Cliffs[1]

Executive Summary

Cliffs	Score	Confidence
Sensitivity	3 Moderate-High	3 High
Exposure	2 Low-Moderate	2 Moderate
Adaptive Capacity	3 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

Cliffs[2] occur as steep, rocky faces of variable height along the coastline and among the Farallon Islands. Key climate sensitivities identified for this habitat by workshop participants include coastal erosion, extreme weather events, wave action, sea level rise, and precipitation. Key non-climate sensitivities include land use changes, roads and armoring and urban runoff. Cliffs are transcontinental in geographic extent, occurring along much of the coastline within the study area. They have moderate-high structural and functional integrity, featuring occasional alterations (i.e., seawalls or revetments). Cliffs have moderate habitat connectivity but low component species and functional group diversity. They feature highly adapted native vegetation and provide critical habitat for a variety of seabirds and pinnipeds. Cliffs are generally resistant to climate changes, though resistance varies by rock type, and have low recovery potential once disturbed or degraded. Cliffs are valued for their aesthetic qualities and recreational opportunities. Management options are primarily limited to urban or developed areas, and include managing urban development and runoff to minimize exposure and contribution to coastal cliff erosion.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[3], confidence[4]): extreme weather events (5, high), wave action (4, high), coastal erosion (4, high), precipitation (3, moderate), sea level rise (3, high), air temperature (2, moderate), salinity (2, low)

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

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

- Confidence of workshop participants: High

Additional participant comments

In general, cliffs are more sensitive to changes in extremes rather than mean changes in these factors.

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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] In completing this vulnerability assessment, workshop participants evaluated cliffs that provide suitable habitat (i.e., not unstable, sandy cliffs).

[3] 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.

[4] Confidence level indicated by workshop participants.

Supporting literature

Literature review was conducted for those factors scoring 3 or higher, although the other sensitivities identified should also be considered.

Extreme Weather Events

Extreme weather events (i.e., storms) increase erosion and can lead to bursts of large-scale coastal erosion (Center for Ocean Solutions 2014). Storm events such as El Niños usually coincide with larger wave heights, which can accelerate basal cliff erosion and lead to large-scale cliff failure or retreat (Griggs and Russell 2012, Sanctuary Integrated Monitoring Network (SIMoN) 2014). For example, the winter 1997-98 El Niño caused 12 coastal homes in Pacifica to be condemned when local cliff tops retreated 13 m and cliff bases retreated 10 m (SIMoN 2014). Compared to annual erosion rates in this area, the 1997-98 El Niño caused the same amount of erosion as would be expected over a 50-year period (SIMoN 2014). Storms also typically increase precipitation, contributing to runoff-based erosion and ground destabilization via saturation (Griggs and Russell 2012). Storms are typically more common in winter, and can vary in intensity, magnitude, and direction according to larger climate forcings such as the El Niño Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO) (Largier et al. 2010).

Wave Action

Wave action contributes to the basal erosion of cliffs and erosion of protective beach fronts (Griggs and Russell 2012). Wave action varies seasonally and according to local and more broad scale climatic processes. For example, wave heights in winter can be in excess of 8 m and are driven by extra-tropical cyclones in the North Pacific, smaller, shorter period waves in summer are generated from winds stemming from the North Pacific High (Wingfield and Storlazzi 2007), and local winds affect wave heights throughout the year. Wave heights can also increase during ENSO events (Storlazzi and Griggs 2000, Wingfield and Storlazzi 2007) and/or shift direction with shifts in the PDO (Sallenger et al. 2002). In general, cliffs along headlands, points, and promontories experience higher wave action and subsequent impacts (Hapke and Reid 2007).

Coastal Erosion

The sensitivity of cliffs to erosion varies by geologic rock type (Hapke and Reid 2007), the presence of internal weaknesses, orientation, wave exposure, the width of protective fronting beaches (Griggs et al. 2005, Griggs and Russell 2012), and terrestrial processes (i.e., runoff) (Griggs and Russell 2012). For example, higher relief cliffs tend to feature more stable rock types (i.e., granite, volcanic, or Franciscan Complex/Formation), while lower relief features such as coastal bluffs or marine terraces are often composed of weaker rock types (i.e., Tertiary sedimentary units such as sandstone, shale, siltstone, or alluvium) (Griggs and Patsch 2004, Hapke and Reid 2007). Rates of erosion vary widely over small spatial scales (Hapke and Reid 2007, SIMoN 2014). Slope failures can greatly increase local rates of erosion, and have occurred in many portions of the study region (i.e., along the south-facing cliffs along the Point Reyes headland and along the Devil's Slide between Half Moon Bay and Point San Pedro) (Hapke and Reid 2007, SIMoN 2014).

Erosion can reduce and/or degrade habitat area. For example, on-going erosion can alter vegetation composition and structure, while large-scale erosion (i.e., landslides, slumps, blockfalls) can degrade or eliminate pinniped resting/haul out areas and nesting habitat for seabirds (Hapke and Reid 2007). In addition, erosion can limit recreational opportunities (i.e., by creating dangerous or impassable trail conditions) (Largier et al. 2010) or affect human infrastructure (i.e., highways, housing, and sewage lines) (Griggs and Russell 2012, SIMoN 2014).

Precipitation

Precipitation can increase erosion potential via runoff and decrease cliff stability, contributing to physical alterations of cliff habitat (Griggs and Patsch 2004, Largier et al. 2010, Griggs and Russell 2012). For example, runoff-induced erosion is one of the main drivers of erosion in cliffs protected from wave action by large fronting beaches (Griggs and Russell 2012). Precipitation can also contribute to ground saturation, which can destabilize cliff areas and potentially lead to landslides (Griggs and Patsch 2004, Griggs and Russell 2012).

Sea Level Rise

Sea level rise can increase the exposure of cliffs to wave action by reducing the width of protective beach front area and/or exposing new, higher cliff areas to wave action (Heberger et al. 2009, Griggs and Russell 2012). This increased exposure to wave attack can accelerate erosion (Heberger et al. 2009). These interconnected impacts may be more prevalent in the study area during El Niño winters, which feature warmer sea surface temperatures, higher sea levels, and stronger storms with higher waves and storm surge (Storlazzi and Griggs 2000). Digital elevation models of the South Farallon Islands indicate that a rise of 0.5m would result in permanent flooding of 23,000 m^2 of island habitat (Point Blue, unpublished data), resulting in a redistribution of wildlife populations that would impact seabird habitat by reducing the available nesting areas and leading to nest destruction (Largier et al. 2010).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms, wind, flooding, and drought

Overall habitat sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Storms can increase wave heights, sea level, and precipitation, potentially increasing erosion rates or leading to cliff failure (Griggs and Russell 2012, Center for Ocean Solutions 2014, SIMoN 2014). Wind affects local wave heights (Wingfield and Storlazzi 2007, Largier et al. 2010). Alongshore winds increased from 1940-1990 (Bakun 1990, Schwing and Mendelssohn 1997, Mendelssohn and Schwing 2002), and are expected to increase in all seasons in the future, particularly in summer and fall, due to increasing differences in land-ocean pressures and temperatures (Snyder et al. 2003, Auad et al. 2006, Largier et al. 2010). Terrestrial flooding can increase runoff-based erosion or ground saturation and destabilization in cliff habitats, while flooding of lower portions of marine terraces can wash away thin soil layers used by burrow nesting species (Largier et al. 2010). Drought can affect vegetation growing in cliff habitat.

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[5], confidence[6]): land use change (4, high), coastal roads/armoring (4, high), urban runoff (3, moderate), recreation (2, high), invasive species (2, moderate), overwater/underwater structures (2, moderate)

Overall habitat sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: High

Overall habitat exposure to non-climate stressors: Low

- Confidence of workshop participants: High

Additional participant comments

Though overall exposure to non-climate stressors is low, exposure in urban areas (especially for runoff and land use change) is much higher than in non-developed portions of the study area.

Supporting literature

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

Land Use Changes

Land use changes (i.e., development, watershed alterations) that disrupt sediment supply to protective fronting beaches can increase the potential for erosion and retreat in coastal cliffs habitats (Willis and Griggs 2003, Hapke and Reid 2007, Slagel and Griggs 2008, Largier et al. 2010). For example, when beaches shrink in response to sediment deficits, cliffs can be exposed to higher wave action (Largier et al. 2010). In addition, development and landscape irrigation on top of coastal cliffs can increase internal pore pressures of cliff materials, decreasing resilience and accelerating coastal erosion (Griggs and Patsch 2004). The construction of jetties or breakwaters can also increase wave attack on down coast cliffs by depriving fronting beaches of sand, while simultaneously decreasing wave attack on up coast cliffs by increasing sediment delivery to their respective fronting beaches (Griggs and Patsch 2004).

Roads and Armoring

Coastal armoring is typically practiced to protect existing infrastructure (i.e., roads, development) (California Department of Boating and Waterways (CDWB) and State Coastal Conservancy (SCC) 2002). For example, engineered structures such as revetments or seawalls placed at cliff bases can reduce erosion and cliff retreat rates by reducing wave exposure (Hapke and Reid 2007). The study region features many of these protective structures, especially in developed areas (CDWB and SCC 2002, Hapke and Reid 2007, Hanak and Moreno 2008). For example, as of 1985, 77% of 14.4 km of shoreline north of Monterey Bay had been armored (Griggs and Patsch 2004). However, these structures only serve as a temporary solution, they typically cannot completely prevent cliff erosion (Hapke and Reid 2007), and they can limit sediment delivery to local beaches and/or prevent migration of beaches in response to sea level rise, effectively reducing protective fronting for coastal cliff habitats (CDBW and SCC 2002,

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[5] 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.

[6] Confidence level indicated by workshop participants.

Hapke and Reid 2007, Dugan et al. 2008, Largier et al. 2010). In addition, armoring can reduce habitat area for coastal cliff species (Barron et al. 2011).

Urban Runoff

Urban runoff can contribute to runoff erosion in coastal cliff habitats and/or increase the likelihood of cliff failure by oversaturating the ground (Griggs and Russell 2012). For example, installed culverts and drains can concentrate runoff to specific portions of bluff faces, accelerating erosion in these areas (Griggs and Patsch 2004). Projected population growth and rapid urbanization along the Central California coastline could lead to the installation of more impervious surfaces (Jaiswal and Newkirk 2005), which can increase rates of urban runoff and exacerbate erosion trends in coastal cliff habitats.

IV. Other sensitivities identified by workshop participants

Other critical factors likely to influence the sensitivity of the habitat: tsunamis and earthquakes

- Confidence of workshop participants: Moderate-High
- Confidence of workshop participants in the degree to which these factors influence habitat sensitivity: Moderate

Supporting literature

Extreme events such as earthquakes and tsunamis can lead to temporary exposure to extreme wave heights or cliff failures. The study region lies along the active San Andreas Fault system, an 800-mile long transform boundary between the Pacific and North American plates (Ryan et al. 2001). More specifically, the study region occurs along the San Gregorio Fault zone, a 250-mile long stretch of coastal faults spanning from Bolinas Bay to Big Sur (Ryan et al. 2001). Earthquakes can cause fracturing, sliding, or slumping of cliffs and bluffs (Ryan et al. 2001, CDBW and SCC 2002), reducing habitat area and/or quality. Tsunamis can be generated locally (i.e., via subaerial or submarine landslides) or in faraway locations when large areas of seafloor are rapidly displaced (Ryan et al 2001). Tsunamis can increase erosion, contribute to cliff failures, and/or scour cliff faces, affecting cliff vegetation and cliff-nesting species.

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: 4 (Minor to moderate alterations)

- 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

Over 72% of California's coastline features cliffs of varying heights (Griggs and Patsch 2004). Cliff habitats are periodically disrupted by coastal lowlands, such as beaches, dunes, and estuaries (Griggs and Patsch 2004). Coastal cliffs occurring along developed areas of the study region feature some alterations, including seawalls and/or revetments used to reduce wave exposure and erosion (Hapke and Reid 2007).

II. Resistance and recovery

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

- Confidence of workshop participants: Moderate

Ability of habitat to recover from stressor/maladaptive human response impacts: Low-Moderate

- Confidence of workshop participants: Moderate

Supporting literature

Cliffs are composed of different uplifted rock types that have been eroding over many centuries (CDBW and SCC 2002, Griggs and Patsch 2004), demonstrating how this habitat is generally resistant to extreme changes in response to changing climate conditions. Resistance also varies by rock type (CDBW and SCC 2002, Hapke and Reid 2007), with the Franciscan Formation, granitic and volcanic rocks being most resistant to erosion (Griggs and Patsch 2004). However, unlike beaches and dunes, which can recede or advance from season to season, cliff erosion only progresses landward (Griggs and Patsch 2004), limiting the recovery potential for cliff habitats.

III. Habitat diversity

Physical and topographical diversity of the habitat: Low-Moderate

- Confidence of workshop participants: High

Diversity of component species within the habitat: Low

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Low

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: none identified

Supporting literature

Cliffs feature many highly adapted native plant species, including herbaceous perennials such as the seaside daisy (Erigeron glaucus) and coastal buckwheat (Eriogonum latifolium) (North Coast Native Nursery 2014). Cliffs provide habitat for several nesting seabirds, including common murres (Uria aalge), pigeon guillemots (Cepphus columba), pelagic cormorants (Phalacrocorax pelagicus), and tufted puffins (Fratercula cirrhata) (Pyle 2001). Cliffs also provide haul-out space for some pinnipeds, including harbor seals (Phoca vitulina), California sea lions (Zalophus californianus), and northern elephant seals (Mirounga angustirostris) (Roletto 2001). The northern coastline of the study area typically features higher relief cliffs, while lower relief coastal bluffs and marine terraces are found more commonly south of Point Reyes (Griggs and Patsch 2004, Hapke and Reid 2007). The Farallon Islands also feature many rocky cliff lines.

IV. Management potential

Value of habitat to people: Moderate-High

- Confidence of workshop participants: Moderate
- Description of value: Cliffs are valued for their aesthetic qualities and recreational opportunities (i.e., scenic vistas along hiking trails).

Likelihood of managing or alleviating climate change impacts on habitat: Low-Moderate

- Confidence of workshop participants: Moderate
- Description of potential management options: Management efforts will likely focus on managing urban development and runoff to minimize exposure and contribution to coastal cliff erosion.

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[7]

Future climate and climate-driven factors identified (score[8], confidence[9]): increased coastal erosion and runoff (4, high), increased storminess (4, high), sea level rise (2, moderate), increased flooding (2, low), changes in precipitation (2, moderate), changes in air temperature (1, moderate), changes in salinity (1, high)

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

- Confidence of workshop participants: Moderate

Supporting literature

Increased coastal erosion and runoff

Over a 70-year period, Central California experienced cliff retreat along 208 km of coastline, with average retreat rates measuring -0.3m/yr and average overall retreat distances measuring 17.3 m, though there was high variability within the study region (Hapke and Reid 2007). For example, the highest rates of erosion in Central California occurred along promontories or points such as Point San Luis, Point Sal, and Point Conception, which typically experience higher wave energy (Hapke and Reid 2007). Hazard erosion areas have been identified and mapped[10], and erosion is likely to increase in the study region in the future due to a combination of increasing storm frequency and intensity, sea level rise, and changing wave activity (Phil William and Associates 2009, Ackerly 2012). For example, if sea levels increase 1.4 m, total alongshore and acrossshore cliff erosion in the study area could reach 15.4 square miles (Largier et al. 2010). Further, by 2100, cliff erosion could extend an average of 61 m inland, with maximum inland erosion distances reaching 206 m (Largier et al. 2010).

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

[8] 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.

[9] Confidence level indicated by workshop participants.

[10] http://www.pacinst.org/reports/sea_level_rise/hazlist.html

Precipitation

In combination with increased development of coastal areas (CDWB and SCC 2002), increased extreme precipitation events may contribute to larger runoff volumes, which can increase coastal cliff erosion and/or contribute to ground saturation, potentially leading to cliff failure (Griggs and Patsch 2004).

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