Marine Sanctuaries Conservation Series ONMS-14-09

Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of National Marine Sanctuaries

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A Working Group of the Gulf of the Farallones National Marine Sanctuary Advisory Council

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Cover

(left) Shoreline along North-central California coast; (middle): Brandt's cormorant; (right, top to bottom): San Francisco tide gauge; Bull kelp; Gopher rockfish.

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Abstract

The impacts of climate change have been observed both globally and on regional scales, such as in the North-central California coast and ocean, a region that extends from Point Arena to Point Año Nuevo and includes the Pacific coastline of the San Francisco Bay Area. Because of the high economic and ecological value of the region's marine environment, Gulf of the Farallones National Marine Sanctuary (GFNMS) and other agencies and organizations have recognized the need to evaluate and plan for climate change impacts.

Climate change indicators provide information about the presence and potential impacts of climate change. While climate change indicators exist for the nation and for the state of California as a whole, no system of ocean climate indicators exist that specifically consider the unique characteristics of the North-central California coast and ocean region. To that end, GFNMS collaborated with over 50 federal, state, and regional natural resource managers, research scientists, and other partners to develop a set of eight physical and four biological ocean climate indicators specific to this region.

A smaller working group of regional experts developed overarching indicator monitoring recommendations, and specific metrics and monitoring goals, objectives, strategies, and activities for each of the twelve ocean climate indicators. Broadly speaking, these strategies are centered on maintaining existing indicator monitoring, and expanding or establishing new monitoring in critical habitats. To maximize the utility of these indicators for decision-makers, priority levels, current and potential future partners, funding requirements, and implementation timelines are provided for each indicator monitoring strategy.

Key Words

Climate change, ocean climate, indicator, Gulf of the Farallones National Marine Sanctuary, GFNMS, climate impact, fishes, seabirds, sensitive species, primary productivity, sea level, sea surface temperature, ocean acidification, dissolved oxygen, salinity, air temperature

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Executive Summary

The impacts of climate change, defined as increasing atmospheric and oceanic carbon dioxide and associated increases in average global temperature and oceanic acidity, have been observed both globally and on regional scales, such as in the North-central California coast and ocean, a region that extends from Point Arena to Point Año Nuevo and includes the Pacific coastline of the San Francisco Bay Area. Because of the high economic and ecological value of the region's marine environment, the Gulf of the Farallones National Marine Sanctuary (GFNMS) and other agencies and organizations have recognized the need to evaluate and plan for climate change impacts.

Climate change indicators can be developed on global, regional, and site-specific spatial scales and they provide information about the presence and potential impacts of climate change. While indicators exist for the nation and for the state of California as a whole, no system of ocean climate indicators exist that specifically consider the unique characteristics of the California coast and ocean region. To that end, GFNMS collaborated with over 50 regional, federal, and state natural resource managers, research scientists, and other partners to develop a set of ocean climate indicators specific to this region. A smaller working group of 13 regional partners developed monitoring goals, objectives, strategies, and activities for the indicators and recommended selected species for biological indicators, resulting in the Ocean Climate Indicators Monitoring Inventory and Plan. The working group considered current knowledge of ongoing monitoring, feasibility of monitoring, costs, and logistics in selecting monitoring activities and selected species.

Physical Indicators

The physical ocean climate indicators include:

- Ocean Water Properties
    - Sea Surface Temperature
    - Dissolved Oxygen
    - Sea Surface Salinity
    - Ocean Chemistry (pH)
- Sea Level
- Wave Height & Direction
- Atmospheric Properties
    - Air Temperature
    - Alongshore Wind Speed

Figure 1. Scientist Sampling Phytoplankton

Biological Indicators

The biological ocean climate indicators include:

- Primary Productivity
- Abundance, Biomass, & Phenology of Mid-Trophic Level Species
- Spatial Extent of Habitat-Forming Organisms
- Phenology, Productivity, & Diet of Seabirds

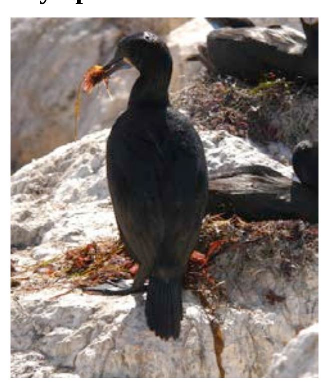

Figure 2. Brandt's Cormorant

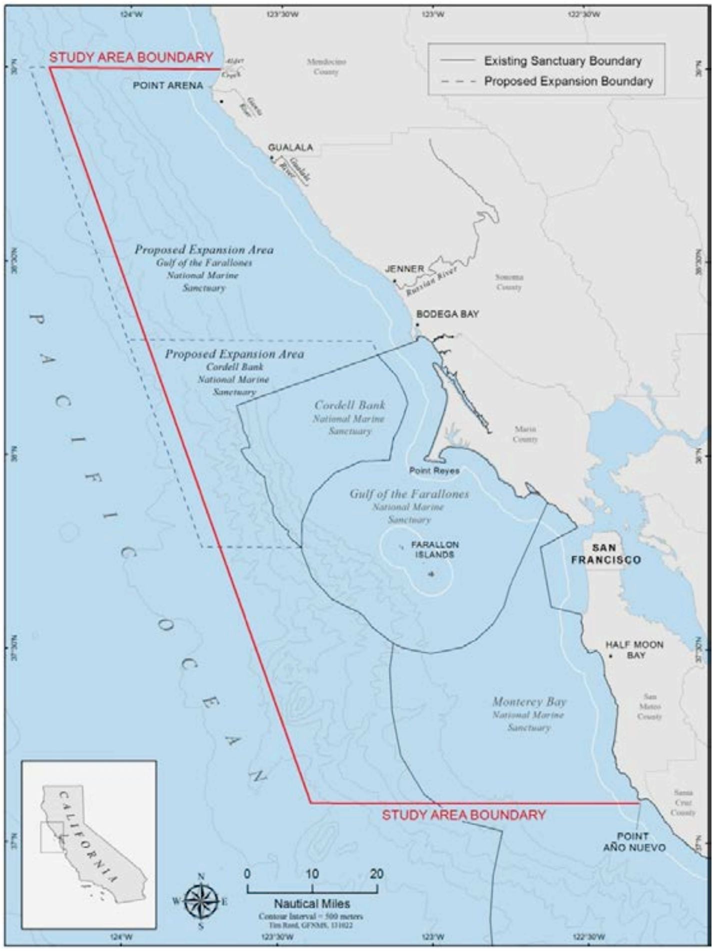

Figure 3. Map of study region (thick red lines), with related sanctuary boundaries (black solid lines) and proposed sanctuary expansion areas(black dashed lines)

Regional Ocean Climate Indicators Monitoring Goal and Objectives

Monitoring Goal:
Promote comprehensive and coordinated management of marine resources by increasing understanding of the ecological impacts of climate change on the North-central California coast and ocean region, through the monitoring and evaluation of physical and biological ocean climate indicators.

Objectives to Meet the Monitoring Goal:

1. Determine the status and trends of ocean climate indicators along the North-central California coast and ocean region through existing monitoring programs and by identifying needs and opportunities for new or expanded monitoring efforts.

2. Assess the vulnerability of specific geographic areas, ecosystems, and ecosystem components within the North-central California coast and ocean region to the impacts of climate

Indicators Monitoring Strategies and Activities

The Indicators Working Group identified several overarching indicator monitoring recommendations:

1. Continued and/or expanded financial support for ongoing indicator monitoring is vital for science-based climate change decision-making because it allows for identification of long-term, climate-scale changes in the region's ecosystems.
2. Expanded or new indicator monitoring would provide important information for natural resource managers.
3. Synthesis of existing regional climate change research is key to ensuring that monitoring is as efficient and useful as possible.
4. There is a need for increased communications with regional and local government agencies to ensure that natural resource managers have access to the information, partners, and resources that they need to assess and reduce their vulnerability to climate change.

Additional Content

The Indicators Monitoring Inventory and Plan also contains the following for each ocean climate indicator:

- An inventory of the best available current and historical monitoring
- Unique monitoring strategies and activities
- Case studies to provide specific examples of the indicators' utility in a decision-making context

Figure 4. Shoreline along North-central California coast

Introduction

Climate Change in the North-central California Coast and Ocean Region

The waters along the North-central California coast are part of one of the world's major coastal upwelling systems (Bakun 1973; Chavez 2009). Extensive fisheries, tourism, and recreation play a significant role in the region's economy (SFEP 2011). The importance of the rich marine ecosystem from Point Arena to Point Año Nuevo has been recognized by the establishment of contiguous national marine sanctuaries by the National Oceanic and Atmospheric Administration (NOAA) and their proposed expansions. Adjacent to the major metropolitan area surrounding San Francisco Bay and encompassing the outflow of California's major river system, the national marine sanctuaries (NMS) included in the study region are Gulf of the Farallones (GFNMS), Cordell Bank (CBNMS), and the northern portion of Monterey Bay (MBNMS).

Climate Change Impacts:

The impacts of climate change are already being observed in the North-central California coast and ocean region. In 2010, a working group of the GFNMS and CBNMS Sanctuary Advisory Councils (SAC) authored a report, "Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries," highlighting recent climate change observations and potential threats to the region, including (Largier et al. 2010):

- Observed increase in air temperature at the South Farallon Islands from 1971 – 2007;
- Observed increase in sea level at the mouth of the San Francisco Bay, by 20cm over the last 100 years;
- Observed increase in frequency and strength of extreme weather events, including North Pacific cyclones;
- Observed increase in the northerly winds that drive coastal upwelling of cold, nutrient-rich waters;
- Observed northward shift of key species including Humboldt squid (*Dosidicus gigas*), volcano barnacle (*Tetraclita rubescens*), and bottlenose dolphins (*Tursiops truncatus*);
- Projected increase in global sea level of 40-75cm by 2050 relative to the sea level in 1990;
- Projected decrease in regional seawater pH due to uptake of carbon dioxide by the ocean; and
- Potential for effects of climate change to be compounded by parallel environmental changes associated with local human activities.

Parallel Ecosystem Stressors:

Additional stressors can act in parallel to anthropogenic climate change to impact the health of North-central California marine ecosystems. These stressors include natural regional-scale climate variability and human activities such as land development, commercial fishing and mariculture, recreation, and water pollution (GFNMS 2010; Largier et al. 2010; SFEP 2011). Regional and global-scale natural climate variability that has been shown to impact the study region includes the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO) (Largier et al. 2010), each of which results in changes to wind patterns, ocean circulation, water temperatures, sea level, storminess, and the extent of coastal fog in the region.

These parallel ecosystem stressors can interact with the effects of anthropogenic climate change to impact the region in new and varied ways. For example, shoreline species whose habitat ranges are already being reduced due to climate change-induced sea level rise may be limited in their ability to migrate shoreward due to land development. Depending on their phase, natural climate variability such as ENSO and the PDO may further exacerbate or reduce sea level rise, thus intensifying or reducing the stress that a particular species may be experiencing.

Regional natural resource managers can act to help ecological systems adapt to climate change and increase ecosystem resilience (ability to resist, recover, or rebound), by reducing non-climate stressors on vulnerable habitats and species. This report and the project as a whole are designed to identify ocean climate indicators that will help managers and researchers track the impacts of climate change on the region and identify habitats and species that are particularly vulnerable. Case studies provide examples of actions that managers can take based on the status and trends of these indicators. This report also provides collaboratively-developed ocean climate indicator monitoring goals, objectives, and activities to better understand the impacts of climate change on the North-central California coast and ocean region.

Ocean Climate Indicators

Ocean climate indicators are measurements that provide information about the presence and impacts of climate change in a region. They can be divided into two categories: biological indicators, which enable monitoring of the biological response of an ecosystem to climate change, and physical indicators, which enable monitoring of changes in the physical environment of an ecosystem to climate change. Examples of biological ocean climate indicators include the abundance of a particular seabird species or the extent of biogenic habitat, such as seagrass, kelp, or mussel beds. Physical ocean climate indicators can include sea level, sea surface temperature, or the pH of ocean waters. Ocean climate indicators have been used by research scientists and decision-makers for a range of spatial scales, including individual estuaries in the U.S. Environmental Protection Agency's Climate Ready Estuaries program; the State of California; the United States; and globally by such agencies as the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA). Whereas locally-scaled indicators can provide insights about important ecosystem changes and processes that might be omitted by globally-scaled indicators, global indicators can provide a broad perspective on climate change impacts.

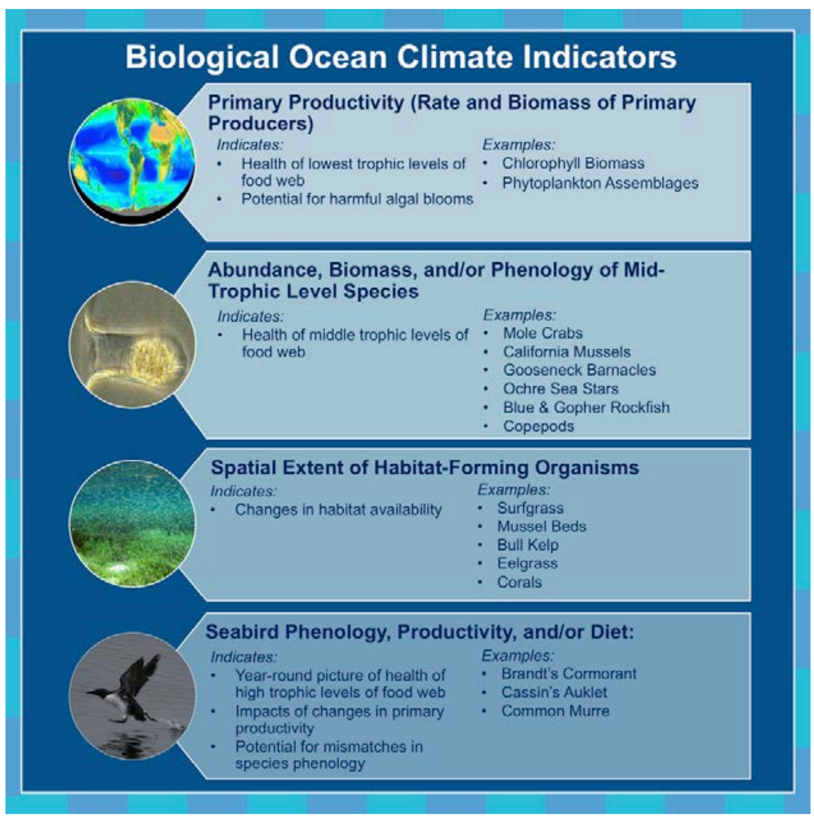

Figure 5. Biological ocean climate indicators for the North-central California coast and ocean region

The GFNMS Ocean Climate Initiative and numerous other local, state, and federal agencies, non-profit organizations, and academic institutions need a clear way to understand and communicate the presence and impacts of climate change within the North-central California coast and ocean region. To help meet this need, a set of physical and biological ocean climate indicators was collaboratively developed for the region from Point Año Nuevo to Bodega Head (Figures 1 and 2). The region of focus was expanded northward to Point Arena because of the consistency among the habitats, ecosystems, and climate forcings in the region. The indicators may also be more broadly informative north and south of the study area. The indicators are, to GFNMS' knowledge, the first system of ocean climate indicators developed specifically for the North-central California coast and ocean region and the first in the National Marine Sanctuary System, representing the consensus of over 50 regional research scientists, natural resource managers, and decision-makers.

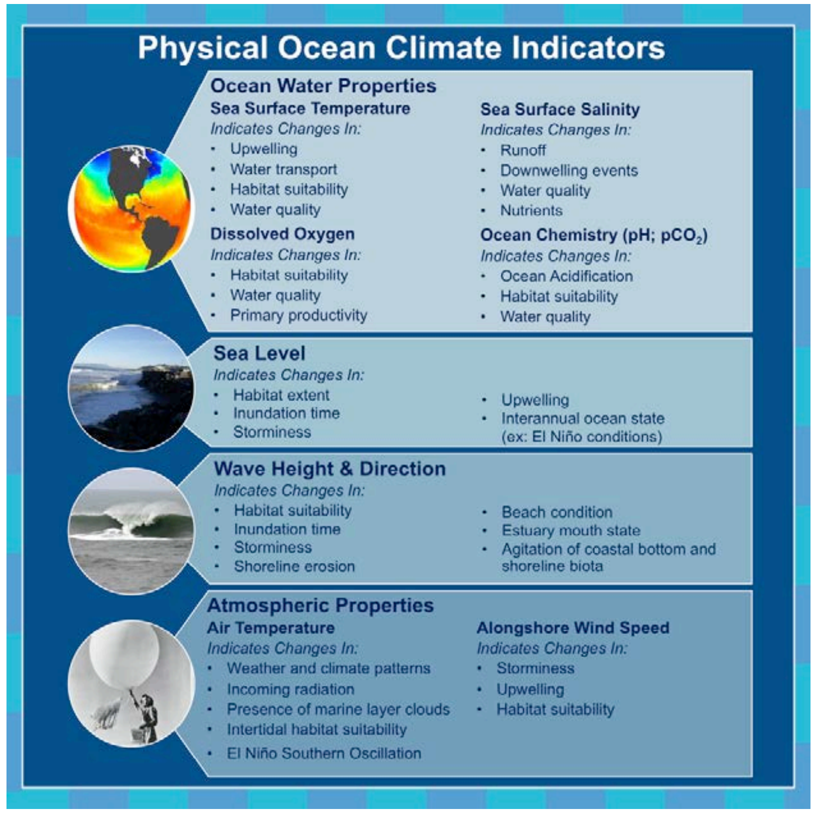

Figure 6. Physical ocean climate indicators for the North-central California coast and ocean region

Details about how these indicators were selected follow in the Ocean Climate Indicators Project overview, and in Appendices A-F. Throughout the indicators development process, emphasis was placed on identifying those physical and biological indicators that had a clear connection to anthropogenic climate change and long pre-existing monitoring programs to allow for identification of climate-scale changes in the study region. The indicators contained in this report provide a clear and concise way of communicating to decision-makers the status and trends of important physical factors of the climate system, and potential concomitant changes in biological/ecological parameters of the North-central California coast and ocean region associated with those factors. Maintaining ongoing and recommended future monitoring to evaluate changes in these factors over time will enable natural resource managers and decision-makers to better evaluate their own unique natural resources in order to inform and improve their management strategies.

For example, indicators such as sea level or sea surface temperature can help with the identification of coastal and marine habitats and species that are particularly vulnerable to the impacts of climate change. These habitats and species can be protected from non-climate stressors to increase their resiliency to climate change.

Research scientists can also use these indicators to assess the status and impacts of climate change in the North-central California coast and ocean region. The indicator monitoring opportunities identified in this report hopefully also will lead to new or expanded monitoring that is of high utility to both research scientists and natural resource managers.

Ocean Climate Indicators Project Overview

The Ocean Climate Indicators project leverages existing relationships between the GFNMS Ocean Climate Initiative and federal, state, local agencies, universities, and NGOs to collaboratively develop a set of physical and biological ocean climate indicators for the North-central California coast and ocean region. Funded by NOAA and the University Corporation for Atmospheric Research (UCAR) as part of the Postdocs Applying Climate Expertise (PACE) Fellowship Program, the Ocean Climate Indicators project is the first ocean climate indicators development project by National Marine Sanctuary staff. Advisors for the Ocean Climate Indicators project include the Ocean Climate Initiative Coordinator at GFNMS and research scientists from the US Geological Survey (USGS), the University of California Davis, and Scripps Institution of Oceanography, with additional consultation provided by Point Blue Conservation Science (formerly PRBO Conservation Science). Collaborating scientists and managers are from 26 institutions, NGOs, and agencies that include the California Academy of Sciences, University of California (UC) Berkeley, UC Davis, and UC Santa Cruz; San Francisco State University; San Francisco Bay Joint Venture; California Department of Fish and Wildlife (CDFW); California Coastal Commission; California Coastal Conservancy; California Ocean Protection Council; National Park Service (NPS); US Fish and Wildlife Service (USFWS); National Weather Service (NWS); and National Marine Fisheries Service (NMFS).

The indicator development process used in the Ocean Climate Indicators project is grounded in the National Research Council publication, “Ecological Indicators for the Nation” (NRC 2000) and detailed in the project flowchart (Figure 3). In the first phase of the Ocean Climate Indicators project, an extensive review of peer-reviewed climate change literature for the North-central California coast and ocean region laid the groundwork for all of the work that followed. Concurrently, GFNMS staff collaborated to develop a set of priority management questions (Appendix A) that the indicators should help to address. Following discussions with project mentors and other partners, the indicator selection criteria used by the National Research Council (NRC 2000) were modified to create selection criteria appropriate to the North-central California coast and ocean region and that addressed core needs of regional natural resource managers (Appendix B). These selection criteria were specifically developed to ensure that each indicator chosen was scientifically and statistically sound, and that it helped to address the priority management questions. A specific emphasis was placed on identifying indicators with a clear link to climate change, and with long-term datasets to allow for statistically sound analysis of the impacts of climate change on the region. An Ecosystem Description (Appendix C) was written to identify the six major habitat types in the North-central California coast and ocean region, key flora and fauna in each habitat, and vulnerabilities of each habitat to climate change. These key components were mapped onto a Conceptual Ecological Model (Appendix D) to further emphasize the processes by which climate change can impact the region.

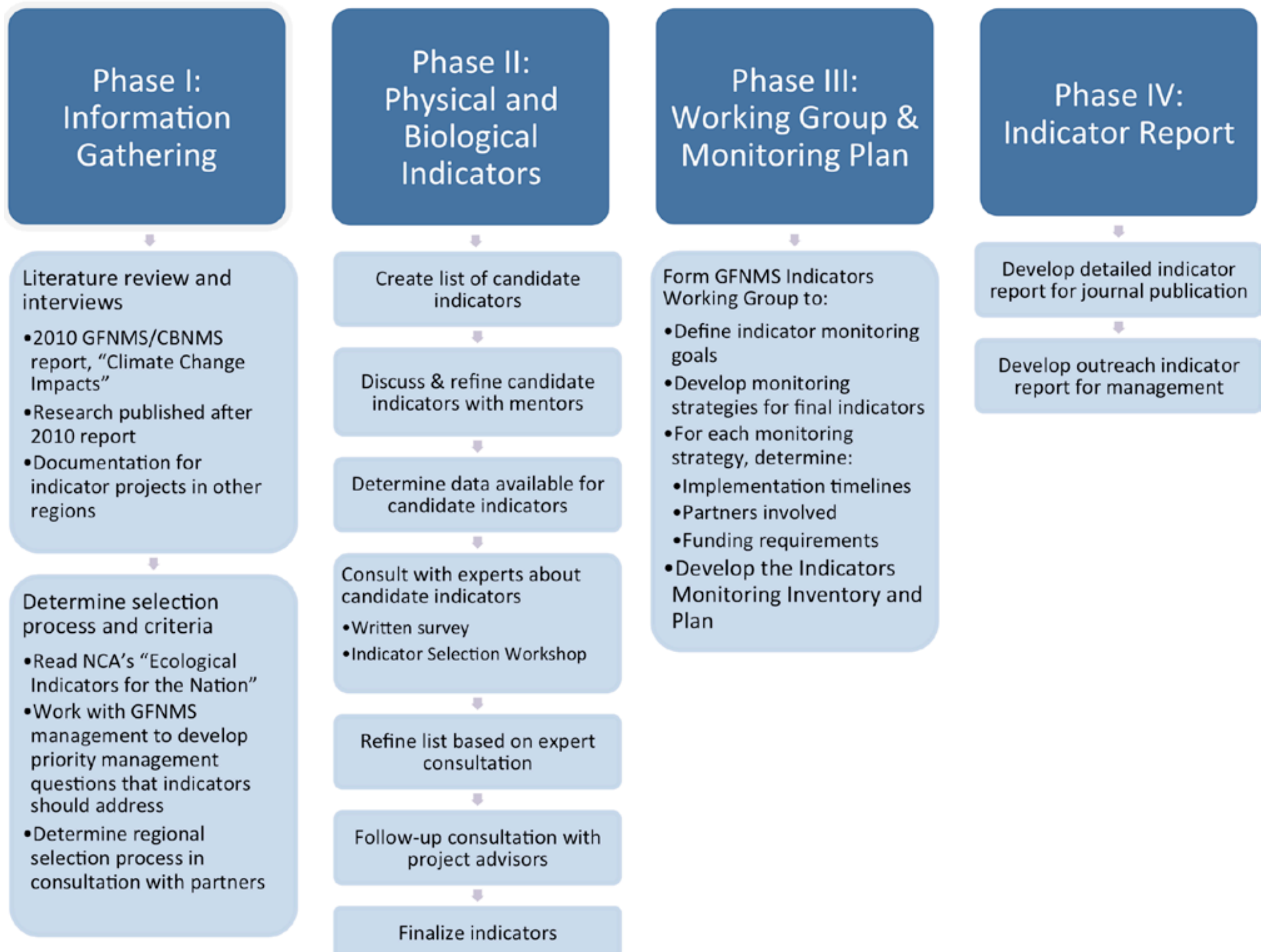

Figure 7. Ocean Climate Indicators Project Flowchart

Phase II of the Ocean Climate Indicators project was focused on determining the indicators themselves. The extensive literature review and the Ecosystem Description from Phase I informed the creation of a large set of candidate ocean climate indicators. These indicators were initially refined to a smaller set of 10 physical and 13 biological ocean climate indicators by the project mentors. These indicators were then assessed by 51 of 76 invited partner scientists and managers via an Indicator Survey, which contained a series of questions to assess how well each indicator met the indicator selection criteria (Appendix B) and allowed respondents to suggest additional indicators. All Indicator Survey respondents were invited to provide additional input at an Ocean Climate Indicators Workshop on August 28, 2012, and 36 of them attended. Each of four breakout groups at the workshop recommended a set of priority indicators for further analysis. Indicators that were recommended by at least three breakout groups were taken to be broadly recommended, and were ultimately selected to be the final set of ocean climate indicators for the North-central California coast and ocean region (Figures 1 and 2). A full summary of the Ocean Climate Indicators Workshop is available online, at http://farallones.noaa.gov/manage/climate/indicators.html.

There is consensus among regional research scientists and managers that these indicators provide important information about the status and trends of physical and biological components of the North-central California coast and ocean region. The recommended biological indicators are distributed across trophic levels to provide an assessment of the impacts of climate change on key biota in the region (Figure 2). For example, primary producers represent the base of the food web, and changes in the presence of photosynthetic organisms like phytoplankton can cascade up through trophic levels to impact mid-trophic level species like macroinvertebrates and higher trophic level seabirds like common murres, Cassin's auklets, and Brandt's cormorants. There are many possible indicators and species that could be chosen, especially for biological indicators. In addition to providing relevant information about current and potential future impacts of climate change on the region, the chosen indicators either already have legacy data, or data can be obtained relatively easily.

Phases III and IV of the Ocean Climate Indicators Project were focused on developing detailed documentation about the indicators and their development, including the Indicators Monitoring Inventory and Plan. A working group of 13 regional research scientists and natural resource managers, many of whom participated in the Indicator Selection Workshop, was approved by the GFNMS Sanctuary Advisory Council to develop this Indicators Monitoring Inventory and Plan. Each member of this interdisciplinary working group had expertise in at least one of the ocean climate indicators, and together, the group worked to maximize the utility of this inventory and plan for both natural resource managers and research scientists.

The working group was convened in a series of five meetings from April – November 2013. At the first Indicators Working Group meeting, attendees approved the indicators monitoring goals and objectives and then formed breakout groups to provide detailed monitoring strategies and activities for each indicator. The working group then provided revisions and final approval of this monitoring inventory and plan at subsequent meetings. A subgroup of working group four members volunteered to identify "selected species" for each of the biological indicators (Figure 2). For these selected species, there is a clear, scientifically accepted mechanism by which climate change can alter their distribution or abundance, and monitoring is already available in some portions of the study region.

Ocean Climate Indicators Monitoring Goal and Objectives

Monitoring Goal:

Promote comprehensive and coordinated management of marine resources by increasing understanding of the ecological impacts of climate change on the North-central California coast and ocean region, through the monitoring and evaluation of physical and biological ocean climate indicators.

Objectives to Meet the Monitoring Goal:

1. Determine the status and trends of ocean climate indicators along the North-central California coast and ocean region through existing monitoring programs and by identifying needs and opportunities for new or expanded monitoring efforts.
2. Assess the vulnerability of specific geographic areas, ecosystems, and ecosystem components within the North-central California coast and ocean region to the impacts of climate change.

Monitoring Inventory and Plan Overview

A working group consisting of 13 regional natural resource managers and research scientists, three GFNMS staff members who provided technical support, and the GFNMS and CBNMS Superintendents helped to develop the Ocean Climate Indicators Monitoring Inventory and Plan. In the pages that follow, for each indicator, monitoring strategies and activities are given; the best available monitoring data are identified; opportunities for improving or expanding existing monitoring or for establishing new indicator monitoring are detailed; and case studies provide specific examples of the indicators' utility in a decision-making context.

It should be noted that the Ocean Climate Indicators Monitoring Inventory and Plan is not intended to serve as a mandate for the research and management communities. Rather, it is a guide for existing and potential future monitoring of ocean climate indicators that represents the consensus of leading regional research scientists and natural resource managers from a range of universities, non-governmental organizations (NGOs), and state and federal government agencies. Long-term monitoring is essential for ensuring that the ecosystem is well understood, observing the impacts of climate change on the region, and identifying habitats that may be particularly vulnerable in the future. Currently, funding is provided for many valuable indicator monitoring projects on a year-to-year basis only.

Key purposes of this document are to:

1. Increase support for long-term monitoring of ocean climate indicators as a high funding priority.
2. Promote expanded and new monitoring of ocean climate indicators that would provide valuable information for natural resource managers.
3. Increase support for the synthesis of existing research about the regional impacts of changes in the ocean climate indicators.
4. Promote increased communications with government agencies to ensure that natural resource managers have access to the information, partners, and resources that they need to assess vulnerability.

Following approval by the GFNMS SAC, the Ocean Climate Indicators Monitoring Inventory and Plan was forwarded to GFNMS sanctuary management to consider how to integrate the report's recommendations into the GFNMS Management Plan and program areas of Research and Monitoring, Ecosystem Protection, and Education and Outreach.

The monitoring strategies and activities are presented in separate tables for each indicator, along with information about each activity's priority level, current and potential partners, funding requirements, and implementation timelines. Indicator monitoring activities with "critical" priority levels have the potential to provide the long time series necessary to better understand climate change impacts on the region, and can capture more critical information about climate change impacts more efficiently than "very important" and "important" priority activities. While all indicator monitoring activities were carefully selected and continued funding for these activities is important, "critical" priority activities are those for which funding is critical, even during times of limited financial resources. We note that continued funding for some indicators is uncertain. To facilitate increased ease of use, all "critical" monitoring activities are compiled in Appendix E. For consistency, the symbols presented in Table 1 are used to describe the priority level and funding requirements in the tables throughout the document:

Table 1. Monitoring Plan Symbols

PRIORITY LEVEL SYMBOLS:		
★★★	★★	★
Support for this indicator monitoring activity is ***critical***, even during times of limited financial resources	Support for this indicator monitoring activity is ***very important***, even during times of limited financial resources	Support for this indicator monitoring activity is ***important***, even during times of limited financial resources
NEED FOR ADDITIONAL FUNDING & INFRASTRUCTURE SYMBOLS:		
$$$	**$$**	**$**
No existing monitoring infrastructure or equipment	Some existing monitoring infrastructure or equipment	Extensive monitoring infrastructure or equipment exists

The working group recommends that the Ocean Climate Indicators Monitoring Inventory and Plan be updated by GFNMS in two ways:

1. On an annual basis, GFNMS staff should consider updating data sources for each indicator.
2. Every 5 years, the GFNMS SAC should consider convening a working group to review the indicators contained in this report, to re-evaluate their utility to managers and their ongoing scientific relevance, and to consider adding any new indicators that reflect advances in scientific understanding of climate change in the North-central California coast and ocean region.

Study Region

The California coast is part of the California Current Ecosystem (CCE), which stretches along the west coast of North America from the northern border of the United States to Baja California. The CCE is one of only four Eastern Boundary Upwelling Ecosystems in the world (Chavez and Messie 2009 and references therein), which are characterized by extremely high biological productivity (e.g., Bakun 1973; Bakun et al. 2010). This productivity is a result of "upwelling," a process that occurs when equator-ward winds combine with the rotation of the Earth to cause offshore transport of coastal surface waters. This surface water is replaced by deeper, colder, more nutrient-rich upwelled water. Nutrients fuel the growth and proliferation of phytoplankton in this upwelled water as they are exposed to sunlight near the surface. As a result of the increased concentrations of phytoplankton that form the base of the food chain, there is increased biological productivity throughout the trophic levels, from zooplankton to fish and top predators (Chavez and Messie 2009; Bakun et al. 2010).

The most intense and persistent upwelling in the North-central California coast and ocean region generally occurs from March through July (Garcia-Reyes and Largier 2010 and references therein) when the atmospheric North Pacific High shifts northward. During relaxation periods in the upwelling season, and during the fall transition season, the prevailing equator-ward winds weaken, sometimes causing ocean currents to flow to the north and halting upwelling.
There are six major habitat types in the North-central California coast and ocean region, from Point Año Nuevo to Point Arena (Figure 8): sandy beaches, rocky intertidal, nearshore subtidal, estuaries and bays, islands, and offshore.

Sandy beaches can generally be found along the coastal border of the region, and they are often accessible to and used by humans. This habitat type constantly changes due to the influence of waves, wind, and tides on sediment transport and inundation time (GFNMS 2008). It is home to wrack consumers and invertebrate communities, and breeding and nesting grounds for some shorebirds (GFNMS 2010). Sandy beaches are also used by smelt and other fish species for spawning and by pinnipeds, including elephant seals and harbor seals, to pup and raise their young (Largier et al. 2010).

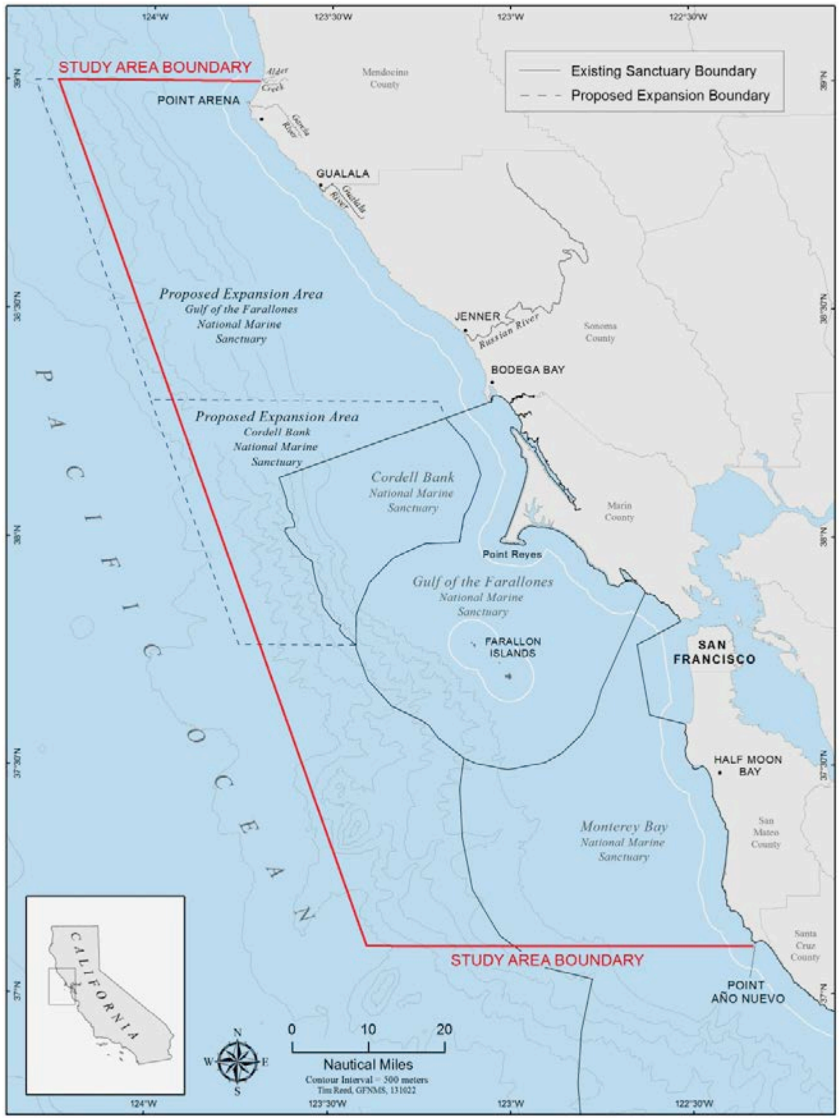

Figure 8. Map of study region (thick red lines), with related sanctuary boundaries (black solid lines) and proposed sanctuary expansion areas (black dashed lines)

Rocky intertidal habitat consists of rocky areas found between high and low tide water levels, including, but not limited to, portions of Duxbury Reef, the Fitzgerald Marine Reserve, the Farallon Islands, Bodega Head, and the Marin Headlands (GFNMS 2008 and 2010; Largier et al. 2010). The conditions found in this habitat type change frequently due to tidal inundation and wave exposure (GFNMS 2008). These changing conditions lead to drying and heating/cooling during low tide and inundation and cooling during high tide (GFNMS 2010). Rocky intertidal habitat is used by organisms that include all trophic levels, from habitat-building coralline algae to marine invertebrates like barnacles, limpets, abalone, mussels, sea anemones, and sea urchins, to a number of fish species, shorebirds, and pinnipeds (GFNMS 2008 and 2010).

Nearshore subtidal habitat lies below the low tide line to depths of up to 30m, with a seafloor that can be sandy shelf or rocky reef. This habitat is strongly affected by upwelling during spring and summer months, and by runoff and precipitation during the winter storm season. Shallow depths allow for good light penetration, which allows for high productivity of benthic algae on hard substrata. For example, kelp forests provide nursery grounds for fish and invertebrates. North of Bodega Head, nearshore subtidal habitat is home to fish species like blue rockfish and perch, which in turn provide a food source for other fishes, seabirds, and marine mammals (GFNMS 2008 and 2010).

Estuaries and bays in the study region are mostly small and sandbar-built and include Pescadero Marsh, Drakes Bay, Drakes Estero, and Estero Americano (GFNMS 2010). Tomales Bay, Bodega Bay, and Bolinas Lagoon are moderately sized bays within the study region, while San Francisco Bay is located outside of the study region but has important influences on the region. Estuaries and bays are home to a range of ecosystems, including mudflats, brackish water, eelgrass beds, salt marshes, and tidal creeks (GFNMS 2010). Estuaries and bays are often highly productive because of warmer water temperatures, abundant light, and high nutrient levels. Many species of fish and invertebrates feed, spawn, and develop in estuaries and bays, including Pacific herring, smelt, sharks, rays, and Coho salmon, which is a federally threatened species (GFNMS 2008 and 2010). Pinnipeds use these habitats to haul out, breed, and feed, while dolphins forage, and birds like dowitchers, sandpipers, and ducks feed on burrowing organisms like clams, worms, crustaceans, and on plants and small fish (GFNMS 2010).

Islands in the study region include the seven Farallon Islands, Año Nuevo Island, and other islands that are part of the Bureau of Land Management (BLM) California Coastal National Monument, Golden Gate National Recreation Area, and Point Reyes National Seashore. These islands are isolated, rocky habitats that allow marine animals to breed away from human activities. The waters surrounding these island habitats are highly productive, and they include a diverse and large assemblage of invertebrates, fishes, seabirds, and marine mammals (GFNMS 2010). For example, over 300,000 seabirds nest on the Farallon Islands annually from May-July (GFNMS 2008). Marine mammals including northern fur seals, elephant seals, harbor seals, California sea lions, and Steller sea lions breed on island habitats (GFNMS 2010).

Offshore habitats encompass a large portion of the study region and include a wide variety of ecosystems. Offshore pelagic ecosystems are located seaward of the 30m bottom contour, and they encompass the entire water column over the continental shelf and slope, from the surface to depths greater than 200m. As a result, offshore pelagic ecosystems can include surface waters and the deep sea. Shallow offshore pelagic ecosystems often contain newly-upwelled water, and can be influenced by the outflow of water from San Francisco Bay (GFNMS 2010). Offshore benthic ecosystems in the study region are found on the seafloor beyond shallow subtidal habitat, at depths ranging from 30-200m (Largier et al. 2010). Offshore pelagic habitat is extremely productive, with a diverse assemblage of organisms that includes phytoplankton, zooplankton, fishes, sea turtles, birds, and mammals. Two important species of krill, a critical food for many predators, are found in offshore pelagic ecosystems (GFNMS 2010 and references therein), as are fish including salmon, northern anchovy, rockfish, and one of the largest known concentrations of great white sharks in the world (GFNMS 2010). Cetaceans observed in offshore pelagic habitats include Pacific white-sided dolphin, Dall’s porpoise, and gray, humpback, and blue whales.

Offshore deep-sea pelagic and benthic ecosystems (> 150m) are characterized by low light, cold water, and high pressure (GFNMS 2008 and 2010). Organisms found in offshore benthic zones include clams, mollusks, shrimp, crabs, sea urchins, deep-sea corals, and a variety of fishes on soft and hard bottoms (GFNMS 2008).

Ocean Climate Indicators Monitoring Strategies: Physical

Physical Indicator #1: Air Temperature

BACKGROUND

Air temperature is a key indicator because it is a direct measure of climate change. Changes in air temperature indicate changes in weather and climate patterns, incoming radiation, the presence of marine layer clouds, and intertidal habitat suitability. Spatial patterns of variability in air temperature vary strongly, with some low-elevation coastal areas showing long-term cooling and other, more inland areas, experiencing warming. For example, mean annual air temperature at the South Farallon Islands showed an increasing trend from 1971 – 2012 (Figure 5) (Largier et al. 2010). Climate change-induced variability in air temperature can be directly forced by the strengthened greenhouse effect or indirectly forced by other climate change impacts on the North-central California coast and ocean region, including strengthened upwelling and changing weather patterns.

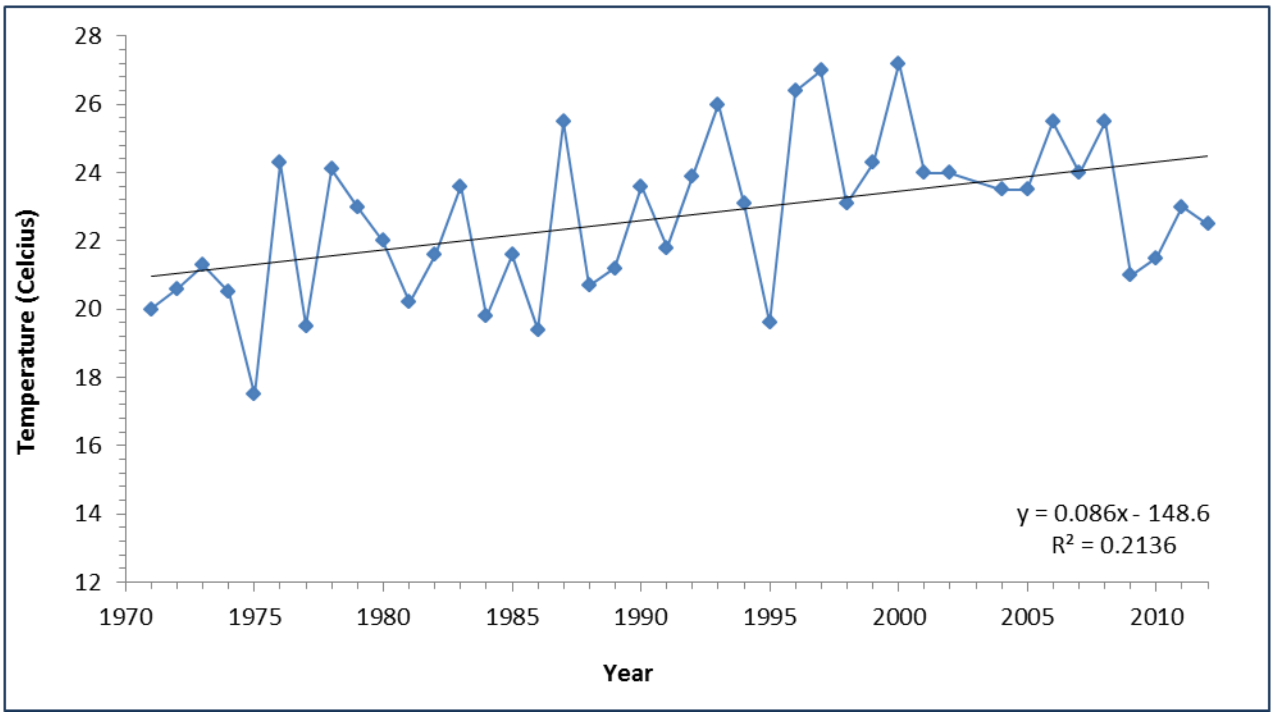

Figure 6. Annual maximum air temperature at Southeast Farallon Island from 1971 – 2012. The diagonal black line illustrates a linear regression indicating the trend in the data (Point Blue Conservation Science, unpublished data).

HABITATS OF INTEREST

Air temperature is an important indicator in all habitats of the North-central California coast and ocean region, especially intertidal habitats.

MEASUREMENT

A technique for assessing regional-scale changes and trends in air temperature is via calibrated air temperature sensors in official weather stations used by the National Weather Service. Potential benchmarks include the length of a season and degree days (i.e., the number of days above or below a particular temperature standard). Specific techniques exist to assess smaller-scale regional or habitat-specific air temperature.

CASE STUDIES FOR MANAGEMENT

Air temperature can be used by natural resource management in many ways, including the following:

- To identify when specific physiological responses associated with changes in air temperature are expected in intertidal and seabird species within the region, allowing management to determine if increased protection of these species is needed through the reduction of other disturbances.
- To improve the design of seabird and other habitat restoration projects to allow for increased species resilience to potential future changes in air temperature. As an example, air temperature inside of Cassin's auklet nests is being used by Point Blue Conservation Science on the Farallon Islands to better understand the response of Cassin's auklets to heat stress and so that management can improve the design of restoration projects such as installing artificial nest boxes for these birds.
- To identify when action is needed to reduce non-climate stressors to increase resilience of elephant seals and other mammals in the region. As an example, ambient air temperature measurements are being compared with elephant seal body temperature by Sonoma State University and NPS. This information will increase understanding of the impacts of warming temperatures on elephant seals in the region, and may help to predict air temperatures above which elephant seal behavior changes.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 2. Monitoring strategies and activities for air temperature

AIR TEMPERATURE MONITORING STRATEGY #1: Maintain existing monitoring of air temperature.
Need for Additional Funding & Infrastructure: $
Gaps in Research: 1. Continued evaluation of long-term temperature trends in the region is key to understanding change in the physical environment, and this requires ongoing observations. 2. There is a need for comparison between atmospheric and oceanic conditions, including interannual, decadal, and longer-timescale climate change. 3. What is the relationship between air temperature at land-based weather stations and in situ coastal and offshore air temperatures? 4. Site-specific air temperature data is lacking, which is important for increased understanding of linkages with other indicators.
Activity 1.1: Encourage continued financial and technical support for monitoring of air temperature at weather stations throughout the North-central California coast, including at local scales.
Priority: ★★★
Current and Potential Partners: • NWS • National Data Buoy Center (NDBC) • Central and Northern California Ocean Observing System (CeNCOOS) • Bodega Marine Laboratory (BML) • NPS weather stations • Point Blue Conservation Science
Implementation Timeline:

Ongoing
AIR TEMPERATURE MONITORING STRATEGY #2: Establish expanded local-scale monitoring in the North-central California coast and ocean region.
Need for Additional Funding & Infrastructure: $
Gaps in Research: 1. Increased understanding of long-term changes in air temperature is needed in major habitats within the study region.
Activity 2.1: Establish additional air temperature monitoring in critical habitats, especially in regions where changes can have a strong impact on biological indicators, as in intertidal and island habitats.
Priority: ★★
Current and Potential Partners: • GFNMS, MBNMS, and CBNMS • NPS • California State Parks • BML • Romberg Tiburon Center (RTC) • Point Blue Conservation Science • Oikonos • CeNCOOS • Local and regional universities • Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)/ Multi Agency Rocky Intertidal Network (MARINe)
Implementation Timeline: <1 year

EXISTING MONITORING

Existing air temperature monitoring is detailed in the table below. Overall, existing monitoring is sufficient to assess large-scale temperature trends and changes. Support for additional and continued local air temperature monitoring is needed.

Table 3. Existing monitoring data sources for air temperature

AIR TEMPERATURE MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
Bodega Ocean Observing Node (BOON)	BML Shoreline	4/15/1988 – 3/31/2001	20-minute means, 1 measurement/ second	
BOON	BML Shoreline	2/5/2001 – 1/1/2009	Every 10 seconds	
BOON	BML Shoreline	1/1/2009 – present	Every 5 seconds	
National Ocean Service (NOS) Center for Operational Oceanographic	Point Reyes, CA	11/29/1999 – present	Every 6 minutes	

Products and Services (CO-OPS) Tidal Gauge Station# 9415020				
NDBC Buoy # 46026	18 nautical miles West of San Francisco, near NDBC #46237	1982 – present	Hourly	http://www.ndbc.noaa.gov/station_history.php?station=46026
NDBC Buoy #46013	Bodega Bay	1981 – present	Hourly	
NDBC Buoy #46012	Half Moon Bay, 24 nautical miles South-Southwest of San Francisco	1980 – present	Hourly	
Point Blue Conservation Science Southeast Farallon Island Weather Station	Southeast Farallon Island	1971 – present	Every 15 minutes	Data is unpublished
AIR TEMPERATURE MONITORING - REANALYSIS DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
National Centers for Environmental Prediction (NCEP) Climate System Forecast Reanalysis v2 (CSFR2)	Ranges 0.2° to 2.5°.	1/1/2011 – 1/1/2013	Hourly, 6-hour, monthly	This is the same model used for the original CFSR Reanalysis, so if choose the same resolution, it is a seamless continuation. OR can choose higher resolution. http://rda.ucar.edu/datasets/ds094.2/
NCEP North American Regional Reanalysis (NARR)	32km	1979 – present	3-hourly	Most Organized Website at: http://rda.ucar.edu/datasets/ds608.0/, also at: http://www.emc.ncep.noaa.gov/mmb/rreanl/#docs

Physical Indicator #2: Alongshore Wind Speed and Direction

BACKGROUND

Changes in alongshore wind speed and direction can indicate that there have been changes in storminess in the region, or that there have been or will be changes in upwelling and associated nutrient availability along the North-central California coast. Wind speed is expected to strengthen as anthropogenic climate change continues, because climate change-induced warming occurs more quickly on land than in the ocean. This uneven heating is hypothesized to cause a greater land-sea heating contrast, leading to a larger land-sea pressure gradient and increased alongshore winds (Bakun 1990 and 2010). Analyses of alongshore winds in the study region support this hypothesis, with increased strength and duration of alongshore winds observed from the 1946 – 1990 (Schwing and Mendlessohn 1997; Mendelssohn and Schwing 2002), and between April and October from 1982 – 2007 (Garcia-Reyes and Largier 2010 and 2012; Largier et al. 2010). Wind observations can provide large-scale information about climate change impacts on the region, while high-resolution data provide information about the smaller-scale structure of wind patterns.

HABITATS OF INTEREST

Alongshore wind speed and direction is a useful indicator in all habitats of the North-central California coast and ocean region, including in offshore habitats, where upwelling is a key oceanic process that affects nutrient delivery to surface waters, which in turn affects the availability of food for higher trophic levels.

MEASUREMENT

A technique for measuring alongshore wind speed and direction in the study region is via calibrated wind speed and direction sensors in official weather stations used by the National Weather Service, in situ radar measurements, and remotely-sensed satellite and airplane observations.

CASE STUDIES FOR MANAGEMENT

Alongshore wind speed and direction can be used by natural resource management in many ways, including the following:

- To predict ocean productivity and food availability. As an example, wind data has been used by local researchers to evaluate upwelling along the North-central California coast, which has in turn been used by decision-makers and natural resource managers to predict productivity and the availability of food for higher trophic levels including salmon and other fish. These predictions can be used to guide fisheries management decisions.
- To evaluate the responses of seabirds to changes in the timing and strength of upwelling in the spring (the “spring transition”).
- To improve public safety among sailors and kayakers who frequent the study region, which may be impacted by changes in the strength and predictability of wind speed and direction.
- To improve the selection of locations for restoration activities, the timing of restoration, and the restoration actions chosen.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 4. Monitoring strategies and activities for wind speed and direction

<table>
<tr><td colspan="2">WIND MONITORING STRATEGY #1:
Maintain monitoring of alongshore wind speed and direction.</td></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. Existing in situ wind observations via offshore buoys have frequent time gaps, making it difficult to use these observations to verify remotely sensed offshore winds or to determine long-term trends in observed offshore winds.
2. Consistent wind observations are needed to allow for solid understanding of the long-term trend of wind speed and direction to help evaluate the impacts of climate change in the region</td></tr>
<tr><td>Activity 1.1:
Maintain wind data collection at as high a quality as possible to minimize data gaps.</td><td>Activity 1.2:
Repair/replace damaged wind sensors on offshore moorings and buoys with the goal of ensuring gaps in data of no longer than one month. Time could be reduced by collaboration between agencies by sharing vessels for repair.</td></tr>
<tr><td>Priority: ★★★</td><td>Priority: ★★★</td></tr>
<tr><td>Current and Potential Partners:
• NWS
• Local universities
• CeNCOOS
• NDBC
• NPS</td><td>Current and Potential Partners:
• NDBC
• GFNMS, CBNMS, and MBNMS
• Local universities</td></tr>
<tr><td>Implementation Timeline:
Ongoing</td><td>Implementation Timeline:
Ongoing</td></tr>
</table>

EXISTING MONITORING

Existing monitoring of alongshore wind speed and direction is detailed in the table below. Overall, monitoring could be expanded to ensure high quality, reliable offshore in situ wind measurements, but this is not as high of a priority as expanding monitoring of other indicators.

Table 5. Existing monitoring data sources for wind speed and direction

ALONGSHORE WIND SPEEED MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
BOON	BML Shoreline	4/15/1988 – 3/31/2001	20-minute means, 1 measurement/ second	Dataset called “Wind Speed and Direction
BOON	BML Shoreline	5/1/2001 – 1/1/2009	Every 10 seconds	Dataset called “Wind Speed and Direction
BOON	BML Shoreline	1/1/2009 – present	Every 1 second	Dataset called “Wind Speed and Direction

BOON	Cordell Bank Buoy	5/8/2007 – 6/15/2007, 6/29/2007 – 8/21/2007, 8/28/2007 – 3/30/2008	10-minute average collected once per hour	Dataset has "Average Wind Speed" and "Instantaneous Peak Wind Speed." Data from 6/29/2007 – 8/21/2007 sporadic.
NOS/CO-OPS Tidal Gauge Station# 9415020	Point Reyes, CA	10/1/1993 – present	Every 6 minutes	
NDBC Buoy #46012	Half Moon Bay, 24 nautical miles South-Southwest of San Francisco	1980 – present	Hourly	Wind speed and wind direction data available
NDBC Buoy #46013	Bodega Bay	1981 – present	Hourly	Wind speed and wind direction data available
NDBC Buoy #46014	Point Arena	1981 – present	Hourly	http://www.ndbc.noaa.gov/station_page.php?station=46014
NDBC Buoy # 46026	18 nautical miles West of San Francisco, near NDBC #46237	1982 – present	Hourly	http://www.ndbc.noaa.gov/station_history.php?station=46026
ALONGSHORE WIND SPEED MONITORING - SATELLITE DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
Oceansat-2 Scatterometer (OSCAT) winds, 12.5km	12.5km	9/2009 – present	12 hours	http://manati.star.nesdis.noaa.gov/datasets/OSCATData.php?parname=wv2
NASA Quick Scatterometer (QuickSCAT) winds, 12.5km	12.5km	1999 – 11/23/2009	Daily	http://manati.star.nesdis.noaa.gov/products/QuikSCAT.php
ALONGSHORE WIND SPEED MONITORING - REANALYSIS DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
NCEP Climate System Forecast Reanalysis v2 (CSFR2)	Ranges 0.2°-2.5°.	Jan 1 2011 – present (delay, actually available to July 2012)	Hourly, 6-hour, monthly	This is the same model used for the original CFSR Reanalysis, so if choose the same resolution, it is a

				seamless continuation. OR can choose higher resolution. http://rda.ucar.edu/datasets/ds094.2/

Physical Indicator #3: Sea Surface Temperature

BACKGROUND

As with air temperature (Physical Indicator #1), sea surface temperature (SST) is a key parameter because it is a direct indicator of climate change and an indirect indicator of changes in upwelling, water transport, habitat suitability, and nutrients. Warming or cooling SST can, in turn, alter water column stratification and circulation, sea level (due to thermal expansion), and climate phenomena like hurricanes (Largier et al. 2010). While global average SST warmed by 0.1^{o}C from 1961 – 2003 (IPCC 2007), regional SST patterns are more complex both within and outside of the study region. Offshore and shore station temperatures have shown an increasing trend since 1955 (Largier et al. 2010 and references therein), but temperatures off of the central California coast, particularly near Bodega Head, decreased from 1982 – 2008. This observed cooling may reflect an increase in upwelling in the region, which may be due at least in part to anthropogenic climate change (Bakun et al. 1990 and 2010; Garcia-Reyes and Largier 2010; Largier et al. 2010).

HABITATS OF INTEREST

SST is a useful indicator in all habitats of the North-central California coast and ocean region because it has a direct impact on the biota in each habitat. It is particularly of interest in sandy beach, rocky shore, estuarine, and island habitats.

MEASUREMENT

A technique for measuring SST in the study region is via in situ thermistors, with accuracy to 0.1^{o}C. High frequency measurements are preferred. It can also be measured via satellite or airplane.

CASE STUDIES FOR MANAGEMENT

SST can be used by natural resource management in many ways, including the following:

- To predict changes in species range due to changes in the availability of habitat at a specific SST, and to evaluate the potential need to reduce high nutrient run-off and/or discharge.
- To assess the risk for increasing harmful algal blooms, which can have important impacts on public safety for recreational visitors to beaches.
- To identify changes in upwelling strength, which can impact primary productivity and thus the productivity of the entire ecosystem. Such changes can be important to fisheries, and may result in managers considering catch limits to improve fish resilience.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 6. Monitoring strategies and activities for SST

SST MONITORING STRATEGY #1: Maintain existing local and regional-scale SST monitoring.
Need for Additional Funding & Infrastructure: $
Gaps in Research:

1. What are the spatial patterns of SST change?
2. How does temperature relate to other parameters, including chlorophyll?

Activity 1.1:
Encourage continued financial and technical support for monitoring of local and regional SST in critical areas throughout the North-central California coast, including the Point Arena Mooring and such as estuaries Drakes Estero, Drakes Bay, and Estero Americano.

Priority: ★★★

Current and Potential Partners:

- GFNMS, CBNMS, and MBNMS
- CeNCOOS
- NPS
- Local universities
- Point Blue Conservation Science

Implementation Timeline:
< 1 year

SST MONITORING STRATEGY #2:
Ensure broad geographic and ecosystem coverage of SST monitoring.

Need for Additional Funding & Infrastructure:
$$

Gaps in Research:

1. What are the spatial patterns of SST change?
2. How does SST relate to other parameters, including chlorophyll, air temperature, and wind speed?

Activity 2.1:
Establish additional SST monitoring in critical areas, including estuarine, offshore, and intertidal habitats.

Priority: ★★

Current and Potential Partners:

- NPS
- California State Parks
- Oikonos
- CeNCOOS
- Local universities

Local community members

Implementation Timeline:
< 1 year

EXISTING MONITORING

Existing SST monitoring is detailed in the table below. Overall, monitoring of SST is sufficiently broad. To ensure broad geographic coverage of all ecosystems in the region, there is a need for additional SST monitoring in Point Arena via mooring, in estuaries, and in offshore habitats.

Table 7. Existing monitoring data sources for SST

SST MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
BOON	BML Shoreline	4/15/1988 – 8/31/2000	20-minute means, 1 measurement/ second	Dataset for this and all BOON measurements below called “seawater temperature”
BOON	BML Shoreline	9/1/2000 – present	Every 10 seconds	
BOON	Fort Point Shoreline	7/10/2007 – present	1 minute	Dataset also available between 10/8/2004 – 6/25/2007, but it is sporadic and has different sampling intervals
BOON	BML Mooring	8/2004 – 1/4/2008 (old buoy) and 7/2010 – present (new buoy)	5 minutes (old buoy) and 10 minutes (new buoy)	
BOON	Cordell Bank Buoy	4/21/2009 – 1/26/2010, 7/13/2010 – 8/19/2013	10-minute average collected once per hour	Dataset also available between 5/8/2007– 9/10/2008, but it is sporadic and has different sampling intervals. Some data abnormalities present
BOON	GFNMS Thermistor – Bodega Head	4/6/2009 – present	Unspecified	Dataset also available 6/26/2005 – 3/24/2009, but sporadic
BOON	GFNMS Thermistor – Southeast Farallon Island	9/4/2008 – present	Unspecified	Dataset also available 6/26/2005 – 8/1/2008, but sporadic
BOON	GFNMS Thermistor –	6/4/2007 – 11/7/2007 and	Unspecified	

	Double Point	8/7/2008 – 12/4/2008		
Bodega Line Oceanographic Transect	Offshore from BML and within Tomales Bay	2008 – present	Monthly	Available by request
Coastal Data Information Program (CDIP)	San Francisco Bay Buoy (#142) NDBC/WMO #46237	7/2007 – present	30 minutes	
CDIP	Cordell Bank Buoy (#029) NDBC/WMO #46214; 22 nautical miles West of Point Reyes	12/1996 – 2/2004, 4/2004 – 1/2009, 9/2010 – present	30 minutes	
NOS/CO-OPS Tidal Gauge Station# 9415020	Point Reyes	4/13/1992 – present	Every 6 minutes	Called "water temperature"
Scripps Shore Station Program	Farallon Islands	1925 – 1943, and 1977 – present	Daily	Data from Aug 2010 – Nov 2011 may be off due to thermometer issues (+0.1 to -0.6°C). Data collected by Point Blue Conservation Science.
CDIP	San Francisco Buoy (#180) (farther in GF than #142); NDBC #46247	2/2011 – 11/2012	30 minutes	Buoy decommissioned
NDBC Buoy #46012	Half Moon Bay, 24 nautical miles South-Southwest of San Francisco	1980 – present	Hourly	
NDBC Buoy #46013	Bodega Bay	1981 – present	Hourly	
NDBC Buoy #46014	Point Arena	1981 – present	Hourly	http://www.ndbc.noaa.gov/station_page.php?station=46014
NDBC Buoy # 46026	18 nautical miles West of San Francisco, near NDBC #46237	1982 – present	Hourly	http://www.ndbc.noaa.gov/station_history.php?station=46026

NDBC Buoy #46042	Monterey Bay	1987 – present	Hourly	http://www.ndbc.noaa.gov/station_page.php?station=46042
SST MONITORING - SATELLITE DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
NOAA Polar-orbiting Operational Environmental Satellites (POES) Advanced Very High Resolution Radiometer (AVHRR)	High Resolution	1985 – present	Daily	Data & plots available through Coastwatch: http://coastwatch.pfel.noaa.gov/index.html
NOAA POES AVHRR Pathfinder V5.2	4km	1981– 2011	2x/day	This is a reanalysis of AVHRR data, available at: http://www.nodc.noaa.gov/SatelliteData/pathfinder4km/ also at: http://www.nodc.noaa.gov/sog/pathfinder4km/
Group for High-Resolution Sea Surface Temperature (GHRSST) climate data records	<10km	Varies; higher resolution is more recent (ex 2008 – present), lower resolution goes back to 1981	Varies	http://www.nodc.noaa.gov/SatelliteData/ghrsst/
SST MONITORING - REANALYSIS DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
ERA-Interim	~0.7°	1979 – present	6-hourly or monthly mean	http://rda.ucar.edu/datasets/ds627.2/ and http://www.ecmwf.int/products/data/archive/descriptions/ei/index.html. Background information about reanalysis products here:

				http://climatedataguide.ucar.edu/reanalysis/era-interim
NCEP CFSR	Ranges 0.3° to 2.5°, depending on grid selected and temporal frequency. 0.3° for diurnal monthly means; 0.5° for regular monthly means	Jan 1 1979 – Jan 1 2011	Hourly, diurnal monthly means, monthly means	http://rda.ucar.edu/datasets/ds093.1/, http://rda.ucar.edu/datasets/ds093.2, and http://rda.ucar.edu/pub/cfsr.html
CFSR2	Ranges 0.2° to 2.5°.	Jan 1 2011 – present (delay, actually to July 2012)	Hourly, 6-hourly	This is the same model used for the original CFSR Reanalysis, so if choose the same resolution, it is a seamless continuation. OR can choose higher resolution. http://rda.ucar.edu/datasets/ds094.2/. Note that SST does not appear in the UCAR monthly CFSR page.
NCEP/National Center for Atmospheric Research (NCAR) Global Reanalysis Products	Ranges 1.8-2.5° (looks like SST is 1.8° grid)	1948 – present	6-hourly or monthly mean	http://rda.ucar.edu/datasets/ds090.0/

Physical Indicator #4: Sea Surface Salinity

BACKGROUND

Sea surface salinity (SSS) is primarily an indicator of changes in freshwater inputs, particularly in nearshore environments. Climate change can cause regional changes in SSS by altering water circulation and currents, vertical mixing, and freshwater input.

HABITATS OF INTEREST

SSS is a particularly useful indicator in nearshore habitats of the North-central California coast and ocean region, including sandy beach, rocky shore, estuarine, nearshore subtidal, and island habitats.

MEASUREMENT

A technique for measuring SSS in the study region is via conductivity measurements. Samples should be calibrated or checked using salinity analyses in a laboratory.

CASE STUDIES FOR MANAGEMENT

SSS can be used by natural resource management in many ways, including the following:

- To track changes in the timing and magnitude of runoff, which can indicate changes in loading from the land that may alter the amount of biogenic material and contaminants in estuaries and bays. These changes can cause damage to farms, mariculture, and fisheries as during severe flooding in January 1982 and January 1998. GFNMS management can work with upland resource managers to reduce nutrient loading during heavy storm events.
- To identify changes in ocean and coastal habitat zones, which can result in areas supporting a new and different biological community with less prey available for existing predators and more prey for new predators. Changes like this can affect species communities, especially fish. GFNMS and other managers can work to reduce non-climate stressors on fish communities.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 8. Monitoring strategies and activities for SSS

<table>
<tr><td colspan="2">SSS MONITORING STRATEGY #1:
Expand monitoring of SSS in shoreline and offshore regions.</td></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. To what extent does runoff or freshwater contribute to local biogeography?
2. Can salinity be related to other water quality constituents?</td></tr>
<tr><td>Activity 1.1:
Establish a linear array of salinity monitoring sites along the North-central CA coast.</td><td>Activity 1.2:
Add salinity monitoring to offshore NDBC buoy sites that are already measuring temperature.</td></tr>
<tr><td>Priority: ★</td><td>Priority: ★★</td></tr>
<tr><td>Current and Potential Partners:
• GFNMS, CBNMS, and MBNMS
• Point Blue Conservation Science
• California Ocean Science Trust (OST)
• NPS
• Local universities
• Local government/agencies, including county water boards
• CA State Water Resources Control Board</td><td>Current and Potential Partners:
• NDBC
• CeNCOOS
• Local universities</td></tr>
<tr><td>Implementation Timeline:
< 1 year</td><td>Implementation Timeline:
< 1 year</td></tr>
</table>

EXISTING MONITORING

Existing SSS monitoring is detailed in the table below. Overall, expanded monitoring of SSS is needed in nearshore sites, focused on the shoreline of the North-central California coast and ocean region. A linear array of monitoring sites is preferred. In areas where SSS monitoring is unavailable, local rainfall and stream discharge measurements can also be used to provide information about local changes in freshwater inputs, particularly in estuarine habitats.

Table 9. Existing monitoring data sources for SSS

SSS MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
BOON	BML Shoreline	4/15/1988 – 4/2/1999	20-minute means, 1 measurement/ second	
BOON	BML Shoreline	1/1/2001 – present	Every 10 seconds	
BOON	Fort Point Shoreline	7/10/2007 – present	1 minute	Data also available between 10/8/2004 – 6/25/2007, but it is sporadic and has different sampling intervals
BOON	BML Mooring	8/2004 – 1/4/2008 (old buoy) and 7/2010 – present (new buoy)	5 minutes (old buoy) and 10 minutes (new buoy)	
BOON	Cordell Bank Buoy	4/21/2009 – 1/26/2010, 7/13/2010 – 8/19/2013	10-minute average collected once per hour	Data also available between 9/14/2007– 9/10/2008, but it is sporadic and has different sampling intervals and some data abnormalities present before 5/27/2008
Bodega Line Oceanographic Transect	Offshore from BML and within Tomales Bay	2008 – present	Monthly	Available by request
Scripps Shore Station Program	Farallon Islands	1925 – 1943, and 1977 – present	Daily	Data collected by Point Blue Conservation Science
NDBC Buoy # 46026	18 nautical miles West of San Francisco, near NDBC #46237	1982 – present	Hourly	http://www.ndbc.noaa.gov/station_history.php?station=46026
NDBC Buoy	Bodega Bay	2007–2008	Hourly	Data not

#46013				consistently available throughout either year

Physical Indicator #5: Dissolved Oxygen

BACKGROUND

Dissolved oxygen (DO) is a key biologically-influenced water property that can indicate changes in habitat suitability, water quality, primary productivity, and degradation of organic matter. Because all macroscopic organisms require oxygen, changes in DO can have cascading impacts on the entire ecosystem. Typically, surface waters contain higher levels of DO than subsurface waters due to photosynthesis and diffusion from the oxygen-rich atmosphere. These oxygen-enriched waters are transported throughout the water column by ocean currents and vertical mixing. Climate change can cause regional changes in DO by altering water circulation and currents, vertical mixing, air-sea oxygen exchange, and biological production and respiration; these impacts can co-occur with ocean acidification, discussed below (Largier et al. 2010 and references therein).

HABITATS OF INTEREST

DO is a particularly useful indicator in nearshore subtidal, and offshore habitats, where it is affected by changes in air-sea oxygen exchange, circulation, and organism respiration. It is also important in estuarine habitats, where changes in DO are indicative of changes in eutrophication. Benthic organisms that cannot easily move are particularly vulnerable to shifts from high to low DO.

MEASUREMENT

A technique for measuring DO in the study region is via in situ electronic or optical sensors, with accuracy to 0.1 mL/L. Calibration should be developed with titration in a lab.

CASE STUDIES FOR MANAGEMENT

DO can be used by natural resource management in many ways, including the following:

- To evaluate shoaling or expansion of oxygen minimum zones (OMZs) (Bograd et al. 2008; Koslow et al. 2011), as is being done off the Oregon coast (Grantham et al. 2004), and which can have important impacts on fish and invertebrates (Keller et al. 2010; Koslow et al. 2011). Migration of OMZs into shallower continental shelf waters would be a major threat to species in areas adjacent to the shelf break. Natural resource managers can adjust fishing limits to help reduce the impact on affected species.
- To establish integration with monitoring of ocean chemistry, which can allow for improved understanding of habitat suitability in the region.
- To evaluate local-scale ocean acidification remediation or mitigation tactics and their efficacy, such as the restoration of seagrass beds for carbon sequestration.
- To facilitate the identification of biogenic habitats that are at the highest risk from acidification. GFNMS managers can develop additional protections for these habitats that can help to reduce or eliminate other anthropogenic impacts.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 10. Monitoring strategies and activities for DO

DO MONITORING STRATEGY #1: Expand monitoring of DO along the North-central California coast.
Need for Additional Funding & Infrastructure:

<table>
<tr><td colspan="2">Activity 1.1: $-$$
Activity 1.2: $$$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. Are we observing changes in the OMZ?
2. What are the relationships between changing pH and changing DO, which may co-occur within the study region?
3. Are offshore changes correlated with conditions in San Francisco Bay? Is this linked to the growing concern about hypoxic waters in San Francisco Bay?</td></tr>
<tr><td>Activity 1.1:
Add oxygen sensors to existing moorings and surveys, especially in nearshore subtidal and estuarine habitats.</td><td>Activity 1.2:
Add new moorings that measure DO in nearshore subtidal, estuarine, and offshore habitats.</td></tr>
<tr><td>Priority: ★★★</td><td>Priority: ★★</td></tr>
<tr><td>Current and Potential Partners:
• GFNMS, CBNMS, and MBNMS
• Applied California Current Ecosystem Studies (ACCESS)
• Point Blue Conservation Science
• Local universities
• Commercial fisheries
• West Coast Ocean Acidification and Hypoxia Science Panel
• West Coast Governors Alliance on Ocean Health</td><td>Current and Potential Partners:
• GFNMS, CBNMS, and MBNMS
• ACCESS
• Point Blue Conservation Science
• Local universities
• Commercial fisheries
• West Coast Ocean Acidification and Hypoxia Science Panel
• West Coast Governors Alliance on Ocean Health</td></tr>
<tr><td>Implementation Timeline:
~ 1 year</td><td>Implementation Timeline:
~ 1 year</td></tr>
</table>

EXISTING MONITORING

Existing DO monitoring is detailed in the table below. Overall, existing monitoring of DO is not sufficient to address the Indicators Monitoring Objectives. Expanded monitoring of DO is needed in existing surveys and moorings, including calibration and regular sample analysis. New moorings are also needed to ensure sufficient DO monitoring.

Table 11. Existing monitoring data sources for DO

DISSOLVED OXYGEN MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
ACCESS Cruise Data	Cruise lines	2004 – present	3-4 times annually, April-October	Partnership between Point Blue Conservation Science and GFNMS
BOON	BML Mooring	July 2010 – present	Every 10 minutes	http://bml.ucdavis.edu/boon/bml_buoy.html
Bodega Line Oceanographic	Offshore from BML and within	2008 – present	Monthly	Available by request

Transect	Tomales Bay			
Bodega Ocean Acidification Research (BOAR)	Tomales Bay	August 2012 – present	Every 30 minutes	Available by request. http://bml.ucdavis.edu/research/research-programs/climate-change/oceanacidification/

Physical Indicator #6: Ocean Chemistry

BACKGROUND

As with air temperature and SST, ocean acidification (OA) is a direct impact of increasing carbon dioxide (CO_2) emissions into the atmosphere and subsequent diffusion through the atmosphere-ocean interface. As humans continue to emit increasing amounts of CO_2 into the atmosphere, a significant portion of these emissions are absorbed by the Earth's oceans. When CO_2 is dissolved into seawater, a chemical reaction causes increased ocean acidity and reduced carbonate availability; this can impact marine organisms in a myriad of different ways, including shell calcification, respiration, and reproduction (Kleypas et al. 1999; Caldeira and Wickett 2003). Changes in ocean chemistry have been documented to have significant impacts on organisms studied in the laboratory and field, including local examples such as foraminifera, pteropods, mussels, oysters, and crabs (e.g. Doney et al. 2009; Largier et al. 2010 and references therein).

As a result, ocean chemistry (including, pH, carbonate saturation state) is a key indicator of OA and associated impacts on marine organisms (Kleypas et al. 1999; Caldeira and Wickett 2003). Ocean acidification is already causing documented shifts in pH and saturation state within the California Current (Feely et al. 2008), and these shifts are predicted to exacerbate in the future (Hauri et al. 2009).

HABITATS OF INTEREST

Measures of ocean chemistry such as carbonate saturation state are particularly useful indicators in rocky intertidal, nearshore subtidal, estuarine, and offshore habitats.

MEASUREMENT

Efforts are underway to develop an understanding of the regional relationships between ocean chemistry (pH) and other parameters (temperature, salinity, dissolved oxygen); a knowledge of these relationships will allow for the development of algorithms to calculate saturation state in the absence of discrete bottle sampling, described below (e.g., Juranek et al. 2009).

There are four frequently used measures of ocean chemistry, all of which rely on analysis of in situ water samples (i.e., "discrete bottle sampling"). Ideally, two of the four should always be measured:

1. Dissolved inorganic carbon (DIC): Should be measured with spectroscopy or infrared analysis of water samples.
2. pH: Best to use spectrophotometric or durafet measurements. It is not preferable to use glass electrodes unless they are carefully calibrated and strongly supported by discrete bottle sampling.
3. Total alkalinity: Measured via titration.

4. pCO_2: Best measured via coulometric analysis of water samples.

CASE STUDIES FOR MANAGEMENT

Ocean chemistry monitoring data can be used by natural resource management in many ways, including the following:

- To evaluate and predict the impact of changes in ocean chemistry, including OA, on local/regional productivity and ecosystems. For example, reproductive failure in recreationally valuable mussel species and other bivalves can impact sustainable aquaculture, with important economic and ecological effects on the region.
- To evaluate local-scale ocean acidification remediation or mitigation tactics and their efficacy, such as the restoration of seagrass beds for carbon sequestration.
- As with DO, to facilitate the identification of biogenic habitats that are of the highest risk from acidification. GFNMS managers can develop additional protections for these habitats that can help to reduce or eliminate other anthropogenic impacts.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 12. Monitoring strategies and activities for ocean chemistry

<table>
<tr><td colspan="2">OCEAN CHEMISTRY MONITORING STRATEGY #1:
Expand the geographic coverage of ocean chemistry monitoring.</td></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. Do organisms respond to average carbonate chemistry conditions, and/or changes in the variability (seasonal, monthly, daily) of these parameters?
2. What is the impact of combined influence of low-pH and low oxygen waters, which may co-occur within the study region?
3. How does ocean chemistry influence local productivity and food webs, and vice versa?</td></tr>
<tr><td>Activity 1.1:
Add pH and pCO_2 instruments to existing moorings and offshore cruises; support with discrete bottle samples.</td><td>Activity 1.2:
Expand monitoring of ocean chemistry in critical habitats, including moorings and surveys.</td></tr>
<tr><td>Priority: ★★★</td><td>Priority: ★★</td></tr>
<tr><td>Current and Potential Partners:
• GFNMS
• CeNCOOS
• California State Water Board
• Regional water boards
• Local universities
• Ocean Margin Ecosystems Group for Acidification Studies (OMEGAS) partner universities
• PISCO/MARINe
• Pacific Marine Environmental Laboratory (PMEL)
• West Coast Ocean Acidification and Hypoxia Science Panel
• West Coast Governors Alliance on</td><td>Current and Potential Partners:
• GFNMS
• CeNCOOS
• California State Water Board
• Regional water boards
• Local universities, including UC Davis and the OMEGAS program
• PISCO/MARINe
• PMEL
• West Coast Ocean Acidification and Hypoxia Science Panel
• West Coast Governors Alliance on Ocean Health</td></tr>
</table>

Ocean Health	
Implementation Timeline: <1 year	Implementation Timeline: ~ 1-2 years

EXISTING MONITORING

Existing ocean chemistry monitoring is detailed in the table below. Overall, existing monitoring of ocean chemistry is not sufficient to address the Indicators Monitoring Objectives. The geographic coverage of ocean chemistry monitoring could be expanded, with a focus on nearshore communities.

Table 13. Existing monitoring data sources for ocean chemistry

OCEAN CHEMISTRY MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
Bodega Line Oceanographic Transect	Offshore from BML and within Tomales Bay	2008 – present	Monthly	Available by request
BOAR	Sensors located offshore Bodega Head, in Tomales Bay, and along shoreline in northern California; monitoring of individual shore-based sites (bottle samples)	2011 – current	30-60min	Available by request. More information at: http://bml.ucdavis.edu/research/researchprograms/climatechange/oceanacidification/
ACCESS Cruise Data	ACCESS lines	2013 – present	3-4 times annually, April-October	Partnership between Point Blue Conservation Science and GFNMS

Physical Indicator #7: Wave Height and Direction

BACKGROUND

Wave height and direction indicate changes in inundation time, storminess, shoreline erosion, beach condition, opening and closing of estuary mouths, agitation of coastal bottom and shoreline biota, and habitat suitability in the North-central California coast and ocean region. It is a key indicator because the stability of shoreline communities in the region depends on wave height and direction. Climate change can modify wave height and direction due to altered atmospheric circulation and sea surface temperature.

HABITATS OF INTEREST

Wave height and direction are particularly useful indicators in shoreline habitats of the North-central California coast and ocean region, especially nearshore subtidal, rocky shore, sandy beach, island, and estuarine habitats.

MEASUREMENT

A technique for measuring wave height and direction in the study region is via buoys.

CASE STUDIES FOR MANAGEMENT

Wave height and direction can be used by natural resource management in many ways, including the following:

- To evaluate the impacts of changes in storminess on the study region. As an example, Our Coast – Our Future (OCOF) provides online decision support tools that allow for visualization of the impacts of sea level rise and storms, including wave heights, along the North-central California coast. Managers can use OCOF to evaluate the potential impacts of flooding and changes in wave height, and to adjust restoration, construction, or management plans as a result.
- To predict the timing of closure of the mouth of Estero Americano, Estero de San Antonio, and the mouth of the Russian River, and other bar-built estuaries. GFNMS management can identify if there is a need to work with state and federal agencies on the maintenance of bar-closures and the necessity of manually opening or closing these estuaries.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 14. Monitoring strategies and activities for wave height and direction

WAVE HEIGHT & DIRECTION MONITORING STRATEGY #1: Maintain existing monitoring of wave height and direction with buoys.
Need for Additional Funding & Infrastructure: $$
Gaps in Research: Long-term wave data are needed to understand climate-scale changes in wave height direction
Activity 1.1: Encourage continued financial and technical support for existing monitoring of wave height and direction, including on buoys.
Priority: ★★★
Current and Potential Partners: NDBC CeNCOOS, Pacific Coast Ocean Observing System (PaCOOS), and United States Integrated Ocean Observing System (IOOS) Point Blue Conservation Science Local universities Local research laboratories including BML and RTC NPS USGS
Implementation Timeline: Ongoing
WAVE HEIGHT & DIRECTION MONITORING STRATEGY #2: Establish expanded monitoring of wave height and direction with buoys.
Need for Additional Funding & Infrastructure: $$$
Gaps in Research: Small spatial scale changes in wave height and direction can have important impacts on estuaries and other coastal locations and therefore need to be better understood.

Activity 2.1:
Establish new monitoring of wave height and direction in critical locations, including offshore, nearshore, and the mouths of estuarine habitats.

Priority: ★

Current and Potential Partners:
NDBC
CeNCOOS, PaCOOS, and IOOS
Point Blue Conservation Science
Local universities
Local research laboratories including BML and RTC
NPS
USGS

Implementation Timeline:
<1 year

WAVE HEIGHT & DIRECTION MONITORING STRATEGY #3:
Utilize monitoring of wave height to allow for high-resolution wave datasets.

Need for Additional Funding & Infrastructure:
$$

Gaps in Research:
Extremely high-resolution wave observations are not currently available. Because wave models are more deterministic than other models, they are very useful tools and can provide a good dataset for use by management.

Activity 3.1:
Support modeling of wave height and direction, which is more deterministic than other ocean modeling products.

Priority: ★★

Current and Potential Partners:
Local universities
USGS

Implementation Timeline:
~1 year

EXISTING MONITORING

Existing monitoring of wave height and direction is detailed in the table below.

Table 15. Existing monitoring data sources for wave height and direction

WAVE HEIGHT AND DIRECTION MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
CDIP	San Francisco Buoy (#142); NDBC/WMO #46237	7/26/2007 – present	30 minutes	9-band Wave Energy and Direction, converted to available daily maximum wave height as well

CDIP	San Francisco Buoy (#180); NDBC/WMO #46247	2/2011 – 11/2012	30 minutes	Buoy decommissioned; 9-band Wave Energy and Direction, converted to available daily maximum wave height as well
NDBC Buoy #46013	Bodega Bay	1981 – present	Hourly	"Significant wave height", swell direction, and wind-wave direction available
NDBC Buoy #46012	Half Moon Bay, 24 nautical miles South-Southwest of San Francisco	1980 – present	Hourly	"Significant wave height", swell direction, and wind-wave direction available

Physical Indicator #8: Sea Level

BACKGROUND

Sea level is a key indicator of climate change in the North-central California coast and ocean region because it is a direct response of the ocean to climate change. As the global average ocean temperature has continued to warm, thermal expansion and the melting of land-based glaciers have caused sea level to increase. Long-term sea level trends are consistent in the region, showing a sea level rise of approximately 2mm/year (e.g., Bromirski et al. 2011).

In recent decades, however, sea level has actually decreased along the North-central California coast (e.g., Bromirski et al. 2011). It has been hypothesized that the current cold phase of the Pacific Decadal Oscillation is a major cause of the recent sea level decrease (Bromirski et al. 2011; Parris et al. 2012 and references therein), although this is not settled in the literature. Other confounding factors for sea level include tectonic movements, tides, and non-anthropogenic changes in local wind and waves.

HABITATS OF INTEREST

Sea level is especially important in nearshore subtidal, rocky shore, and estuarine habitats.

MEASUREMENT

A technique for measuring sea level in the study region is via official in situ tide gauge observations, many of which are provided by NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS), and by USGS.

CASE STUDIES FOR MANAGEMENT

Sea level change data can be used by natural resource management in many ways, including the following:

In the context of long-term coastal planning:

- To determine if vulnerable habitat is currently protected.
- To determine if there are areas protected by seawalls that prevent marine species from moving shoreward. If so, are there ways to restore habitat or otherwise reduce species vulnerability in these areas?
- To plan for wetland restoration projects. As an example, in the Giacomini Wetland Restoration Project, wetland restoration was modified to accommodate sea level rise and associated changes in biogenic habitat.
- To evaluate the potential impacts of sea level changes in the region. As described for Physical Indicator #7 – Wave Height, Our Coast–Our Future provides sea level rise decision support tools for the study region. It uses a newly developed high resolution digital elevation model and best available sea level rise projections, and has already been used by managers to determine the best location to relocate park facilities that faced inundation due to sea level rise.
- To identify locations where seabird, shorebird, and pinniped habitats are threatened, and to work to reduce non-climate stressors to increase their resilience. This is because sea level rise can greatly impact seabirds, shorebirds, and pinnipeds that live in coastal habitats. Increasing sea level reduces the habitat available for birds and pinnipeds, and can result in mortality of these animals.
- To inform decisions about the need for potential re-surveying of GFNMS boundaries. The shoreline boundary of GFNMS and MBNMS is the mean-high-water line mark. As sea level changes, so can the landward boundary of GFNMS.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 16. Monitoring strategies and activities for sea level

SEA LEVEL MONITORING STRATEGY #1: Ensure that existing sea level monitoring is maintained at tide gauges along the North-central California coastline and in San Francisco Bay.
Need for Additional Funding & Infrastructure: $
Gaps in Research: An increased understanding of the interaction between sea level rise and erosion/sediment transport is needed.
Activity 1.1: Support sustained financial resources for valuable long-term tide gauge sea level monitoring, which is vital for supporting comparisons within the region and between partners.
Priority: ★★★
Current and Potential Partners: CO-OPS USGS Local universities BML Point Blue Conservation Science NPS Other sea level data-users
Implementation Timeline: Ongoing

SEA LEVEL MONITORING STRATEGY #2: Establish new monitoring of sea level at local scales.
Need for Additional Funding & Infrastructure: $$-$$$
Gaps in Research: In addition to changes in the long-term trends of sea level, variability is also changing, and it is best identified at local scales.
Activity 2.1: Establish new sea level monitoring at more closely spaced sites, particularly in critical habitats, to enhance the ability to identify local scale changes in sea level.
Priority: ★
Current and Potential Partners: GFNMS OCOF BML Point Blue Conservation Science California Coastal Commission California Ocean Protection Council Other federal agencies
Implementation Timeline: <1 year

EXISTING MONITORING

Existing monitoring of sea level is detailed in the table below. Overall, monitoring of sea level is sufficient in the North-central California coast. Existing tide gauges show a consistent pattern along the study region, and along most of the California coast.

Table 17. Existing monitoring data sources for sea level

SEA LEVEL MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
NOS/CO-OPS Tidal Gauge Station# 9414290	San Francisco, CA	6/30//1854 – present	Every 6 minutes, hourly, or monthly	Verified hourly data available since 6/30/1854
NOS/CO-OPS Tidal Gauge Station# 9415020	Point Reyes, CA	1/1/1975 – present	Every 6 minutes, hourly, or monthly	Verified hourly data since 1/1/1975; hourly and 6-min data since 1/1/1996

Ocean Climate Indicators Monitoring Strategies: Biological

Biological Indicator #1: Primary Productivity

BACKGROUND

Primary productivity is a vitally important indicator that serves as the foundation of the ecosystem indicators contained in this report. Primary producers in the region include phytoplankton, algae, seagrass, and kelp. Changes in primary productivity, as measured by changes in primary producer biomass, can indicate changes in the lowest trophic levels of the food web, the potential for harmful algal blooms, and the success of management actions to mitigate the impacts of climate change on the coast and ocean region.

Please note that an expanded discussion of large habitat-forming primary producers such as kelp and seagrass can be found in Biological Indicator #3: Spatial extent of habitat-forming organisms.

HABITATS OF INTEREST

Primary producer biomass is a particularly useful indicator in all habitats because it is the foundation of the aquatic food web.

MEASUREMENT

A proxy for measuring primary producer biomass (as chlorophyll-a) in pelagic areas of the study region is via analysis of water samples with a fluorometer or by extraction of chlorophyll. It can also be measured via sensors on satellites or airplanes, as with the Moderate Resolution Imaging Spectroradiometer (MODIS). Benthic primary producer biomass in rocky intertidal areas can be assessed directly by sampling in benthic quadrats.

CASE STUDIES FOR MANAGEMENT

Primary Productivity can be used by natural resource management in many ways, including the following:

- To determine food availability in pelagic ecosystems and habitat availability in benthic ecosystems. A reduction in either would provide a warning that other stressors need to be reduced to protect fish and other species.
- To help predict the overall health of the ecosystem and abundance of mid and upper trophic groups. It is often the first biological response to physical changes. It is important to note that very high levels of primary productivity can result in phytoplankton blooms causing low oxygen conditions, thus negatively impacting the overall health of an ecosystem.
- To provide a warning of harmful algal blooms through data on phytoplankton species composition.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 18. Monitoring strategies and activities for primary productivity

PRIMARY PRODUCTIVITY MONITORING STRATEGY #1: Maintain existing monitoring of chlorophyll and ensure that measurements are calibrated.
Need for Additional Funding & Infrastructure: $-$$
Gaps in Research: 1. Long-term observations of primary productivity are needed to ensure ability to identify climate-related changes. 2. A better understanding of the causes of an observed disconnect between reduced primary

<table>
<tr><td colspan="2">productivity and fish populations in the study regions since 2007 is needed.</td></tr>
<tr><td>Activity 1.1:
Support continued funding for existing chlorophyll monitoring.</td><td>Activity 1.2:
Check chlorophyll seawater samples for calibration.</td></tr>
<tr><td>Priority: ★★★</td><td>Priority: ★</td></tr>
<tr><td>Current and Potential Partners:
• Local universities
• Point Blue Conservation Science
• NOAA</td><td>Current and Potential Partners:
• Local universities
• Point Blue Conservation Science</td></tr>
<tr><td>Implementation Timeline:
Ongoing</td><td>Implementation Timeline:
~ 1 year</td></tr>
<tr><td colspan="2">PRIMARY PRODUCTIVITY STRATEGY #2:
Expand measurement of primary productivity via sensors on moorings and surveys, being careful to maintain good quality control.</td></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. Lack of existing in-situ monitoring on a regular basis
2. Increased nutrient sampling is needed to allow for improved primary productivity projections and increased knowledge about eutrophication in estuarine habitats.</td></tr>
<tr><td>Activity 2.1:
Expand chlorophyll monitoring at shoreline stations and at existing moorings and surveys.</td><td>Activity 2.2:
Add nutrient sampling to existing moorings and surveys.</td></tr>
<tr><td>Priority: ★★</td><td>Priority: ★</td></tr>
<tr><td>Current and Potential Partners:
• Local universities
• Point Blue Conservation Science
• NDBC</td><td>Current and Potential Partners:
• Local universities
• Point Blue Conservation Science
• NPS</td></tr>
<tr><td>Implementation Timeline:
~ 1 year</td><td>Implementation Timeline:
~ 1 year</td></tr>
<tr><td colspan="2">PRIMARY PRODUCTIVITY MONITORING STRATEGY #3:
Establish harmful algal bloom monitoring by quantifying phytoplankton assemblages.</td></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. Increased monitoring of harmful algal blooms is needed.
2. Increased ability to predict harmful algal blooms is needed.</td></tr>
<tr><td colspan="2">Activity 2.1:
Sample phytoplankton assemblages periodically at set observing stations alongshore, with more intensive monitoring during harmful algal bloom events.</td></tr>
<tr><td colspan="2">Priority: ★</td></tr>
<tr><td colspan="2">Current and Potential Partners:
• GFNMS, CBNMS, and MBNMS
• NOAA</td></tr>
</table>

- CA Department of Public Health
- Point Blue Conservation Science
- Local universities

Implementation Timeline:
~ 1 year

PRIMARY PRODUCTIVITY MONITORING STRATEGY #4:
Increase availability of remote monitoring of primary producer biomass.

Need for Additional Funding & Infrastructure:
$$-$$$, depending on the technology being used, and if that technology is already in use in a region.

Gaps in Research:
1. Need to have the ability to compare surface imagery and biomass, as with multispectral kelp canopy surveys and rocky intertidal algae.

Activity 3.1:
Use hyperspectral imaging to monitor seagrass, kelp, and large algal blooms, ensuring that measurements are ground-truthed.

Priority: ★

Current and Potential Partners:
- NOAA
- CDFW

Implementation Timeline:
~ 1 year

EXISTING MONITORING
Existing primary productivity monitoring is detailed in the table below. Overall, primary producer biomass is not measured routinely except some phytoplankton analysis by the California Department of Public Health, and sporadic measurements of algal cover in the intertidal. Note that the California Cooperative Oceanic Fisheries Investigations (CalCOFI) is a valuable source of primary productivity and monitoring data for many physical indicators, but because data collection is focused on the region from San Diego to Point Conception, it is not listed in this data sources table. Overall, monitoring of primary productivity needs to be expanded and integrated.

Table 19. Existing monitoring data sources for primary productivity

PRIMARY PRODUCTIVITY MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
PISCO/MARINe	Numerous sites along CA coast	Unspecified	Unspecified	http://data.piscoweb.org/DataCatalogAccess/DataCatalogAccess.html
ACCESS Cruises	Cruise lines	May 2004 – present	3-4 cruises from April – October annually	Partnership between Point Blue Conservation Science and GFNMS; Phytoplankton

				abundance collected to supplement California Department of Public Health monitoring, below.
California Department of Public Health	Numerous stations along CA coast	1993 – present	Monthly	Volunteer-based monitoring of toxic phytoplankton; http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/phytoplanktonmonitoringprogram.aspx
PRIMARY PRODUCTIVITY MONITORING - SATELLITE DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
MODIS through Coastwatch	Ranges, high resolution	Unspecified	Daily	http://coastwatch.noaa.gov/cwn/cw_products_oc.html
Visible Infrared Imaging Radiometer Suite (VIIRS) through Coastwatch	4km	Unspecified	Unspecified	http://coastwatch.noaa.gov/cwn/cw_products_oc.html

Biological Indicator #2: Mid-Trophic Level Species Abundance, Biomass, & Phenology

BACKGROUND

Changes in mid-trophic level species abundance, biomass, and phenology can indicate changes in the health of the middle trophic levels of the food web. This indicator is intentionally broad because it provides the flexibility needed to choose the best possible selected species for each habitat within the study region.

Figure 7. Giant Green Anemone

The Indicators Working Group identified selected species for major habitat types within the study region, and these are provided in Table 20 below. In identifying these selected species, working group members focused on native species and avoided selecting fished species except when they were key to an ecosystem's health. Note that these selected species were identified based on currently available monitoring data, and they represent a shortlist among many possible mid-trophic level species in the North-central California coast and ocean region. The abundance of rocky intertidal selected species is a reflection of the relatively long history of monitoring in this habitat. Some species, which would provide valuable information if long-term datasets were underway or already available, have been designated as promising species and are provided in Appendix F.

Table 20. Selected mid-trophic level species by habitat type

SELECTED MID-TROPHIC LEVEL SPECIES	
SANDY BEACH	
	Mole crab (*Emerita analoga*)
ROCKY INTERTIDAL	
	California mussel (*Mytilus californianus*)
	Ochre sea star (*Pisaster ochraceus*)
	Gooseneck barnacle (*Pollicipes polymerus*)
	Giant green (*Anthopleura xanthogrammica)* & Sunburst anemone (*Anthopleura sola*)
	Volcano barnacle (*Tetraclita rubescens*)
ESTUARIES & BAYS	
	Gaper clam (*Tresus capax* and/or *Tresus nuttalli*)
	Staghorn sculpin (*Leptocottus armatus*)
	Shiner surfperch (*Cymatogaster aggregata*)
NEARSHORE SUBTIDAL	
	Blue (*Sebastes mystinus*) and Gopher (*Sebastes carnatus*) rockfish
	Cabezon (*Scorpaenichthys marmoratus*)
OFFSHORE (BENTHIC & PELAGIC)	
	Copepods (e.g., *Pseudocalanus mimus* in boreal and *Calanus pacificus* in transition zone)
	Shortbelly rockfish (*Sebastes jordani*)
	Pteropods (e.g., *Clione limacina* and *Limacina helicina*)

HABITATS OF INTEREST

Mid-trophic level species abundance, biomass, and phenology are particularly useful indicators in all habitat types in the North-central California coast and ocean region.

MEASUREMENT

Techniques for measuring mid-trophic level species abundance, biomass, and phenology in the study region vary by organism and habitat type.

CASE STUDIES FOR MANAGEMENT

Abundance, biomass, and phenology of mid-trophic level species can be used by natural resource management in many ways, including the following:

- To identify vulnerable populations of mid-trophic species, and to reduce non-climate stressors on these species to increase their resilience to climate change.
- To provide an 'early warning system' about ocean chemistry, including OA, in a region.
- To identify the impacts of climate change on California mussels, which are a foundation species in the study region. Because mussel beds support hundreds of other species within

the mussel matrix, decreases in California mussel populations could have large impacts on many other species, including some higher tropic level organisms and economic impacts on the region. Evaluations of the connections between California mussels and wave action are already being done on Southeast Farallon Island and could be applied anywhere in the study region.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 21. Monitoring strategies and activities for mid-trophic species

MID-TROPHIC SPECIES MONITORING STRATEGY #1: Maintain monitoring of mid-trophic level selected species.
Need for Additional Funding & Infrastructure: $$$
Gaps in Research: 1. A common output format with metadata for datasets from multiple monitoring programs is needed, because this gap in data management might hinder synthetic research. 2. Ensuring long-term data collection is needed so that climate-scale changes in mid-trophic species can be identified.
Activity 1.1: Maintain current monitoring of mid-trophic selected species.
Priority: ★★★
Current and Potential Partners: • GFNMS • PISCO/MARINe • Monterey Bay Aquarium Research Institute (MBARI) • BML • ACCESS • Point Blue Conservation Science • Farallon Institute • CDFW • California Ocean Protection Council • NMFS • NPS • California Academy of Sciences • OST • Local universities, including Sonoma State University, San Francisco State University, and UC Davis
Implementation Timeline: Ongoing
MID-TROPHIC SPECIES MONITORING STRATEGY #2: Expand monitoring of mid-trophic level selected species and increase frequency of existing monitoring.
Need for Additional Funding & Infrastructure: $$$
Gaps in Research: 1. Spatial and temporal gaps in monitoring need to be filled by adding new sites and monitoring more frequently, especially those that are located away from anthropogenic factors. This will help to identify connections between key habitats, including South

Farallon Island, Duxbury Reef, Fitzgerald Marine Reserve, and PISCO/MARINe/National Park Service monitored sites. Supporting and investing in citizen science and volunteer monitoring with staff and resources will help achieve these goals.

2. Lack of observations about range expansion and migration of offshore mid-trophic species upslope.
3. Changes in schooling fish recommended as mid-trophic selected species above need to be assessed, including changes in age distribution and population responses to changing climate.

Activity 2.1: Establish new monitoring of selected mid-trophic species in habitats throughout the study region, with a focus on locations away from anthropogenic factors.	*Activity 2.2:* Increase frequency of existing monitoring to allow for analysis of the impact of storm events on mid-trophic species.
Priority: ★	Priority: ★★
Current and Potential Partners: • GFNMS • PISCO/MARINe • CalCOFI • ACCESS • Point Blue Conservation Science • Farallon Institute • CDFW • NMFS • NPS • California Academy of Sciences • Local universities, including Sonoma State University, San Francisco State University, and UC Davis	Current and Potential Partners: • GFNMS • PISCO/MARINe • NPS • California Academy of Sciences • Local and statewide universities, including Sonoma State University, San Francisco State University, UC Santa Barbara, and UC Davis • CDFW
Implementation Timeline: >1 year	Implementation Timeline: ~1 year

EXISTING MONITORING

Existing monitoring of selected mid-trophic species is detailed in the table below.

Table 22. Existing monitoring data sources for selected mid-trophic species

MID-TROPHIC SPECIES MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
PISCO/MARINe	Pigeon Point, Slide Ranch, Agate Beach and Bolinas Point, Chimney Rock, Bodega Head	Unspecified	Unspecified	Monitoring of a variety of species including CA mussel, black & red abalone, gooseneck barnacle, giant green and sunburst anemone
GFNMS	South Farallon	1992 – current	1-3 times per year	Monitoring of a

	Islands			variety of species including CA mussel, Gooseneck barnacle, Owl limpet, Giant Green and Sunburst anemone
GFNMS and CBNMS	Rocky reefs throughout North-central CA coast	Sporadically	Sporadically	Species inventory, density, and distribution of some selected mid-trophic species
ACCESS Cruise Data	Cruise lines	2004 – present	3-4 times annually, April-October	Copepods, zooplankton, and krill; Partnership between Point Blue Conservation Science, GFNMS, and CBNMS
Bodega Line Oceanographic Transect	Offshore from BML and within Tomales Bay	2008 – present	Monthly	Copepods; Available by request
Academy Citizen Science (California Academy of Sciences and GFNMS partnership)	Duxbury Reef (Bolinas) and Pillar Point (Half Moon Bay)	2009 – present	Monthly as tides allow	Rocky intertidal invertebrates, including mussels, Ochre sea star, and Gooseneck barnacle; http://www.calacademy.org/science/citizen_science/rocky_shore_partnership/
GFNMS Long-term Monitoring Program and Experiential Training for Students (LiMPETS)	Sandy beach and rocky intertidal habitats within the study region	Unspecified	Unspecified	Rocky intertidal and sandy beach monitoring of a variety of species including Mole crab, CA mussel, Ochre sea star, Gooseneck barnacle, and

				Giant Green and Sunburst anemone. http://limpetsmonitoring.org/index.php
NPS San Francisco Area Network (SFAN) Inventory & Monitoring	8 National Parks within San Francisco Bay Area	Unspecified	Unspecified	http://science.nature.nps.gov/im/units/sfan/index.cfm
Fitzgerald Marine Reserve docents	Fitzgerald Marine Reserve and Pillar Point Reef	Unspecified	Unspecified	Nudibranchs
NMFS Rockfish Cruises	Cruise lines off of central California	1986 – present	Annually in May or June	Standardized annual midwater trawl surveys to monitor abundance and distribution patterns of young-of-the-year pelagic juvenile rockfish; http://swfsc.noaa.gov/GroundfishAnalysis
CDFW Statewide Settlement Data	Statewide	20 years	Unspecified	Statewide settlement data exist with UCSB's Steven Schroeter as PI. See http://dfg.ca.gov/marine/impact.asp

Biological Indicator #3: Spatial Extent of Habitat-Forming Organisms

BACKGROUND

The spatial extent of habitat-forming organisms, also known as "biogenic habitat," provides key information about changes in habitat availability for other species that depend on these resources. Reductions in biogenic habitat availability can have large impacts on organisms at all trophic levels in the North-central California coast and ocean region. Beyond providing habitat,

Figure 8. California Mussels

macroalgae, seagrasses, and kelp are also important primary producers providing a trophic base to portions of the ecosystem food web. As climate change alters the physical conditions in the marine environment, it can reduce the success of habitat-forming organisms like mussels, kelp forests, and seagrasses in areas in which they were previously productive.

Figure 9. Seagrass bed along North-central California coast

As with Biological Indicator #2 (mid-trophic level species abundance, biomass, and phenology), this indicator is intentionally broad to allow the flexibility to choose the best possible indicator for relevant habitats within the study region. Key habitat-forming organisms to monitor are organized by habitat type below:

Table 23. Selected habitat-forming organisms by habitat type

SELECTED HABITAT-FORMING ORGANISMS	
ROCKY INTERTIDAL & ISLAND	
	Mussel beds (*Mytilus californianus*)
	Surfgrass (*Phyllospadix scouleri* and/or *Phyllospadix torreyi*)
NEARSHORE SUBTIDAL	
	Bull kelp (*Nereocystis luetkeana*)
ESTUARIES & BAYS	
	Pickleweed (*Salicornia virginica* and/or *Sarcocornia pacifica*)
	Eelgrass (*Zostera marina*)
	Cordgrass (*Spartina foliosa*)
OFFSHORE (ROCKY BENTHIC)	
	California hydrocoral (*Stylaster californicus)*

HABITATS OF INTEREST

The spatial extent of habitat-forming organisms is a particularly useful indicator where the organisms are most frequently found: in rocky intertidal, nearshore subtidal, estuarine, and offshore benthic habitats.

MEASUREMENT

Techniques for measuring the spatial extent of habitat-forming organisms in the study region vary by organism and habitat type and can include overflight transects, percent coverage, and quadrats.

CASE STUDIES FOR MANAGEMENT

The spatial extent of biogenic habitat can be used by natural resource management in many ways, including the following:

- To inform modifications of management strategies that help protect sensitive species associated with sensitive biogenic habitats, such as eelgrass beds.
- To inform decisions about additional restrictions that may be needed on harvesting of habitat-forming organisms, including kelp, other macro-algae, and mussels.
- To support planning efforts for wetland restoration projects.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 24. Monitoring strategies and activities for habitat-forming organisms

<table>
<tr><td colspan="3">HABITAT-FORMING ORGANISMS MONITORING STRATEGY #1:
Maintain in situ and aerial monitoring of the spatial extent of habitat-forming organisms.</td></tr>
<tr><td colspan="3">Need for Additional Funding & Infrastructure:
$</td></tr>
<tr><td colspan="3">Gaps in Research:
1. Are there long-term changes in the spatial extent of habitat-forming organisms?
2. Are there changes in the range of habitat-forming organisms?</td></tr>
<tr><td colspan="3">Activity 1.1:
Maintain funding for existing in situ monitoring of selected habitat-forming organisms.</td></tr>
<tr><td colspan="3">Priority: ★★★</td></tr>
<tr><td colspan="3">Current and Potential Partners:
• PISCO/MARINe
• Ocean Imaging</td></tr>
<tr><td colspan="3">Implementation Timeline:
Ongoing</td></tr>
<tr><td colspan="3">HABITAT-FORMING ORGANISMS MONITORING STRATEGY #2:
Increase in situ and aerial monitoring of the spatial extent of habitat-forming organisms.</td></tr>
<tr><td colspan="3">Need for Additional Funding & Infrastructure:
$$$</td></tr>
<tr><td colspan="3">Gaps in Research:
1. Are changes in the spatial extent of habitat-forming organisms consistent across the region? This consistency would allow for increased confidence in conclusions drawn from observations.
2. Increased monitoring of habitat-forming organisms is needed in regions that are difficult to access via in situ monitoring methods. Remote monitoring provides information about the status of many of these regions.
3. Greater knowledge about deep-sea corals in the study region is needed.</td></tr>
<tr><td>Activity 2.1:
Restore funding for aerial surveys of the spatial extent of habitat-forming organisms.</td><td>Activity 2.2:
Increase the number of aerial surveys of the spatial extent of habitat-forming organisms.</td><td>Activity 2.3:
Increase in situ monitoring of the spatial extent of habitat-forming organisms in key habitats.</td></tr>
<tr><td>Priority: ★★</td><td>Priority: ★</td><td>Priority: ★★</td></tr>
<tr><td>Current and Potential Partners:
• USGS
• CDFW</td><td>Current and Potential Partners:
• PISCO/MARINe</td><td>Current and Potential Partners:
• PISCO/MARINe
• California Academy of Sciences
• GFNMS, CBNMS, and MBNMS</td></tr>
<tr><td>Implementation Timeline:
<1 year</td><td>Implementation Timeline:
>1 year</td><td>Implementation Timeline:
~1 year</td></tr>
</table>

EXISTING MONITORING

Existing monitoring of the spatial extent of the habitat-forming organisms listed above is detailed in the table below. Overall, monitoring is limited and should be expanded.

Table 25. Existing monitoring data sources for selected habitat-forming organisms

HABITAT-FORMING ORGANISMS MONITORING - IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
CDFW Aerial Surveys	Tomales Bay	Unspecified	Unspecified	Eelgrass
CDFW Aerial Surveys	Aerial Survey	Unspecified	Unspecified	Bull kelp and Mussel beds
PISCO/MARINe	Numerous locations in CA coast and ocean	Unspecified	Unspecified	Mussel beds, Bull kelp; http://data.piscoweb.org/DataCatalogAccess/DataCatalogAccess.html
Academy Citizen Science (California Academy of Sciences and GFNMS partnership)	Duxbury Reef (Bolinas) and Pillar Point (Half Moon Bay)	Unspecified	Monthly as tides allow	Extent of mussel beds http://www.calacademy.org/science/citizen_science/rocky_shore_partnership/
San Mateo County Parks/Tenera	San Mateo County coast	1994 – 2004	Unspecified	Aerial coverage of macroalgae
NOAA Deep Sea Coral Cruises	GFNMS, CBNMS, MBNMS	2010 – present	Sporadic, annual at most	Deep sea coral
Ocean Imaging baseline mapping of California North-central Coast Marine Protected Areas	Numerous locations in North-central California coast and ocean region	2010	One-time baseline dataset	http://oceanspaces.org/project/north-central-coast-nearshore-habitat-mapping-using-multispectral-aerial-imagery

Biological Indicator #4: Seabird Phenology, Productivity, & Diet

BACKGROUND

Seabird phenology, productivity, and diet provide a year-round picture of health of one category of higher trophic levels. It is important to note that seabirds are being used as indicators of higher trophic level organisms rather than pinnipeds, sharks, or other apex predators because the species listed below are less migratory and can be more effectively and directly linked to changing climate. There exist long-term monitoring data for other regionally important apex species such as sharks and pinnipeds, collected by universities, NGOs like Point Blue Conservation Science, and agencies that include NMFS, and NPS (Crocker et al. 2008; Lee and Sydeman 2009; Allen et al. 2011). Monitoring of these additional apex species will likely continue.

Changes in seabird phenology, productivity, and diet can indicate changes in primary productivity. Furthermore, simultaneous monitoring of seabird phenologies and environmental conditions can provide information about potential mismatches in species phenology in the North-central California coast and ocean region (e.g., Wells et al. 2008). Seabird mortality events (as part of seabird phenology) can indicate changes in prey, atmospheric or oceanic conditions, or the presence of harmful algal blooms. Changes in seabird productivity can indicate changes in prey availability or environmental conditions (Wells et al. 2008; Field et al. 2010). Monitoring of seabird diet can be used to identify and track changes in prey availability (Roth et al. 2007).


Figure 10. Brandt's Cormorant


Figure 11. Common Murre

Factors beyond anthropogenic climate change that can also impact seabird phenology, productivity, and diet include changes in human use, disturbances, and non-anthropogenic climate forcings that impact primary productivity and atmospheric or oceanic conditions.

As with Biological Indicators #2 and #3 (mid-trophic level species abundance, biomass, and phenology and the spatial extent of habitat-forming organisms), this indicator is intentionally broad because it provides the flexibility needed to choose the best possible indicator for relevant habitats within the study region.

Table 26. Selected seabird species by habitat type

SELECTED SEABIRD SPECIES	
	Brandt's cormorant (*Phalacrocorax penicillatus*)
	Cassin's auklet (*Ptychoramphus aleuticus*)
	Common murre (*Uria aalge*)

HABITATS OF INTEREST
Seabird phenology, productivity, and diet are particularly useful indicators in rocky, nearshore subtidal, offshore, and island habitats.

MEASUREMENT
Seabird Phenology: Seabird phenology is often monitored by tracking the timing of egg laying for all selected species, often using seabirds breeding in nesting boxes.

Seabird Productivity: Seabird productivity can be monitored by evaluating the reproductive success of each species, as indicated by the number of eggs, hatchlings, and fledglings in seabird nests.

Often, monitoring occurs for seabirds breeding in nesting boxes. Seabird mortality events can also be monitored, as this allows for an assessment of post-fledgling success.

Seabird Diet: Seabird diet is often monitored by evaluating the regurgitated meals of seabird chicks, direct observations, or recovery of regurgitated pellets.

CASE STUDIES FOR MANAGEMENT

Seabird data can be used by natural resource management in many ways, including the following:

- To predict salmon stock abundance using modeled and observed seabird productivity (e.g., Roth et al. 2007).
- To identify changes in seabird prey base, as was done during a seabird mortality event in the region in 2009. Changes in prey base can have implications beyond seabirds, to other species that consume the same prey. Identifying reductions in prey can help management to identify vulnerable seabird and other high trophic level species, providing additional justification for reducing non-climate stressors on those vulnerable species, such as increasing protection or supporting restoration of seabird breeding and roosting sites.
- To identify the onset of a seabird mortality event using baseline and trend monitoring of mortality cycles and unusual mortality events.
- To provide an early warning of potential reductions in rockfish population size and associated future impacts on higher trophic level species, through monitoring of common murre diet and phenology, particularly delayed egg laying.

STRATEGIES AND ACTIVITIES TO ACHIEVE MONITORING GOALS

Table 27. Monitoring strategies and activities for seabirds

<table>
<tr><th colspan="2">SEABIRD MONITORING STRATEGY #1:
Maintain monitoring of seabird diet and abundance as an indicator of changes in prey availability and primary productivity.</th></tr>
<tr><td colspan="2">Need for Additional Funding & Infrastructure:
$</td></tr>
<tr><td colspan="2">Gaps in Research:
1. A better understanding of the causes behind seabird diet variability, which cannot be fully explained by large-scale climate indicators, is needed.
2. Changes in seabird prey availability need to be tracked.
3. Continued observations of the locations of nesting colonies are needed to ensure that any potential shift in the distribution of nesting colonies is identified.</td></tr>
<tr><td>Activity 1.1:
Continue to monitor seabird diets on the Farallon Islands, Año Nuevo Island, and rocky shore habitats.</td><td>Activity 1.2:
Continue to monitor seabird species abundance, both on land and at sea, through in situ and at-sea surveys.</td></tr>
<tr><td>Priority: ★★★</td><td>Priority: ★★★</td></tr>
<tr><td>Current and Potential Partners:
• Point Blue Conservation Science
• US Fish and Wildlife Service (USFWS)
• NPS
• Audubon Society
• Oikonos
• CDFW</td><td>Current and Potential Partners:
• GFNMS, CBNMS, and MBNMS
• Farallones Marine Sanctuary Association (FMSA)
• Point Blue Conservation Science
• USFWS
• NPS</td></tr>
</table>

• Sea Ranch CCNM Stewardship Task Force • BLM • Bureau of Ocean Energy Management (BOEM) • OST • USGS-WERC	• Audubon Society • Oikonos • CDFW • UC Santa Cruz • Sea Ranch CCNM Stewardship Task Force • Stewards of the Coast and Redwoods • BLM • USGS-WERC
Implementation Timeline: Ongoing	Implementation Timeline: Ongoing

SEABIRD MONITORING STRATEGY #2:
Increase monitoring of seabird phenology to provide information about the impacts of potential changes in upwelling on higher trophic level species.

Need for Additional Funding & Infrastructure:
$$$

Gaps in Research:

1. An increased understanding of changes in upwelling and their impacts on high trophic-level species is needed.
2. The impacts of harmful algal blooms, storm events, prey availability, and pathogens on seabirds need to be better tracked.

Activity 2.1:
Survey seabird phenology, especially the timing of breeding and causes of mortality, in key habitats.

Priority: ★★

Current and Potential Partners:

- FMSA
- Point Blue Conservation Science
- NPS
- USFWS
- USGS
- CDFW
- Oikonos
- PFEL
- OST

Implementation Timeline:
Ongoing

SEABIRD MONITORING STRATEGY #3:
Maintain monitoring of seabird productivity in key habitats, as defined by seabird reproductive success (number of eggs, hatchlings, and fledglings).

Need for Additional Funding & Infrastructure:
$

Gaps in Research:

1. The impacts of climate change on seabird productivity, which can provide insight into potential changes in other high trophic-level species productivity, need to be tracked.

Activity 3.1:

Continue to monitor seabird productivity in key habitats, particularly on the Farallon Islands and Año Nuevo Island.
Priority: ★★★
Current and Potential Partners: • GFNMS • NPS • USGS • USFWS • CDFW • California State Parks • Point Blue Conservation Science • UC Santa Cruz • Oikonos
Implementation Timeline: Ongoing

EXISTING MONITORING

Existing monitoring of selected seabird species is detailed in the table below. Overall, seabird monitoring could be expanded and analyzed to help meet the monitoring objectives.

Table 28. Existing monitoring data sources for selected seabird species

SEABIRD PHENOLOGY MONITORING – IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
GFNMS and FMSA BeachWatch	42 shoreline locations in study region	1993 – present	Every 2 weeks	Abundance and distribution of seabirds
Point Blue Conservation Science	Southeast Farallon Island	1969 – present	Every 1-7 days	Variety of species, info available at: http://www.pointblue.org/our-science-and-services/conservation-science/oceans-and-coasts/farallon-islands-research#seabirds
USFWS	Point Reyes, Devils Slide	1996 to present	Every 1-7 days	
CDFW Office of Spill Prevention and Response Seabird Health Study	Unspecified, but based in Santa Cruz, CA	Unspecified	Unspecified	http://www.dfg.ca.gov/ospr/Science/marine-wildlife-vetcare/SeabirdHealth.aspx

SEABIRD PRODUCTIVITY MONITORING – IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
Point Blue Conservation Science	Southeast Farallon Island	1969 – present	Every 1-7 days	Variety of species, info available at: http://www.pointblue.org/our-science-and-services/conservation-science/oceans-and-coasts/farallon-islands-research#seabirds
Oikonos Año Nuevo Island Restoration Project	Año Nuevo Island	1996 – present	Unspecified	http://www.anonuevoisland.org/page/about-1
Marin Audubon Christmas Bird Count	Point Reyes and Bolinas Lagoon	Varies by location	Annual	http://www.marinaudubon.org/christmas-bird-count.php
CDFW-UC Santa Cruz	Aerial Survey	Unspecified	1-2 times a month	Patchy 1994-1997
USFWS	Point Reyes, Devils Slide	1996 to present	Every 1-7 days	

SEABIRD DIET MONITORING – IN SITU DATA:				
DATA SOURCE	LOCATION OR GRID SIZE	DATE RANGE	FREQUENCY	COMMENTS
Point Blue Conservation Science	Southeast Farallon Island	1969 – present	Every 1-7 days	Variety of species, info available at: http://www.pointblue.org/our-science-and-services/conservation-science/oceans-and-coasts/farallon-islands-research#seabirds
USFWS	Point Reyes, Devils Slide	1996 – present	Every 1-7 days	

Summary and Conclusion

Given the strong scientific consensus about anthropogenic climate change and the observed and projected global and regional impacts of this change (Bindoff 2007; Largier et al. 2010 and sources therein), natural resource managers in the North-central California coast and ocean region are actively planning for climate change. The physical and biological ocean climate indicators presented in this monitoring inventory and plan (Figures 1 and 2) provide vital information about the presence and impacts of climate change on the ecosystems within the region, which extends from Point Año Nuevo to Point Arena (Figure 4). They were specifically developed to support science-based decision making at local, state, and federal agencies, and they are the first regional ocean climate indicators developed by the National Marine Sanctuary System.

The indicators were developed at Gulf of the Farallones National Marine Sanctuary (GFNMS) over the course of the two-year, highly interdisciplinary and collaborative Ocean Climate Indicators Project. A core project team consisting of sanctuary managers and federal and university research scientists developed the indicator selection criteria and an initial set of candidate ocean climate indicators. The selection criteria were based on those developed by the National Research Council (NRC 2000), and they assessed each candidate indicator's ability to answer priority management questions, its link to climate change, and its relative statistical strength. A much larger group of more than 50 regional research scientists and natural resource managers provided input about how well a refined set of candidate indicators met the selection criteria in an Indicator Selection Survey. Of the survey respondents, 36 participated in the Indicator Selection Workshop, where smaller groups of natural resource managers and research scientists used the survey results to inform conversations about the relative merits of each candidate indicator and selected a smaller number of finalist ocean climate indicators. Indicators that were recommended by at least three of the four breakout groups were taken to represent a consensus. As a result, the ocean climate indicators in this document represent the consensus of over 50 regional research scientists and managers, and they provide the best-available information about the impacts of climate change on the ecosystems of the North-central California coast and ocean region.

Following the indicator development process, the GFNMS Advisory Council approved the formation of a working group to incorporate the indicators into a monitoring inventory and plan. The resulting Indicators Working Group consisted of a subset of 13 Ocean Climate Indicators Project collaborators from a broad cross-section of disciplines and expertise, including research scientists from universities and NGOs, and managers from many of the federal and state agencies with jurisdiction in the region. The working group met in a series of three meetings with the objectives of developing an indicator-based climate change monitoring goal for the region, discussing the best-available physical and biological indicator observations, determining selected species for biological indicators, and developing monitoring strategies and activities for each indicator to meet the monitoring goals and objectives. For these selected species there is a clear, scientifically accepted mechanism by which climate change can alter their distribution or abundance, and monitoring is already available in some portions of the North-central California coast and ocean region.

The Indicators Working Group has identified several overarching indicator monitoring recommendations:

1. Continued and/or expanded financial support for ongoing indicator monitoring is vital for science-based climate change decision-making because it allows for identification of long-term, climate-scale changes in the region's ecosystems.
2. Synthesis of existing regional climate change research is key to ensuring that monitoring is as efficient and useful as possible.
3. There is a need for increased communications with regional and local government agencies to ensure that natural resource managers have access to the information, partners, and resources that they need to assess and reduce their vulnerability to climate change.

Specific monitoring strategies and activities are also suggested for each ocean climate indicator in this document. Broadly speaking, these strategies are centered on maintaining existing indicator monitoring, and expanding or establishing new monitoring in critical habitats. To maximize the utility of these indicators for decision-makers, priority levels, current and potential future partners, funding requirements, and implementation timelines are provided in tables for each indicator monitoring strategy.

The Indicators Working Group recognizes that regular evaluations of and updates to the Ocean Climate Indicators Monitoring Inventory and Plan are key to ensuring that the recommended indicators are scientifically sound and relevant to regional decision-makers. Ongoing evaluation of the indicators may result in the development of indicator benchmarks like those available for ecological indicators in the San Francisco Bay Estuary (SFEP 2011), further increasing their utility to decision-makers. The Indicators Working Group recommends that the Ocean Climate Indicators Monitoring Inventory and Plan be updated by GFNMS in two ways:

1. On an annual basis, GFNMS staff should consider updating data sources for each indicator.
2. Every 5 years, the GFNMS SAC should consider convening a working group to review the indicators contained in this report, to re-evaluate their utility to managers and their ongoing scientific relevance, and to consider adding any new indicators that reflect advances in scientific understanding of climate change in the North-central California coast and ocean region.

Moving forward, the Indicators Working Group also recommends that the indicators be integrated into a web-based indicator decision support tool, for which additional financial support would be needed. Such a tool would provide quick and easy access to pre-processed, pre-screened, and pre-interpreted indicator observations and available pre-existing indicator projections that are produced by other researchers. Increasing decision-maker access to interpreted ocean climate indicator monitoring and projections, and ensuring that long-term, consistent indicator monitoring exists, are key to ensuring that the best-available science is informing decisions in order to maximize the resiliency of the North-central California coast and ocean region. In addition, financial support is needed at GFNMS, other government agencies, and partner institutions and organizations to maintain and expand indicator monitoring.

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List of Acronyms

Acronym	Full Name
ACCESS	Applied California Current Ecosystem Studies
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
BML	Bodega Marine Laboratory
BOAR	Bodega Ocean Acidification Research
BOEM	Bureau of Ocean Energy Management
BOON	Bodega Ocean Observing Node
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CBNMS	Cordell Bank National Marine Sanctuary
CCS	California Current Ecosystem
CDIP	Coastal Data Information Program
CDFW	California Department of Fish and Wildlife
CeNCOOS	Central and Northern California Ocean Observing System
CO_2	Carbon Dioxide
CO-OPS	Center for Operational Oceanographic Products and Services
CSFR2	Climate System Forecast Reanalysis, v2
DIC	Dissolved Inorganic Carbon
DO	Dissolved Oxygen
ENSO	El Niño Southern Oscillation
FMSA	Farallones Marine Sanctuary Association
GFNMS	Gulf of the Farallones National Marine Sanctuary
GHRSST	Group for High-Resolution Sea Surface Temperature
IOOS	United States Integrated Ocean Observing System
LiMPETS	Long-term Monitoring Program and Experiential Training for Students
MARINe	Multi Agency Rocky Intertidal Network
MBARI	Monterey Bay Aquarium Research Institute
MBNMS	Monterey Bay National Marine Sanctuary
MODIS	Moderate Resolution Imaging Spectroradiometer
NARR	North American Regional Reanalysis
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDBC	National Data Buoy Center
NGO	Non-governmental Organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPGO	North Pacific Gyre Oscillation
NPS	National Park Service
NWS	National Weather Service
OA	Ocean Acidification
OCOF	Our Coast–Our Future
OMEGAS	Ocean Margin Ecosystems Group for Acidification Studies

OMZ	Oxygen Minimum Zone
ONMS	Office of National Marine Sanctuaries
OSCAT	Oceansat-2 Scatterometer
OST	California Ocean Science Trust
PACE	Postdocs Applying Climate Expertise
PaCOOS	Pacific Coast Ocean Observing System
PDO	Pacific Decadal Oscillation
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
PMEL	NOAA Pacific Marine Environmental Laboratory
POES	Polar-orbiting Operational Environmental Satellites
QuickSCAT	NASA Quick Scatterometer
RTC	Romberg Tiburon Center
SAC	Sanctuary Advisory Council (NOAA GFNMS and CBNMS)
SFAN	NPS San Francisco Area Network
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
UC	University of California
UCAR	University Corporation for Atmospheric Research
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
WERC	Western Ecological Research Center

Report Photo and Figure Credits

Figure	Description	Credit
Cover photo, left	Shoreline along North-central California coast	NOAA GFNMS BeachWatch
Cover photo, middle	Brandt's cormorant	Chad King, MBNMS
Cover Photo, right top	San Francisco tide gauge	NOAA Tides and Currents
Cover photo, right middle	Bull kelp	Steve Lonhart, MBNMS
Cover photo, right bottom	Gopher rockfish	Chad King, MBNMS
Figure ES-1	Scientist sampling phytoplankton	NOAA MBNMS
Figure ES-2	Juvenile blue rockfish	Steve Lonhart, MBNMS.
Figure ES-3	Surfgrass	Steve Lonhart, MBNMS.
Figure ES-4	Brandt's cormorant	Jason Thompson, NOAA GFNMS BeachWatch
Figure ES-5	Map of study region (thick red lines), with related sanctuary boundaries (black solid lines) and proposed sanctuary expansion areas (black dashed lines)	Tim Reed, GFNMS
Figure ES-6	Shoreline along North-central California coast	NOAA GFNMS BeachWatch
Figure 1	Physical ocean climate indicators for the North- central California coast and ocean region	Benét Duncan
Figure 2	Biological ocean climate indicators for the North-central California coast and ocean region	Benét Duncan
Figure 3	Ocean Climate Indicators Project flowchart	Benét Duncan
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Figure 5	Annual maximum air temperature at Southeast Farallon Island from 1971 – 2012. The diagonal black line illustrates a linear regression indicating the trend in the data.	Point Blue Conservation Science, unpublished data
Figure 6	Giant green anemone	NOAA GFNMS BeachWatch
Figure 7	California mussels	Steve Lonhart, MBNMS.
Figure 8	Seagrass bed along North-central California coast	NOAA GFNMS BeachWatch
Figure 9	Brandt's cormorant	Chad King, MBNMS
Figure 10	Common murre	Dru Devlin, NOAA GFNMS/ACCESS

Appendix A: Climate Change Priority Management Questions

Note: These questions are based on the 2008 Condition Report and on the updated ONMS Condition Report questions.

As a result of climate variability and change (as outlined in the Ecosystem Description and Conceptual Ecological Model):

1. What is the integrity of major habitat types and how is it changing? That is, are there changes in the extent of habitat available to organisms or in the quality of that habitat, whether it is non-living or biogenic?
2. Have water conditions changed? Conditions include all potential impacts of climate change on water, including temperature, acidity, sea level, upwelling, storminess, erosion, sedimentation, and freshwater delivery, and the cascading effects of these impacts.
3. What is the status of biodiversity, most especially the functional interactions between species? How is it changing?
4. What is the status and health of keystone and foundation species, and how is it changing? Changes in the status and health of either type of species can affect ecosystem structure and integrity through changes in the abundance of dependent species.
5. What is the status and health of key species and how is it changing?
6. What is the status of non-indigenous species, and how is it changing? That is, is the recruitment, establishment, or severity of impacts of non-indigenous species changing?

Definitions:

Biogenic Habitat – Habitat whose presence is due to the growth of animals or plants which create substrates and floating habitats that attract or support other organisms.

Key Species – Species of particular interest from the perspective of sanctuary management. May not be abundant or provide high value to ecosystem functioning, but their presence and health is important for the provision of sanctuary services. Key species include those targeted for special protection, those with specific regulations to minimize perturbations from human disturbance, indicator species, and "flagship" species.

Keystone Species – Species on which the persistence of a large number of other species in the ecosystem depends. Their impact is important at the community or ecosystem level. Keystone species can include habitat creators like corals and kelp; predators that control food web structure like sea otters and Humboldt squid; and herbivores that regulate benthic recruitment like certain sea urchins.

Foundation Species – Single species that define much of the structure of a community by creating locally stable conditions of other species, and by modulating and stabilizing fundamental ecosystem processes. Foundation species have a higher abundance than keystone species. In the GFNMS, they include krill, kelp, rockfish, coral, and mussels.

Appendix B: Indicator Selection Criteria & Post-Assessment Questions

Note: The indicator selection criteria presented below:

1. *Is based on the peer-reviewed work presented in the National Research Council's "Ecological Indicators for the Nation" report, and in the San Francisco Estuary Partnership's "State of the San Francisco Bay 2011" report.*
2. *Was used as the basis of the Indicator Survey, which was sent to Ocean Climate Indicator Workshop participants.*

<u>Selection Criteria:</u>

1. General importance:
    a. Does indicator tell about changes in important attributes due to changes in climate?
    b. Will changes in the indicator result in an identifiable change in the system?
    c. Can it inform direct or indirect actions by sanctuary management?
    d. Is the indicator compatible with those being developed by other groups in the region?
    e. Is it based on the GFNMS ecosystem description (see above)?
2. Temporal and spatial scales of applicability
    a. Can indicator detect changes at appropriate temporal and spatial scales?
3. Statistical properties of indicator data:
    a. Is the available indicator data good enough in accuracy, sensitivity, precision, and robustness?
    b. Is it insensitive to changes in monitoring technology?
    c. Can it detect signals above "noise" of other environmental variation?
4. Reliability:
    a. Has past experience with indicator demonstrated its reliability?
    b. If not, is there other historical evidence that is reliable?
5. Data requirements:
    a. Does enough information exist to develop reliable indicator measurements?
    b. Can new information be collected to develop reliable indicator measurements?
    c. What is required for indicator to detect a trend?
    d. Would another dataset provide sufficient information about this indicator? That is, are proxies available?
6. Necessary skills:
    a. Can the indicator be easily monitored without extensive training, or does it require specialized knowledge?

<u>Additional Assessment Questions:</u>

1. Data requirements:
    a. What new data, if any, needs to be collected to monitor the indicator?
    b. Are historical datasets available for this indicator?
    c. Where is existing indicator available? Can we use it?
2. Costs, benefits, and cost-effectiveness:
    a. What are the clear benefits of using this indicator?
    b. What are the costs of obtaining data for the indicator?
    c. Do the benefits of using this indicator exceed the cost of obtaining data?

Appendix C: Gulf of the Farallones Regional Ecosystem Description

All information included in the Ecosystem Description is excerpted from the Gulf of the Farallones National Marine Sanctuary's 2010 Condition Report and 2008 Management Plan, with the exception of the Nearshore Subtidal Habitat discussion, and all sections on Potential Impacts of Climate Change, which are excerpted from the 2010 Gulf of the Farallones and Cordell Bank National Marine Sanctuaries Climate Change Impacts Report.

General Overview

Physical Setting

The project study region extends along the North-central California coast from Point Arena in the north to Point Año Nuevo in the south, and offshore along the continental slope at the western boundaries of the Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries. The North-central California coastline includes sandy beaches, rocky cliffs, open bays (including Bodega and Drakes Bays), enclosed bays or estuaries that are open to the ocean year-round (Bolinas Lagoon, Tomales Bay, and Bodega Harbor), and seasonally closed lagoons (Esteros Americano and de San Antonio). Six general habitat types exist within the study region: Sandy Beaches, Rocky Intertidal, Nearshore Subtidal, Estuaries and Bays, Islands, and Offshore. Subsequent sections will describe each habitat type in depth.

This region contains the widest portion of the continental shelf on the west coast of the United States. Here, the gently sloping continental shelf extends westward nearly 57km from the California coast, with an average depth of approximately 120m. A thin layer of generally coarse sediments surrounds patches of rocky outcroppings at the shelf break and the continental slope.

The Farallon Islands are located along the outer edge of the continental shelf, approximately 48km to the west of San Francisco. Consisting of 7 islands and large rocks, they are part of a larger submarine ridge that includes South, Middle, and North Farallon Islands, Hurst Shoal, Fanny Shoal, Noonday Rock, Rittenburg Bank, and Cordell Bank. The variable bathymetry along Farallon Escarpment is associated with significant ecological richness, high species diversity, and spawning and feeding areas.

Physical Processes

Water circulation within the study region is dominated by the California Current, which travels southward along the west coast of the United States. In this wind-driven upwelling system, northerly winds during spring and summer months drive a shallow surface layer, which travels offshore due to the Coriolis Effect. This offshore movement of surface water is also known as Ekman Transport. Deep, cold, nutrient-rich water move upwards to replace the surface water lost along the coastline, and it creates a food-rich environment that promotes the growth of organisms at all levels of the marine food web.

During relaxation periods, the prevailing northerly winds weaken, causing currents to flow to the north and halting upwelling. Relaxation periods can occur during spring and summer, but weakened winds are typical during the fall season. As a result, water temperatures increase during fall months, and warm, lower-salinity waters move onshore.

Winter months are characterized by rain-bearing cold fronts that pass through the study region. Winds are typically from the west and south, which contributes to northward surface currents and downwelling over the continental shelf. The northward-traveling California Undercurrent comes to the surface.

Sediments are transported throughout the study region by currents year-round. As a result, seasonal deposition and erosion of sediments change the width and steepness of beaches from season to season. For example, sediments are washed into the region by rivers and from shoreline erosion during the winter storm season. Esteros become closed off from the ocean during summer and fall by seasonally formed sand bars. At the same time, beach sand is moved downcoast by longshore drift.

Habitat #1: Sandy Beaches

Physical Setting

Sandy beaches are mostly located along the coastal border of the study region. Five distinct zones within sandy beach habitat are defined by the level of tidal inundation: The upper intertidal beach zone has a short inundation time, while the mid-littoral beach zone has a moderate inundation time. The swash zone is located where waves break along the beach and is submerged for approximately 12 hours daily. The low intertidal beach zone has a long inundation time and is exposed to near-constant wave action, while the surf zone is submerged continuously and exposed to constant wave action.

Physical Processes and Components

Sandy beach habitat constantly changes due to the influence of waves on each of the five zones, with a wide temperature range due to changing wave action and tidal exposure.

Biological Processes and Components

The species distribution within sandy beach habitat is strongly influenced by the physical factors listed above, which can vary between zones. Food and shelter are provided by detached plant and algal debris, and by corpses of fishes, seabirds, and marine mammals, especially in upper intertidal beach zones. Sandy beaches are home to numerous invertebrate communities, and they are breeding grounds for birds and pinnipeds.

Potential Impacts of Climate Change

Sea level rise and increased erosion are expected to intensify pressure on sandy beaches, particularly in mid and upper beach zones, which can in turn impact the biota, biodiversity, and food web in this habitat. Sand dunes may need to retreat landward. Shorebirds that live in sandy beaches could face lower availability of invertebrate prey, reduced macroalgae wrack, and habitat loss. Fish and pinnipeds could lose habitat that they depend on for reproduction.

Habitat #2: Rocky Intertidal (aka Rocky Shore)

Physical Setting

Rocky intertidal habitat consists of rocky areas found between high and low tide water levels. It covers approximately 22% of the shoreline in the Gulf of the Farallones National Marine Sanctuary and can be found at Bodega Head and Duxbury Reef.

Physical Processes and Components

Frequent wave action, changing tide levels, and wind have strong impacts on rocky intertidal habitat, causing drying and heating/cooling during low tide.

Biological Processes and Components

Organisms living in rocky intertidal habitats must survive extreme physical conditions that change rapidly, and their distribution is influenced by tidal inundation and wave exposure. Coralline algae provide cover and food for a diverse array of marine invertebrates that include barnacles, limpets, black turban snails, mussels, sea anemones, and sea urchins. Different fish are common at different depths within rocky intertidal habitats, but they include rockfish, Cabazon, and small surfperches. Pinnipeds also breed along rocky shores (see the Islands section for more details).

Potential Impacts of Climate Change

Climate change-induced increases in average water and air temperature, prevalence of extreme events, ocean acidification, and changes in upwelling patterns, are of primary concern in rocky intertidal habitats. Most organisms there are ectothermic, and changes in ambient temperatures could cause an increased susceptibility to disease, population declines, and even mass mortality of some organisms. Upwelling can bring increasingly acidic waters to intertidal organisms, decreasing the ability of calcifying organisms to produce shells, and altering the delivery of food, nutrients, and larvae to intertidal habitats. Rising sea level will pressure organisms to migrate if upland habitat is available. Increased wave activity is expected to alter the temperature and physical forces that intertidal organisms experience. Populations of larval and adult organisms may respond to the wide array of climate change-induced pressures by shifting their ranges.

Habitat #3: Nearshore Subtidal (aka Shallow Subtidal)

Physical Setting

Nearshore subtidal habitat can be found at depths up to 30-50m, below the tide line, where coastal habitat meets the mainland. The seafloor there is often described either as sandy continental shelf or as rocky reef.

Physical Processes and Components

Upwelling plays an important role in delivering cool, nutrient-rich water to nearshore subtidal habitat. Shallow depths allow for good light penetration, while runoff and precipitation provide freshwater input, especially during the winter storm season.

Biological Processes and Components

Kelp forests are located in many of the rocky reef zones within nearshore subtidal habitat. Common kelp species include Macrocystis and Nereocystis. These kelp forests provide a home for other organisms like Black Rockfish, which in turn provide a food source for seabirds and pinnipeds. Dislodged kelp provides a critical food resource to sandy beach, intertidal, and deep-water offshore habitats. In addition, calcifying organisms, benthic macroalgae, phytoplankton, larvae, and spores are all found within nearshore subtidal habitat.

Potential Impacts of Climate Change

Changes in upwelling, stratification, and offshore transport could impact the delivery of nutrients from deep and offshore waters to nearshore subtidal habitat, and could also affect the dispersion of larvae and spores. Increased ocean acidification would affect the shell thickness and survival of calcifying organisms. Rising sea level would decrease the amount of light available in bottom water layers, which could cause a shoreward migration of nearshore subtidal habitat. At the same time, increasing sea level could also alter the substrate composition and the shape of the shoreline, which would reduce the amount of land available for a shoreward migration. Increased storminess associated with climate change could increase wave heights, which in turn could alter sediment redistribution and coastal topography. Increased precipitation and runoff associated with more frequent storminess would increase freshwater input, while increased turbidity and light attenuation could decrease the growth of kelp. In addition, increased storminess would likely cause an increase in the dislodgement of kelp holdfasts, which would further the loss of kelp forests within nearshore subtidal habitat.

Habitat #4: Estuaries and Bays

<u>Physical Setting</u>

Estuaries and bays are mostly small and sandbar-built within the study region. Examples of small estuaries include Bolinas Lagoon, Estero Americano, and Estero de San Antonio. Tomales Bay is a moderately sized bay, and San Francisco Bay is a major estuary located outside of the study region, but with important impacts on the region.

<u>Physical Processes and Components</u>

Small estuaries are often built with the seasonal inflow of sediments that are transported by coastal ocean circulation. They are protected from the open ocean, and as a result, bays and estuaries typically have shallow, warm water with good light penetration. Tributaries provide high nutrient input.

<u>Biological Processes and Components</u>

The combination of warm temperatures, abundant light, and high nutrient levels makes estuaries and bays a highly productive habitat type. A variety of ecosystems can be found within this habitat, including mudflats, brackish water, eelgrass beds, salt marshes, and tidal creeks. Mudflats contain a high concentration of burrowing organisms like clams, snails, worms, and crabs, which in turn provide a food source for shorebirds and wading birds. Eelgrass beds are home to juvenile stages of coastal fish, and pacific herring, and they provide a place for invertebrates to spawn and feed.

Estuaries and bays also provide a feeding, spawning, and nursery area for fish that include Pacific herring, smelt, starry flounder, sharks, rays, and surfperch. Low-level carnivores of invertebrates and planktivores are the most common fish in estuaries and bays. There is higher abundance and species richness during summer, when young marine species invade these habitats. Coho salmon, a federally threatened species, travel from the ocean through bays and estuaries, and they depend on this habitat for reproduction.

Over 180 species of birds have been observed on the beaches between Bodega Head and the northern border of Santa Cruz County. Within estuaries and bays, shorebirds probe the shore to feed on buried clams, worms, crustaceans, and small fishes. Commonly seen birds include black oystercatchers, dowitchers, sandpipers, herons, ducks, rails, and geese. The black rail is a California threatened species with rapidly diminishing numbers in its habitat in Tomales Bay and Bolinas Lagoon. It is now rarely seen in salt marshes in the region. In addition, populations of sea lions and seals haul out and reproduce in Drakes Estero, Bolinas Lagoon, and Tomales bay.

<u>Potential Impacts of Climate Change</u>

Sea level rise due to changing climate is expected to impact estuaries and bays differently, depending on the ability of an estuary to migrate inland and upward, and its reliance on organic versus inorganic deposition. The potential loss of estuarine intertidal mudflats could have a large effect on shorebirds and harbor seals. Increased interannual variation of watershed outflow may favor invasive species and alter the salinity gradient. Increased air and water temperatures may put greater stress on some plants and animals, magnify pathogen and parasite problems, and favor the range expansion of other plants and animals. Increasing atmospheric carbon dioxide causes an increase in ocean acidity, which strongly impacts estuaries because freshwater input reduces their ability to buffer acidic ocean inflow. Acidification of estuarine waters decreases animal fertilization and embryo development, and it can cause shell dissolution in juvenile bivalves. Changes in currents and atmospheric circulation may alter the transport of organisms within and between estuaries.

Habitat #5: Islands

Physical Setting

Island habitats within the study region include the Farallon Islands and Año Nuevo Island. See the General Overview for more details.

Physical Processes and Components

The Farallon Islands and Año Nuevo Island are isolated, rocky habitats that provide remote breeding and feeding areas away from intense human activities.

Biological Processes and Components

Marine productivity is extremely high in the waters surrounding the Farallon Islands. As a result, a diverse assemblage of invertebrates, fish, seabirds, and marine mammals has been observed there. The Farallon Islands are home to the largest concentration of nesting seabirds within the contiguous United States. Over 300,000 seabirds nest on the islands annually from May-July, and 11 of 16 breeding seabird species along the US Pacific coast have colonies there. Common aquatic birds include waterfowl and shorebirds like black oystercatchers, pelicans, loons, and grebes.

Island habitat is also an important location for breeding populations of northern fur seals, elephant seals, harbor seals, California sea lions, and Steller sea lions. One of the last California populations of federally threatened Steller sea lions lives in the study region. The Farallon Islands lie in the southern part of the species' range, and the population has decreased there by 80% over the past 50 years. A small breeding colony of fur seals has lived on the Farallon Islands since 1996, after not being seen there for the prior 176 years. The California sea lion is the most conspicuous and widely distributed pinniped in the study region, where it can be found year-round. The population of California sea lions increases by 8-12% yearly. The northern elephant seal is the largest pinniped species in the study region. Approximately 20% of the harbor seals in California breed in the sanctuary.

Potential Impacts of Climate Change

Increased sea level could significantly alter island habitats and cause a redistribution of wildlife populations as organisms are forced to move upland or abandon flooded areas. Intensified winter precipitation and increased rainfall may increase erosion of hillsides and cause flooding of low-lying areas, which would in turn degrade nesting habitat and alter vegetation structure. Rising average air temperatures could also alter vegetation and stress wildlife within island habitats.

Habitat #6: Offshore

Physical Setting

Offshore habitats can be subdivided into three distinct zones: pelagic shelf, pelagic slope, and offshore benthic (which includes submarine canyons). The pelagic shelf and slope zones consist of water above the seafloor of the continental shelf and slope, respectively. Waters in the pelagic shelf zone range in depth from 0-200m, and the pelagic slope zone occurs where the depth of the seafloor rapidly increases from 200-2000m. The pelagic zones often contain newly upwelled water, with some warmer water in retention zones, plume-influenced water from San Francisco Bay, and surf zone water near the surface. In the deep-sea pelagic zone, there is generally low light, cold water temperature, and high pressure. In the deep-sea portions of the pelagic zone, there is generally low light, cold water temperature, and high pressure. Benthic habitat contains the seafloor, which can vary by depth and region. Along the continental shelf, the substrate can be sandy or rocky, with a nearly continuous blanket of mud up to 30m thick found at depths from 40-90m. The seafloor along the continental slope typically has a soft bottom with some rocky outcroppings, except along submarine canyons, which have steep, rocky walls with complex physical structures that hold sediments.

Physical Processes and Components

Along the continental shelf (in the offshore benthic zone), wave action and subsurface currents cause shifting sediments that consist of varying combinations of sand, silt, and clay. During high wave action along the continental shelf, substrate that had previously settled can be resuspended and transported offshore. Kelp forests within the pelagic shelf zone alter turbulent flow patterns due to the large size and high density of kelp. Because of the depth of the pelagic slope zone, organisms there are exposed to extremely low light, cold temperatures, and very high pressure.

Biological Processes and Components

In all offshore habitat zones, white sharks, turtles, and cetaceans are present. The study region has one of the largest known concentrations of white sharks in the world, with a stable, genetically isolated population of 175-299 adults. White sharks arrive nearshore during summer months, near pinniped haul-out and breeding colonies between Point Año Nuevo, the Farallon Islands, Tomales Point, Point Reyes, and Bodega Headlands. They leave during winter months to migrate southward to the central Pacific and the Hawaiian Islands. White sharks are an apex predator, which means that they are a key species. Their removal could have cascading trophic impacts on the population dynamics of their prey, and on the food web as a whole.

Turtles are also seasonally present in offshore habitats where they forage on jellyfish. They follow warmer waters during summer and fall, and their location is greatly influenced by the timing of the relaxation of upwelling winds. Leatherback turtles are observed annually in the study region, while other species are rarely seen.

There are 12 regularly seen species of cetaceans in offshore habitats. Minke whale, harbor porpoise, Dall’s porpoise, and Pacific white-sided dolphin are all observed year-round, while gray, humpback, and blue whales are observed seasonally. The study region is a nursery for harbor porpoise and Pacific white-sided dolphins, and a major migration route for gray whales from December-March. From April-November, offshore habitats are a destination feeding and migration route for humpback and blue whales. In fact, the study region has one of the largest concentrations of both gray and humpback whales in the northern hemisphere. In addition, offshore seabirds such as Sooty Shearwaters consume small schooling fish, squid, and zooplankton in the highly productive California Current waters.

Offshore pelagic shelf zones contain nearshore kelp beds, which support juvenile finfish, pinnipeds (especially harbor seals and Steller and California sea lions), birds, and occasionally gray whales. Below 60ft, kelp growth is limited due to a lack of light. Two species of krill, which are the keystone invertebrate species for the entire study region, are based in the offshore continental shelf.

Thysanoessa spinifera is a coastal species, and it is dominant during summer months when upwelling is relaxed. Euphausia pacifical is an oceanic species, and it is dominant during the late winter and spring upwelling season. Productive commercial fisheries are also found here, with the location and composition dependent on oceanographic conditions. Pelagic shelf zones along the study region coastline also retain larval and juvenile salmon, northern anchovy, rockfish, and flatfish, which reduces pressure on these fishes and ensures their continuing populations.

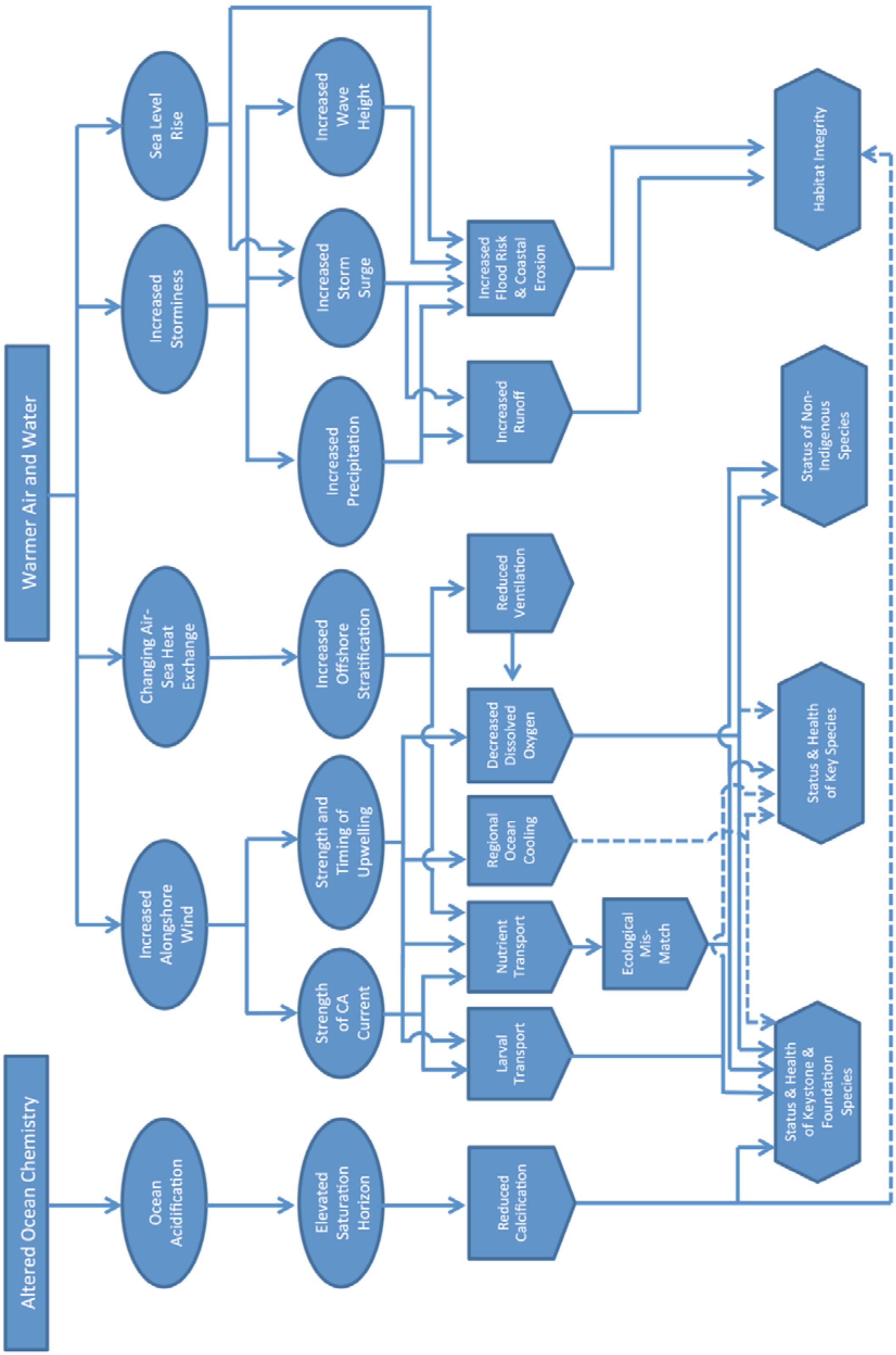
Organisms found in the offshore pelagic slope zone are specialized for high pressure, low oxygen, and low light. Some adapt to produce their own light with bioluminescence. Organisms here depend on surface-level primary production. Common invertebrates include coralline algae, brittle stars, and serpulid worms. Productive commercial fisheries are located in offshore continental slope zones, where rockfish, thornyfish, sablefish, and Dover sole are found.

In offshore pelagic zones, there is a diverse and complex food web that consists of plankton, invertebrates, fishes, sea turtles, birds, and mammals. Fish species vary with migration and spawning, but they include predatory finfish, northern anchovy, Pacific mackerel, and market squid nearshore, and juvenile finfish in kelp beds. Deep-sea pelagic invertebrates like jellies, squids, octopuses, barnacle larvae, copepods, and shrimp are slow growing and eat less frequently. Benthic zones with sandy substrate along the continental shelf contain animals that live in tubes and burrows (i.e. clams, crustaceans, and mollusks), and shrimp, prawns, flatfish, and Dungeness crabs. Benthic zones with rocky substrate along the continental shelf contain extensive macroalgae, abalones, sea urchins, rockfishes, surfperches, and Cabazon. The seafloor along the continental slope is home to deep-sea pelagic invertebrates like cold-water corals, sea anemones, worms, snails, clams, barnacles, copepods, and crabs. The rocky walls of offshore submarine canyons are home to species like flatfishes and invertebrates like polychaete worms, mollusks, shrimp, and brittle stars.

Potential Impacts of Climate Change

Changes in upwelling and stratification due to climate change can affect nutrient delivery to offshore pelagic shelf and slope habitats. Reduced nutrient delivery and primary productivity (decreased zooplankton and phytoplankton) could have a large impact cascading through the entire ecosystem. Increasing water temperatures will pressure some organisms to shift their geographic range northward, and will alter reproductive rates and the timing of growing seasons for others. Reduced numbers of some species, like juvenile rockfish, during breeding times for common seabirds can cause mass mortality events. As in other habitats, ocean acidification is likely to result in decreased calcification rates of calcifying organisms, including shell-building pteropods and foraminifera that are key to ocean food webs. Reduced numbers of calcareous organisms, combined with warming temperatures, could allow gelatinous organisms like jellyfish to increase in size and population. Increased ocean storminess, wave activity, and turbidity can negatively impact kelp growth, which could reduce the available feeding and breeding grounds for a variety of fish, seabirds, cetaceans, and pinnipeds.

Appendix D: Conceptual Ecological Model for North-central California Coast and Ocean



Definitions from ONMS Condition Report:

Keystone Species – Species on which the persistence of a large number of other species in the ecosystem depends. Their functional contribution to ecosystem function is disproportionate to their numerical abundance or biomass.

Foundation Species – Single species that create locally stable conditions for other species, and that modulate and stabilize fundamental ecosystem processes. Their high abundance distinguishes them from keystone species.

Key Species – Species of particular interest from the perspective of sanctuary management. Their presence and health is important for the provision of other services, but they may not be abundant or provide high value to ecosystem function.

Appendix E: Priority Levels of Indicator Monitoring Strategies

Indicator monitoring activities with "critical" priority levels are identified in the table below. While all indicator monitoring activities were carefully selected and continued funding for these activities is important, "critical" priority activities are those for which funding is critical, even during times of limited financial resources because they can capture more critical information about climate change impacts more efficiently than "very important" and "important" priority activities.

Indicator	Monitoring Activity	Brief Description	Page #
Physical Indicators			
#1: Air Temperature	Activity 1.1	Continued support for air temperature monitoring at weather stations	12
#2: Alongshore Wind Speed and Direction	Activity 1.1	Maintain wind data collection	16
#2: Alongshore Wind Speed and Direction	Activity 1.2	Repair/replace damaged offshore wind sensors	16
#3: SST	Activity 1.1	Continued support for SST monitoring	18-19
#5: DO	Activity 1.1	Add oxygen sensors to existing moorings and surveys	26-27
#6: Ocean Chemistry	Activity 1.1	Add pH and CO_2 instruments to existing moorings and offshore cruises	29
#7: Wave Height and Direction	Activity 1.1	Continued support for existing wave monitoring, including on buoys	31-32
#8: Sea Level	Activity 1.1	Sustained resources for long-term sea level monitoring	35
Biological Indicators			
#1: Primary Productivity	Activity 1.1	Continued support for existing chlorophyll monitoring	37-38
#2: Mid-Trophic Level Species Abundance, Biomass, and Phenology	Activity 1.1	Maintain current mid-trophic species monitoring	41-42
#3: Spatial Extent of Habitat-Forming Organisms	Activity 1.1	Maintain support for existing in situ monitoring of habitat-forming organisms	47
#4: Seabird Phenology, Productivity, and Diet	Activity 1.1	Continue monitoring of seabird diets on islands and rocky shore habitats	50-51
#4: Seabird Phenology, Productivity, and Diet	Activity 1.2	Continue monitoring of seabird abundance on land and at sea	50-51
#4: Seabird Phenology, Productivity, and Diet	Activity 3.1	Continue monitoring of seabird productivity in key habitats	52

Appendix F: Promising Mid-Trophic Level Species

Some mid-trophic level species (Biological Indicator #2), which would provide valuable information if long-term datasets were underway or already available, have been designated as promising species and are provided below:

PROMISING **MID-TROPHIC LEVEL SPECIES**	
ROCKY INTERTIDAL	
	Purple sea urchin (*Strongylocentrotus purpuratus*)
	Owl limpet (*Lottia gigantea*)
	Black (*Haliotis cracherodii*) & Red (*Haliotis rufescens*) abalone
	Nudibranch (Nudibranchia)
ESTUARIES & BAYS	
	Large annelid (Polychaeta)
	Goby (Gobiidae)
OFFSHORE (BENTHIC & PELAGIC)	
	Krill (Euphausiacea)
	Gelatinous zooplankton (Gelata)
	Foraminifera (Foraminifera)