Kelp Forest

Rocky nearshore environment characterized by dense forests of kelp growing at depths from 2 meters to more than 30 meters. The bull kelp, *Nereocystis luetkeana*, is the dominant canopy-forming kelp and tolerates high wave action. The shallow areas inshore of kelp forests are often characterized by canopies of the feather boa kelp, *Egregia menziesii*, and an understory of other kelp species (e.g. *Pterygophora californica,* and other Laminarials) can be found under the bull kelp canopy.

<u>**Habitat Sensitivity**</u>

1. Direct Sensitivities to water temperature and precipitation

A. Water Temperature (content excerpted from Largier et al. 2010)

- **Water temperature** over the north-central California continental shelf has 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 (Mendelssohn and Schwing 2002; Garcia-Reyes and Largier 2010)

Habitat's sensitivity and response to changes in water temperature (content excerpted from Largier et al. 2010, except Vadas 1972.)
Schiel et al. (2004) document the effect of a 3.5°C increase in seawater temperature at Diablo Cove (San Luis Obispo county) caused by the thermal outfall of a nuclear power plant. Prior to the increase in temperature, subtidal habitat in this study was dominated by a canopy of the bull kelp *Nereocystis luetkeana* and an understory mostly comprised of *Pterygophora californica* and *Laminaria setchelli*. After initiation of the thermal outfall, bull kelp was replaced by the giant kelp *Macrocystis pyrifera* and subcanopy kelps decreased while the foliose red algae *Cryptopleura violacea* increased in abundance. Within the study region, this highlights the potential for bull kelp to be negatively affected by increased water temperatures and for giant kelp to increase in abundance. Overall, predicting responses to climate change is challenging and may yield unforeseen outcomes based on the response of a few key species (Schiel et al. 2004). A sustained sea temperature increase of 3°C is projected to greatly reduce kelp forests, which were temporarily damaged by the very warm 1998 El Niño. Damaged kelp reduces habitat for marine mammals such as sea otters and reduces their prey that are associated with kelp forests.

Culture studies with *Nereocystis* show that the thermal conditions allowing reproduction of the microscopic stages range from 3°C to 17°C (Vadas 1972).

B. Precipitation (content excerpted from Largier et al. 2010)

Historical

- The past 200 years have consistently been wet when compared with longer-term records (Meko et al. 2001).
- Statistically significant trends indicate that precipitation (Groisman et al. 2001, Mote et al. 2005) in California has increased since the early 20th century. This is consistent with a 10% increase in precipitation for all of North America since 1910.
- However, analyses by California state climatologist James Goodridge suggest no trend in precipitation from 1890-2002 for the entire state (DWR 2006). When California is divided into three regions (northern, central, southern), a slight increase in precipitation is seen in northern California, as opposed to slight decreases for central and southern California.
- Observed increases in extreme precipitation during single-day events (Groisman et al. 2001; Kundzewicz et al. 2007).
- Observed increase in precipitation variability (drier dry years, wetter wet years) (Largier et al. 2010)

Future

- Kim et al. (2002) and Snyder et al. (2002) used global climate models to show that precipitation in California is likely to continue to increase, with the greatest change centered in northern California.
- However, using low and medium-high IPCC emissions scenarios and two global climate models, Cayan et al. (2008) see small to no effects of warming on precipitation.
- Increased frequency of extreme events is expected, as is increased variability (drier dry years, wetter wet years).

Habitat's sensitivity and response to changes in precipitation (content excerpted from Largier et al. 2010)

Kelp forest systems are not known to be directly sensitive to changes in precipitation, though Brown (1915) found that exposure to freshwater for periods of up to a week could cause tissue deterioration and Hurd (1916) confirmed this finding, showing that bull kelp sporophytes develop blisters and wilt when subjected to rapid reductions in environmental salinity. However, the most likely impact of changes in precipitation may result from increasingly intense run-off during extreme winter precipitation events. This can result in increased sedimentation that may negatively impact understory growth due to sand scour, and increased freshwater input to the nearshore subtidal that may lead to higher resuspension of sediment resulting in increased turbidity and light attenuation. Increased turbidity will compromise kelp growth, and culture experiments indicate that total light quantity is the single most important factor in the development of the microscopic stages of bull kelp (Vadas 1972).

2. Sensitivities to other climate and climate-driven changes (content excerpted from Largier et al. 2010)

A. Sea Level Rise

Sea level rise will affect kelp forest communities on rocky reefs in the nearshore subtidal (Graham et al. 2003, 2008). Increased sea level will decrease light availability to sessile macroalgae and cause a shoreward migration, which will depend on available rocky substrate at shallower depths. Sea level rise may also change the shape of the coastline and substrate composition (i.e., rocky vs. sandy shores; Graham 2007), and thus impact the availability and living conditions of macroalgae and their associated species.

B. Storm activity and increased wave action

Increasing significant wave heights will affect sediment redistribution and may change the coastal topography of the area. Increased storm activity may increase precipitation in this area, leading to greater freshwater input to the nearshore subtidal, including inputs from the San Francisco Bay outflow. An increase in terrestrial inputs as well as storm activity will lead to higher resuspension of sediment resulting in increased turbidity and light attenuation. Increased turbidity will compromise kelp growth. Increased storm activity may also move nearshore kelp forests into deeper water (Graham 1997) and create greater intra-annual variability in kelp productivity and abundance (Graham et al. 1997). Greater turbidity may compromise the growth and recruitment of some kelp species (e.g., Macrocystis) while promoting others (e.g., Nereocystis). For kelp forest communities on rocky reefs (which form a physical habitat for reef-associated species), increased storm activity may also increase dislodgement of kelp holdfasts resulting in a loss of physical habitat for kelp forest associated species (Seymour et al. 1989; Graham et al. 1997). Some of these effects may also be modulated by alterations in mean transport, perhaps tied to alterations in upwelling phenomena, through subtle interactions between waves and currents (Gaylord et al. 2003). The loss of kelp forests can have further effects due to their immense importance as subsidizing agents to other communities. Dislodged kelp biomass serves as a critical food resource both to deep-water ecosystems as well as for intertidal and (in particular) beach fauna (ZoBell 1971; Harrold et al. 1998; Vetter and Dayton 1999; Colombini and Chelazzi 2003).

C. Water Chemistry

The northern and central California coast is especially vulnerable to acidification because of upwelling, which transports acidified waters (under-saturated with respect to aragonite) from offshore onto the continental shelf, potentially reaching the coastal shallow subtidal (Feely et al. 2008). The acidified upwelled water may affect calcifying organisms utilizing the nearshore subtidal habitat, although, unlike the rocky intertidal, few nearshore subtidal habitats in this region are dominated by calcifying organisms.

D. Species range shifts

Forecasting changes in marine communities is limited because of the large number of complex interactions that can result from climate change. Theory predicts that species will shift their ranges towards the poles in response to warming (Peters and Darling 1985). However this prediction is complicated by the fact that species not only respond to climate but they also respond to other species (e.g., predators, habitat-forming flora and fauna) and pathogens (e.g. HABs, sea star wasting). For the purposes of evaluating climate change, it can therefore be useful to focus on the response of key species that have large roles in structuring marine communities. In subtidal kelp forest habitats, the range expansion of the snail Kellet's whelk (*Kelletia kelletii*) from Point Conception to Monterey, CA was attributed in part to warming seawater temperatures that resulted in greater recruitment success (Zacherl et al. 2003). Reef fish communities in Southern California have also shifted in dominance from northern to southern species over a 20-year period beginning with a climate regime shift in 1976-1977 (Holbrook et al. 1997).

E. Upwelling

Enhanced upwelling in the study region will affect nutrient delivery to the nearshore subtidal. Increased nutrient availability in the nearshore may benefit benthic macroalgae as well as phytoplankton. However, intensification of upwelling could also alter the strength of offshore transport, increasing the dispersion of larvae and spores released in the nearshore subtidal, as well as enhance turbulent mixing, thus disturbing food particle concentrations critical to larval survival (Bakun 1990).

F. Stratification and Mixing

Thermoclines have become stronger and deeper in offshore waters in the study region (Palacios et al. 2004) and a similar increase in stratification could be expected in sheltered bays (e.g., Monterey Bay). In offshore waters, stratification as a consequence of climate change has already been reported to change zooplankton communities in the California Current (Roemmich and McGowan 1995). In nearshore regions sheltered from the direct effects of upwelling, an increase in stratification would reduce nutrient delivery to surface waters and thus to subtidal habitats, as well as decrease offshore transport of larvae and spores. In Southern California, where stratification is observed during summer, nitrate availability limits kelp forest productivity (Zimmerman and Kremer 1984; 1986; Zimmerman and Robertson 1985), and if conditions in sheltered northern waters approached those found further south, it is conceivable that these important ecosystems could be significantly altered. Further, changes in horizontal mixing and transport is expected to occur with changes in upwelling and the associated mesoscale (10s-100s km) circulation, such as recirculation cells in the lee of headlands. Mesoscale features are important corridors between offshore and nearshore habitats. Climate moderates mesoscale circulation in the California Current System, thereby affecting nearshore-offshore connections (Keister and Strub 2008).

3. Sensitivities to non-climate stressors

A. Shoreline armoring

In a study of bull kelp distribution in Lincoln Park, Seattle, kelp bed coverage increased in area following the construction of a seawall in 1936; authors suggest that the seawall may have decreased the supply of sediment to the area and increased erosion, thus exposing rocky substrate for kelp recruitment (Antrim et al. 1996).

B. Human use (excerpted from Springer et al. 2006)

"*Nereocystis* has been harvested for human consumption, agricultural purposes, and for use as mariculture feed….harvesting of bull kelp often involves the removal of the pneumatocyst and associated fronds. By removing most of an individual plant's photosynthetic and meristematic tissue this method of collection eliminates the potential for further vegetative growth and eventually kills the plant by removing its source of buoyancy and causing the stipe to sink to the benthos…[causing] immediate, dramatic, and long lasting effects on the extent of bull kelp canopy cover in harvested beds." As of 2006, there were no active commercial permits for the harvest of bull kelp in California.

"Commercial fishing activities can cause directly physical damage to kelp via propeller cuts to blades and stipes. This occurs as boats travel through kelp beds and during the process of "backing down" when engines are run in reverse to dislodge propellers fouled by kelp fronds and stipes (CEQA 2001b). Additionally, the deployment and retrieval of fishing gear, particularly crab, lobster, and live fish traps, can cause breakage of fronds and stipes and have the potential to dislodge kelp plant holdfasts from the substrate. Similar effects can be produced during the retrieval of anchors. While deleterious effects on kelp arising from these activities can be appreciable in locations where commercial fishing activity is high and/or chronic, the extent of kelp damage due to boats and fishing gear is thought to be minimal (CEQA 2001b)."

C. Pollutants/Contaminants

Nutrient run-off associated with agriculture and extreme precipitation events (i.e. "first flush") can trigger phytoplankton blooms that significantly reduce water clarity, greatly impacting the survival and growth of bull kelp (Springer et al. 2006).

Non-point and point source pollution including sewage, industrial disposal, and coastal runoff might contribute to kelp forest degradation. For instance, high sedimentation from coastal run-off may bury new plant shoots. Similarly, kelp may experience reduced growth rates and reproductive success in more toxic waters and sediments. Studies on microscopic stages of kelp suggest that kelp is sensitive to sewage, industrial waste discharges, and other causes of poor water and sediment quality (Ecosystems: Impacts on Kelp Forests 2013).

Falkenburg et al. (2013) demonstrated that the combined effect of increased CO2 and increased nutrients on kelp forest habitat quality is greater than the sum of the individual impacts, and that by limiting the nutrient input to kelp forest habitat, managers can substantially limit the negative impact of increased levels of CO2.

D. Invasive Species (content excerpted from Largier et al. 2010)

Of particular concern is the invasive kelp *Undaria pinnatifida*, which has primarily been documented in wave protected habitats in California including the northernmost site, Monterey Bay (Silva et al. 2002) and in 2009, San Francisco Bay. Locations in Northern California may be susceptible to invasion by this species where cooler seawater temperatures may favor its survival (Thornber et al. 2004).

E. Harmful Algal Blooms

MPA baseline data showed that red abalone (*Haliotis rufescens*) exhibited a 40% decline in density between 2010 and 2011 at sites along the Sonoma Coast, which coincided with a harmful algal bloom in that region that occurred in 2011 (Carr 2013). A CenCOOS report of this 2011 HAB in Sonoma County (Bodega Bay to Anchor Bay) documented the largest die-off of marine invertebrates ever associated with a HAB in this region.

F. Disease

Kelp forests are indirectly affected by disease; impacts of a sea otter or sea star disease may result in increased grazing by urchins (Conrad et al. 2005), and disease presence in local urchin populations may limit the grazing impact on kelp (Behrens and Lafferty 2004).

“The only known parasitic alga that commonly infects *Nereocystis* is *Streblonema* sp., a brown alga that apparently causes distortions of the stipe ranging from galls to extended rugose areas. These deformations can weaken the stipe and could result in breakage during exposure to strong surge or storm conditions (CEQA 2001a).” (excerpted from Springer et al. 2006)

<u>Habitat Adaptive Capacity</u>

1. Extent, Integrity and Continuity

A. Geographic extent of habitat: endemic, transcontinental, etc? (content summarized from Largier et al. 2010 except Abbott and Hollenberg 1976)

Kelp forests can be found world-wide, though forests of Bull kelp exist primarily along the Pacific coast of North America and are the dominant kelp forest north of Santa Cruz, California. Extensive beds of bull kelp can be found from Point Conception, CA to Unmak Island, AK

(Abbott and Hollenberg 1976). When it grows alongside Giant Kelp (*Macrocystis pyrifera*), Bull Kelp will form a forest understory.

B. Structural and functional integrity in study region: is the habitat typically pristine or degraded?

Based on available data and observations, overall, the resources of the sanctuary's outer coastal and offshore areas appear to be in relatively good condition. However, water quality parameters are of some concern, primarily due to impacts of outflow from San Francisco Bay and agricultural runoff from surrounding rural areas. Little is known about the eutrophic conditions of the sanctuary; however, new data may reveal improving water quality. Pressures that threaten the integrity of coastal and offshore habitat include trampling, extraction along the intertidal areas, and bottom trawling, yet overall the outer coast and offshore habitats are improving due to increased management actions (2010 GFNMS Condition Report).

C. Continuity of the habitat: is it continuous or occur in isolated spots?

The kelp forest habitat is, by nature, patchy, and does not form extensive continuous beds in the study region, but rather exists in more isolated pockets.

2. Habitat Diversity

A. Diversity in topographic and physical characteristics

Kelp beds form on bedrock, reefs and boulder fields 3 to 20 meters deep (Nicholson 1970; Vadas 1972).

B. Diversity in species/functional groups

This system is incredibly diverse. For example, data were collected for 129 taxa for MPA baseline monitoring in North-central California kelp forests: 36 taxa of fishes, 25 taxa of algae, 63 taxa of invertebrates (Carr 2013).

C. Dependence on a single keystone species?

This habitat is entirely dependent on the presence of the foundational canopy-forming species Bull kelp, *Nereocystis Luetkeana.* This species alone supports a very diverse community of invertebrates, fishes and understory algae that rely on its presence. Sea urchins (*Strongylocentrotus spp.*) and their predators (large fish, birds, crabs, sunflower stars, and sea otters only in the very southern stretch of the study area) play critical roles in the stable equilibrium ecosystem. Sea urchins graze kelp and may reach population densities large enough to destroy kelp forests at the rate of 30 feet per month. Urchins move in "herds," and enough urchins may remain in the "barrens" of a former kelp forest to negate any attempt at regrowth. Sea urchin predators, playing a critical role in containing the urchin populations, prey on urchins and thus control the numbers of kelp grazers (Ecosystems: Impacts on Kelp Forests 2013).

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