Rocky Intertidal[1]

Executive Summary

Rocky Intertidal	Score	Confidence
Sensitivity	4 Moderate-High	2 Moderate
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	4 Moderate-High	2 Moderate
Vulnerability	3 Moderate	2 Moderate

The rocky intertidal habitat consists of rocky substrate found between high and low tide water levels. This habitat has a transcontinental geographic extent, is moderately continuous throughout the study region, and is considered to be in relatively pristine condition by workshop participants. Key climate sensitivities identified for this habitat by workshop participants includes air temperature, salinity, wave action, pH, and erosion. Key non-climate sensitivities include armoring, pollution/oil spills, recreation/trampling, and invasive species/species range expansions. Rocky intertidal habitat is widespread, continuous, and a dominant feature of the study region, composing 39% of the shoreline. This system generally displays high recovery potential, in part due to species' short lifespans and high fecundity, as well as high species diversity, due to the diversity in substrate type. Community dynamics are dependent on the abundance, distribution, and interactions of the California mussel (*Mytilus californianus*) and the ochre sea star (*Pisaster ochraceus*). Management potential is considered low due to the inability to prevent climate impacts from affecting the habitat. However, societal value for this habitat is considered high due to its importance in research, recreation, and harvest.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): air temperature (5, high), salinity (5, moderate), pH (4, low-moderate), wave action (5, high), coastal erosion (4, low-moderate) sea surface temperature (3, low-moderate), sea level rise (3, moderate-high), dynamic ocean conditions (currents/mixing/stratification) (3, low), precipitation (2, low), dissolved oxygen levels (2, low-moderate)

Climate and climate-driven changes that may benefit the habitat: none

Overall habitat sensitivity to climate and climate-driven factors: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

Intertidal zonation plays a role in the degree of sensitivity experienced; lower intertidal areas are not as adapted to variation in physical factors as compared to higher intertidal areas, though the high intertidal will be expected to encounter more extremes.

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[1] Refer to the introductory content of the results section for an explanation of the format, layout and content of this summary report.

[2] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high sensitivity and 1 indicating low sensitivity.

[3] Confidence level indicated by workshop participants.

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered.

Air Temperature

Most rocky intertidal organisms are ectothermic, and therefore sensitive to changes in air and water temperature (Largier et al. 2010). As extreme heat events are expected to increase along California's coast (Ekstrom and Moser 2012), many organisms may be negatively impacted by heat stress and surpass critical lethal high body temperatures, such as the California mussel (*Mytilus californianus*) (Mislan et al. 2014). Entire intertidal areas may more frequently experience mass mortality events (as documented in the Bodega Marine Reserve, Harley 2008). These effects will likely not be consistent across the boundaries of the habitat, as organisms in more northerly latitudes and higher in the intertidal zone have been documented to show greater sensitivity (Gilman et al. 2006).

Salinity

Salinity plays a strong role in rocky intertidal tide pools and is directly influenced by changes in precipitation patterns. Extreme high salinities can occur during low tides that coincide with high temperatures, enhancing evaporation rates. Conversely, extreme precipitation events may cause a sudden decrease in salinity for exposed tidal organisms. Studies on the effect of salinity extremes (both high and low) indicate that, when combined with temperature stress, salinity can negatively impact rocky intertidal invertebrates through increased embryonic mortality (Przeslawski 2005, Deschaseaux 2009) and decreased adult aerobic performance (Vajed Samiei 2011).

pH

The effects of decreased pH on intertidal habitat will likely be felt most strongly during upwelling events that bring cold and deep water to the surface (Feely et al. 2008). This water is undersaturated in aragonite, and may impede the ability of calcifying organisms to build calcium carbonate shells, and potentially result in the dissolution of existing shells (Largier et al. 2010). Many studies have shown this effect on intertidal organisms, including the California mussel, which precipitated weaker, thinner and smaller shells under projected 2100 CO_2 concentrations (Gaylord et al. 2011) and coralline algae, which demonstrated decreased recruitment and growth under more acidic conditions (Kuffner et al. 2008).

Wave Action and Erosion

Projected increase in storm activity suggests that intertidal organisms will experience more frequent and more intense physical forces due to wave action (Largier et al. 2010). Wave action can result in varying effects, from the selective removal of larger intertidal organisms, which may influence size structure and species interactions (Largier et al. 2010), to increased coastal erosion that may result in the burying of intertidal habitat (Vulnerability Assessment Workshop, pers. comm., 2014). Coastal cliff and bluff erosion may also impede the ability of intertidal organisms to migrate inland in response to rising sea levels (Largier et al. 2010).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind, storms, disease, flooding, and extreme heat events

Overall habitat sensitivity to disturbance regimes: High

- Confidence of workshop participants: Moderate

Supporting literature

Wind is highly desiccating to intertidal organisms and can dry out species that need to retain moisture for survival, enhancing the negative impact of increased air temperature (Bell 1995). Storms increase physical forces through enhanced wave exposure and increased erosion of coastal cliffs that can bury intertidal habitats (see wave action section above). Flooding may have a similar effect by increasing sedimentation to the intertidal area, but may also result in compromised water quality (PISCO 2014), including an increase in harmful algal bloom events. Disease has the potential to greatly impact key species within the intertidal habitat, as demonstrated by the sea star wasting syndrome and the black abalone withering foot syndrome (Vulnerability Assessment Workshop, pers. comm., 2014). Increase in disease is often linked to increase in water temperature, as both pathogen survival and host susceptibility are enhanced (Friedman et al. 1997, Harvell et al. 1999, Raimondi et al. 2002, Largier et al. 2010). Extreme heat events can result in mass mortality of intertidal organisms (see air temperature section above).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): armoring (4, moderate), pollution/oil spills (4, low), recreation (4, low-moderate), invasive species (4, low), and boat groundings (3, low-moderate), land use change (3, low), harvest (3, low)

Overall habitat sensitivity to non-climate stressors: Moderate-High

- Confidence of workshop participants: Low

Overall habitat exposure to non-climate stressors: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

Coastal armoring limits the ability of intertidal habitat to migrate upland or inland with rising sea level, but can also enhance intertidal areas by creating additional hard substrate. Oil can inhibit the resilience of rocky intertidal habitat and can smother and kill intertidal organisms, including mussels, acorn barnacles, limpets and other species. These effects are highly localized – near San Francisco Bay, Pillar Point Harbor, and Bodega Harbor. Trampling of the intertidal system by recreational users, researchers and harvesters is a documented negative stressor. Land-use change alters run-off and sediment supply to intertidal areas. Boat groundings are highly localized events that can cause significant damage to the habitat.

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[4] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high sensitivity and 1 indicating low sensitivity.

[5] Confidence level indicated by workshop participants.

Supporting literature

Non-climate stressors will likely exacerbate the impacts of climate-driven stressors by reducing the resiliency of the rocky intertidal habitat – the ability to absorb and respond to perturbations – and enhancing vulnerability (Largier et al. 2010).

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered.

Armoring

The impact of coastal armoring on rocky intertidal habitat depends on the specific armoring structure utilized. As sea level rises and increasing coastal erosion threaten the coastal cliffs and bluffs along California's shoreline, bluff revetments and coastal armoring will be more frequently used, effectively prohibiting upland migration of the habitat (Largier et al. 2010).

Pollution and oil spills

Pollutants, 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 (Largier et al. 2010), inhibiting the resilience of intertidal habitat and stimulating phytoplankton growth. This habitat is also sensitive to oil spills, with over 6,000 commercial vessels using the San Francisco Bay every year (Largier et al. 2010).

Recreation and trampling

The high visitation levels that occur in the rocky intertidal habitat (including Pillar Point, Duxbury Reef, Pescadero Point and Salt Point) can cause crushing of organisms and changes in the diversity and abundance of organisms (Largier et al. 2010).

Invasive species and species range expansions

Invasive species effectively out-compete native species and decrease native species diversity and abundance. These impacts are more largely felt near harbors, including San Francisco Bay, Pillar Point Harbor, and Bodega Harbor. To date, almost 150 species of introduced marine algae and animals have been identified in the study region. Invasive species threaten the abundance and/or diversity of native species, disrupt ecosystem balance and threaten local marine-based economies (SIMoN 2014b). Climate change is likely to enhance the negative impacts of coastal invaders. Stachowicz et al. (2002) documented earlier and greater recruitment of invasive tunicates as well as increased growth under warmer sea surface temperatures, and predicted that increasing temperatures will ultimately lead to more successful invasive species. Species range expansions have also been documented for coastal California, likely due to increasing sea surface temperature. In Monterey over a 60-year period, Barry et al. (1995) documented an increase in abundance of 10 to 11 Southern species and a decrease in 5 to 7 Northern species. Connolly and Roughgarden (1998) documented a northward range expansion of 300 km (from San Francisco to Cape Mendocino) by volcano barnacles (*Tetraclita rubescens*), a common intertidal species.

IV. Other sensitivities: none identified

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 5 (Pristine)

- Confidence of workshop participants: High

Continuity of habitat: 3 (Patchy across an area with some connectivity among patches)

- Confidence of workshop participants: High

Supporting literature

Rocky intertidal habitat accounts for 39% of the shoreline in the southern portion of the study region (SIMoN 2014a), and is a dominant feature along the coastline. Intertidal habitat is interrupted by coastal cliffs, sandy beaches, and estuaries and lagoons but biologically connected through larval transport (SIMoN 2014b). Rocky shore habitat within the study region 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 (SIMoN 2014b).

II. Resistance and recovery

Habitat resistance to the impacts of stressors/maladaptive human responses: Low-Moderate

- Confidence of workshop participants: Moderate

Ability of habitat to recover from stressor/maladaptive human response impacts: High

- Confidence of workshop participants: High

Additional participant comments

High recovery potential may be attributed to the species' far-reaching dispersal capabilities, short generation times, short lifespans and high fecundity.

Supporting literature

A recovery study of four intertidal assemblages along the California coast demonstrated that the fastest recovery rate occurred in zones dominated by short-lived species (Conway-Cranos 2009).

III. Habitat diversity

Physical and topographical diversity of the habitat: Moderate-High

- Confidence of workshop participants: High

Diversity of component species within the habitat: High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: High

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: California mussel and ochre sea star

Additional participant comments

Other diversity factors that impact species diversity include zonation, rock type, rugosity, and wave action – all of these factors have diverse outcomes and diverse associated communities.

Supporting literature

More than 320 invertebrate species and 250 algal species have been identified by various surveys and monitoring programs in the southern portion of the study region's boundaries. High species diversity 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" (SIMoN 2014b).

Rocky intertidal habitat is dependent on the abundance, distribution, and interactions of the California mussel, *Mytilus californianus*, and ochre sea star, *Pisaster ochraceus* . *P. 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 et al. 2004) by setting the lower limit of mussel beds. Paine (1966) concluded that predation by *P. ochraceus* facilitates species coexistence among competitors and sets the biological zonation in the rocky intertidal 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. ochraceus* present, mussels dominate the higher zone, and a diversity of invertebrates dominates the middle zone. When *P. ochraceus* are removed, mussels expand into the middle zone and out-compete the other invertebrate species.

IV. Management potential

<u>Value of habitat to people</u>: Moderate-High

- Confidence of workshop participants: Low-Moderate
- Description of value: Rocky intertidal habitat has a moderate value to the general public for its aesthetics and recreational opportunities, high value to researchers in studying ecological relationships, zonation, community dynamics, and many other tenants of ecology, and is valued by resource managers for the shoreline protection the habitat provides.

<u>Likelihood of managing or alleviating climate change impacts on habitat</u>: Low-Moderate

- Confidence of workshop participants: High
- Description of potential management options: The challenge lies in the inability to prevent many climate impacts from occurring (e.g., increasing air temperature and wave exposure) or to enhance the habitat's ability to respond to potential impacts. Managers may be able to protect and make room for inland/upland migration by limiting development, and areas that receive high visitation could be surrounded by protected areas that can serve as a source of species propagules.

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven factors identified (score[7], confidence[8]): changes in air temperature (5, high), changes in precipitation (5, high), changes in salinity (5, moderate), changes in sea surface temperature (5, moderate-high), decreased pH (5, high), sea level rise (5, high), altered currents and mixing (4, low-moderate), increased coastal erosion and runoff (3, moderate), increased flooding (3, moderate), increased storminess (3, moderate), decreased dissolved oxygen(2, low)

Degree of exposure to future climate and climate-driven factors: Moderate-High

- Confidence of workshop participants: Moderate

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[6] Supporting literature for future exposure to climate factors is provided in the introduction.

[7] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high exposure and 1 indicating low exposure.

[8] Confidence level indicated by workshop participants.

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