Rocky Intertidal and Offshore Rocks

rocky areas found between high and low tide water levels

The bulk of the content for this report comes from the Climate Change Impacts Report (Largier et al. 2010), a working group report of the Gulf of the Farallones Sanctuary Advisory Council. Additional sources since the publication of this report are also cited.

Habitat Sensitivity

1. Direct Sensitivities to air and water temperature and precipitation

A. Air and Water Temperature (content excerpted from Climate Impacts Report, except Mislan et al. 2014)

- **Water temperature** over the north-central California continental shelf has cooled over the last 30 years (by as much as 1C 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)
- Lebassi et al. (2009) analyzed 253 California National Weather Stations from 1950 – 2005 and found that **air temperature** in low-elevation coastal areas cooled (-0.30°C/decade) and inland stations warmed (0.16° C/decade). However, a gradual retraction of the North Pacific High could contribute to decreased formation of the marine layer with declines in coastal fog and increases in temperature (Johnstone and Dawson 2010)
- By the end of the century **extreme heat days are expected to increase** dramatically for all areas in the Bay Area, but coastal areas (including San Francisco) are estimated to endure a much higher number of such events (Ekstrom and Moser 2012).
- During a low tide, intertidal organisms can experience body temperatures as high as 40°C and as low as 10°C when the tide comes in (Denny and Wethey 2003).
- Mislan et al. (2014) found that **38°C was the critical lethal high body temperature for the California Mussel**. These temperatures occurred along the upper limits of the mussel bed at only 2/15 study sites, Santa Cruz and Alegria (Mendocino County), and daily maximum air temperature during low tide was the variable that distinguished these sites. Authors concluded that there was no evidence of local acclimation or adaptation, and that local zonation limits are variable in their vulnerability to climate change, causing zonation shifts to differ between even close sites.

Habitat's sensitivity and response to changes in temperature (information excerpted from Climate Impacts Report)

Rocky intertidal habitat is characterized by complex environmental conditions that are driven by both aquatic and terrestrial forces. Of primary concern are possible increases in average water and air temperature as well as the prevalence of extreme conditions that can result in mass mortality of intertidal organisms. Most rocky intertidal organisms are ectothermic ("cold-blooded") and are therefore sensitive to ambient temperatures. The temperature perceived by intertidal organisms is determined by apparent variables such as water and air temperature. However, temperature is also influenced by more subtle factors such as long-term tidal cycles, fog, wind speed, wave splash, and the spatial orientation of the organism in question. Working on intertidal California mussels, Gilman et al. (2006) found that body temperature was most sensitive to climate drivers at northern latitudes (including the study region) and also in those organisms living in the high intertidal zone. Increased temperature may also heighten the susceptibility of intertidal organisms to disease. Raimondi et al. (2002) found that increased warm water conditions associated with ENSO events may accelerate the development of withering foot syndrome in the black abalone, *Haliotis cracherodii*. Similar results have been found in farmed red abalone *H. rufescens* that were raised in the lab at elevated temperatures of 18°C (Moore et al. 2000).

California Mussel's sensitivity and response to changes in temperature (information excerpted from Climate Impacts Report)

Many climate change studies of rocky intertidal communities have focused on the response of the California mussel *Mytilus californianus* (Fig 6.7) to climate change stressors. Mussels are a competitively dominant species that can decrease the diversity of other space competitors but also increase the diversity of organisms that live within dense mussel beds. Mussels generally appear to increase growth rates in response to increased water temperatures and increased food supply (Blanchette et al. 2007; Menge et al. 2008). Increasing temperature trends have been observed across coastal California and mussels may therefore exhibit increased growth. In contrast, intertidal mussels may see population declines depending on the occurrence of extreme environmental conditions. **Extreme heat waves have resulted in mass mortality events of California mussels and limpets** (*Lottia scabra*) in the Bodega Marine Reserve (Harley 2008). Mussel mortality patterns are also related to predation rates by their primary predator, the ochre sea star *Pisaster ochraceus*. These sea stars set the lower limit of mussel beds in the intertidal throughout California and Oregon (Menge et al. 2004). Small changes in water temperature have been documented to greatly modify the rate of sea star predation on mussels (Sanford 1999). Cold upwelling waters decreased sea star activity whereas increased seawater temperatures increased sea star consumption. Thus, mussel susceptibility to predation will in large part depend on broad temperature trends (increasing predation) as well as upwelling conditions that can bring cool deep waters onto the rocky intertidal (decreasing predation).

B. Precipitation (information excerpted from Climate Impacts Report)

Historical

- The past 200 years have consistently been wet when compared with longer-term records (Meko et al. 2001), and 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), with a slight increase in precipitation in northern California.
- Observed increases have been documented in extreme precipitation during single-day events (Groisman et al. 2001; Kundzewicz et al. 2007) and in precipitation variability (drier dry years, wetter wet years).

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.
- The rising temperature will cause the form of some precipitation to shift from snow to rain. This is especially important for areas like California that depend on snowpack for water supply. The timing and intensity of precipitation may also change.
- 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

The sensitivity of the rocky intertidal system of the PNW to climate stressors was assessed in a March 2012 workshop of experts. The four experts rated the system's sensitivity to precipitation as "very low" with a confidence rating of "good" and supplied the following conclusion: "Precipitation plays a much lesser role and interactions between the two will be minimal - except perhaps in changes in cloud cover."

2. Sensitivities to other climate and climate-driven changes

A. Sea Level Rise (information excerpted from Climate Impacts Report)

Intertidal organisms will respond to sea level rise by shifting their distributions to keep pace with rising sea level. It has been suggested that all but the slowest growing organisms will be able to keep pace with rising sea level (Harley et al. 2006) but few studies have thoroughly examined this phenomenon. As in soft sediment systems, the ability of intertidal organisms to migrate will depend on available upland habitat. If these communities are adjacent to steep coastal bluffs it is unclear if they will be able to colonize this habitat. Further, increased erosion and sedimentation may impede their ability to move. The elevational range of species can shift in response to sea level rise on the scale of meters. Intertidal species will be most affected by this process, particularly when it is considered that these species are already under duress because they must deal with variable marine and terrestrial forces (e.g., heavy wave action, desiccation stress, and ultra-violet radiation). These impacts may be the most pervasive when rising sea level reduces the area available for intertidal species to persist. Increased air temperatures and solar radiation may also compress the range of high intertidal species into lower zones (Harley 2003).

B. Erosion

Rocky intertidal systems may be less susceptible to the direct impact of erosion, but the ability of the habitat and its species to migrate inland as a response to sea level rise may be impeded by coastal cliff and bluff erosion (Largier et al. 2010).

C. Flooding and increased wave action (information excerpted from Climate Impacts Report)

Greater wave activity suggests that intertidal and subtidal organisms may experience greater physical forces. A number of studies indicate that the strength of organisms does not always scale with their size (Denny et al. 1985; Carrington 1990; Gaylord et al. 1994; Denny and Kitzes 2005; Gaylord et al. 2008), which can lead to selective removal of larger organisms, influencing size structure and species interactions that depend on size. However, the relationship between offshore significant wave height and hydrodynamic force is not simple. Although local wave height inside the surf zone is a good predictor of wave velocity and force (Gaylord 1999, 2000), the relationship between offshore Hs and intertidal force cannot be expressed via a simple linear relationship (Helmuth and Denny 2003). In many cases (89% of sites examined), elevated offshore wave activity increased force up to a point (Hs > 2-2.5 m), after which force did not increase with wave height. Since many northern sites on the west coast of North America already experience wave heights of this magnitude, forces may not increase with increasing Hs. On the other hand, the remaining 11% of sites examined exhibited a positive relationship with Hs that did not level off (Helmuth and Denny 2003). At sites such as these, larger wave forces may accrue, as well as greater wave splash and ensuring modulated temperatures by means of chronic wetting. Also note that the above percentages reflect at least in part the spectrum of bathymetries represented in the sites examined, suggesting that a greater or lesser fraction of shores could be influenced by changes in wave height than implied in the analysis of Helmuth and Denny (2003).

D. Water Chemistry (information excerpted from Climate Impacts Report, with the exception of Gaylord et al. 2011)
The effects of ocean acidification on intertidal habitats will probably be felt most intensely through upwelling events that will bring undersaturated deep waters to the surface (Feely et al. 2008). Undersaturated conditions decrease the ability of calcifying organisms to produce shells and may dissolve already existing shell structure while the organism is still alive. Upwelling will also influence the delivery of food (phytoplankton), nutrients (for algae and plants), and larvae to intertidal habitats. Many rocky intertidal organisms produce calcium carbonate skeletons. Ocean acidification can make production of calcium carbonate structures more difficult as well as acidify internal body fluids (Doney et al. 2009).

Gaylord et al. (2011) demonstrated that California Mussel larvae cultured in seawater with CO2 concentrations expected by 2100 "precipitated weaker, thinner and smaller shells than individuals raised under present-day seawater conditions (380 ppm), and also exhibited lower tissue mass". In addition, a closely related mussel *Mytilus edulis* exhibits decreased calcification rates with increasing aqueous CO2 concentrations (Gazeau et al. 2007). Decreased abundances of mussels on rocky intertidal shores could thus create significant space for other species to attach to. Further, sea star populations may be forced to switch to other prey items in the absence of mussels, although it is not clear what species it could feed upon since other documented prey items are calcifiers as well.

Coralline algae are another dominant species within the sanctuary that will likely be affected by acidic conditions. In one of the few studies examining acidification effects on this taxonomic group, Kuffner et al. (2008) evaluated the response of crustose coralline algae, a widespread non-branching coralline alga (Fig. 6.8). Experiments revealed decreased recruitment and growth of calcifying coralline algae with increased growth of non-calcifying species. Reduced coralline algae abundance within the study region may create space for non-calcifying algal species to establish. Coralline algae dominate shallow marine habitats that have hard substrate and an abundance of herbivores (Steneck 1986).

E. Runoff (information summarized from Climate Impacts Report)
With increased variability in precipitation, the region may experience more intense run-off and pollution events associated with greater extreme precipitation events. Stronger winter run-off events and reduced spring run-off are expected from San Francisco Bay. 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. This may result in increased sedimentation to rocky intertidal areas. From the PISCO California North-central Coast webpage:
"Threats to the rocky intertidal in North Central California include…land use issues that can impact water quality and sedimentation levels. Increased coastal development in this region has led to concerns about elevated levels of sediment and urban runoff. This region is also an important agricultural area, and the impact of runoff containing pesticides and increased nutrients on marine communities is a concern."

F. Species range shifts (information excerpted from Climate Impacts Report)
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). 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. By comparing 46 rocky intertidal species over a 60-year period in Monterey, CA, Barry et al. (1995) detected an increase in abundance of 10 of 11 southern species with a decrease of 5 of 7 northern species. The nature of the historical data only allowed a comparison at one site, making it difficult to generalize to multiple locations. However, range shifts by these species have been confirmed by other studies. For example, Connolly and Roughgarden (1998) documented a shift by volcano barnacles (*Tetraclita rubescens*), a common intertidal species historically found from Cabo San Lucas, Baja California, Mexico to San Francisco. Sometime after 1980, a northward range expansion of 300 km (to Cape Medocino) occurred with the regular recruitment of individuals north of San Francisco Bay (Connolly and Roughgarden 1998; Sanford and Swezey 2008). Although the exact cause for this expansion is unknown, it is thought that warmer waters along the California coast may have influenced this change in distribution (Enfield and Mestas-Nuñez 1999; Sagarin et al. 1999; Sanford and Swezey 2008).

3. Sensitivities to non-climate stressors (information excerpted from Climate Impacts Report)

A. Shoreline armoring

Though shoreline armoring is expected to have a greater impact on sandy beach ecosystems, the ability of the rocky intertidal habitat and its species to migrate upland in response to sea level rise would be effectively limited or prohibited by shoreline armoring.

B. Human use (fishing, recreation)

Trampling of the intertidal system by recreational users and by harvesters is a documented negative stressor. The high visitation levels that occur on rocky shores can cause changes in the diversity and abundance of intertidal organisms. Harvesting, when combined with habitat degradation, poor recruitment, and anomalous oceanographic conditions can contribute to declines of some marine species (Barnes and Thomas 2005; Ralston 2002).

C. Pollutants/Contaminants

Precipitation intensity is expected to increase with climate change, exacerbating the control of non-point source pollution. Contaminants – including agricultural and livestock waste, wastewater, sewage outfalls, historic mining and industrial wastes – can be carried into the study region via the freshwater outflow from San Francisco Bay. The plume extends as far as the Farallon Islands and Cordell Bank after heavy rainfall (unpublished data); and carries nutrients during spring and summer that stimulate phytoplankton growth within the study region. The intertidal system is also highly vulnerable to oil spills - over 6,000 commercial vessels (excluding domestic fishing craft) enter and exit the San Francisco Bay every year. Oil can smother mussel beds and kill acorn barnacles, limpets and other species.

D. Invasive Species

Climate change is likely to interact with coastal invaders in ways that are likely to increase their impacts, facilitate their spread and necessitate additional management actions.
Stachowicz et al. (2002) examined long-term data in recruitment of native and invasive tunicates relative to winter minima and summer maxima in sea surface temperatures. They found that increasing sea surface temperatures resulted in both earlier and greater recruitment of invasive species as well as increased growth rates of invasives relative to natives. They predicted that increasing temperatures will lead to greater success of invasive species. Other climate factors such as increasing atmospheric CO2 would favor C3 over C4 plants, thus potentially affecting competition among marine plants (Craft et al. 2009). Increasing ocean acidification associated with increasing CO2 (Feely et al. 2008) could influence species interactions and success of invading species in numerous ways, such as predator-prey interactions among invasive whelks and native prey.

To date, almost 150 species of introduced marine algae and animals have been identified in the sanctuary. Invasive invertebrates, such as the green crab, *Carcinus maenas*, make up more than 85 percent of all introductions in sanctuary waters. They threaten the abundance and/or diversity of native species, disrupt ecosystem balance and threaten local marine-based economies (SIMoN website).

E. Harmful Algal Blooms

According to the Southern California Marine Institute's website, harmful algal blooms have increased in frequency and severity along the California coast during the past few decades, with blooms of dinoflagellates and Pseudo-nitzschia becoming more common. Harmful algal blooms have been documented to cause damage to rocky intertidal systems, both due to toxic products from the algae as well as resulting eutrophication. In a study of a South African intertidal community, Branch et al. (2013) documented a 95% loss of biomass, changes in community structure and a decline in diversity due to a harmful algal bloom. These communities did not recover after 4 years. Substantial mortality of filter feeders, grazers and predators have been documented following a bloom (Southgate et al. 1984 and Robertson 1991) and the impacts can often resemble an oil spill, with an abundance of algae due to the decrease of grazers (Southgate et al. 1984).

F. Disease

The prevalence of disease in marine ecosystems has been projected to increase in response to a warming climate (Harvell et al. 2002). These increases have been documented in corals, seagrasses, oysters, and sea urchins and may act in concert with climate change to reduce the abundance of marine organisms (Harvell et al. 1999). This is because warming can result in increased pathogen development and survival rates, as well as favoring transmission and host susceptibility. One such link has been suggested for black abalone (Haliotis cracherodii) that can be afflicted with "withering foot syndrome". Greater temperatures appear to increase mortality of abalone infected in lab experiments (Friedman et al. 1997) and in the field (Tissot 1995). Furthermore, observations suggest that the disease is spreading from parts of southern California to the north (Raimondi et al. 2002).

<u>Habitat Adaptive Capacity</u> (information summarized from SIMoN website)

1. Extent, Integrity and Continuity

A. Geographic extent of habitat: endemic, transcontinental, etc?

Rocky intertidal habitat exists on rocky shores worldwide. In California, rocky intertidal systems are a dominant feature of the shoreline. 39% of the shoreline in MBNMS and GFNMS is characterized as rocky shoreline.

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

This probably varies depending on the degree of visitation, protection, and other impacts.

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

The rocky intertidal habitat is a dominant feature of the study region's shoreline and in many places exists as a continuous rocky bench (e.g. Duxbury Reef, Fitzgerald Marine Reserve). Intertidal systems are interrupted by coastal cliffs, sandy beaches, and estuaries and lagoons but are biologically connected through larval transport. The rocky shore habitat within the Gulf of the Farallones includes areas such as Bodega Head, Duxbury Reef, the Point Reyes Headlands, the rocky shores of Tomales Bay and the intertidal shores of the Farallon Islands.

2. Habitat Diversity

A. Diversity in topographic and physical characteristics

The high diversity of species in the rocky intertidal in this region may be attributed, in part, to the unusual mix of substrate – such as the soft shale at Duxbury Reef and hard shale at Estero de San Antonio – and the alternating estuaries and lagoons that line the sanctuary's shores.

B. Diversity in species/functional groups

More than 320 invertebrate species and 250 algal species have been identified by various surveys and monitoring programs in GFNMS boundaries.

C. Dependence on a single keystone species?

Pisaster ochraceus has long been considered a keystone species in the rocky intertidal system that exerts great predator influence, especially on its primary food source, the California Mussel (Paine 1966, Menge 2004) by setting the lower limit of mussel beds. Ecologist Bob Paine concluded that predation by *P. orchaceaus* facilitates species coexistence among competitors and sets the biological zonation by maintaining a diversity of molluscs (e.g., mussels), crustaceans (e.g., barnacles), and cnidarians (e.g., sea anemone) in coastal intertidal communities. With *P. orchaceaus* present, mussels dominate the higher zone, and a diversity of invertebrates dominates the middle zone. When *P. orchaceaus* are removed, mussels expand into the middle zone and out-compete the other invertebrate species.

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