to have coastal protection benefits in locations outside of GFNMS. There were nearly 880 acres of saltmarsh habitat and 2,026 acres of eelgrass cover in estuarine areas of GFNMS. Trend: No trend data were available.	ES.CP.1

Indicator	Source	Data Summary	Figures
Sandy beaches and dunes	George et al., 2018; Griggs & Patsch, 2019	Status: Both beaches and dunes have been shown to have coastal protection benefits in locations outside of GFNMS. Natural erosion and deposition processes on GFNMS beaches have changed due to historic alteration of sediment supplies resulting from watershed modifications, coastal armoring, and climate impacts. The majority of beaches in GFNMS are experiencing erosion. The coastline of GFNMS is less impacted by armoring compared to other areas in California; however, armoring accounted for a higher percentage of the shoreline in estuarine areas. Trend: No trend data were available.	N/A
Data gaps	Trend data were unavailable for most indicators; information on large-scale changes in shoreline hardening and habitat condition is also needed.		

The coastline of GFNMS is characterized by rocky cliffs, sandy beaches, bays, and estuaries (George et al., 2018). Cliff erosion has occurred along much of the coastline (Swirad & Young, 2022). The region is less densely developed than many portions of coastal California, with agricultural uses dominating much of the area (George et al., 2018). Given its widespread steep slopes and rocky shorelines, recreation tends to be concentrated in pockets of high use in coastal areas protected by these geographical features (George et al., 2018). Popular recreational areas include beaches, like Stinson Beach and Doran Beach, along with several protected areas managed at the local, state, and national levels. Developed areas that are exposed to coastal hazards include communities like Bolinas, Inverness, and Bodega Bay, along with public infrastructure, notably Highway 1 (NOAA Office for Coastal Management, 2022b).

Flooding

Coastal vulnerability to flooding along GFNMS shorelines depends on the rate of global and local sea level rise, along with the frequency and intensity of extreme events, like ENSO events, storm waves, and high tides (Griggs & Patsch, 2019). As measured at the NOAA data buoy at Point Reyes, California, the number of high tide flood days varied without trend from 2010–2022, with an annual average of 1.4 flood days[33] and a maximum of seven flood days in 2017 (NOAA, 2022e). Data collected at the same buoy indicated a relative sea level rise trend of 2.14 millimeters per year (with a 95% confidence interval of ± 0.79 mm yr^{-1}; NOAA, 2022e). Research suggested a weakly increasing trend in significant wave height offshore of the West Coast and California (Young, et al., 2011; Gemmrich, et al., 2011).

[33] A flood day occurs when verified hourly water levels exceed a flood threshold for at least one hour. The minor flood threshold for this location is two feet about Mean Higher High Water, as defined by Sweet et al. (2018).

Several areas within and adjacent to the bays and estuaries in GFNMS fall within moderate- or high-risk flood zones, as designated by the Federal Emergency Management Agency. For example, most of Bolinas Lagoon is classified as a type A flood zone by the Federal Emergency Management Agency (corresponding to a 1% or greater annual chance of flooding), while the spit enclosing Bolinas Lagoon is designated as either a high-risk, type V flood zone (1% or greater annual chance of flooding with an additional hazard associated with storm waves) or a moderate-risk (0.2% chance of flooding) zone (NOAA Office for Coastal Management, 2022b). Similarly, the area within Tomales Bay, including portions of developed areas like Marshall, Inverness, and Point Reyes Station, is designated as either a type A or type V flood zone depending on location (NOAA Office for Coastal Management, 2022b).

Saltmarsh and Eelgrass Beds

Vegetated habitats, including saltmarsh and eelgrass beds, can provide coastal protection through flood and erosion control within estuarine environments.[34] Saltmarshes provide coastal protection by attenuating wave energy and stabilizing shorelines (Shepard et al., 2011). They provide additional flood protection by promoting water storage capacity and surface resistance through their plant and soil components (Ballard et al., 2016). No studies have estimated the economic value of saltmarsh for coastal protection specifically within GFNMS or Central California. The range of value of wetlands, which includes saltmarsh and other habitats, for flood and storm protection was estimated to be $20 per acre to $10,533 per acre in 2020 U.S. dollars, based on studies from Colorado (Batker et al., 2014) and southern California (Ballard et al., 2016). Other studies in Galveston, Texas and Northwest Mexico estimated the flood and storm protection value of saltmarshes to be roughly $7,683 per acre and $6,677 per acre, respectively (Feagin et al., 2010; Camacho-Valdez et al., 2013). Within GFNMS, there are nearly 880 acres of saltmarsh habitat: 637 acres in Tomales Bay, 196 acres in Bolinas Lagoon, 33 acres in Estero Americano, and 14 acres in Estero de San Antonio (Golden Gate National Parks Conservancy et al., 2021). No data were available to indicate trends in saltmarsh cover from 2010–2022.

In a study of wave attenuation by eelgrass (*Zostera marina*) in South Bay, Virginia, researchers found that wave heights were reduced by 25–49% in eelgrass plots compared to adjacent bare sites (Reidenbach & Thomas, 2018). Wave attenuation was greatest in spring and summer, when eelgrass biomass was greatest (Reidenbach & Thomas, 2018). This implies that eelgrass beds provide less protection during the winter, when significant wave heights are largest. Importantly, reductions in wave energy are greatest when eelgrass beds are broad and when plant size is scaled to water depth (i.e., when plants occupy the entire water column; Fonseca & Cahalan, 1992), which may occur at low tide or when the plants have long reproductive stems (Koch et al., 2007). Under those conditions, wave attenuation by eelgrass is comparable to that provided by salt marshes (Fonseca & Cahalan, 1992). In addition to reducing wave energy, eelgrass can provide erosion control by trapping sediments and stabilizing the substrate (NOAA

[34] Kelp forest was investigated as a nearshore habitat type for inclusion in coastal protection. However, there is evidence that bull kelp (*Nereocystis luetkeana*; the predominant species in GFNMS), like other large floating-canopy species, has a negligible effect on wave attenuation (e.g., Friedland & Denny, 1995; Koehl & Alberte, 1988; Hondolero & Edwards, 2017).

Fisheries, 2014), but these effects vary by sediment type and eelgrass bed width (Marin-Diaz et al., 2020).

Within the sanctuary, there is a total of about 2,026 acres of eelgrass cover, of which 2,019 acres are located in Tomales Bay (Figure ES.E.1; Merkel & Associates, Inc., 2017a; PSMFC, 2018). Several shellfish farms operating within Tomales Bay are co-located with eelgrass beds (CDFW, 2011b) and may benefit from protection provided by the submerged vegetation. The remaining eelgrass cover is located within Estero Americano (~5.5 acres) and Estero de San Antonio (~1.3 acres; Merkel & Associates, Inc., 2017a; PSMFC, 2018). Trend data were limited for eelgrass cover in GFNMS within the study period. A small extent of eelgrass beds in Bolinas Lagoon has largely disappeared (Gulf of the Farallones National Marine Sanctuary, 2008), but there have been no recent surveys. There has not yet been a robust valuation of the benefits of eelgrass habitat for coastal protection (Barbier et al., 2011).

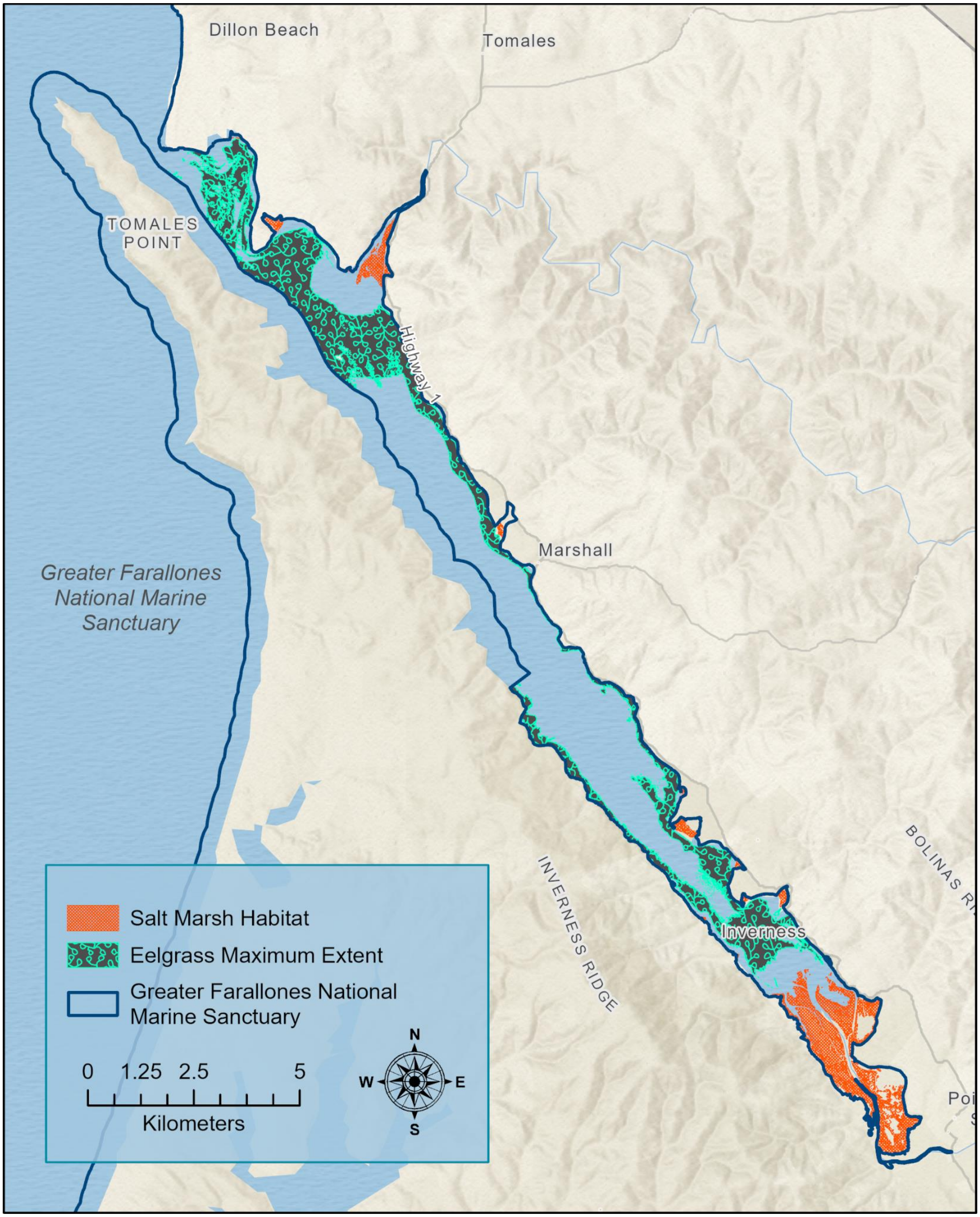

Figure ES.CP.1. Salt marsh and eelgrass cover in Tomales Bay. Image: NOAA; Source: Golden Gate National Parks Conservancy et al., 2021; Merkel & Associates, Inc., 2017a; PSMFC, 2018; Esri, 2016

Sandy Beaches and Dunes

As waves reach the shore, they are attenuated by the beach slope and, at high tide, by the foredune, the structure that forms behind the beach where sand accumulates into mounds or ridges parallel to the shoreline (Barbier et al., 2011). The foredune can also provide erosion protection through sediment stabilization and soil retention in vegetation root structures (Barbier et al. 2011). The degree of wave attenuation afforded by sandy shores depends on the shape of the beach and foredunes, which in turn depends on factors like presence of vegetation and sand supply (Barbier et al., 2011). The economic value of beaches for coastal protection has not been calculated but is substantial (Barbier et al., 2011).

Natural erosion and deposition processes along sandy beaches at GFNMS have changed because of historic alteration of sediment supplies caused by modification of watersheds and coastal armoring, combined with climate impacts. Dams, culverts, and shoreline armoring are among the infrastructure types that have altered sediment delivery by the region's rivers and affected sediment supplies to downstream beaches. Analysis of shoreline change in Sonoma and Marin counties showed that the mouths of the Russian River, Tomales Bay, and Drakes Estero are particularly dynamic (George et al., 2018). Hardened, or armored, shorelines along GFNMS consist of coastal development and highways. Of the entire length of California's shoreline in 2018, 13.8% was armored with seawalls and revetments (Griggs & Patsch, 2019). Comparatively, the coastline of GFNMS is less impacted by armoring, with only 4.7% of Marin County, 1.2% of Sonoma County, and 1% of Mendocino County being hardened (Griggs & Patsch, 2019). There are 216 instances of armoring within GFNMS, totalling 8.6 km (California Coastal Commission, 2022).

Hardened structures accounted for a much higher percentage of the shoreline in areas of GFNMS with private development and public infrastructure. In 2019, 35% of Bolinas Lagoon's 24.4-kilometer shoreline consisted of hard armored structures (i.e., transportation structure; human-made bulkhead or seawall; human-made ramp, rip rap, or shoreline protection structure; California Coastal Commission, 2022). As of 2022, there were 125 instances of armoring in Tomales Bay within GFNMS, and around 4.4 kilometers of the 63 kilometers (or around 7%) of bay's shoreline was armored (California Coastal Commission, 2022).

Data were not available to indicate a trend in shoreline hardening within the study period for this condition report (2010–2022). Results from a case study in Imperial Beach in Southern California indicated that coastal armoring provided the least public benefit over time of the evaluated adaptation strategies (i.e., armoring, nourishing, living shorelines, groins, and managed retreat; Revell et al., 2021). Fifteen sites within GFNMS were identified as high-priority areas for nature-based action in the next 10 years (Kordesch et al., 2019), and a number of nature-based restoration projects are currently in the planning phase. The *GFNMS Coastal Resilience Sediment Plan* provides more detail on sediment management issues, priority sites, and review and assessment of sediment management actions (Kordesch et al., 2019).

Conclusion

This ecosystem service was rated fair/poor based on a variety of factors. First, the ability of eelgrass and saltmarsh habitats to provide protection to private development and public infrastructure was limited, because the extent of these habitats is small compared to the area of the sanctuary. A small percentage of the uplands and sanctuary shoreline contained built infrastructure to protect property, manage water, and produce power, but this infrastructure can significantly alter local erosion and produce cascading downstream impacts. Furthermore, the entirety of the GFNMS coast is actively erosive, to varying degrees. High natural rates of erosion have been amplified by the downstream effects of sediment starvation, exacerbated by the influence of climate change on processes like sea level rise and intensifying weather extremes (principally drought and floods). The trend was undetermined due to a lack of time series data for indicators like eelgrass and saltmarsh habitat cover or sandy beach and dune extent. Other data gaps included a lack of information for Bolinas Lagoon, Tomales Bay, and the northern coastline of the sanctuary; site-specific, empirical data on the physical processes, like wave attenuation and erosion control, that modulate coastal protection afforded by natural features; information connecting those physical processes to property value or livelihoods protected; and cumulative effects on deteriorating shorelines.

Response to Pressures on the Sanctuary

The Pressures section of this report describes a variety of issues and human activities occurring within and beyond the sanctuary that warrant attention, tracking, study, and, in some cases, specific management actions. Addressing any of these issues requires participation by and coordination with a variety of agencies and organizations. ONMS is fortunate to be able to work with many entities that contribute to managing human activities and addressing marine and estuarine conservation issues. In many cases, GFNMS relies on partnerships with federal, state, and local government agencies, businesses, and non-profit organizations to address pressures on the sanctuary.

This section summarizes activities and management actions that GFNMS has led or coordinated. The activities described below are not exhaustive of all the ways GFNMS serves the surrounding community and sanctuary ecosystems. The activities highlight significant contributions that are responsive to known or emerging pressures and are focused on responses related to human activities where direct ONMS interventions or GFNMS-led partnerships have protected or restored sanctuary resources.

Recommendations for future actions are not included in this section; however, information is provided on potential future needs to address pressures that were not assessed as indicators in this condition report, but are emerging issues that need attention. Current responses outlined in this section will be evaluated against all known pressures to help shape future priority needs for GFNMS management. The next step is management planning, and the findings of this condition report will serve as an important foundation to help GFNMS set future priorities based on known needs.

Introduction

Regulatory Responses

Sanctuary regulations include prohibitions (15 C.F.R. § 922.82) that are intended to limit human activities known to cause harm to sanctuary resources. GFNMS has implemented a variety of regulations that are intended to:

- Prevent discharges of solid and liquid materials such as sewage, hazardous chemicals, and oil;
- Protect benthic habitat from activities such as dredging or coastal development;
- Prevent disturbance to wildlife, including white sharks; and
- Prohibit other specific activities, such as oil exploration, introducing non-indigenous species, anchoring in designated seagrass protection zones, deserting a vessel, leaving harmful matter aboard a grounded or deserted vessel, or taking historic resources.

GFNMS is not responsible for enforcing regulations. However, GFNMS has worked with enforcement partners, including NOAA Office of Law Enforcement, USCG, and other federal and state agencies with authority to enforce sanctuary regulations to conduct training for airmen, boarding officers, wardens, and rangers on sanctuary priorities, projects, and regulations, and has also provided technical expertise when violations occurred.

GFNMS also supported the development and use of the electronic Fisheries Information Network System, known as eFINS. This pilot mobile application is a data collection and sharing tool that allows participating marine enforcement partners to electronically record, store, reference, and share geospatial data taken during patrols as they conduct compliance checks with commercial and recreational users of the sanctuary.

GFNMS documented 502 reported violations of sanctuary regulations between 2014–2022 (GFNMS, 2023a); most of these were forwarded to NOAA's Office of Law enforcement to assist with enforcement case development. Many cases included multiple violations. One of the most significant violations was 190 documented discharges from multiple cruise ships from 2017–2019 (Blank Rome LLP, 2017). GFNMS worked with NOAA's Office of Law Enforcement and Office of General Counsel to fine the cruise ship companies for illegally discharging in the sanctuary.

Non-Regulatory Responses

GFNMS developed and maintained partnerships and engaged the community in actions that addressed pressures on sanctuary resources. Projects and programs that sanctuary staff have led, coordinated, or jointly conducted with partners helped address conservation challenges that arose from human activities. Since 2010, GFNMS focused most of its non-regulatory actions to address the following human-caused pressures:

- Climate change;
- Land use;
- Marine harvest;
- Vessel traffic;
- Wildlife disturbance;
- Marine debris; and
- Non-indigenous species.

The National Marine Sanctuaries Act creates a powerful pathway to engage stakeholders through sanctuary advisory councils. The GFNMS Sanctuary Advisory Council, as a public advisory body with subcommittees and working groups, has forwarded recommendations to address many of the pressures in the sanctuary. The advisory council served as a forum for consultation and deliberation among its members and as a source of advice and recommendations to the sanctuary superintendent. The advisory council includes governmental (state, local, and federal agencies) and non-governmental (education, conservation, research, fishing, tourism, industry, marine activities, and citizens at large) seats. Since 2010, the advisory council has contributed to recommendations and reports that have helped GFNMS respond to climate impacts, including shoreline change and sediment transport; benthic habitat impacts, including vessel groundings and sinkings and damage from anchors and moorings; vessel traffic impacts, including preventing ship strikes, understanding acoustic impacts, and reducing oil pollution; and marine debris prevention (GFNMS, 2023b).

Responses to Pressures on the Sanctuary

Responses to Climate Change

Since 2010, GFNMS has developed a comprehensive approach to better understand and respond to climate-related impacts in an effort to ensure GFNMS resources are resilient. In 2010, the Sanctuary Advisory Council co-produced a report titled *Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries* (Largier et al., 2010) that identified and synthesized information on potential climate change impacts to habitats and biological communities along the North-Central California coast. The report was created through a collaborative process involving 16 agencies, organizations, and academic institutions. In 2013, the Sanctuary Advisory Council applied the findings from the that report and from the 2013 GFNMS Ocean Climate Summit and produced *Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-Central California Coast and Ocean Region* (Duncan et al., 2013). This report was informed by more than 50 regional, federal, and state natural resource managers, research scientists, and other partners to develop a set of ocean climate indicators and monitoring objectives and strategies for the North-Central California coast and ocean region. These indicators were used by the U.S. team on the Intergovernmental Panel on Climate Change to develop national and global ocean climate change indicators. GFNMS and its partners have included the indicators in monitoring projects to track the status and trends of climate impacts in the region. From 2014 to 2015, the sanctuary applied the findings from Largier et al. (2010) and Duncan et al. (2013), as well as input from the 2013 GFNMS Ocean Climate Summit, to develop a *Climate Change Vulnerability Assessment for the North-Central California Coast and Ocean* (Hutto et al., 2015). Over 60 scientists and experts provided input to identify how and why various habitats, species, and ecosystem services across the North-Central California coast were likely to be affected by future climate conditions. The vulnerability assessment workshop determined that blue whales and coastal habitats, along with their associated species and ecosystem services, were most vulnerable to climate change.

In 2016, GFNMS developed a climate adaptation plan (National Marine Sanctuary Program, 2016) based on recommendations from the Sanctuary Advisory Council. The plan outlined actions GFNMS could take to address the most vulnerable habitats, species, and ecosystem services, with the objective of reducing the vulnerability of coastal and ocean resources in order to build resilience to climate change. GFNMS has advanced many of the recommendations from the plan, including increasing resilience by reducing vessel strikes to endangered and threatened blue, humpback, and fin whales; developing and implementing a coastal resilience plan; actively pursuing and supporting living shoreline and shoreline restoration projects; restoring eelgrass; developing a native oyster living shoreline and restoration plan; supporting additional protections for sanctuary deep-sea coral communities; and understanding blue carbon habitats and processes in the sanctuary. In 2016, the Council on Environmental Quality designated California's North-Central Coast and Russian River Watershed, which includes the sanctuary, as a Resilient Lands and Waters site.

In addition, although multiple factors contribute to kelp forest ecosystem health, climate-related stressors have been a major driver of kelp declines in GFNMS since 2014. In response to a >90%

decline in bull kelp habitat along the Sonoma and Mendocino coast, the advisory council adopted and forwarded recommended actions to restore sanctuary kelp forests in 2018. These recommendations were incorporated into the *Sonoma-Mendocino Bull Kelp Restoration Plan* (Hohman et al., 2019), the first of its kind for California. GFNMS and the Greater Farallones Association have partnered on implementing the recommendations from this plan to research and restore bull kelp in the sanctuary.

Responses to Land Use

From 2010–2022, GFNMS reviewed and commented on environmental compliance documents, plans, or regulatory proposals from other agencies related to land uses that could potentially result in discharges into the sanctuary. The scope of comments were focused on management plans, action plans, strategic plans, proposals for road maintenance, culvert cleanings, construction projects, and proposed regulations that could alter land adjacent to GFNMS.

Coastal sediment is a natural resource that contributes to a healthy coastline. GFNMS developed and implemented the *Coastal Resilience Sediment Plan* (Kordesch et al., 2019), which identified sediment-related adaptation strategies in response to recommendations from the climate adaptation plan (National Marine Sanctuary Program, 2016). The North-Central California Coast Sediment Coordination Committee, a group of 17 federal, state, and local agencies committed to collaborating on coastal resilience initiatives across the region, was also established. The plan provided a 50-year road map to help shorelines on the North-Central California coast adapt to hazards, such as severe storm surge, sea level rise, erosion, flooding, and human impacts, and identified sediment imbalances within the sanctuary caused by land use. GFNMS has partnered with Marin County Parks to identify projects to restore historic floodplains and reconnect Bolinas Lagoon wetlands that have been bisected by roads.

Since 2010, GFNMS has implemented actions described in *Bolinas Lagoon Ecosystem Restoration Project: Recommendations for Restoration and Management* (Gulf of the Farallones National Marine Sanctuary, 2008) that have specifically focused on improving the hydrological function of the lagoon. The first project that contributed to this effort, completed in 2011, was an extensive culvert replacement on Highway 1 on the east shore of Bolinas Lagoon using porous materials that retain runoff, thus reducing the amounts of sediment and toxins entering the lagoon. This project helped Bolinas Lagoon adjust to tidal fluctuations and storms by preventing additional sediment flow from the watershed. This project also removed invasive species from the east shore of the lagoon.

GFNMS has also partnered with the Greater Farallones Association to initiate design of a living shoreline project along the south end of Bolinas Lagoon to restore wetland habitat that was lost with the creation of the Seadrift Lagoon housing development. In addition, GFNMS has partnered with the Greater Farallones Association to coordinate monitoring of the sanctuary shoreline to characterize and understand changes so that GFNMS can focus on actions that have the greatest impacts and are supported by the best available information. In addition, based on the recommendations in the *Coastal Resilience Sediment Plan*, the Marin County Development Agency conducted a dune restoration feasibility study to determine if dunes could be used as a living shoreline project to protect development along Stinson Beach.

GFNMS has also worked with partners to pursue restoration of native oyster species, which declined due to a variety of factors, including habitat loss, non-indigenous predators, and historic overharvesting. Restoration efforts aimed to support healthy ecosystem function, protect coastal habitats, and reestablish ecosystem services (e.g., recreational harvest). At the request of GFNMS, the Sanctuary Advisory Council convened a working group that recommended actions to increase the native Olympia oyster population in Tomales Bay and explore coastal protection benefits associated with oyster restoration (GFNMS Advisory Council, 2019). Based on these recommendations, GFNMS adopted the Sanctuary Advisory Council recommendations native oyster restoration, and the Marin County Development Agency conducted a native oyster living shoreline feasibility study.

Responses to Marine Harvest Activities

The sanctuary encompasses living and non-living habitats such as rocky reefs and kelp beds. From 2010–2022, GFNMS has strived to protect and restore habitats within the sanctuary by commenting on other agency actions that affect sanctuary habitat and partnering on efforts to restore habitat. Prior to 2010, GFNMS participated in CDFW's Marine Life Protection Act process, which established 25 state marine protected areas that prohibit impacts to habitat from fishing along the North-Central California coast. GFNMS also continued to be an active participant in the MPA Collaborative Network, a group established to empower diverse communities to engage in marine protected area stewardship for a healthy ocean. GFNMS also participated in PFMC's decade-long review of Pacific Coast groundfish Essential Fish Habitat Conservation Areas within sanctuary waters by providing seafloor, coral, sponge, and fish assemblage data that were instrumental in protecting sanctuary habitats from bottom trawling impacts. Five areas were closed to bottom trawling throughout the sanctuary, and two areas retained their closed status. During deep-sea coral and sponge habitat and damage assessment cruises, GFNMS documented fishing marine debris on the seafloor.

Responses to Vessel Activity

Many types of vessels (e.g., commercial, barges, recreational, and research) transit through the sanctuary and have impacted sanctuary water quality, habitat, and wildlife. In 1993, in response to recurring oil spill events from vessels in the sanctuary, GFNMS established the Beach Watch community monitoring project (see Box 2). Beach Watch surveyors are trained to collect oil samples and dead oiled wildlife and have often been the first people to observe an oil spill event. The evidence gathered by Beach Watch volunteers has helped the federal and state government document damage to wildlife and habitat from oil spills, determine clean up end points, identify birds and mammals at risk from oil pollution, and inform restoration projects.

Based on historic levels of oil and dredge spills, illegal discharges from cruise ships, and the high level of risk these violations pose to sanctuary habitats and wildlife, GFNMS focused on supporting enforcement cases and responding to and preparing for oil spills, boat groundings, and sinkings of large items (e.g., dry dock, cargo containers, and airplanes) in the sanctuary. As a resource trustee, GFNMS participated as a member of two Area Committees led by USCG and participated in sub-committees to identify sensitive sites and resources at risk, develop response strategies, and identify potential places of refuge for vessels in distress, in addition to reviewing draft planning documents and participating in response drills.

GFNMS either facilitated or coordinated the removal of grounded and sunken vessels when feasible by working with emergency responders, responsible parties, and enforcement personnel. Between 2012 and 2022, GFNMS funded (directly or through cost-sharing with other agency partners) the removal of five vessels that were abandoned, grounded, or sunk in the sanctuary, including the FV *Marian*, which grounded in 2019, damaged eelgrass, and subsequently sank in Tomales Bay in 2021.

Following several high-profile ship strikes to whales in 2009, GFNMS, based on recommendations from the Sanctuary Advisory Council, implemented voluntary vessel speed reduction measures. Since 2010, GFNMS has advised operators of vessels of all sizes and classes to watch out for whales and reduce speeds. From 2012–2021, GFNMS further requested vessels 300 gross tons or larger to voluntarily travel at 10 knots or less in the San Francisco TSS. Beginning in 2022, at the recommendation of the GFNMS and CBNMS advisory councils, the voluntary vessel speed reduction zone was expanded throughout the full extent of both sanctuaries. Since 2015, GFNMS—first in partnership with CBNMS and then later in partnership with ONMS, the National Marine Fisheries Service, USCG, and EPA—has analyzed AIS data for large vessel traffic and has sent letters to shipping companies reporting on vessel speed reduction cooperation. In the San Francisco region, cooperation with the voluntary requests by all large vessels grew from 28% in 2015 to 61% in 2022. Point Blue Conservation Science estimated that this level of cooperation resulted in a reduction in ship strike risk of ~25% for blue and humpback whales in the region compared to 2014 levels. ACCESS (see Box 1) monitored the distribution and abundance of whales in the sanctuary, and these data have been used to inform management actions and assess effectiveness of reducing the risk of lethal vessel strikes to whales.

In 2017, in order to motivate greater cooperation with the federal voluntary vessel speed reduction requests from cargo and tanker vessels in the region, GFNMS began partnering with Channel Islands National Marine Sanctuary, the Bay Area Air Quality Management District, and non-profit partners on the Protecting Blue Whales and Blue Skies Program. In early years, the program offered financial incentives for enrolled shipping lines to cooperate with voluntary speed reduction requests to increase protections for endangered whales and reduce air emissions. Since 2017, shipping lines enrolled in the program have collectively contributed to a reduction of three tons of diesel particulate matter, 487 tons of nitrogen oxides, and 15,989 metric tons of CO_2 emitted in the San Francisco region.

In 2012, the Sanctuary Advisory Council recommended GFNMS monitor and reduce acoustic impacts to whales. GFNMS worked with CBNMS, which initiated a program to characterize the sanctuary's soundscape to better understand acoustic impacts. In 2015, a noise reference station was installed in CBNMS at the GFNMS border to record underwater ambient sound in the two sanctuaries. These data have allowed scientists to create a local low-frequency soundscape profile, identifying significant sources and intensity of noise and its variability.

In response to water quality concerns in Tomales Bay, GFNMS, in partnership with the California State Lands Commission, implemented the Tomales Bay Vessel Mooring Program in 2015. This program removed vessel moorings and unpermitted docks from sensitive eelgrass habitat and designated official mooring zones in areas where eelgrass beds were unlikely to spread. The mooring program prohibited installation of moorings in or near eelgrass beds in order to prevent damage to the beds from the anchors and chains. All moorings are subject to annual inspections, liability insurance, and current vessel registration. Since 2016, GFNMS has worked with NOAA's Office of Law Enforcement and the California State Lands Commission to remove moorings from eelgrass beds and relocate them. The eelgrass beds previously impacted by mooring anchors and chains have begun to show signs of recovery. The small number of moorings known to exist in Bolinas Lagoon are currently in the permit review process by Marin County.

Responses to Wildlife Disturbance

GFNMS continued to lead projects that prevented disturbances to wildlife to ensure healthy populations in the sanctuary. In 2009, GFNMS white shark disturbance and attraction regulations became effective, and soon after, GFNMS implemented the White Shark Stewardship Project to increase awareness of the regulation and the importance of white sharks to the sanctuary ecosystem. The project included public and boater outreach, white shark boat tour naturalist training, school education programs, permitting of white shark tours, and monitoring. In September 2022, Governor Gavin Newsom signed into law Assembly Bill 2109, which adds additional protections for white sharks in California waters under the California Fish and Game Code, section 5517 (CDFW, 2022g). Effective on January 1, 2023, this new law prohibits the use of shark bait, shark lures, or shark chum to attract a white shark (including, but not limited to, blood, fish, or other material upon which sharks may feed, as well as decoys on the surface or underwater). This state law is expected to further reduce disturbances to white sharks in sanctuary waters.

Protecting seabird colonies from disturbance increases local seabird population resilience to climate-related pressures by reducing the need for seabirds to unnecessarily expend energy. The Seabird Protection Network, led by GFNMS and the U.S. Fish and Wildlife Service, collaborated with multiple federal and state agencies to study, characterize, and address disturbance to seabirds using a combination of regulations and outreach focused on the most vulnerable colony locations. By employing environmental behavior design tools, boaters and pilots, the main sources of disturbance, pledged to avoid disturbing wildlife within the sanctuary. This engagement campaign, combined with NOAA regulated overflight zones and state special closures, proved effective at reducing wildlife disturbances within GFNMS.

Responses to Marine Debris

To reduce marine debris and pollution, GFNMS regulations prohibit the discharge of material or matter into the sanctuary; placing or abandoning any structure on sanctuary submerged lands; deserting a vessel aground, at anchor, or adrift in the sanctuary; and leaving harmful matter aboard a deserted vessel (15 C.F.R. 922.82). However, grounded vessels have been abandoned by uninsured or underinsured vessel owners. To address this problem, GFNMS staff participated in committees and working groups with partner agencies and the public devoted to addressing vessel incidents. GFNMS also worked with the NOAA Marine Debris Program to track debris, identify potential salvage funding sources, and strategize on future management actions. GFNMS contributed information on grounded and sunken vessels for an ONMS West Coast Regional Office report to the ONMS director and provided recommendations to improve response and prevent future incidents. The recommendations included seven strategies that aimed to track incidents, understand causes, develop best practices, improve insurance coverage, support investigations, and seek stable funding. Additionally, in response to a dry dock that sank on the border of GFNMS and MBNMS, GFNMS developed a draft restoration plan in partnership with MBNMS that proposed to restore deep-sea coral habitat in both sanctuaries.

MBNMS served as the ONMS West Coast Region representative on a California Dungeness Crab Fishing Gear Working Group established to identify and respond to the elevated risk of whale entanglements in California Dungeness crab fishing gear as a result of changing ocean conditions and habitat compression. A Risk Assessment and Mitigation Program was developed by the working group to assess circumstances where entanglement risk may be elevated and, as needed, identify possible management measures to reduce whale entanglements, including in GFNMS.

Responses to Non-Indigenous Species

Since 2009, GFNMS has worked with the Greater Farallones Association, the Smithsonian Environmental Research Center, University of California Davis, Portland State University, and community volunteers to implement the Green Crab Removal Project. During the summer, project managers implemented a four-week-long removal event, dispersing 90 crab traps each day and recording data (size, sex, physical characteristics) for every crab. Thousands of crabs were removed from Seadrift Lagoon, a water body adjacent to the sanctuary that is connected by underwater culverts, and donated to local farms to compost for fertilizer. Green crab population numbers in Seadrift Lagoon have stabilized at a reduced number, supporting the goal of limiting the introduction of green crabs into Bolinas Lagoon, a UNESCO Ramsar Site.

Starting in 2012, GFNMS partnered with the Greater Farallones Association and Marin County to reduce non-indigenous plants on Kent Island, which impact sediment flow in Bolinas Lagoon. The multiple invasive species, including Monterey pine, European beach grass, iceplant, and French broom, capture and stabilize the island's sands, anchoring it in place and preventing it from functioning as a flood shoal island. The project is still underway, but has already improved hydrologic function and reduced siltation (Baye & Carmen, 2012).

Conclusion

GFNMS, a nationally and internationally significant marine environment located next to a major metropolitan area of almost 8 million people, faces many pressures locally as well as globally, including from climate change. Responding to pressures requires a long-term commitment and partnerships with international, national, state, and local entities. To successfully reduce stress on the ecosystem, GFNMS must continue to conduct scientific research and monitoring, enforce regulations, increase regulatory compliance, identify and address emerging threats, restore degraded habitats and impacted species, and engage communities as stewards to increase ecosystem resilience and health.

The above responses to threats to sanctuary summarize major GFNMS actions from 2010 to 2022. The dynamic and emerging nature of external pressures requires recurring assessment and adaptation as part of the sanctuary management cycle. This condition report will inform the next sanctuary management plan update by identifying threats and areas of concern, helping the public and GFNMS identify priority actions, and providing a baseline to measure the effectiveness of management actions in order to manage human activities that allow the sanctuary and the communities that rely upon the sanctuary to thrive.

Concluding Remarks

Concluding Statement from Greater Farallones National Marine Sanctuary Superintendent Maria Brown

This is the first time GFNMS will have a condition report that provides a snapshot of the status and trends of human activities and resources in the sanctuary, as well as the importance of the sanctuary for providing ecosystem services, prior to developing a management plan. The first condition report for GFNMS, published in 2009 when the sanctuary was 1,282 square miles in size, provides a reference point, but not a direct comparison of status and trends within the sanctuary. The sanctuary expanded in 2015 to its current size of 3,295 square miles, adding new habitat, such as bull kelp forests, and new areas to characterize and monitor.

The 2010–2022 condition report establishes a baseline for the status and trends of resources and ecosystem services in the expanded sanctuary. The data presented in this report will guide recommendations for research and monitoring; education and outreach; and policies and programs in the next GFNMS management plan review, which will be conducted jointly with CBNMS. The executive summary provides a succinct overview of findings and a summary of the overall condition of the sanctuary.

The development of a condition report is an important step in a sanctuary's management process. The report summarizes the health of the ecosystem and community engagement through recreational and commercial activities within the ecosystem over the last 10 or more years. Through extensive data collection and analysis, GFNMS staff, along with over 110 experts, summarized and reviewed 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. GFNMS is scheduled to begin 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 GFNMS 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

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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 includes 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. These criteria include 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 GFNMS condition report began with sanctuary staff conducting a literature review of previous work focused on indicators in the region. GFNMS 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 GFNMS 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 May, June, and July of 2022 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 (science, education, heritage, sense of place, consumptive recreation, non-consumptive recreation, commercial harvest, and coastal protection). 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 data sets ONMS collected prior to the meeting.

Attendees were then asked to review the indicators and data sets, identify data gaps or misrepresentations, and suggest any additional data sets that may be relevant. Once all data sets were reviewed, experts were asked to provide status and trend recommendations and supporting arguments. GFNMS'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. 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 October 2023, 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.

Greater Farallones National Marine Sanctuary Confidence Ratings from May, June, and July 2022 Virtual Expert Workshops

Table App.C.1. A summary of ratings and associated confidence levels for resources in the coastal and offshore region of GFNMS.

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
2. Human Activities/ Water Quality	July 11	Status: Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	High	High
3. Human Activities/ Habitat[35]	July 11	Status: Fair/Poor	Medium	High	High
		Trend: Undetermined	Limited	High	Medium
4. Human Activities/Living Resources	July 11	Status: Fair	Medium	High	High
		Trend: Mixed	Medium	High	High
5. Human	July 6	Status: Good/Fair	Limited	High	Medium

[35] During the workshop to assess status and trend for this question, experts were initially divided on whether to rate the status “fair” or “fair/poor.” They chose a final rating of “fair/poor” because effects appeared to be widespread or persistent based on several indicators, especially marine debris, which is persistent and accumulates over time in habitats. Most experts were also concerned about widespread impacts to benthic and water column habitats from crab pots and to benthic habitats from trawling activities. The experts rated the evidence for this rating as medium and the agreement and confidence both as high. However, GFNMS staff subsequently changed this rating to “fair.” While GFNMS concurs that impacts are widespread and have caused damage in some areas, the data did not sufficiently show that impacts were severe, and the “fair/poor” rating was therefore unwarranted. GFNMS staff also changed the evidence for this status rating to “low” based on the limited data available for these indicators and the agreement to “medium” given the difference of opinion between experts and staff, resulting in a “low” confidence score.

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Activities/Maritime Heritage Resources		Trend: Improving	Medium	Medium	Medium
6. Water Quality/ Eutrophication	May 16	Status: Good	Medium	High	High
		Trend: Undetermined	Limited	High	Medium
7. Water Quality/Risk to Human Health	May 16	Status: Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	Medium	Medium
8. Water Quality/Climate Change	June 6	Status: Fair	Medium	High	High
		Trend: Worsening	Medium	Medium	Medium
9. Water Quality/Other Stressors[36]	May 19	Status: Good/Fair	Limited	Medium	Low
		Trend: Mixed	Medium	Medium	Medium
10. Habitat/Integrity	June 9	Status: Fair	Medium	Medium	Medium
		Trend: Mixed	Limited	High	Medium
11. Habitat/ Contaminants	May 19	Status: Good/Fair	Medium	High	High
		Trend: Mixed	Medium	High	High
12. Living Resources/ Keystone and Foundation Species	June 7	Status: Fair/Poor	Medium	High	High
		Trend: Mixed	Medium	High	High
13. Living Resources/Other Focal Species	June 7	Status: Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	High	High
14. Living	May 24	Status: Good	Limited	Medium	Low

[36] A status rating and associated confidence score were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Resources/Non-Indigenous Species		Trend: Undetermined	Limited	High	Medium
15. Living Resources/ Biodiversity	June 9	Status: Good/Fair	Medium	High	High
		Trend: Mixed	Medium	High	High
16. Maritime Heritage Resources/ Condition	July 6	Status: Good/Fair	Limited	High	Medium
		Trend: Not changing	Limited	Medium	Low

Table App.C.2. A summary of ratings and associated confidence levels for resources in the estuarine and lagoon region of GFNMS.

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
2. Human Activities/Water Quality	May 17	Status: Fair	Limited	Medium	Low
		Trend: Mixed	Limited	Medium	Low
3. Human Activities/Habitat	May 17	Status: Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
4. Human Activities/Living Resources	May 17	Status: Good/Fair	Limited	High	Medium
		Trend: Not changing	Limited	High	Medium
5. Human Activities/Maritime	July 6	Status: Good	Medium	Medium	Medium

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
Heritage Resources		Trend: Improving	Medium	Medium	Medium
6. Water Quality/ Eutrophication	May 16	Status: Good/Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
7. Water Quality/Risk to Human Health	May 16	Status: Fair	Medium	High	High
		Trend: Undetermined	Medium	High	High
8. Water Quality/Climate Change[37]	June 6	Status: Fair	Limited	Medium	Low
		Trend: Undetermined	Limited	High	Medium
9. Water Quality/Other Stressors	May 19	Status: Fair	Medium	High	High
		Trend: Undetermined	Limited	Medium	Low
10. Habitat/Integrity	June 9	Status: Fair/Poor	Limited	High	Medium
		Trend: Not changing	Medium	High	High
11. Habitat/ Contaminants	May 19	Status: Fair	Limited	Medium	Low
		Trend: Mixed	Limited	Medium	Low

37 Status and trend ratings and associated confidence scores were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status and trend ratings and associated confidence scores.

Question	Virtual Workshop Date (2022)	Rating	Evidence (Limited, Medium, Robust)	Agreement (Low, Medium, High)	Confidence (Very Low, Low, Medium, High, Very High)
12. Living Resources/ Keystone and Foundation Species[38]	June 7	Status: Fair	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
13. Living Resources/Other Focal Species	June 7	Status: Fair/Poor	Limited	High	Medium
		Trend: Undetermined	Limited	Medium	Low
14. Living Resources/Non-Indigenous Species	May 24	Status: Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	High	High
15. Living Resources/ Biodiversity	June 9	Status: Undetermined	Limited	High	Medium
		Trend: Undetermined	Limited	High	Medium
16. Maritime Heritage Resources/ Condition	July 6	Status: Good	Limited	High	Medium
		Trend: Not changing	Limited	Medium	Low

[38] A status rating and associated confidence score were not determined during the expert workshop. Following the workshop, GFNMS staff reevaluated the indicators, data sets, and expert input that was received during the workshop and made a final determination for the status rating and associated confidence score.

Table App.C.3. A summary of ratings and associated confidence levels for ecosystem services in GFNMS.

Ecosystem Services	**Virtual Workshop Date**	**Rating**	**Evidence (Limited, Medium, Robust)**	**Agreement (Low, Medium, High)**	**Confidence (Very Low, Low, Medium, High, Very High)**
Science	June 10	Status: Good/Fair	Medium	High	High
		Trend: Improving	Medium	Low	Low
Education	June 15	Status: Good/Fair	Robust	High	Very High
		Trend: Improving	Robust	High	Very High
Heritage	July 6	Status: Good	Medium	High	High
		Trend: Improving	Medium	High	High
Sense of Place	June 15	Status: Good/Fair	Medium	High	High
		Trend: Improving	Medium	High	High
Consumptive Recreation	July 7	Status: Fair	Medium	High	High
		Trend: Undetermined	Limited	Medium	Low
Non-Consumptive Recreation	July 7	Status: Good/Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	Medium	Medium

Ecosystem Services	**Virtual Workshop Date**	**Rating**	**Evidence (Limited, Medium, Robust)**	**Agreement (Low, Medium, High)**	**Confidence (Very Low, Low, Medium, High, Very High)**
Commercial Harvest	July 7	Status: Good/Fair	Medium	Medium	Medium
		Trend: Mixed	Medium	High	High
Coastal Protection	July 5	Status: Fair/Poor	Medium	Medium	Medium
		Trend: Undetermined	Limited	High	Medium

Appendix D: Selection of Indicator Focal Species and Definition of Habitat Importance

Selection of Indicator Focal Species

Of the 1,140 species known to occur in GFNMS (ONMS, 2014a), 92 are considered to be focal species in this report (i.e., species and taxa that require close attention from the perspective of sanctuary management and may be targeted for special protection; Table App.D.1). Of the 92 focal species of highest concern to sanctuary management, 14 taxa were selected as indicators of the status and trends of focal species and taxa (Table S.LR.13.1; Table S.LR.13.2). The indicator species represent species or taxa that forage at different trophic levels, may be federally listed as endangered or threatened, are important prey species for birds and mammals, and/or are species that are highly dependent on the sanctuary for breeding, productivity, and foraging.

The following taxa were selected to indicate status and trend of focal species in the coastal and offshore and estuarine and lagoon regions of the sanctuary:

1. Brant (*Branta bernicla*)
2. Brandt's cormorant (*Urile penicillatus*)
3. Common murre (*Uria aalge*)
4. White shark (*Caracharodon carcharias*)
5. California mussel (*Mytilus californianus*)
6. Cassin's auklet (*Ptychoramphus aleuticus*)
7. Humpback whale (*Megaptera novaeangliae*)
8. Juvenile rockfish (*Sebastes* spp.)
9. Olympia oyster (*Ostrea lurida*)
10. Red abalone (*Haliotis rufescens*)
11. Sea palm (*Postelsia palmaeformis*)
12. Shorebirds
13. Snowy plover (*Charadrius nivosus*)
14. Willet (*Tringa semipalmata*)

Definition of Habitat Importance

The GFNMS management plan (ONMS, 2014a) categorized the level of importance of sanctuary habitats to the health and integrity of 92 of focal species. These "habitat importance" categories include: 1) extremely important (EI), 2) very important (V), and 3) somewhat important (S). Table App.D.1 indicates Habitat Importance for each GFNMS focal species.

Sanctuary habitat is extremely important (EI) to a species when a significant portion of the population occurs in the sanctuary year-round or is seasonally present; the species forages in the sanctuary during its breeding season or the sanctuary is a destination feeding ground; and the species or a distinct population segment is federally listed as endangered, threatened, or delisted, or has critical habitat within the sanctuary.

Sanctuary habitat is very important (V) to a species when the species may be uncommon in sanctuary or is a foundation or keystone species; a significant portion of the population occurs in the sanctuary year-round or is seasonally present; and the species forages in the sanctuary during its breeding season or the sanctuary is a destination feeding ground, or is federally listed as endangered or threatened or has critical habitat within the sanctuary, or a significant portion of the population is found in the sanctuary and uses the sanctuary as a destination feeding ground.

Sanctuary habitat is somewhat important (S) to the species when the species is common in sanctuary and forages in the sanctuary during its breeding season or uses the sanctuary as a destination feeding ground.

Table App.D.1. List of focal species at GFNMS. Federal status indicates whether a species is endangered (E), threatened (T), or delisted since designation of the sanctuary (D). Habitat importance categories are extremely important (EI), very important (V), or somewhat important (S). Source: ONMS, 2014a

Common Name	Scientific Name	Category	Federal Status	Forages in Sanctuary	Breeds in Sanctuary	Critical Habitat in Sanctuary	Habitat Importance
Brant	*Branta bernicla*	Bird		x			S
Canada goose	*Branta canadensis*	Bird		x	x		S
Black-footed albatross	*Phoebastria nigripes*	Bird		x			V
Short-tailed albatross	*Phoebastria albatrus*	Bird	E	x			EI
Dark-rumped /Hawaiian petrel	*Pterodroma sandwichensis*	Bird	E	x			EI
Sooty shearwater	*Ardenna griseus*	Bird		x			S
Ashy storm-petrel	*Oceanodroma homochroa*	Bird		x	x		V
Brandt's cormorant	*Phalacrocorax penicillatus*	Bird		x	x		V
Brown pelican	*Pelecanus occidentalis*	Bird		x			S
Bald eagle	*Haliaeetus leucocephalus*	Bird	D	x	x		EI
Black oystercatcher	*Haematopus bachmani*	Bird		x	x		V
Snowy plover	*Charadrius alexandrinus*	Bird	T	x	x	x	EI
Willet	*Catoptrophorus semipalmatus*	Bird		x			S
Common murre	*Uria aalge californica*	Bird		x	x		V
Pigeon guillemot	*Cepphus columba*	Bird		x	x		V
Marbled murrelet	*Brachyramphus marmoratus*	Bird	T	x	x	x	EI
Cassin's auklet	*Ptychoramphus aleuticus*	Bird		x	x		V
Rhinoceros auklet	*Cerorhinca monocerata*	Bird		x	x		V
Peregrine falcon	*Falco peregrinus*	Bird	D	x	x		EI
Blue whale	*Balaenoptera musculus*	Mammal	E	x			EI
Fin whale	*Balaenoptera physalus*	Mammal	E	x			V
Sei whale	*Balaenoptera borealis*	Mammal	E	x			V

Common Name	Scientific Name	Category	Federal Status	Forages in Sanctuary	Breeds in Sanctuary	Critical Habitat in Sanctuary	Habitat Importance
Minke whale	*Balaenoptera acutorostrata*	Mammal		x	x		S
Humpback whale, Mexico DPS	*Megaptera novaeangliae*	Mammal	T	x		x	EI
Humpback whale, Central America DPS	*Megaptera novaeangliae*	Mammal	E	x		x	EI
Gray whale, eastern population	*Eschrichtius robustus*	Mammal	E	x			V
Gray whale, western population	*Eschrichtius robustus*	Mammal	D				V
Right whale, North Pacific	*Eubalaena japonica*	Mammal	E	x			V
Harbor porpoise	*Phocoena phocoena*	Mammal		x	x		S
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*	Mammal		x	x		S
Killer whale, southern resident stock	*Orcinus orca*	Mammal	E	x		x	EI
Killer whale, offshore stock	*Orcinus orca*	Mammal		x			S
Killer whale, transient stock	*Orcinus orca*	Mammal		x			S
Sperm whale	*Physeter macrocephalus*	Mammal	E	x			V
Steller sea lion, WA, OR, CA stock	*Eumetopius jubatus*	Mammal	D	x		x	EI
Northern fur seal	*Callorhinus ursinus*	Mammal		x	x		S
Guadalupe fur seal	*Arctocephalus townsendi*	Mammal	T	x			S
Northern elephant seal	*Mirounga angustirostris*	Mammal		x	x		S
Harbor seal	*Phoca vitulina richardii*	Mammal		x	x		S
Southern sea otter	*Enhydra lutris nereis*	Mammal	T	x			V
Southern green sturgeon	*Acipenser medirostris*	Fish	T	x	x	x	EI
White shark	*Carcharodon carcharias*	Fish		x			S
Pacific herring	*Clupea pallasii*	Fish		x	x		S
Northern anchovy	*Engraulis mordax*	Fish		x	x		V
Pacific halibut	*Hippoglossus stenolepis*	Fish		x	x		S

Common Name	Scientific Name	Category	Federal Status	Forages in Sanctuary	Breeds in Sanctuary	Critical Habitat in Sanctuary	Habitat Importance
Tidewater goby	*Eucyclogobius newberryi*	Fish	E	x	x	x	EI
Chum salmon	*Oncorhynchus keta*	Fish	T	x			V
Coho salmon (silver salmon)	*Oncorhynchus kisutch*	Fish	E & T	x			V
Rainbow trout (steelhead)	*Oncorhynchus mykiss*	Fish		x			S
Chinook salmon	*Oncorhynchus tshawytscha*	Fish	E & T	x			V
Pacific sardine	*Sardinops sagax*	Fish		x	x		V
Starry rockfish	*Sebastes constellatus*	Fish		x	x		S
Widow rockfish	*Sebastes entomelas*	Fish		x	x		S
Yellowtail rockfish	*Sebastes flavidus*	Fish		x	x		S
Bocaccio	*Sebastes paucispinis*	Fish		x	x		S
Rosy rockfish	*Sebastes rosaceus*	Fish		x	x		S
Yelloweye rockfish	*Sebastes ruberrimus*	Fish	T	x	x		V
Cowcod	*Sebastes levis*	Fish		x	x		S
Petrale sole	*Eopsetta jordani*	Fish		x	x		S
Canary rockfish	*Sebastes pinniger*	Fish		x	x		S
Darkblotched rockfish	*Sebastes crameri*	Fish		x	x		S
Pacific ocean perch	*Sebastes alutus*	Fish		x	x		S
Blue rockfish	*Sebastes mystinus*	Fish		x	x		S
Cabezon (CA)	*Scorpaenichthys marmoratus*	Fish		x	x		S
Pacific whiting (hake)	*Merluccius productus*	Fish		x	x		S
Sablefish	*Anoplopoma fimbria*	Fish		x	x		S
Kelp greenling	*Hexagrammos decagrammus*	Fish		x	x		S
Starry flounder	*Platichthys stellatus*	Fish		x	x		S
Blackgill rockfish	*Sebastes melanostomus*	Fish		x	x		S
Black rockfish (OR/CA)	*Sebastes melanops*	Fish		x	x		S

Common Name	Scientific Name	Category	Federal Status	Forages in Sanctuary	Breeds in Sanctuary	Critical Habitat in Sanctuary	Habitat Importance
Shortspine thornyhead	*Sebastolobus alascanus*	Fish		x	x		S
Dover sole	*Microstomus pacificus*	Fish		x	x		S
Longnose skate	*Raja rhina*	Fish		x	x		S
Splitnose Rockfish	*Sebastes diploproa*	Fish		x	x		S
Chilipepper	*Sebastes goodei*	Fish		x	x		S
Longspine thornyhead	*Sebastolobus altivelis*	Fish		x	x		S
Lingcod (CA)	*Ophiodon elongatus*	Fish		x	x		S
Arrowtooth flounder	*Atheresthes stomias*	Fish		x	x		S
Greenstriped rockfish	*Sebastes elongatus*	Fish		x	x		S
California scorpionfish	*Scorpaena guttata*	Fish		x	x		S
Gopher rockfish	*Sebastes carnatus*	Fish		x	x		S
English sole	*Parophrys vetulus*	Fish		x	x		S
Green sea turtle, East Pacific DPS	*Chelonia mydas*	Reptile	T	x			V
Loggerhead turtle, North Pacific DPS	*Caretta caretta*	Reptile	E	x			V
Leatherback turtle, East Pacific DPS	*Dermochelys coriacea*	Reptile	E	x		x	EI
Pacific (olive) ridley, East Pacific DPS	*Lepidochelys olivacea*	Reptile	E	x			V
Black abalone	*Haliotis cracherodii*	Invertebrate	E	x	x	x	EI
Red abalone	*Haliotis rufescens*	Invertebrate		x	x		V
Eelgrass	*Zostera marina*	Plant/algae		x	x		V
Surf grass	*Phyllospadix scouleri*	Plant/algae		x	x		V
Bull kelp	*Nereocystis luetkeana*	Plant/algae		x	x		V
Sea palm	*Postelsia palmaeformis*	Plant/algae		x	x		S

Appendix E:
Ratings From the 2010 Gulf of the Farallones Condition Report

Table App.E.1. Questions, status and trend ratings, and basis for judgment for the **coastal and offshore region** from the *2010 Gulf of the Farallones Condition Report*. Note that question numbering and wording in the 2010 report differs from that of the 2010–2022 report. Source: ONMS, 2010

#	Question	Rating	Basis for Judgment
1	Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?	—	Decreased oil pollution, decreased sediment spills from barges, few harmful algal blooms, continued nonpoint source discharges from San Francisco Bay and Russian River, and coastal 303(d) listings.
2	What is the eutrophic condition of sanctuary waters and how is it changing?	?	No obvious problems, healthy phytoplankton constituents; only 15 years of monitoring for phytoplankton so trend undetermined.
3	Do sanctuary waters pose risks to human health?	—	Coastal 303(d) listings for discharges and beach closures; offshore dilution.
4	What are the levels of human activities that may influence water quality and how are they changing?	▲	Increasing vessel traffic (discharges and noise) and increasing urbanization are of concern, but decrease in acute and chronic oil pollution, decreasing sediment discharge; increasing management and enforcement actions.
5	What are the abundance and distribution of major habitat types and how are they changing?	▲	Some benthic habitat loss from localized pressures related to increased human activities, reduced trawling impacts and improved enforcement of dredge disposal practices.
6	What is the condition of biologically structured habitats and how is it changing?	?	Prior alteration and loss due to trawling; substantial data gaps for a number of habitat types, including drift algae and beach wrack.
7	What are the contaminant concentrations in sanctuary habitats and how are they changing?	▲	New but limited data indicate reduction of persistent contaminants and no obvious problems.
8	What are the levels of human activities that may influence habitat quality and how are they changing?	—	Activities relating to increased urbanization, visitation, and shipping; decrease in trawling and chronic oil pollution, cessation of discharging of radioactive waste, increased regulations to prevent introduced species.
9	What is the status of biodiversity and how is it changing?	—	Changes in relative abundance, particularly in targeted, bycatch, and sensitive species (e.g., Steller sea lions, northern fur seals, seabirds, rockfish, and sea otters).

#	Question	Rating	Basis for Judgment
10	What is the status of environmentally sustainable fishing and how is it changing?	▲	Historical fishing impacts; recent improvements in some populations due to take reductions.
11	What is the status of non-indigenous species and how is it changing?	–	Non-indigenous species are present (e.g., green crabs, plankton, and striped bass), but there are no known ecosystem impacts; monitoring is required.
12	What is the status of key species and how is it changing?	?	Among the sanctuary's list of 49 key species, populations are in varying states of integrity.
13	What is the condition or health of key species and how is it changing?	▲	Underweight gray whales; reduced Steller sea lion health and pupping rates; removal of oil from SS *Jacob Luckenbach* has reduced seabird and marine mammal oiling incidents.
14	What are the levels of human activities that may influence living resource quality and how are they changing?	–	Impacts from human population increases, urbanization, and increased use of coastal areas. Increasing vessel traffic (discharges and noise) and increased documented disturbances to seabirds and marine mammals are of concern, perhaps offset by reductions in trawling and fishing pressure, and establishment of new marine zones.
15	What is the integrity of known maritime archaeological resources and how is it changin?	?	Sanctuary inventory contains information on known vessel losses; archaeological survey and monitoring needs to be conducted to determine status and trend.
16	Do known maritime archaeological resources pose an environmental hazard and how is this threat changing?	▼	Deterioration of offshore wrecks could result in the release of hazardous cargo of bunker fuel.
17	What are the levels of human activities that may influence maritime archaeological resource quality and how are they changing?	?	Trawling, anchoring or dragging of anchors, diving; lack of monitoring to determine trend; regulations to prohibit trawling in some areas; regulations to prohibit laying of cables.

Table App.E.2. Questions, status and trend ratings, and basis for judgment for the **estuarine and lagoon region** from the *2010 Gulf of the Farallones Condition Report*. Note that question numbering and wording in the 2010 report differs from that of the 2010–2022 report. Source: ONMS, 2010

#	Question	Rating	Basis for Judgment
1	Are specific or multiple stressors, including changing oceanographic and atmospheric conditions, affecting water quality?	?	Land use pressures have caused changes to sediment and freshwater regimes; increased restoration activities and best management practices may offset water quality problems that have historically resulted in loss of eelgrass beds.
2	What is the eutrophic condition of sanctuary waters and how is it changing?	?	High levels of nutrient input have caused eutrophication, severe oxygen depletion, and shellfish contamination in the Tomales Bay watershed. However, there have not been associated problems of reported loss of fish populations.
3	Do sanctuary waters pose risks to human health?	?	Nonpoint source contamination has resulted in aquaculture and shellfish closures in Tomales Bay; two norovirus outbreaks in Tomales Bay. Best management practices have been implemented and further studies are required to determine their success.
4	What are the levels of human activities that may influence water quality and how are they changing?	▲	Land use pressures have caused changes to sediment and freshwater regimes; loss of eelgrass beds; increased restoration activities, increased regulations, and best management practices may allow for improvements.
5	What are the abundance and distribution of major habitat types and how are they changing?	—	Habitat loss due to erosion, habitat conversion, and sedimentation.
6	What is the condition of biologically structured habitats and how is it changing?	▼	Loss of eelgrass in Bolinas Lagoon due to watershed issues causing sedimentation and elevation of mudflats. Loss of native oyster beds in Tomales Bay due to sedimentation, roadside maintenance activities, anchoring, and mooring.
7	What are the contaminant concentrations in sanctuary habitats and how are they changing?	?	Limited data, though bird studies in other estuarine areas strongly suggest the need for increased monitoring.
8	What are the levels of human activities that may influence habitat quality and how are they changing?	—	Impacts from continued land use, urbanization, erosion, pollutants from closed mines, and vessel activities may be offset by reduced mining activities, restoration activities, and new regulations.
9	What is the status of biodiversity and how is it changing?	▼	Species diversity changes due to eelgrass loss in Bolinas Lagoon and invasive species.

#	Question	Rating	Basis for Judgment
10	What is the status of environmentally sustainable fishing and how is it changing?	—	Minimal extraction.
11	What is the status of non-indigenous species and how is it changing?	?	High numbers of invasive species including European green crabs, Japanese mud snails, and smooth cordgrass. Limited data are available on the density or geographic extent of most non-indigenous species.
12	What is the status of key species and how is it changing?	▼	Keystone and some key species are at reduced levels; eelgrass in Bolinas Lagoon is likely to diminish recovery potential; abundance of the tidewater goby has declined substantially due to habitat loss and degradation; brant populations had been on the decline and are now increasing, but recovery is slow.
13	What is the condition or health of key species and how is it changing?	?	Insufficient data. Some fish have high mercury levels; it is unknown how this may impact fish populations. Disturbance to harbor seals may impact their health.
14	What are the levels of human activities that may influence living resource quality and how are they changing?	▼	Impacts resulting from urbanization, changing uses that affect watershed, and wildlife disturbance caused by visitor activities; management activities to increase monitoring of and outreach about introduced species are needed; restoration planning needs to be implemented in Bolinas Lagoon and completed for vessel activities in Tomales Bay.
15	What is the integrity of known maritime archaeological resources and how is it changin?	?	No wreck sites have been visited or investigated.
16	Do known maritime archaeological resources pose an environmental hazard and how is this threat changing?	—	Unlikely that the wrecks (mostly wooden schooners) contain hazardous cargo.
17	What are the levels of human activities that may influence maritime archaeological resource quality and how are they changing?	?	Bottom fishing, aquaculture, and habitat and living resource restoration activities could affect resources.

Appendix F: Glossary of Acronyms

ACCESS	Applied California Current Ecosystem Studies
AIS	automatic identification system
BOEM	Bureau of Ocean Energy Management
CBNMS	Cordell Bank National Marine Sanctuary
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CHRIS	California Historical Resources Information System
CO_2	carbon dioxide
CPUE	catch per unit effort
CSWRCB	California State Water Resources Control Board
CUTI	Coastal Upwelling Transport Index
DDT	dichlorodiphenyltrichloroethane
DPSER	Driving Forces (Drivers)-Pressure-State-Ecosystem Services-Response
EGCS	exhaust gas cleaning system
ENSO	El Niño-Southern Oscillation
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GDP	gross domestic product
GFNMS	Greater Farallones National Marine Sanctuary
GLM	generalized linear model
HAB	harmful algal bloom
LiMPETS	Long-term Monitoring Program and Experiential Training for Students
LUSI	Length of Upwelling Season Index
MARINe	Multi-Agency Rocky Intertidal Network
MBNMS	Monterey Bay National Marine Sanctuary
MHW	marine heatwave
MTL	mean trophic level
MV	motor vessel
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPGO	North Pacific Gyre Oscillation
NPP	net primary productivity

ONMS	Office of National Marine Sanctuaries
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PDO	Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
PSP	paralytic shellfish poisoning
RAI	relative abundance index
ROV	remotely operated vehicle
SF-DODS	San Francisco Deep Ocean Disposal Site
SFPUC	San Francisco Public Utilities Commission
SS	steamship
SST	sea surface temperature
TMDL	Total Maximum Daily Load
TSS	Traffic Separation Scheme
UAS	uncrewed aerial systems
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USCG	U.S. Coast Guard
USS	United States Ship
VMS	vessel monitoring system
XBT	expendable bathythermograph

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