Coastal Cliffs

Located along rocky portions of the coastline including the Farallon Islands, these are vertical or near-vertical rocky faces above the water line that provide habitat for pinnipeds, birds and rare native plants and are subject to erosion due to exposure to wave action, sun, wind, and rain.

Habitat Sensitivity

1. Direct Sensitivities to air and water temperature and precipitation

A. Temperature (content excerpted from Largier et al. 2010, except Ekstrom and Moser 2012)

- 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).
- 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)
- Average annual air temperature at the Farallon Islands has exhibited an increasing trend over a 36-year period, from 1971- 2007 (PRBO unpublished data; Fig. 6.4).

Habitat sensitivity and response to changes in temperature (modified from Largier et al. 2010) Warmer temperature may alter physical structure of coastal cliffs due to drying and expanding along fractures, causing landslides in formations prone to landsides such as the cliffs at the southern end of Point Reyes Peninsula. Warmer temperatures may also affect habitat by altering the vegetation structure and facilitating the proliferation of more heat tolerant non-native species, such as grasses. Increasing air temperatures will also have important implications for wildlife. Many of these species are adapted to cold and windy conditions and quickly become stressed when conditions change. During unusually warm weather, seabirds may abandon their nests, neglect dependent offspring, and die of heat stress (Warzybok and Bradley 2008). Lee et al. (2007) linked low seabird breeding propensity to high sea surface temperature and other studies have shown correlations between low seabird reproductive success and warm, non-productive conditions (Ainley et al. 1995; Abraham and Sydeman 2004; Sydeman et al. 2006; Jahncke et al. 2008; Roth et al. in preparation). Several species of terrestrial birds also nest along the rocky cliffs of the mainland and the islands including swifts, swallows, rock wrens, and peregrine falcons.

Pinnipeds that haul out on rocky cliffs include sea lions and northern fur seals on the Farallon Islands and at Point Reyes Headland. Pinnipeds are particularly sensitive to elevated temperatures because of their fur or blubber for insulation against the cold. This thermal regulatory benefit works against them when they are resting onshore on rocky habitat. Since pups cannot swim at birth and stay onshore until they are able to swim after a couple of months, they are especially at risk to overheating.

B. Precipitation
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) (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.
- 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 sensitivity and response to changes in precipitation (excerpted from Largier et al. 2010)
Intensified winter precipitation and more significant rainfall later in the season may alter physical habitat in many ways. Increased erosion of the hillsides can alter vegetation structure, increase the frequency of rockslides and degrade nesting habitat and resting/haul out habitats, particularly for species that rely on rock crevices such as auklets and storm petrels, but also for pinnipeds that rely on access to rocky cliff ledges for resting and birthing. Flooding of low lying areas on the marine terrace will also decrease suitable habitat for burrow nesting species and carry away the thin layer of soil in which they dig their burrows.

2. Sensitivities to other climate and climate-driven changes
A. Sea Level Rise/Erosion

- Coastal erosion is expected to increase as a result of multiple climate change impacts, including sea level rise, increased precipitation and runoff, and increased extreme wave and storm conditions (Ackerly et al. 2012).
- "Large sections of the Pacific coast, especially those with rocky headlands or sea cliffs,

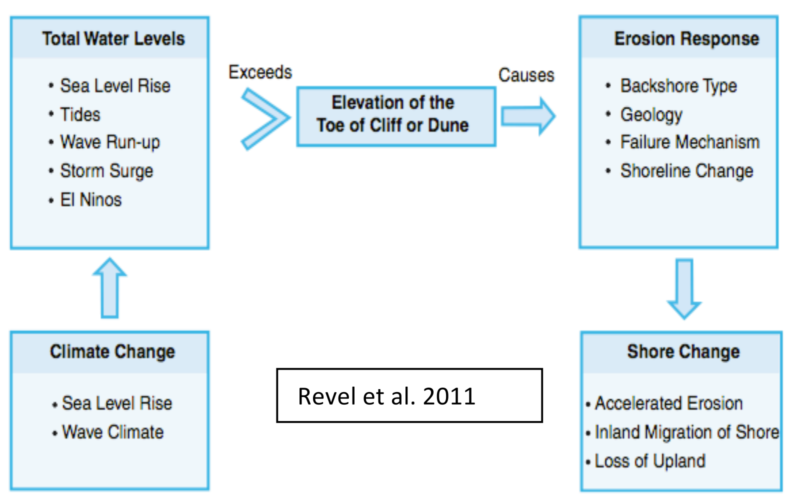

Fig. 1 Conceptual model of coastal response methodology

are not vulnerable to flooding, but are highly susceptible to erosion. In areas where the coast erodes easily, higher sea levels are likely to accelerate shoreline erosion due to increased wave attack. In addition, erosion of some sand spits and dunes may expose previously protected areas to flooding" (Heberger et al. 2009).

- During El Niño winters, sea surface temperatures are warmer, leading to thermal expansion and higher sea levels. Storms are stronger during El Niño winters (especially with a strong El Niño) that produce higher precipitation, waves, and storm surge. These factors will also increase sea levels, which will cause more coastal erosion. Climate change would increase El Niño like conditions and increase sea-cliff erosion (esp. along the Central California Coast) (Storlazzi and Griggs 2000, as cited in McCarthy et al. 2001).

(Content excerpted from Largier et al. 2010)

- Erosion results from the interaction of coastal processes with coastal geological formations, although terrestrial processes such as elevated groundwater also influence it. Sea cliffs are more or less susceptible to erosion depending on the hardness of the geologic rock type. Other important factors that control erosion include the shoreline orientation, width of the protective beach, and wave exposure (Griggs et al. 2005, as cited in Largier et al. 2010).
- The magnitude of coastal erosion is related to the coastal geomorphology. PWA (2009a) characterized the California coast into sea cliffs and dunes, and developed a methodology intersecting the USGS shoreline change rates with the variability in geology and erosion rates alongshore to then predict future erosion hazards. Maps of these erosion hazard areas can be found at http://www.pacinst.org/reports/sea_level_rise/hazlist.html. Most of the coastline in the study area is backed by seacliffs, with Mendocino County projected to lose the largest area of land to coastal erosion (see figure below).

Table 1. *Total erosion area (alongshore + acrossshore) with a 1.4 m sea-level rise, for counties intersecting the study region.*

County	Dune erosion miles^2 (km^2)	Cliff erosion miles^2 (km^2)	Total erosion miles^2 (km^2)
Marin	1.0 (2.6)	3.7 (9.6)	4.7 (12.2)
Mendocino	0.7 (1.9)	7.5 (19.4)	8.3 (21.5)
San Francisco	0.2 (0.6)	0.3 (0.8)	0.5 (1.4)
San Mateo	0.8 (2.1)	2.4 (6.2)	3.2 (8.3)
Sonoma	0.6 (1.6)	1.6 (4.1)	2.2 (5.7)
Total (study area)	**3.3 (8.8)**	**15.4 (40.1)**	**18.7 (48.9)**

Table 2. *Average and maximum inland erosion distance in 2100, for counties in the study region.*

County	Dune erosion		Cliff erosion	
	Average distance (m)	Maximum distance (m)	Average distance (m)	Maximum distance (m)
Marin	140	270	110	240
Mendocino	190	440	33	160
San Francisco	150	230	90	220
San Mateo	230	430	31	220
Sonoma	150	320	41	190
Average m (ft)	**172 (564)**	**338 (1,109)**	**61 (200)**	**206 (676)**

- Cliffs in Santa Cruz County are experiencing average retreat rates of 0.17 to 2.1 feet per year; 1.8 square miles of shoreline may be lost by 2100 (Heberger et al. 2009).
- Erosion caused by sea level rise and an expected increase in storm and wave intensity will place many oceanfront facilities at risk and may cause permanent damage to transportation infrastructure, major sewage pipelines, beachfront hotels, condominiums, and private residences. Large, episodic events (such as storms that occur at extreme high tides) pose the greatest erosion threats, and these are forecast to become more frequent. Forecasts suggest that over 4,600 properties along the Monterey Bay shoreline may be lost, and that 3,420 people in Santa Cruz and Monterey Counties may lose their homes. Coastal armoring strategies such as sea walls, bulkheads and revetments are already common in the sanctuary and may have long-term impacts on natural processes such as sediment transport (Content excerpted from SIMoN).
- Over the past 120 years, beaches have been eroding at approximately 0.2 meters (.06 feet) per year (from San Francisco to Monterey). Maximum erosion rates (1.8 meters per year) were documented just north of Point Ano Nuevo. Overall, erosion rates appear to be increasing from the long-term (within the past 120 years) to the short-term (within the past 30 to 50 years). Most erosion (landslides, beach erosion, cliff erosion and other coastal processes) within the sanctuary happens during severe El Niño winter storms, when wave power is strong and rainfall is high. For example, the tops of cliffs were found to have retreated 13 meters over the 1997-1998 El Niño winter in Pacifica, where 12 coastal homes were condemned because of cliff erosion (content excerpted from SIMoN).
- Some of the highest rates of erosion in the study region can be found at Bodega Head, the south-facing cliffs of Point Reyes Headland, the cliffs backing McClures Beach north of Pt Reyes, cliffs backing Palomarin and Double Point south of Pt Reyes, the promontory connecting Bolinas and Duxbury Points, and between Half Moon Bay and Point San Pedro, especially the north side of Pillar Point (Hapke and Reid 2007, see excerpted maps and table below).

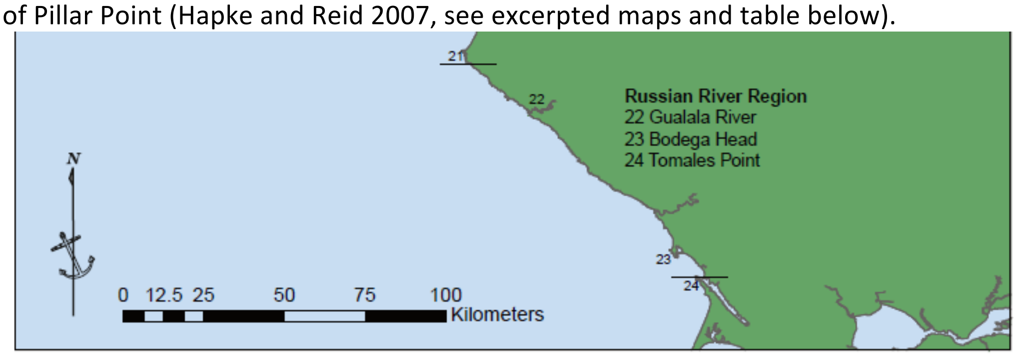

Table 4. Number of transects, coastal extents and average cliff retreat rates for California

REGION	Number of Transects	Length of Region (km)	Length of Measured Cliffs (km)	Average Retreat Rate (m/yr) ± 0.2	Average Retreat amount (m) ±10.9
Klamath	319	101	6	-0.5	-36.2
Eureka	135	154	3	-0.7	-53.4
Navarro	1441	142	29	-0.4	-28.9
Russian River	433	102	9	-0.2	-15.3
Northern CA	**2325**	**499**	**47**	**-0.5**	**-28.8**
San Francisco N	1092	119	22	-0.5	-36.2
San Francisco S	1551	99	31	-0.2	-16.4
Monterey Bay	1098	76	22	-0.4	-24.4
Big Sur	1929	145	39	-0.3	-17.2
Morro Bay	738	91	15	-0.2	-12.6
Santa Barbara N	3982	174	80	-0.2	-11.3
Central CA	**10390**	**704**	**208**	**-0.3**	**-17.3**

Hapke and Reid 2007

B. Flooding and increased wave action

- During El Niño years the occurrence of extreme wave heights and storms is likely to occur in late winter, a time when most beaches are at their narrowest width. Coastal erosion, flooding, runoff, and property loss will likely increase, and human responses (e.g., coastal armoring) will affect near shore habitats (excerpted from SIMoN website).
- Erosion rates were highest along promontories and headlands in the study region. The focusing of wave energy at headlands is likely driving these high rates, and underscores the importance of wave energy and water level on processes of coastal cliff retreat (Hapke and Reid 2007).

C. Species range shifts

Changes in ocean circulation patterns could lead to changes in the locations of mesoscale features and to subsequent changes in seabird and pinniped distributions. The persistence of seabird populations is dependent on their ability to potentially forage further from the colony during the breeding season or to find alternative nesting areas closer to abundant food supplies (excerpted from Largier et al. 2010). Pinnipeds are limited to locations where their colonies occur for resting and breeding. Access to cliffs and proximity to foraging areas affect where pinnipeds occur onshore.

3. Sensitivities to non-climate stressors

A. Shoreline armoring

Birds have been shown to be highly sensitive to the effects of coastal armoring, including seawalls, revetments and bulkheads (Dugan et al. 2008), and numerous armoring structures exist along the Central California coast to mitigate coastal cliff erosion and beach erosion (Hapke et al. 2006, Hanak et al. 2008 – see table below). Armoring directly impacts coastal cliff species by reducing the extent of cliff habitat (Barron et al. 2011).

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Table 2 Extent of armoring on California's ocean coastline. (Authors' calculations using coastal armoring and bluff erosion geographic information system created by Jennifer Dare (n.d.), NOAA Coastal Management Fellow at the California Coastal Commission)

County	Miles of seawall[a]	Percent of coastline	Number of levees or breakwaters
Del Norte	2.2	4.6	3
Humboldt	1.8	1.1	1
Mendocino	0.7	0.5	1
Sonoma	0.9	1.5	0
Marin	1.9	1.9	0
San Francisco	2.4	45.1	0
San Mateo	4.9	8.3	2
Santa Cruz	11.3	24.8	0
Monterey	4.5	3.7	0
San Luis Obispo	6.5	5.7	4
Santa Barbara	14.3	12.4	1
Ventura	25.7	61.1	2
Los Angeles	17.5	15.9	4
Orange	16.7	36.8	2
San Diego	24.7	31.5	3
California	136.0	10.9	23

[a] Includes: bluff walls, bulkheads, revetments, and seawalls

Hanak et al. 2008

B. Human use/Disturbance (Content excerpted from Largier et al. 2010)
Close vessel passes and low-flying aircraft are known to create behavioral changes in wildlife, including flushing (startle into flight), stampeding (a rush of frightened animals) and abandonment (of nest, eggs or young) for seabirds and pinnipeds.

Halpern et al. (2009) mapped the cumulative impacts of 25 human activities and found that central California is one of the most heavily impacted areas within the California Current. With increasing human populations, and more individuals migrating to coastal areas, pressures on marine resources will intensify (Halpern et al. 2009) and access to nearshore and offshore environments will become easier. Nature tourism activities, such as wildlife viewing from aircrafts, boats, kayaks and land (including wildlife photography and videography) will also continue to increase. These activities have the potential to harm wildlife and disrupt breeding, feeding, nesting/pupping, roosting/hauling out, young-rearing and mating rituals.

Breeding and roosting seabird and pinniped species, particularly those species that nest or roost on cliffs or offshore rocks, are highly susceptible to human disturbances (Carter et al. 1998; Carney and Sydeman 1999; Sydeman and Allen 1999). These disturbances can cause nesting seabirds and breeding pinnipeds to flee from and abandon
their nests/colonies, leaving eggs or chicks exposed to predators, or causing eggs to fall from the nest. In some cases, disturbances can cause complete breeding failure of a seabird colony, and/or colony abandonment. These disturbance events can result in a reduction in the long-term health and survival of affected marine species, and when coupled with changing oceanic conditions and other human induced stressors, cumulative small impacts can impart large-scale harm.

Habitat Adaptive Capacity

1. Extent, Integrity and Continuity

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

Over 70% of the coastline of California (1,340 km of 1,860 km total open ocean coastline) is backed by cliffs (Griggs and Patsch, 2004), and these are generally categorized as either high-relief cliffs or as marine terraces. High cliffs occur where mountains directly border the coast such as along the Big Sur coast and much of northern California. The high cliffs may be hundreds of meters or more in height, they occupy about 13% of the California coastline (Griggs and Patsch, 2004), and are typically composed of more resistant rock types such as granite and the Franciscan Complex. Lower relief marine terraces and coastal bluffs form the remaining majority of cliff-backed coast and are more frequently associated with less resistant rock types, especially Tertiary sedimentary units. Marine terraces and coastal bluffs are well developed south of Pt Reyes, high relief coastal slopes occur at the Marin headlands and Devils Slide.

B. Structural and functional integrity in study region:

Degradation of coastal cliffs and continuous loss of habitat for cliff-dwelling species is ubiquitous in the study region due to impacts from erosion and shoreline armoring (Hapke and Reid 2007).

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

Coastal cliff habitat is continuous in many parts of the study region, but can occur in more isolated areas, fractured by coastal lowlands that are typically associated with creek and river mouths (Hapke and Reid 2007).

2. Habitat Diversity

A. Diversity in topographic and physical characteristics

(Content excerpted from Hapke and Reid 2007)

- North of San Francisco to Point Arena is a relatively undeveloped, remote and rocky coastline, with high-relief coastal slopes or narrow beaches backed by high coastal cliffs. The exception is the developed communities around Dillon Beach, Bodega, Bolinas and Stinson Beach. The average retreat rate for this region was -0.5 m/yr up to Tomales Point (with average retreat of 36.2 m) and -0.2 m/yr from Tomales Point to Point Arena (with average retreat of 15.2 m).
- South of San Francisco to Davenport, the geomorphology of the coastline is variable, with linear beaches backed by dunes, steep cliffs with narrow fronting beaches, rocky coast with small pocket beaches, and steep, high-relief coast with no sandy shoreline. The average cliff retreat rate in this region was relatively low, -0.2 m/yr, and the average amount of retreat was 16.4 m, as measured along 31 km.

B. Diversity in species/functional groups

Seabirds gather in large groups on offshore rocks, cliffs and islands, to nest and raise their young. These large colonies are found all along the California coast. Around 10 species nest on coastal cliffs in the study region, including the focal species Common Murre, Brandt's Cormorant and Pigeon Guillemot.

- Common Murre are gregarious, and nest in dense colonies on wide ledges of flat tops of cliffs, primarily those that face northwest. Because competition for nesting space is tight and pair bonding is important, they begin to arrive at their territories during late October and early November. They maintain their territories throughout the winter, especially during spring weather, when the sky is clear and the north westerly's blow. Eggs are laid primarily in April and May, most chicks hatch in June, and nestlings fledge in July (Karl et al. 2000).

- Brandt's Cormorant are only found in estuaries and open ocean. These colonial nesters make a nest of guano, seaweed, and grasses on the top of rocky islands often in association with murres.
- The Pigeon Guillemot are cavity nesters on rocky cliffs and islands and often form loose colonies. Both parents care for the nestlings. They use their wings to propel them underwater in nearshore dives where they forage on small bottom-fish

Peregrine falcons nest all along the rocky cliffs of the mainland, including Point Reyes Headland, Kehoe Bluffs, and Arch Rock. Pinnipeds that use coastal rocky cliffs include northern fur seal, Steller sea lion, California sea lion and harbor seals. All four species breed on rocky areas on the Farallon Islands. On the mainland, Steller sea lions breed at Cap May Rocks north of Fort Ross, and sea lions haul out on several rocky outcrops. Harbor seals haul out and birth on numerous rocky areas throughout the region.

C. Dependence on a single keystone species
Unknown.

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