CLIMATE CHANGE IMPACTS

GULF OF THE FARALLONES AND CORDELL BANK NATIONAL MARINE SANCTUARIES

Report of a Joint Working Group of the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries Advisory Councils

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Executive Summary

On global and regional scales, the ocean is changing due to increasing atmospheric carbon dioxide (CO_2) and associated global climate change. Regional physical changes include sea level rise, coastal erosion and flooding, and changes in precipitation and land runoff, ocean-atmosphere circulation, and ocean water properties. These changes in turn lead to biotic responses within ocean ecosystems, including changes in physiology, phenology, and population connectivity, as well as species range shifts. Regional habitats and ecosystems are thus affected by a combination of physical processes and biological responses. While climate change will also significantly impact human populations along the coast, this is discussed only briefly.

Climate Change Impacts, developed by a joint working group of the Gulf of the Farallones (GFNMS) and Cordell Bank (CBNMS) National Marine Sanctuary Advisory Councils, identifies and synthesizes potential climate change impacts to habitats and biological communities along the north-central California coast. This report does not assess current conditions, or predict future changes. It presents scientific observations and expectations to identify potential issues related to changing climate – with an emphasis on the most likely ecological impacts and the impacts that would be most severe if they occur. *Climate Change Impacts* provides a foundation of information and scientific insight for each sanctuary to develop strategies for addressing climate change. These strategies will outline priority management actions for the next 10 years to address the impacts of climate change specific to the site, its communities, and the region.

Key Issues

- ⇒ Observed increase in sea level (100 year record at mouth of San Francisco Bay)
- ⇒ Expected increase in coastal erosion associated with changes in sea level and storm waves
- ⇒ Observed decrease in spring runoff of freshwater through San Francisco Bay (decreased Sierra snowpack)
- ⇒ Observed increase in precipitation variability (drier dry years, wetter wet years)
- ⇒ Observed increase in surface ocean temperature offshore of the continental shelf (50 year record)
- ⇒ Observed increase in winds driving coastal upwelling of nutrient-rich waters and associated observed decrease in surface ocean temperature over the continental shelf (30 year record)
- ⇒ Observed increase in extreme weather events (winds, waves, storms)
- ⇒ Expected decrease in seawater pH, due to uptake of CO_2 by the ocean
- ⇒ Observed northward shift of key species (including Humboldt squid, volcano barnacle, gray whales, bottlenose dolphins)
- ⇒ Possible shift in dominant phytoplankton (from diatom to dinoflagellate blooms)
- ⇒ Potential for effects of climate change to be compounded by parallel environmental changes associated with local human activities

Physical Effects of Climate Change

The observed rise in *sea level* at the mouth of San Francisco Bay over the last century is 20 cm, and this rise is expected to continue. The State of California is using a projection of 40 cm rise in sea level by 2050 and 140 cm by 2100 for planning purposes. However, the most recent sea level rise analysis projects 75 to 190 cm respectively. The rise in sea level exacerbates coastal flooding, shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threatens cultural and historic resources as well as infrastructure (see 3.4 Sea Level Rise).

As a result of rising sea level, together with more intense precipitation/runoff events and an increase in extreme wave and storm conditions, an increase in *coastal erosion* is expected. If sea level rises 1.4 m by 2100, scientists project that the total erosion area for the five counties along the study region will reach nearly 50 km^2. Coastal habitats may be directly affected by erosion through habitat loss, or indirectly via human responses such as coastal armoring, beach nourishment, or planned retreat (see 3.5 Coastal Erosion).

Climate-related changes in *precipitation and runoff* are primarily related to reduced snowpack due to warmer winter storms. Reduced Sierra snowpack will result in stronger winter runoff events and reduced spring runoff through San Francisco Bay. In smaller coastal watersheds, as well, more extreme winter precipitation events are expected. Further, it is projected that there will be a greater variability in annual precipitation during the 21st century (i.e., drier dry years and wetter wet years). In turn, these changes in runoff can be expected to lead to increased flooding of coastal lowlands, erosion of estuarine habitats, increased delivery of watershed material to the ocean, expanded plume areas, and increased nearshore stratification (see 3.2 Precipitation and Land Runoff).

Surface *ocean temperatures* have increased in the North Pacific, offshore of the north-central California continental shelf. This increase in temperature has significant effects on water column structure (i.e., stratification), sea level rise, and ocean circulation patterns. While sea temperature also appears to have increased in shallow bays, estuaries and sheltered nearshore locations, waters over the north-central California continental shelf have cooled over the last 30 years (by as much as 1°C in some locations) due to stronger and/or more persistent *upwelling winds* during spring, summer and fall (see 3.6.1 Temperature; 3.5 Coastal Upwelling).

Stronger *alongshore winds* are expected as a result of an increasing difference in land-ocean atmospheric pressure associated with an increasing difference in land-ocean temperature as climate warms. These stronger winds push surface waters away from the coast more rapidly and force a stronger upwelling of deep, cold, nutrient-rich waters along the coast. This upwelled supply of nutrients is the foundation of the high biological productivity of the ocean in the study region. Both the strength of upwelling winds and the variability in winds affect the amount of primary production available, and the amount delivered to coastal ecosystems rather than offshore ecosystems. Enhanced upwelling results in less phytoplankton availability in coastal waters and a greater but more diffuse supply of phytoplankton to offshore waters. Further, there is preliminary evidence that upwelling will also be more persistent, extending into the fall – but results from analyses of changes in the start of the upwelling season (“spring transition”) are mixed (see 3.5 Coastal Upwelling).

In addition to the increase in average coastal winds during spring, summer, and fall, data from the San Francisco tide gauge (from 1858 to 2000) show an increase in intense *winter storms* since 1950, consistent with an observed increase in the largest waves (see 3.3.2 Waves). Coastal flooding events that were previously 1-in-100 events are now projected to occur with a probability of 1-in-10 years (see 3.1 Atmosphere).

Coastal waters are expected to become more acidic as *pH is lowered* in response to increased concentration of carbon dioxide in ocean waters. While data and model studies are insufficient to be certain how pH will change in the study region, this phenomenon is critical, as it will decrease the availability of chemical building blocks for marine life with shells and skeletons made out of calcium carbonate. Ocean acidification leads to decreased shell growth in key species such as sea urchins, mussels, oysters, abalone, and crabs, thus making the animal more susceptible to predation, as well as decreased skeleton production of deep sea corals and hydrocorals. As deeper water tends to be more acidic already, deepwater corals such as the hydrocorals located at Cordell Bank may be one of the first to experience deleterious effects of acidification. Also, of particular concern are the larval and juvenile stages of these organisms, which may be more susceptible to ocean acidification due to their small size. In addition, there is concern for negative effects on shell-building plankton at the base of the food web (see 3.6.2 Ocean Acidification; 4.1 Physiology; 5.3 Invertebrates).

In addition to trends in the physical climate, natural climate fluctuations occur in association with El Niño and other phenomena, e.g., Pacific Decadal Oscillation (PDO). The combination of climate change trends with this natural variability may create new extreme conditions. For example, high waves that occur during El Niño events are likely to be more extreme when combined with higher sea level and increased wave heights due to climate change. Similarly, during the positive phase of the PDO, the trend for warmer weather with increased rain, runoff and waves will be enhanced; whereas climate-change trends will be temporarily alleviated during the negative phase of the PDO, yielding periods in which climate change appears to have stalled only to be followed by years of apparently rapid climate change (see 3.0 Physical Effects of Climate Change).

Marine Species Respond

Physical changes in sea level, winds, waves, temperature, pH, and runoff may influence a variety of critical biotic processes, such as metabolic rates, planktonic transport, prey availability, and/or predation rates (see 5.0 Responses in Marine Organisms). The response of a single species to climate change depends not only on environmental changes, but also upon how other interacting species will respond to this change. Marine organisms may respond in a variety of ways to the changing ocean conditions, e.g., (i) remain in the same area but adapt to changing conditions, (ii) persist in sub-optimal conditions but with potentially significant physiological costs, (iii) move to environmental conditions that suit their physiological tolerances by expanding or contracting their range in space (along latitudinal, depth, or intertidal gradients), or (iv) adjust the timing of their life history (e.g., breeding events) – see 4.0 Regional Biotic Responses. In *Climate Change Impacts* available data and detailed studies are discussed to provide a sense of the nature of species-specific changes that may result from climate change in this region.

A general northward *range expansion* of organisms is anticipated owing to warming of ocean waters. Consistent with this projection, there have been observed northward expansions of volcano barnacles, gray whale calving, bottlenose dolphins, and Humboldt squid. However, not all organisms exhibit this shift, suggesting that species responses will likely differ, and that non-uniform changes in ocean temperature from the nearshore to the continental shelf to offshore of the shelf will complicate expectations (see 4.2 Range Shifts; 3.6.1Temperature).

Changes in the timing of the spring transition or the seasonal peak in upwelling could have significant population level impacts for many species. Marine fish likely time their spawning efforts to ensure maximum food availability for larval fish later in the season. Similarly, seabirds likely time their breeding to maximize prey abundance during the critical chick-rearing period. Peak upwelling (and peak food production) may occur too late in the season for successful reproduction if marine fish and seabirds begin breeding in response to an early spring transition. Late upwelling is generally associated with poor ocean productivity, low krill abundance, and late seabird breeding. In turn, late breeding is generally associated with poor seabird reproductive success and could ultimately lead to breeding population declines in the region (see 4.3 Phenology).

Recent increases in *dinoflagellate blooms* in Monterey Bay are consistent with warmer surface temperatures and an associated increase in water stratification in the Bay over the last decade. In contrast, a decrease in phytoplankton concentration is expected along open coasts due to a 30-year increase in upwelling winds and associated offshore movement of phytoplankton – with an increased supply of phytoplankton to offshore waters. Longer data records are needed to determine if these are long-term trends or decadal variability (see 5.1 Plankton).

Macroalgae can be impacted as well through a variety of changes including: (i) increasing nearshore sea surface temperatures; (ii) sea level rise – which can reduce light availability and the availability of suitable attachment surfaces; (iii) changes in upwelling – which can affect the availability of nutrients for photosynthesis; and (iv) increased waves and turbulence – which can detach algae and compromise growth (see 5.2 Macroalgae and Plants).

The availability of prey species for *fish, seabirds, and marine mammals* may be negatively affected by changes in upwelling, as well as ocean acidification. Changing temperatures will directly influence fish physiology, as most fishes are cold-blooded. Fish could respond to these changes by shifting their distributional range to preferred temperatures (see 4.2 Range Shifts). Seabirds and marine mammals may also be impacted by expected increases in sea and air temperature, sea level rise, and extreme storm events – leading to altered migration patterns as well as changes in abundance, timing of breeding, reproductive success, and behavior (see 5.5 Seabirds; 5.6 Marine Mammals).

And Marine Habitats Respond

Productivity in open-ocean *pelagic habitats* is controlled through a delicate balance between wind-driven upwelling and stratification of the water column due to surface warming. Increasing surface temperatures offshore and in bays appear to be reducing vertical mixing and causing a shift in the phytoplankton community, while increased upwelling over the continental shelf may be having the opposite effect. Further, changes in large-scale ocean circulation may be altering the zooplankton community and increasing gelatinous zooplankton (which are undesirable prey for higher trophic levels; see 6.1 Pelagic Habitat).

During weak-upwelling years such as 2005 and 2006, a reduction in phytoplankton and zooplankton abundances was seen in the region. Not only did abundances of krill (adult krill, in particular) and copepods decline, but abundances of gelatinous zooplankton appeared to increase. Due to the lack of available prey, (e.g., adult krill), Cassin's auklets abandoned nests and failed to breed in these years. Further, the decreased survival of Chinook salmon entering the ocean that year and low salmon returns in California in 2008 appear to be related. Also, sightings of blue whales (another krill predator) decreased significantly from 2004.

Because of their limited ability to move, communities associated with *benthic habitats* are particularly susceptible to changes in water properties (e.g., temperature, dissolved oxygen, and ocean pH). While short-lived species with dispersive life stages may shift their spatial distribution, other members of benthic communities will have to adapt in order to survive (see 6.2 Offshore Benthic Habitat).

Of particular concern to *island habitats* is rising sea level and increased wave/storm intensity. Models show that a sea level rise of 0.5 m would result in permanent flooding of approximately 5% of the surface area of the Farallon Islands, including many of the intertidal areas where seals and sea lions haul out. In turn this will shrink the area available for seabirds to nest and breed, reducing the capacity of the largest seabird-breeding colony in the contiguous United States. In addition, the average annual air temperature at the Farallones has exhibited an increasing trend over 36 years (1971- 2007), which will impact many island species that are adapted to cold and windy conditions and quickly become stressed when conditions change. During unusually warm weather, seabirds have abandoned their nests, neglected dependent offspring, and died of heat stress. Marine mammals spend less time hauled out (resting) and would be expected to abandon young in the rookeries if temperatures become too warm (see 6.3 Island Habitat).

In *nearshore subtidal habitats* organisms are susceptible to a variety of changes affecting the habitat, including ocean acidification, changes in upwelling and water stratification that affect nutrient delivery, increases in wave heights that affect sediment redistribution, and sea level rise that decreases light availability to macroalgae (see 6.6 Nearshore Subtidal).

Of primary concern for *rocky intertidal habitat* are possible increases in average water and air temperature, specifically the occurrence of extreme conditions that can result in mass mortality of intertidal organisms. Further, ocean acidification is likely to severely affect the ability of intertidal organisms to produce shells. Sea level rise will also affect habitat distribution for intertidal organisms (i.e., increased sea level rise and increased air temperatures may compress the range of high intertidal species into lower zones; see 6.5 Rocky Intertidal Habitat).

Sea level rise and increased storminess are expected to have significant impact on *beach habitats* within the study region, by increasing rates of shoreline erosion and retreat, and degrading habitat quality. Aggravating this habitat change is the loss of habitat due to the expected increase in shoreline armoring to protect properties from rising sea levels. Threatened species include birds such as the western snowy plover and California least tern that nest in dry sand, fish such as the California grunion and smelt that depend on open sandy beaches for spawning, and pinnipeds such as elephant seals, sea lions, and harbor seals that pup and raise their young on sandy beaches (see 6.4 Sandy Beach Habitat).

Estuary habitats in the study region may be most affected by changes in the timing and persistence of seasonal mouth closure and the intensity and timing of seasonal runoff, as well as the continued rise in sea level. Sediment delivery and availability will strongly influence the ability of estuary morphology to adjust to rising sea level and maintain intertidal estuarine habitat. Also, water properties such as temperature, salinity, dissolved oxygen, and pH can be expected to change significantly, as well as patterns of primary production (see 6.7 Estuarine Habitat).

Climate Change is Not Alone

In parallel with global climate change impacts to the regional ocean environment, land- and marine-based human activities impose additional stress to these habitats, species and ecological communities in the study region. *Multiple stressors* may interact to produce unexpectedly severe impacts on biodiversity and ecosystem health. Additional stressors within the study region include pollution, invasive species, fishing, disease, habitat modification, wildlife disturbance, and development of infrastructure along the coast and at sea. Given that reducing the threats of climate change is a large and global challenge, local and regional natural resource managers should focus on reducing local stressors in order to maintain the resiliency of the ecosystem (so that it can adapt to changes caused by changing climates; see 7.0 Parallel Ecosystem Stressors).

Coastal Communities Feel the Heat

People living and working along the coast will be directly impacted by climate change. While this is not the focus of this report, human responses to these direct impacts on society and the economy are expected to significantly impact marine ecosystems. Issues of particular concern for human populations living along the coast include: water pollution and public health; shoreline safety; and the economic impact from the loss of beaches, loss or damage to coastal infrastructure, damage or loss of homes and commercial structures, and losses incurred by ocean-related businesses. These losses will have significant effects on a variety of economic sectors, including transportation (such as roads and highways, airports, ports and shipping), tourism, fishing, and coastal businesses; see 8.0 Direct Impacts on Humans).

So Now What?

It is certain that marine wildlife, coastal ocean ecosystems, and human populations along the coast will be subject to significant changes. The changes discussed in this report present daunting challenges for long-term management of the Gulf of Farallones and Cordell Bank national marine sanctuaries. While it is unlikely that we will ever be able to fully predict future states of a system as complex as the coastal ecosystem within the study region, we can improve our understanding through monitoring and study and we can define a range of potential impacts. Sanctuary staff needs to develop an action plan, which includes monitoring and adaptive management approaches that can be implemented as the environment continues to change, seeking to maximize benefits of change while mitigating the negative impacts (see 9.0 Conclusion).

Recommendations

⇒ ***Educate society*** *– inform people to allow for optimum decisions*

⇒ ***Put ecosystems in context*** *– link greenhouse gas emissions with marine ecosystem health*

⇒ ***Anticipate change*** *– obtain best available information on changing and future conditions*

⇒ ***Mitigate impacts on the system*** *– reduce manageable stressors that compromise system resiliency*

⇒ ***Adapt to change*** *– create policies and management strategies that are flexible to future changes*