List of Figures and Tables

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California Hydrocoral (*Stylaster californicus*) and Red Sponge (*Ophlitaspongia pennata*)[1]

Executive Summary

California Hydrocoral and Red Sponge	Score	Confidence
Sensitivity	3 Moderate	2 Moderate
Exposure	3 Moderate	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

The California hydrocoral and red sponge are important deep-water habitat-forming invertebrates for benthic communities of offshore banks, ranging from British Columbia to Baja California, Mexico. The hydrocoral is restricted to depths of 30-75 meters, whereas the red sponge is observed from these depths up to the intertidal zone. Relatively little information exists regarding these deep-water species, especially experimental data regarding climate impacts. Key climate sensitivities identified for these species by workshop participants include dissolved oxygen, pH, and dynamic ocean conditions (currents/mixing/upwelling), and key non-climate sensitivities include pollution and poisons, harvest and invasive species. Hydrocorals and sponges exhibit patchy distributions across their range and populations that are diminished, but generally stable. Both species may have limited dispersal due to their short larval stage. Genetic, behavioral, and morphological diversity is not well studied, though some examples of phenotypic plasticity have been documented. The societal value for the California hydrocoral and red sponge is considered moderate-high due to their function as critical components of offshore reef communities and valuable habitat/protection for juvenile fishes, but the likelihood of managing or alleviating climate impacts was rated as low-moderate.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): dynamic ocean conditions (currents/mixing/stratification) (4, high), dissolved oxygen (DO) levels (3, low), pH (3, low)

Climate and climate-driven changes that may benefit the species: ocean temperature

- Description of benefits: Changes in ocean temperatures can affect the distribution of these species.

Overall species sensitivity to climate and climate-driven factors: Low-Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

There are few climate factors that impact these species, but they are highly sensitive to those that do.

[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

Oxygen

When dissolved oxygen (DO) concentrations fall to hypoxic levels, there are severe consequences for offshore benthic communities, as the oxygen depleted water mass suffocates everything that cannot move out of the area, including corals and sponges (Largier et al. 2010). Areas adjacent to upwelling centers like Point Arena are particularly susceptible to low DO levels as the upwelling process naturally delivers low oxygen water onto the continental shelf from the deep ocean (Largier et al. 2010).

pH

Ocean acidification leads to decreased skeleton production in hydrocorals due to the undersaturation of aragonite, which is required for calcification. Because these organisms are found in deeper water, the exposure to low-pH water associated with upwelling events will likely be more immediate (Largier et al. 2010). Decline in the biomass of plankton will also affect deeper benthic communities, especially hydrocorals that feed largely on plankton. Ocean acidification may also impact coral and sponge larval stages during the developmental phase of their early life history, as has been experimentally demonstrated for copepods, urchins and mussels (Kurihara et al. 2004).

Dynamic ocean conditions (currents/mixing /upwelling

Corals and sponges depend on currents to deliver food, so any significant disruption to the timing or intensity of seasonal upwelling winds resulting in reduced productivity over time would have negative impacts on long term survival of benthic animals (Largier et al. 2010). These species spend the first part of their lives as free-floating plankton, which facilitates dispersal, feeding and predator avoidance, and change in the timing or magnitude of seasonal winds driving coastal upwelling could reduce coral and sponge larval survival (Largier et al. 2010).

II. Sensitivity to disturbance regimes: none identified

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: rocky substrate

Species dependence on specific prey or forage species: Low-Moderate

- Confidence of workshop participants: Moderate

Other critical dependencies: none

Specialization of species (1=generalist; 5=specialist): 3

- Confidence of workshop participants: Low

Supporting literature

An additional dependency, as noted in the climate impacts section, for both species is the consistency of currents to provide an abundant food supply (ONMS 2009): microzooplankton, bacterial particulates, and small particulate organic matter for the hydrocoral, and dissolved organic matter for sponges.

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): invasive species (5, high), pollution and poisons (4, high), harvest (4, high)

Overall species sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Low

- Confidence of workshop participants: High

Supporting literature

Pollution and poisons

Runoff of sediments, contaminants, and nutrients from agriculture, industry, sewage, and land clearing have been documented to cause extensive damage to coral and sponge species in tropical coral reefs worldwide by reducing recruitment, reducing growth and calcification, encouraging the growth of benthic competitors, and causing hypoxic conditions (ISRS 2004). However, because of the offshore nature of these banks and the distance from population centers on the mainland, water quality is considered to be in fairly good condition (ONMS 2009). Oil spills continue to pose a threat to the health of this ecosystem, and there have been several large spills in the region over the last decade (ONMS 2009).

Harvest

The impacts from harvest on corals and sponges largely results from the use of bottom-tending gear (Vulnerability Assessment Workshop, pers. comm., 2014) and lost fishing gear that has been documented entangling these species (ONMS 2009). Significant amounts of derelict fishing gear have been documented in rocky areas of Cordell Bank and in surveys from 2001-2005, fishing gear was consistently observed on the bottom, with long-lines and gill nets the most common gear type observed (ONMS 2009). This gear becomes entangled on high relief areas that are frequently covered with hydrocorals and sponges. As 86% of Cordell Bank NMS's boundaries are now closed to some type of bottom-tending gear, the condition of biologically structured habitats should improve (ONMS 2009).

Invasive Species

A number of non-native species are present in the vicinity of offshore benthic communities in the study region, but none are currently confirmed to exist in these habitats. However, there is some concern regarding an invasive tunicate, *Didemnum sp*. that has been observed in nearby coastal areas (Tomales and Bodega Bays) and has covered large areas of Georges' Bank on the east coast (Bullard et al. 2007). The invasive tunicate is similar to a native *Didemnum* species, and is known to spread rapidly and overgrow native benthic species, including corals and sponges (Bullard et al. 2007). Sampling will be necessary to determine which species is present on offshore banks in the study region (ONMS 2009).

V. Other sensitivities: none identified

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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.

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 3

- Confidence of workshop participants: High

Population status of the species (1=endangered; 5=robust): 3

- Confidence of workshop participants: Moderate

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 3

- Confidence of workshop participants: Moderate

Dispersal ability of the species: Moderate-High

- Confidence of workshop participants: High

Maximum annual dispersal distance: no answer provided

Supporting literature

Though these species were identified as having moderate-high dispersal capability by workshop participants, the literature indicates that dispersal may be limited. Studies of related Alaskan hydrocoral species indicated a very short larval lifespan that led to settlement in close proximity to the parent colony, unless sufficiently strong currents are able to transport larvae long distances in a short amount of time (Brooke and Stone 2007). Limited dispersal implies potential recovery of a colony that has experienced light disturbance, but limited capability for the recovery and re-colonization of seriously impacted areas (Brooke and Stone 2007). Similarly, most sponge larvae have a short dispersal period, usually less than three days, before settling, and will spend a few hours in a "creeping" stage to find suitable habitat (Shanks 2001).

II. Intraspecific/Life history diversity

No information or ratings for these characteristics of diversity were provided by workshop participants, as much of this information is unknown at this time for these species.

Supporting literature

Understanding the genetic diversity of the California hydrocoral is complicated by its variable morphology (including coloration and branching pattern), and recent analysis suggests that the deep-water species considered here may be genetically the same as the intertidal *Stylantheca porphyra* encrusting coral (Cairns and Macintyre 1992). Behavioral plasticity is likely low for both species as they are sessile organisms that are not able to escape exposure to stressors. However, some indications of phenotypic plasticity can be found for these species, including the morphological variation seen in hydrocorals (mentioned above), the ability to asexually reproduce from fragments by the red sponge, and the ability for cyclosystems on hydrocorals (small openings in the tissue that house the stinging tentacles used for feeding) to rapidly regenerate on damaged branches (Ostarello 1973).

Hydrocorals have slow growth rates, long lives, and internal fertilization with brooded larvae (Brook and Stone 2007). Studies indicate a short larval lifespan (3-8 hours) with larvae dispersing very short distances and settling near the parent colony (Ostarello 1973, Fritchman 1974). It is unknown how long it takes for hydrocorals to reach reproductive maturity or how frequently they can reproduce (Vulnerability Assessment Workshop, pers. comm., 2014), though studies of related Alaskan species indicate that reproduction is either continuous or seasonal and protracted (Brook and Stone 2007). The red sponge reproduces both sexually through broadcast spawning, and asexually through fragmentation (regeneration from a broken off fragment, Shanks 2001).

III. Management potential

Value of species to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: Valued for their function as critical components of offshore reef communities and valuable habitat for juveniles of several commercially important species of groundfish

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

- Confidence of workshop participants: Moderate
- Description of possible management options: none identified because it will be difficult to mitigate for oceanographic conditions such as changing pH, temperature, and altered currents/mixing that will likely affect corals and sponges

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified: decreased pH (4, high), changes in sea surface temperature (3, high), altered currents/mixing (3, high), decreased dissolved oxygen (DO) levels (2, low)

Degree of exposure to future climate and climate-driven changes: Moderate

- Confidence of workshop participants: Moderate

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California Mussel (*Mytilus californianus*)[1]

Executive Summary

California Mussel	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

The California mussel is a bivalve invertebrate that forms dense, clustered aggregates of individuals in the rocky mid-intertidal habitat from Alaska to Baja California (SIMoN 2014). Key climate sensitivities identified by workshop participants include air temperature, salinity, wave action, pH and erosion, and key non-climate sensitivities include armoring, pollution and poisons, recreation and introduced species. The California mussel exhibits a transcontinental geographic extent, a healthy, continuous population, and a high dispersal capability. The entire California mussel population is genetically homogenous, but variation in gene expression allows for varied physiological responses and local adaptation. The societal value for this species was rated as moderate due to harvest and scientific value, and management potential was considered to be low-moderate, with some possibility to better manage disturbance from tidepool visitation and to better protect upland habitat for migration.

Sensitivity

I. Sensitivity to climate and climate driven changes

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

Climate and climate-driven changes that may benefit the species: wave action

- Description of benefit: Increased wave action could benefit the California mussel by negatively impacting *Pisaster*, one of its major predators.

Overall species sensitivity to climate and climate-driven factors: High

- Confidence of workshop participants: Moderate

Supporting literature

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

[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.

Air temperature

Mussels are well adapted to large variations in temperature exposure due to daily emersion at low tide, with daily internal body temperature ranges of close to 15˚C (Carefoot 1977), and annual ranges around 34˚C (Elvin and Gonor 1979). Larger individuals, and those growing in close clusters, are able to maintain a lower body temperature than others (Helmuth 2008). Individuals began to die when body temperature exceeded 36 °C as a function of thermal stress; around half were killed by exposure to 38 °C, and all died when their body temperature exceeded 41 °C (Denny et al. 2011). Body temperature, however, is not solely a function of air temperature, and can be impacted by wind velocity, the timing and duration of tides, solar irradiation, wave splash and orientation to the sun (Helmuth et al. 2011), so the direct impact of increasing air temperature will likely not be straight-forward.

Salinity

Low salinity impacts the survival of mussel gametes and larvae, with susceptibility beginning at salinities lower than 300/00 (with seawater typically around 350/00), which may explain why this species is not found in brackish water (Young 1941).

Wave action

Considered the competitive dominant species in wave-exposed rocky shores, mussels are highly adapted to high wave action through the use of strong filaments called byssal threads that attach them securely to bare rock (SIMoN 2014). Mussels may benefit from an increase in wave action if it results in a decrease in the abundance of its main predator, the ochre sea star, or a decrease in the overlap of the two species' tidal extents (Vulnerability Assessment Workshop, pers.comm., 2014). Recovery from storm disturbance can be fairly rapid if the number of removed individuals is small and surrounded by mussels that can move in, or can take 10 years or more if entire beds of mussels are removed (Vesco and Gillard 1980, Kinnetics 1992). Enhanced wave action may result in the selective removal of larger individuals.

Ocean pH

pH levels predicted to occur by 2100 were found to degrade the mechanical integrity of larval mussel shells, which may result in a lengthened larval phase, and/or enhance vulnerability to predation and desiccation upon settling on the substrate (Gaylord et al. 2011). In another study, elevated pCO2 did not impact adult tissue or shell growth of mytilid mussels (which includes the California mussel), but did alter the strength of the byssal threads that attach the mussel to the substrate (O'Donnell et al. 2013). Threads were weaker and less extensible, decreasing individual tenacity by 40%, which has serious implications for the viability of mussels with increased wave action and decreased pH both predicted to occur.

Coastal erosion

Enhanced coastal erosion, due to sea level rise and an increase in wave and storm severity, may result in the burying of intertidal habitat (Vulnerability Assessment Workshop, pers. comm., 2014) and may also impede the ability of intertidal organisms to migrate inland in response to rising sea levels (Largier et al. 2010).

II. Sensitivity to changes in disturbance regimes

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

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: Moderate

Additional participant comments

Disease has the potential to greatly impact the California mussel indirectly if the sea star wasting syndrome results in decreased abundance of its main predator, the ochre sea star.

Supporting literature

Wind

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), but can also result in lower body temperatures in California mussels due to cooling.

Disease

In addition to the potential indirect effects of disease as mentioned by workshop participants, a general increase in disease is often linked to increases 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).

Storms

Storms increase physical forces through enhanced wave exposure and increased erosion of coastal cliffs that can bury intertidal habitats (see wave action and erosion sections above).

Flooding

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.

Extreme heat events

Extreme heat events can result in mass mortality of intertidal organisms; though temperature interacts with a number of other factors to affect the internal temperature of the California mussel (see air temperature section above).

III. Sensitivity and exposure to non-climate stressors

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

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: Low

Overall current exposure to non-climate stressors: Low-moderate

- Confidence of workshop participants: Moderate

Additional participant comments

In addition to invasive species, rocky intertidal organisms, including the California mussel, will likely be impacted by species range expansions due to increasing sea surface temperature. Oil spills are a component of localized pollution that can smother organisms and inhibit the resilience of the rocky intertidal habitat.

[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

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

Coastal armoring

As sea level rises and increasing coastal erosion threatens the coastal cliffs and bluffs along California's shoreline, bluff revetments and coastal armoring will be more frequently used, and the effect depends on the specific armoring structure utilized (Largier et al. 2010). Coastal armoring would likely limit the ability of intertidal organisms, including the California mussel, to migrate upland or inland with rising sea level, but may also add additional available habitat by creating hard substrate (Vulnerability Assessment Workshop, pers. comm., 2014).

Invasive species

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 2014), and climate change is likely to enhance the negative impacts of coastal invaders. Species range expansions have been documented for coastal California, likely due to increasing sea surface temperature, including a documented increase in abundance of 10 to 11 Southern species and a decrease in 5 to 7 Northern species (Barry et al. 1995) and a northward range expansion of 300 km (from San Francisco to Cape Mendocino) by volcano barnacles (*Tetraclita rubescens*), a common intertidal species (Connolly and Roughgarden 1998). The direct impact of these species on the California mussel may be through increased competition for space, though more complex ecological interactions and impacts are unknown (Vulnerability Assessment Workshop, pers. comm., 2014).

Pollution and poisons

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. Because mussels are highly efficient filter feeders, the concentration of heavy metals and organic pollutants in their tissues is a concern for human consumption; harvest of mussels is prohibited from May through October due to red tides, blooms of dinoflagellates and diatoms (SIMoN 2014) that are caused, in part, by enhanced nutrient run-off.

Recreation

Trampling of the intertidal system by recreational users, researchers and harvesters is a documented negative stressor (Largier et al. 2010). 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). Though there is some indication that mussels remain unaffected by trampling (Beauchamp and Gowing 1982), there are many documented instances of negative impacts, including reduced percent cover of mussels, reduced adult density, reduced mussel bed thickness, and reduced mussel biomass at sites with higher visitation rates compared to lower visitation rates across the California coast (Brosnan and Crumrine 1994, Smith and Murray 2004, Smith et al. 2008, Van De Werfhorst and Pearse 2007).

IV. Dependencies

Species dependence on one or more sensitive habitat types: Low

- Confidence of workshop participants: High

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: availability of existing mussel beds or bare rock in the mid-intertidal of wave-exposed shores for settling larvae

- Degree of dependence: High
- Confidence of workshop participants: High

Specialization of species (1=generalist; 5=specialist): 3

- Confidence of workshop participants: High

V. Other sensitivities: none identified

Additional participant comments

The overall sensitivity of California mussels is primarily driven by sea level rise.

Adaptive Capacity

I. Extent, Status, and Dispersal Ability

Geographic extent of the species (1=endemic; 5=transboundary): 5

- Confidence of workshop participants: High

Population status of the species (1=endangered; 5=robust): 5

- Confidence of workshop participants: Moderate

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 5

- Confidence of workshop participants: Moderate

Dispersal ability of the species: High

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: 50-100km for larvae

- Confidence of workshop participants: High

II. Intraspecific/Life History Diversity

Diversity of life history strategies: Low

- Confidence of workshop participants: High

Genetic diversity: Moderate-High

- Confidence of workshop participants: High

Behavioral plasticity: Low

- Confidence of workshop participants: High

Phenotypic plasticity: Moderate

- Confidence of workshop participants: High

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: High

Supporting literature

In contrast to the workshop participants scoring, the literature indicates a nearly genetically homogenous population across the entirety of the mussel's geographic range, due in part to extensive gene flow and lack of strong selective gradients (Addison et al. 2008). However, there is geographic variation in thermal tolerance, with individuals from the northern-most range exhibiting adaptations to cooler conditions (Logan et al. 2012). This variation could not be completely attributed to phenotypic plasticity, and the authors concluded that genetic diversity (through local adaptation) may be one contributing factor to this variation (Logan et al. 2012). Additionally, Place et al. (2008) documented variation in physiological response to emersion across the mussel's range due to significant variation in gene expression.

III. Management Potential

Value of species to people: Moderate

- Confidence of workshop participants: High
- Description of value: value to the general public for harvest and tidepool recreation, and to the scientific community as an important component of rocky intertidal and ecology research.

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

- Confidence of workshop participants: High
- Description of potential management options: manage visitation to decrease trampling impacts, and secure upland habitat for migration in response to sea level rise.

Supporting literature

There is added value for the species due to its role as a critical indicator of water quality, due to its efficient filtering capabilities that concentrate organic pollutants and heavy metals in their tissues (SIMoN 2014).

IV. Other adaptive capacity factors: none identified

Additional participant comments

An additional component to this species' adaptive capacity that is important to consider is the predator-prey relationship with the ochre sea star that will likely be altered by climate impacts. Mussel beds are largely limited to expanding to the low intertidal by predation from the ochre sea star, so any negative impacts on the sea star due to a changing climate (including enhanced disease virulence and wave action) may result in a benefit to the California mussel.

Exposure

I. Future climate exposure[6]

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

<u>Degree of exposure to future climate and climate-driven changes</u>: 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.
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Cassin’s Auklet (*Ptychoramphus aleuticus*)[1]

Executive Summary

Cassin’s Auklet	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	2 Low-Moderate	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

The Cassin’s auklet is a resident zooplanktivorous seabird that spends a majority of life at sea, coming ashore only to breed on offshore islands. Key climate sensitivities identified by participants include sea surface temperature, dynamic ocean conditions (currents/mixing/stratification), and extreme weather events, and key non-climate sensitivities include oil spills and invasive rodents. Cassin’s auklets have a transcontinental geographic extent, with diminished but generally stable populations within the study region and high population connectivity. The Farallon Islands breeding colonies have experienced significant declines, and future population declines are projected due to shifting oceanographic conditions and associated impacts on marine food webs. Cassin’s auklets have a moderate-high dispersal ability with a maximum annual dispersal distance of over 100 km. Cassin’s auklets have moderate-high life history strategy diversity, low-moderate genetic diversity (within the study region), and moderate behavioral and phenotypic plasticity. Cassin’s auklets were evaluated to be of low societal value and to have a low likelihood of managing or alleviating climate impacts. Potential management options to protect breeding populations of this species include eradicating house mice on Southeast Farallon Island, eradicating invasive plant species and restoring native vegetation on breeding colony islands to facilitate soil stabilization for burrowing, and reducing recreational and vessel disturbance.

Sensitivity

I. Sensitivities to climate and climate-driven factors

<u>Climate and climate-driven changes identified (score[2], confidence[3])</u>: extreme weather events (4, high), sea surface temperature (3, high), dynamic ocean conditions (currents/mixing/stratification) (3, moderate), salinity (for prey species) (2, low), oxygen (for prey species) (2, low), pH (for prey species) (2, low), sea level rise (2, high), coastal erosion (2, moderate), air temperature (1, moderate), precipitation (1, high), wave action (1, moderate)

<u>Climate and climate-driven changes that may benefit the species</u>: sea surface temperature and dynamic ocean conditions

- Description of benefit: Increased upwelling, ocean cooling, and stronger and/or repositioned currents could all benefit the Cassin’s auklet by enhancing marine food webs

<u>Overall species sensitivity to climate and climate-driven factors</u>: Low-Moderate

- Confidence of participants: Moderate

[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 participants.

Additional participant comments

Cassin's auklets were evaluated to have low-moderate sensitivity to a variety of climate and climate-driven factors, and are mainly sensitive to factors that affect their prey base or burrow habitat, such as sea surface temperature, currents/mixing/stratification, and extreme weather events

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 rainfall can flood low-lying areas and burrows, causing egg or chick mortality (Point Blue, pers. comm., 2014, Sydeman, pers. comm., 2014).

Sea Surface Temperature

Sea surface temperatures reflect general ocean conditions, and can have indirect impacts on the Cassin's auklet through altering ecological interactions (i.e., prey availability) (Sydeman, pers. comm., 2014). For example, warmer ocean temperatures resulted in a 90% reduction in zooplankton biomass (Roemmich and McGowan 1995), potentially contributing to the major decline of the Farallon Island Cassin's auklet population during the early 1970s to late 1980s (Ainley et al. 1994). Further, abundance of North Pacific krill (*Euphausia pacifica*), a key prey species for Cassin's auklets, is thought to be negatively correlated with the Pacific Decadal Oscillation (PDO) and sea surface temperature, declining during warm ocean periods (Brinton and Townsend 2003). Major basin-scale shifts in oceanographic conditions, such as shifts in the Southern Oscillation Index (SOI), El Niño Southern Oscillation (ENSO), and PDO can affect sea surface temperature and other oceanographic conditions, impacting demographic patterns of Cassin's auklets. For example, Lee et al. (2007) found that survival, breeding propensity, breeding success, and recruitment all decreased for the Southeast Farallon Island Cassin's auklet population during El Niño years, likely as a result of climate-driven perturbations in local food webs. In comparison, La Niña years increased survival and reproduction (Lee et al. 2007).

Dynamic ocean conditions (currents/mixing/stratification)

The Cassin's auklet is a zooplanktivore that forages within the California Current System (CCS) (Lee et al. 2007). The CCS has highly variable productivity, and is largely influenced by SOI and ENSO patterns (Goericke et al. 2004, Lee et al. 2007) and equatorial wind-driven upwelling (Huyer 1983). Productivity patterns tend to be current-wide, affecting Cassin's auklets throughout their range (Lee et al. 2007). Changes in currents, mixing, and stratification in conjunction with shifts in upwelling and other ocean conditions (i.e., sea surface temperature, salinity, pH) can affect the Cassin's auklet by affecting marine productivity and prey availability (Lee et al. 2007, Sydeman, pers. comm., 2014). For example, breeding success and recruitment increased after 1998 as a result of stronger upwelling and mixing mechanisms and higher marine productivity (Peterson and Schwing 2003, Goericke et al. 2004).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease, storms, flooding, drought

Overall species sensitivity to disturbance regimes: Moderate-High

- Confidence of participants: High

Supporting literature

As colonial nesters (Harfenist 2004), infectious disease can spread rapidly and extensively. Storms, bringing precipitation and higher wave heights, could contribute to the flooding of low-lying breeding habitat and burrows, causing egg or chick mortality (Point Blue pers. comm., 2014). Higher winds during storms can also decrease foraging success, requiring longer foraging effort (Bailey and Kaiser 1993, Ronconi and Hipfner 2009). Drought could affect vegetation that stabilizes burrows (Adams 2008).

III. Dependencies

Species dependence on one or more sensitive habitat types: breeding habitat: High; feeding habitat: Low-Moderate

- Confidence of participants: High
- Sensitive habitats species is dependent upon: breeding habitat: offshore, predator-free islands; feeding habitat: mid-water pelagic

Species dependence on specific prey or forage species: High

- Confidence of participants: High

Other critical dependencies: timing of breeding

- Degree of dependence: High
- Confidence of participants: High

Specialization of species (1=generalist; 5=specialist): 4

- Confidence of participants: High

Supporting literature

Cassin's auklets breed colonially on offshore islands that are free of predators (Harfenist 2004, Adams 2008), nesting in rock crevices or excavated dirt burrows that are stabilized by vegetation (e.g., Maritime Goldfields, *Lasthenia maritima*) (Ainley and Boekelheide 1990, Lee et al. 2007, Adams 2008). They will also nest in artificial nest boxes (Ainley and Boekelheide 1990). They are obligate zooplanktivores, feeding on copepods and krill (Sydeman et al. 1997). However, Cassin's auklets have only a low-moderate dependency on feeding habitat, as they forage in a diversity of offshore pelagic areas (i.e., at mid-water column over the continental shelf break or continental shelf) and along coastal headlands (e.g., Point Reyes) where predictable upwelling occurs leading to higher zooplankton densities (Adams 2008).

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): oil spills (5, high), invasive rodents (5, high), fisheries (2, low), energy production (2, high), land use change (2, high), pollution (1, moderate), invasive plants (1, low), researcher disturbance (1, moderate)

Overall species sensitivity to non-climate stressors: Low-Moderate

- Confidence of participants: Moderate

Overall species exposure to non-climate stressors: Low

- Confidence of participants: High

Supporting literature

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

Oil Spills

Cassin's auklets are vulnerable to oil spills as they are very small, spend a majority of their life at sea, and forage through wing-propelled diving (Nisbet 1994, Carter et al. 2000). There are documented cases of oil spills leading to Cassin's auklet mortality (Page et al. 1990). The at-sea flocking behavior of Cassin's auklets increases the likelihood of large population impacts should an oil spill occur within the foraging vicinity of breeding colonies (Nisbet 1994, Carter et al. 2000); such an event could drastically exacerbate the on-going population decline of this species (Adams 2008).

Invasive Rodents

Invasive rodents change ecological relationships (e.g., by eating native vegetation and/or drawing new predators) and can cause direct mortality of Cassin's auklet eggs and chicks (Adams 2008). Cassin's auklets typically have to make a tradeoff between foraging and incubation; foraging is critical to adult survival, but foraging expeditions leave eggs vulnerable to rodent predation (Bailey and Kaiser 1993, Ronconi and Hipfner 2009). Cassin's auklets typically have longer foraging forays than other nesting bird species (e.g., tufted puffins), especially during poor conditions (e.g., strong winds), increasing their vulnerability to rodent predation (Bailey and Kaiser 1993, Ronconi and Hipfner 2009). Cassin's auklets are most sensitive to rats, but have higher exposure to mice, especially to house mice (*Mus musculus*) on the Farallon Islands (U.S. Fish and Wildlife Service 2013). Disturbance or predation from invasive rodents can exacerbate the on-going population decline of this species (Adams 2008).

V. Other sensitivities

Other critical factors likely to influence the sensitivity of the species: climate impacts on zooplankton (krill and copepods), and major basin-scale oceanographic change (e.g. El Niño events)

- Degree to which these factors impact the sensitivity of the species to climate change: High
- Confidence of participants: High

[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 participants.

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 4.5

- Confidence of participants: High

Population status of the species (1=endangered; 5=robust): 3

- Confidence of participants: High

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 3.5

- Confidence of participants: High

Dispersal ability of the species: Moderate-High

- Confidence of participants: Moderate

Maximum annual dispersal distance: >100km

- Confidence of participants: High

Supporting literature

The Cassin's auklet is a resident zooplanktivorous seabird that spends a majority of life at sea, coming ashore only to breed on offshore islands within the study region (Sydeman et al. 1997, Lee et al. 2007). The Cassin's auklet has a transcontinental geographic extent, ranging from Alaska to Baja California (Harfenist 2004). Within the study region, Cassin's auklets feature diminished but generally stable populations with moderate-high (i.e., almost continuous) population connectivity. Studies of the Cassin's auklet population on Southeast Farallon Island indicate that the population may have declined 75% or more between 1971 and 2002, including a 50% decline from the early 1970s to late 1980s (Ainley et al. 1994) and declining an average of 6.1% per year from 1991-2002 (Lee et al. 2007). The population rebounded slightly after 1998 in response to cooler ocean temperatures (Peterson and Schwing 2003, Goericke et al. 2004). Future projections for the Farallon Island colonies indicate further decline (i.e., -11 to -45% absolute decline in population growth rate by the end of the century) due to changing ocean conditions and prey availability (Wolf et al. 2010). While incubating and rearing chicks, they are usually found within 50 km of nest sites (Hunt et al. 1981, Briggs et al. 1987, Allen 1994, Adams et al. 2004a cited in Adams 2008).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate-High

- Confidence of participants: High

Genetic diversity: Moderate

- Confidence of participants: Moderate

Behavioral plasticity: Moderate

- Confidence of participants: High

Phenotypic plasticity: Moderate

- Confidence of participants: High

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of participants: High

Supporting literature

Indications of reproductive plasticity in the Cassin's auklet include a high geographic variability in the timing of breeding, and delayed breeding according to prey availability (Bertram et al. 1999, Harfenist 2004). The species typically has one reproductive event per year, resulting in one chick (Harfenist 2004), but the Farallon Island population will sometimes raise 2 broods if conditions are ideal (Ainley and Boekelheide 1990, Harfenist 2004). Breeding periods are variable and can last from January through August (Ainley and Boekelheide 1990). The species displays high breeding and nest site fidelity, is socially monogamous (Harfenist 2004, Lee et al. 2007), and takes 2-4 years to reach reproductive maturity (Speich and Manuwal 1974). Wallace et al. (2015) demonstrate that there is high genetic connectivity between Cassin's auklets breeding between the Aleutian and Farallon Islands; however, Cassin's auklets breeding in the Channel Islands and along the coast of Mexico show genetic diversity and separation from northern populations. Examples of behavioral plasticity include nocturnal tending of nests, which may be an adaptation to avoid predation from large gulls (Cornell Lab of Ornithology 2014), and feeding on larval fish and squid in addition to zooplankton (Adams 2008).

III. Management potential

Value of species to people: Low-Moderate

- Confidence of participants: Moderate
- Description of value: Most people, aside from pelagic bird watchers, are unaware of this species due to its offshore range and nocturnal behavior on land.

Likelihood of managing or alleviating climate change impacts on species: Low

- Confidence of participants: High
- Description of potential management options: no answer provided

Supporting literature

Potential management options to protect breeding populations of this species include eradicating house mice on Southeast Farallon Island (Adams 2008, USFWS 2013), eradicating invasive plant species and restoring native vegetation on breeding colony islands to facilitate soil stabilization for burrowing (Adams 2008), and reducing recreational and vessel disturbance (Adams 2008).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): altered currents/mixing (4, moderate), increased air and sea surface temperatures (3, moderate), changes in salinity (3, moderate), decreased pH (3, moderate), decreased dissolved oxygen (3, moderate),

[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 participants.

changes in precipitation (2, moderate), increased coastal erosion and run-off (2, moderate), increased flooding (2, moderate), increased storminess (2, moderate)

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

- Confidence of participants: Moderate

Additional participant comments

Increased air temperatures and/or heat events are of particular concern for Cassin's auklets nesting in constructed nest boxes on the Farallon Islands, as high temperatures could cause adult mortality (Sydeman, pers. comm., 2014).

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Cavity Nesters: Ashy Storm Petrel (*Oceanodroma homochroa*), Tufted Puffin (*Fratercula cirrhata*), Pigeon Guillemot (*Cepphus columba*)[1]

Executive Summary

Ashy Storm Petrel	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	2 Low-Moderate	2 Moderate
Adaptive Capacity	1 Low	3 High
Vulnerability	4 Moderate-High	3 High

Tufted Puffin and Pigeon Guillemot	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	2 Low-Moderate	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

Cavity nesting species, including the ashy storm petrel, tufted puffin, and pigeon guillemot, inhabit offshore rocky outcrops and islands within the study region, forage on a diversity of marine species, and are sensitive to both anthropogenic and natural disturbance. Key climate sensitivities identified for these species by workshop participants include sea surface temperature, dynamic ocean conditions (currents/mixing/stratification), and extreme weather conditions. Key non-climate sensitivities include aircraft and vessels, recreation, invasive species, harvest, and pollution and poisons. Tufted puffins and pigeon guillemots have a transcontinental geographic extent and healthy and/or expanding populations within the study region, while ashy storm petrels have a declining endemic population within the study region and are classified as a species of concern. All of these species feature low to moderate genetic diversity, life history strategy diversity, and behavioral and phenotypic plasticity. Tufted puffins have moderate-high societal value, while ashy storm petrels and pigeon guillemots have low to low-moderate societal value. Management potential for mitigating or alleviating climate stressors is considered low, but managing non-climate stressors (i.e., predation, disturbance) has higher potential.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): extreme weather events (5, high), sea surface temperature (3, moderate), dynamic ocean conditions (currents/mixing/stratification) (3, moderate), air temperature (2, moderate), salinity (2, low), dissolved oxygen (DO) levels (2, low), pH (2, low), coastal erosion (2, moderate), sea level rise (1, high), wave action (1, moderate), precipitation (1, moderate)

Climate and climate-driven changes that may benefit the species: no answer provided

Overall species sensitivity to climate and climate-driven factors: Low-Moderate

- Confidence of workshop participants: Moderate

[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.

Additional participant comments

Cavity nesting species are mainly sensitive to factors that affect prey availability or breeding habitat, including sea surface temperatures, currents/mixing/stratification, and extreme weather conditions.

Supporting literature

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

Sea Surface Temperatures

Warmer sea surface temperatures can cause large thermoclines in the water column, increasing stratification, reducing ocean mixing and nutrient delivery to upper ocean photic zones and resulting in decreased primary productivity and forage fish abundance, which can shift seabird breeding timing, reduce seabird breeding success, and/or lead to adult starvation (Mills et al. 2005, Warzybok and Bradley 2011, Young et al. 2012, Warzybok et al. 2012, Audubon Society 2014). For example, rockfish become much less abundant in pigeon guillemot diets during periods of warm ocean temperature, a trend that is often correlated with decreased fledgling success (Sydeman et al. 2001). Further, in 2011 and 2012, pigeon guillemots on Southeast Farallon Island were only able to fledge one chick, likely due to a higher dependence on less favorable prey species (i.e., saury and flatfishes) following a reduction of favored rockfish (Warzybok and Bradley 2011, Warzybok et al. 2012). Different prey species likely exhibit different sensitivities to shifts in water temperature and other ocean conditions, and their relative abundance impacts survival, reproductive timing, and reproductive success of nesting seabirds (Mills et al. 2005) within the study region.

Water temperatures are influenced by both long- and short-term climate trends (Young et al. 2012). For example, El Niño events and warm (positive) phases of the Pacific Decadal Oscillation (PDO) are often associated with warmer water temperatures, while La Niñas and cool (negative) phases of the PDO are associated with cooler water temperatures and higher productivity (Largier et al. 2010, Young et al. 2012). Both ENSO phases affect cavity nesting species (Sydeman et al. 2001, Mills et al. 2005). For example, the 1982-83 El Niño led to large population declines in tufted puffins breeding on the Farallon Islands (Ainley et al. 1990), likely due to warmer water temperatures and reduced ocean productivity (Mills et al. 2005). Pigeon guillemots are also very sensitive to the ENSO cycle, thriving during La Niña years and struggling during El Niño years (Mills et al. 2005). In comparison, ashy storm petrels have shown little population and/or breeding success fluctuation in response to ENSO events (Carter et al. 2008).

Dynamic ocean conditions (currents/mixing/stratification)

Ashy storm petrels, tufted puffins, and pigeon guillemots forage on a variety of prey species delivered by the California Coastal Current and different upwelling zones, and reproduction timing is correlated with high prey availability (Carter et al. 2008, McChesney and Carter 2008, Young et al. 2012, Sanctuary Integrated Monitoring Network (SIMoN) 2014). For example, the ashy storm petrel relies on fronts and eddies to provide concentrated prey foraging locations (Yen et al. 2006). Changes in currents, wind, upwelling rates and timing, stratification, and ocean mixing can alter the delivery timing and availability of prey species (Young et al. 2012), which could affect seabird reproductive success and survival. El Niño events can decrease upwelling and mixing, reducing nutrient delivery to photic zones and decreasing primary productivity, which can lead to food web collapses and negative impacts on seabird fitness and reproduction (Young et al. 2012).

Extreme Weather Conditions
Extreme weather conditions (i.e., downpours, storms) can degrade and/or eliminate breeding habitat and/or affect survival of adults and chicks (Mills et al. 2005).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease, storms, flooding, drought, and interspecific disturbance related to climate-driven behavior changes of other species

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

Climate-driven changes in the distributions or behavioral activities of gull and burrowing owl species within the breeding ranges of ashy storm petrels, tufted puffins, and pigeon guillemots could affect foraging and/or breeding success.

Supporting literature

No information was found in the peer-reviewed literature regarding the impact of storms, flooding and drought on these species.

Disease
As colonial nesters, infectious disease can spread quickly and extensively, and cavity nesting seabirds are particularly susceptible to fungi and fleas (Muzaffar and Jones 2004).

Interspecific disturbance
Cavity nesting seabirds are also sensitive to interspecific disturbance and predation. For example, Western Gulls (*Larus occidentalis*) prey on ashy storm petrels (Carter et al. 2008), and have also been documented to prey on tufted puffin chicks or kleptoparasitize foraging puffin adults bringing food back to nests (Speich and Wahl 1989, Jaques and Strong 2001 cited in McChesney and Carter 2008). Western gull populations have expanded on the Farallon Islands, and current gull habitat overlaps puffin and petrel habitat, increasing the potential for negative interspecific interactions (Carter et al. 2008, McChesney and Carter 2008). Gulls (various spp.) also pirate prey from pigeon guillemots (SIMoN 2014). In addition, burrowing owls (*Athene cunicularia*) have been documented to prey upon ashy storm petrels when house mice populations decline in fall and winter (Carter et al. 2008). Recent population modeling from Farallon Islands data show that Burrowing Owl predation on storm petrels has helped lead to recent declines in that population (Nur et al. *Submitted*).

III. Dependencies

Species dependence on one or more sensitive habitat types: Moderate-High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon[4]: ASSP: pelagic and surface waters; TUPU: pelagic and offshore foraging; PIGU: benthic and nearshore

Species dependence on specific prey or forage species: Moderate

- Confidence of workshop participants: High

Other critical dependencies: timing of breeding and forage availability

- Degree of dependence: High
- Confidence of workshop participants: High

Specialization of species (1=generalist; 5=specialist): 3

- Confidence of workshop participants: High

Supporting literature

Ashy storm petrels nest on offshore islands between the southern Channel Islands and central Mendocino County, including a major breeding colony on the South Farallon Islands with at least 50% of the world's population (Carter et al. 2008). They breed in crevices found in rock walls, sea caves, cliffs, talus slopes or driftwood piles, which can be structurally unstable (James-Veitch 1970, Carter et al. 1992, Ainley 1995, McIver 2002 cited in Carter 2008). They feed in surface pelagic waters over and seaward of the continental shelf (Carter et al. 2008), and prey species include euphausiids, other crustaceans, larval fish, and squid (Carter et al. 2008).

Tufted puffins breed on offshore rocks and islands, and occasionally will breed on mainland sites that have minimal disturbance (McChesney and Carter 2008). They nest primarily in burrows, though they will use rock crevices if suitable burrowing soil is unavailable (McChesney and Carter 2008). Tufted puffins forage in offshore pelagic areas, visiting the continental shelf and slope during breeding season and a variety of more distant pelagic settings during the non-breeding season (McChesney and Carter 2008). Juveniles primarily eat fish, while adults show more plasticity in prey choice (Ainley et al. 1990, Gaston and Jones 1998 cited in McChesney and Carter 2008).

Pigeon guillemots breed on rocky outcrops or islands and occasionally along coastal cliffs and rocky shores on the mainland, nesting in crevices, holes, tree roots, abandoned puffin burrows, or in man-made structures that provide suitable crevices (i.e., beached ship hulls, pipes, old tires) (SIMoN 2014). Pigeon guillemots are pelagic foragers, diving for prey nearshore in both the water column and benthic habitats (SIMoN 2014). Chicks consume mainly fish while adults forage on a variety of vertebrates and invertebrates (SIMoN 2014).

[4] ASSP = ashy storm petrel; TUPU = tufted puffin; PIGU = pigeon guillemot

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[5], confidence[6]): land use change (2, high), pollution and poisons (5, high), harvest (3, high), energy production (2, high), recreation (4, high), invasive species (5, high), aircraft and vessels (3, high)

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

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Low

- Confidence of workshop participants: High

Supporting literature

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

Aircraft and Vessels

Aircraft and vessel disturbance can cause nest abandonment. For example, squid fishing boats can illuminate nesting colonies of ashy storm petrels at night, causing them to abandon breeding sites (Carson et al. 2008). In addition, too frequent disturbance or visitation for research purposes can also cause nest or site abandonment of pigeon guillemots (Audubon Society 2014).

Recreation

Recreation (i.e., walking, hiking) in sensitive breeding habitat can disturb breeding activity and/or kill cavity nesting seabirds. For example, the ashy storm petrel nests in unstable locations (i.e., driftwood piles) that can shift and crush adults, chicks, or eggs if physically disturbed (Carter et al. 2008). In addition, pigeon guillemots will abandon their nests if they experience too frequent disturbance from human activities (Audubon Society 2014).

Invasive Species

Rodents, particularly house mice (*Mus musculus*), were introduced to the Farallon Islands in the 19th century (U.S. Fish and Wildlife Service (USFWS) 2013). House mice can have direct impacts on seabirds; for example, they have been rarely documented to eat the eggs and small chicks of ashy storm petrels (Mills 2000). Rodents also change ecological relationships on islands (e.g., by eating native plants and invertebrates and/or by drawing in new predators), which can affect resident seabird populations. For example, Burrowing Owls have been documented to prey on ashy storm petrels on the South Farallon Islands when house mice populations decline in fall and winter (Carter et al. 2008), and have substantial population impacts on those storm petrels (Nur et al. *Submitted*). Other invasive species can also affect seabirds by altering competition dynamics. For example, introduced rabbits on Southeast Farallon Island may have increased competition for nest sites for the tufted puffin during the early to mid-20th century, leading to local population declines (McChesney and Carter 2008).

Harvest

Fishery harvests can lead to direct mortality and/or prey reduction for cavity nesting seabirds. For example, gill net fisheries[7] can kill ashy storm petrels (Carter et al. 2008) and pigeon

[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.
[7] Gill net fisheries are banned along much of the California coastline.

guillemots (SIMoN 2014). Harvest of fish prey species could reduce food availability for foraging seabirds such as the tufted puffin, ashy storm petrel, and pigeon guillemot (Carter et al. 2008, McChesney and Carter 2008, Farallones Marine Sanctuary Association 2014), potentially exacerbating climate-driven trends in prey availability and reproductive success. For example, there are established fisheries for some well-known tufted puffin prey species, including the Pacific sardine, *Sardinops sagax*, (McChesney and Carter 2008) which may already be declining locally due to changing ocean conditions (Warzybok et al. 2012).

Pollution and Poisons

Seabirds are vulnerable to oil spills, oil operations, and water pollution. Oil spills have led to the direct mortality of tufted puffins (Page et al. 1990, McChesney and Carter 2008) and pigeon guillemots (Cornell Lab of Ornithology 2014, SIMoN 2014). Ashy storm petrels have so far largely escaped impact from oil spills due to their foraging locations further out at sea[8], but a large spill could threaten the large at-sea aggregations around the Farallon Islands and Monterey Bay (Spear and Ainley 2007). In addition, deceased ashy storm petrels have been found on at-sea oilrigs and at mainland sites with bright flights (i.e., San Francisco Bay) (Carter et al. 2008). In addition, seabirds are vulnerable to bioaccumulation of marine contaminants. For example, eggshell thinning due to contaminants has been documented in ashy storm petrels, affecting reproductive success (Carter et al. 2008). Ashy storm petrels are also sensitive to plastic pollution, often ingesting plastic particles when they mistake them for prey (Ainley et al. 1990).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary)[9]: ASSP: 2; TUPU: 5; PIGU: 5

- Confidence of workshop participants: High

Population status of the species (1=endangered; 5=robust)[5]: ASSP: 2; TUPU: 5; PIGU: 5

- Confidence of workshop participants: High

Population connectivity of the species (1=isolated/fragmented; 5=continuous): ASSP: 2; TUPU: 5; PIGU: 5

- Confidence of workshop participants: no answer provided

Dispersal ability of the species: no answer provided

Maximum annual dispersal distance: no answer provided

Ashy storm petrels are endemic to California, and are found only from central Mendocino County to the southern end of the Channel Islands (Carter et al. 2008). They are a threatened species, classified as a “Bird Species of Special Concern (breeding), priority 2” in California, as over 95% of their breeding activity occurs on offshore islands and rocks along the California

[8] Alternatively, ashy storm petrels could have been impacted by regional oil spills, but due to their distant at-sea foraging locations their carcasses may never have washed ashore (Center for Biological Diversity 2007).

[9] ASSP = ashy storm petrel; TUPU = tufted puffin; PIGU = pigeon guillemot

coastline (Carter et al. 2008). A majority of ashy storm petrels in the study region are resident seabirds, spending non-breeding season in offshore waters near breeding habitats, and congregating in Monterey Bay during the fall (Roberson 2002). The South Farallon Islands host a large portion of the world's breeding ashy storm petrels, as do the Channel Islands (Carter et al. 2008). However, the South Farallon Islands population declined 40% from 1972-1992, has been declining since 2007, and is likely to face future declines due to predation from Burrowing Owls (Mills 2000, Warzybok et al. 2012, Nur et al. *Submitted*).

Tufted puffins breed along the Pacific Coast of North America and Asia (McChesney and Carter 2008); in California, they can be found from the Oregon border to the southern Farallon Islands, as well as further south at Prince Island (McChesney and Carter 2008). Tufted puffins are considered a "Bird Species of Special Concern (breeding), priority 1" in California, as they have been extirpated from some parts their historic California range (i.e., the Channel Islands) (McChesney and Carter 2008). However, within the study region, they have healthy and/or expanding populations (Abraham et al. 2000) with high (i.e., continuous) population connectivity. For example, the breeding colony on Southeast Farallon Island has been rebounding since population lows in the early to mid-20th century and in 2004 (Ainley et al. 1990, Warzybok and Bradley 2011), and recent population estimates (2009-2011) indicate that the colony now has more active nests than at any other recorded point in history (Warzybok and Bradley 2011). Tufted puffins can be found year-round in the study area (McChesney and Carter 2008). During breeding season, tufted puffins are typically found within 40 miles of the breeding colony, while during the non-breeding season, they may travel several hundred kilometers away to forage (Briggs et al. 1987, Briggs et al. 1992 cited in McChesney and Carter 2008).

Pigeon guillemots breed throughout the North Pacific from Alaska to California and from the Bering Sea to the Kuril and Aleutian Islands (SIMoN 2014). The Farallon Islands hosts one of the world's largest breeding colonies of pigeon guillemots (SIMoN 2014), and the colony on Southeast Farallon Island had the highest population numbers ever recorded in 2012 (Warzybok et al. 2012). Pigeon guillemots can be migratory during the non-breeding season, migrating as far north as British Columbia (SIMoN 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies[10]: ASSP: 1; TUPU: 2; PIGU: 3

- Confidence of workshop participants: High

Genetic diversity[10]: ASSP: 3; TUPU: 3; PIGU: 3

- Confidence of workshop participants: Low

Behavioral plasticity[10]: ASSP: 2; TUPU: 2; PIGU: 2

- Confidence of workshop participants: Moderate

Phenotypic plasticity[10]: ASSP: 1; TUPU: 2; PIGU: 2

- Confidence of workshop participants: Moderate

Overall degree of diversity/plasticity of the species: Low-Moderate

- Confidence of workshop participants: High

[10] ASSP = ashy storm petrel; TUPU = tufted puffin; PIGU = pigeon guillemot

Supporting literature

Examples of behavioral plasticity in ashy storm petrels includes their tendency to scavenge food from fishing vessels rather than forage in surface waters (Ainley et al. 1990), and their nocturnal behavior (Mills 2000), which is believed to be an adaptation to avoid predation from diurnal predators (Ainley et al. 1990). Nur et al. (1999) suggest that there is no genetic differentiation between the subpopulations living on the Farallon and Channel Islands, as roughly 1.6% of regional populations disperse between these islands. Ashy storm petrels have one reproductive event per year, laying only one egg anywhere from mid-March to late October and incubating for long periods; chicks fledge anytime between late July and January (James-Veitch 1970, Ainley et al. 1974, Ainley 1995, McIver 2002 cited in Carter et al. 2008). Low reproductive potential leads to slow population growth and makes it difficult for this species to recover from impacts (i.e., predation, breeding disturbance, food web collapses) (Carter et al. 2008).

U.S. populations of tufted puffins are non-migratory and physically separated from other northern populations, and display altered breeding timing depending on location (National Resources Defense Council 2014). They may adjust breeding phenology to compensate for within-season shifts in sea surface temperature and prey availability (Gjerdrum et al. 2003). Tufted puffins have one reproductive event per year (but can relay after breeding failure), breeding from late April through September and lay only one egg (Ainley et al. 1990). Incubation lasts for 45 days (Ainley et al. 1990).

Breeding timing in pigeon guillemots is highly correlated with food availability, and even within a single population, breeding times will be highly variable depending on favored prey species of each adult pair (i.e., schooling fish or non-schooling fish) (Ainley et al. 1990). Pigeon guillemots with different foraging ecologies have also been documented to differentially adjust their time budgets (i.e., foraging versus resting time) according to clutch size, prey choice, and prey availability (Litzow and Piatt 2003). For example, pairs foraging on schooling fishes were able to maintain food delivery rates to chicks despite decreasing food abundance by increasing forage time, while individuals foraging on non-schooling fishes delivered fewer meals to chicks rather than increasing forage time (Litzow and Piatt 2003). Pigeon guillemots have one reproductive event per year, breeding from May to late June and typically laying 2 eggs (SIMoN 2014). Incubation last from 30-32 days, and fledging occurs 29-39 days after hatching (SIMoN 2014).

III. Management potential

Value of species to people[11]: ASSP: 1; TUPU: 4; PIGU:2

- Confidence of workshop participants: High
- Description of value: none answer provided

Likelihood of managing or alleviating climate change impacts on species: Low

- Confidence of workshop participants: High
- Description of potential management options: no answer provided

[11] ASSP = ashy storm petrel; TUPU = tufted puffin; PIGU = pigeon guillemot

Supporting literature

For ashy storm petrels, controlling disturbance from western gulls and burrowing owls, maintaining and creating important breeding habitat features (i.e., crevice-containing structures), and establishing protective at-sea perimeters and human visitation closures to reduce visitation and disturbance to breeding colonies from fishing vessels, kayakers, and tourists (Carter et al. 2008). For tufted puffins and pigeon guillemots, prioritize and enforce the protection of offshore breeding islands and rocks to minimize human disturbance and introduction of other competitors or predators (McChesney and Carter 2008, SIMoN 2014).

IV. Other adaptive capacity factors: none identified

Exposure[12]

I. Future climate exposure

Future climate and climate-driven changes identified (score[13], confidence[14]): altered currents and mixing (4, moderate), changes in salinity (3, moderate), increased storminess (3, moderate), changes in sea surface temperature (3, moderate), decreased dissolved oxygen (DO) levels (3, moderate), decreased pH (3, moderate), changes in precipitation (2, moderate), increased flooding (2, moderate), increased coastal erosion and runoff (2, moderate), changes in air temperature (2, moderate), sea level rise (1, moderate)

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

- Confidence of workshop participants: Moderate

Additional participant comments

Climate change will likely have indirect impacts on these cavity nesting species by affecting prey availability and breeding habitat.

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[12] Supporting literature for future exposure to climate factors is provided in the introduction.
[13] 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.
[14] Confidence level indicated by workshop participants.

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Boreal Copepods[1]

Executive Summary

Copepod	Score	Confidence
Sensitivity	2 Low-Moderate	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	1 Low
Vulnerability	3 Moderate	2 Moderate

Boreal copepods are a group of small, cold-water planktonic crustaceans that serve as an important food source for many marine organisms in the study region and are the most abundant and diverse zooplankton taxon. Key climate sensitivities identified by workshop participants include sea surface temperature, salinity, and dynamic ocean conditions (currents/mixing/stratification) and key non-climate sensitivities include pollution and poisons. Boreal copepods have a moderate geographic distribution, a continuous, stable population at abundant levels, and high dispersal capabilities. In contrast to transitional and equatorial copepod species, boreal copepods rely on the presence of cold water and are much higher in fat content, providing optimal food for many of the region's marine organisms. Copepods exhibit moderate phenotypic and behavioral plasticity, including the ability to convert the oil in their bodies to more dense fats in order to sink to greater depths to avoid predation and suboptimal oceanographic conditions. Copepods have low societal value, though they are recognized as critical components of the food web and important prey for higher trophic organisms. Management potential of these species is also considered low because abundance is driven by oceanographic processes, including upwelling and currents that vary the salinity and temperature of the region's seawater.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): sea surface temperature (4, high), salinity (4, high), and dynamic ocean conditions (currents/mixing/stratification) (4, high)

Climate and climate-driven changes that may benefit the species: no answer provided

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

- Confidence of workshop participants: High

Additional participant comments

The future direction of copepod abundance in the study region is tightly linked to the direction and magnitude of change in coastal upwelling, which is not currently well understood. As the primary delivery method of deep, cold, nutrient-rich water, upwelling is the primary driver of boreal copepod abundance in the region.

[1] Refer to the introductory content of the results section for an explanation of the format, layout and content of this summary report. Boreal copepods are cold water species found along the Oregon and North-central California coast.

[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

Sea Surface Temperatures

Warmer sea surface temperatures can cause large thermoclines in the water column, increasing stratification, reducing ocean mixing and nutrient delivery to upper ocean photic zones, resulting in decreased primary productivity that impacts trophic functioning (Young et al. 2012). Warmer temperatures have been correlated with lower boreal copepod abundance and higher abundance of transitional and equatorial species, which has been correlated to lower coho salmon survival (Peterson and Schwing 2003, Peterson 2009, Bi et al. 2011). This may be attributed to the higher lipid content of boreal copepod species compared to their southern counterparts, which make them a better food source for juvenile salmon that need to accumulate enough body fat to survive their first winter at sea (Beamish et al. 2004) and to make it upstream to spawn (Bi et al. 2011). Peak biomass of one dominant boreal copepod species has been documented to occur earlier in the year and for a shorter duration due to increasing sea surface temperature, which will have severe implications for trophic functioning and survival of predators (Batten and Mackas 2009).

Inter-annual variation in boreal copepod abundance can be explained by variation in water temperatures that are influenced by both long- and short-term climate trends (Bi et al. 2011, Young et al. 2012). El Niño events and warm (positive) phases of the Pacific Decadal Oscillation (PDO) are often associated with warmer water temperatures, while La Niña events and cool (negative) phases of the PDO are associated with cooler water temperatures and higher productivity (Largier et al. 2010; Young et al. 2012). Abundance of boreal copepods also exhibits intra-annual variability between winter and summer seasons due to the alternation of coastal currents that bring warmer water to the region in winter and cooler water in summer (Peterson and Miller 1977). Colder sea surface temperatures during the winter correlated with higher boreal copepod abundance in our region (Fontana et al. 2014).

Salinity

Boreal copepods are sensitive to decreased salinity levels, as observed in the Baltic Sea when the biomass of copepods declined in response to enhanced freshwater run-off and subsequent decrease in seawater salinity (Vuorinen et al. 1998). This decline in neritic copepods resulted in lower carbon content of the food eaten by herring, a lower stomach fullness index, and a lower mesenteric fat amount in herring, despite an increase in total zooplankton biomass, indicating that bottom-up processes such as changes in salinity can have far-reaching food web impacts (Flinkman et al. 1998). Increased boreal copepod abundance was correlated with higher salinity waters in our region (Fontana et al. 2014).

Dynamic ocean conditions (currents/mixing/stratification

Upwelling may counteract rising sea surface temperatures and promote primary productivity (Largier et al. 2010), but intense upwelling could shift zooplankton to deeper waters (Pringle 2007), potentially decreasing food availability for marine organisms (Largier et al. 2010). El Niño events decrease upwelling and mixing, and positive phases of the PDO lead to downwelling, reducing nutrient delivery to photic zones, decreasing primary productivity, and decreasing the abundance of lipid-rich boreal copepod species (Bi et al. 2011, Young et al. 2012). Boreal copepod abundance in our region was higher in years where stronger alongshore wind stress and weaker westward cross-shore flow were observed during the previous winter (Fontana et al. 2014).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: Wind

Overall species sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Boreal copepods exhibit moderate-high sensitivity to wind-driven upwelling which brings cold, salty and nutrient-rich water to the surface, enhancing primary productivity and resulting in increased abundance of boreal copepods (see “climate factors” section above for more information).

III. Dependencies

Species dependence on one or more sensitive habitat types: Low

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: none

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: Low

Other critical dependencies: ability to diapause

- Degree of dependence: Low-Moderate
- Confidence of workshop participants: Moderate

Specialization of species (1=generalist; 5=specialist): 2

- Confidence of workshop participants: High

Additional participant comments

Copepods have very low dependency both on specific habitats and food sources, feeding on a variety of phytoplankton, organic detritus and other small crustaceans, and are considered to more closely resemble generalists. The species assemblage does, however, rely on its ability to go into diapause, sinking to deeper waters when oceanographic conditions are not favorable for reproduction. If conditions do not improve, reproductive opportunities may be missed altogether, so optimum conditions of cold, nutrient-rich water is critical to maintain abundance.

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution and poisons (1, high)

Overall species sensitivity to non-climate stressors: Low

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Low

- Confidence of workshop participants: High

[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

Pollution and poisons

Copepods are particularly sensitive to dispersants used in response to oil spills, more so than other zooplankton, displaying increased mortality when exposed to dispersants alone, and interrupted swimming behavior when exposed to dispersants and crude oil (Cohen et al. 2014). In another study, dispersant-treated oil was found to be 3 times more toxic than crude oil alone to mesozooplankton, copepods included, and the presence of protozoans in oil-microbial food web interactions was found to reduce sublethal effects of oil on copepods (Almeda et al. 2013). Over 6,000 commercial vessels transit in and out of San Francisco Bay every year, with 5% of these as large cargo vessels that can carry up to one million gallons of bunker fuel (GFNMS 2008). All transiting vessels, including military, research and fishing vessels, carry crude oil or fuel, posing a potential risk to copepod populations in the region (Largier et al. 2010).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 3

- Confidence of workshop participants: Low

Population status of the species (1=endangered; 5=robust): 4

- Confidence of workshop participants: Low

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 5

- Confidence of workshop participants: Low

Dispersal ability of the species: High

- Confidence of workshop participants: Low

Maximum annual dispersal distance: >100km

- Confidence of workshop participants: Low

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Low

Genetic diversity: Low-Moderate

- Confidence of workshop participants: Low

Behavioral plasticity: Moderate

- Confidence of workshop participants: Moderate

Phenotypic plasticity: Moderate

- Confidence of workshop participants: Moderate

Overall degree of diversity/plasticity of the species: Low-Moderate

- Confidence of workshop participants: Low

Additional participant comments

An example of behavioral plasticity is diapause, a physiological state of dormancy in response to unfavorable environmental conditions. Some species (including *Calanus* and *Neocalanus* spp.) can go into diapause, sinking to greater depths when oceanographic conditions are unfavorable and returning to surface waters when conditions improve.

Supporting literature

An additional example of behavioral plasticity is the ability for copepods to feed near the surface at night, and then sink into deeper waters during the day by changing oils into more dense fats to avoid visual predators (Pond and Tarling 2011).

Some species of copepods may reproduce only once in their lifetime, while others may be able to reproduce multiple times, with females either releasing eggs directly into the water or retaining them in a sac until they hatch into nauplius larvae (Barnes 1982). Boreal copepods in this region reach sexual maturity within 12 months (Conover 1988; Vulnerability Assessment Workshop, pers. comm., 2014) with the entire life cycle taking anywhere from a week up to one year, depending on the species (Barnes 1982).

III. Management potential

<u>Value of species to people</u>: Low

- Confidence of workshop participants: Low
- Description of value: Copepods are valued as a food source to culturally, recreationally, and commercially important species such as salmon and rockfish.

<u>Likelihood of managing or alleviating climate change impacts on species</u>: Low

- Confidence of workshop participants: Moderate
- Description of potential management options: None available, as copepods are so completely influenced by large-scale oceanographic processes, they would be expected to "retreat" to higher latitudes if conditions become consistently unfavorable in this region.

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

<u>Future climate and climate-driven changes identified (score[7], confidence[8])</u>: altered currents/mixing (5, high), changes in sea surface temperature (5, high), changes in salinity (5, high)

<u>Degree of exposure to future climate and climate-driven changes</u>: High

- Confidence of workshop participants: no answer provided

[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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Coralline Algae (various species)[1]

Executive Summary

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

Coralline algae are a family of calcifying red algae composed of many species that occur in two morphologies, articulate and crustose, and can be found in subtidal and intertidal habitats throughout the study region, inhabiting depths of up to 500 feet. Key climate sensitivities identified by workshop participants include air and sea surface temperature and pH, and key non-climate sensitivities include nutrient pollution. The coralline algal assemblage exhibits a transcontinental geographic extent, a healthy and/or expanding population that is somewhat fragmented, and a low dispersal capability. Coralline algae exhibit moderate life history strategy diversity (with microscopic and macroscopic stages), low behavioral plasticity, and low-moderate phenotypic plasticity, though the literature indicates that this species assemblage has high diversity in morphology and reproductive strategy, enabling the group to respond to changing environmental conditions. The societal value for coralline algae was rated as low, though managers and scientists realize the ecological value of the assemblage, with a low-moderate likelihood of managing or alleviating climate impacts.

Sensitivity

I. Sensitivity to climate and climate driven changes

<u>Climate and climate-driven changes identified (score[2], confidence[3])</u>: air temperature (4, high), sea surface temperature (4, high), ocean pH (4, moderate), coastal erosion (2, high), salinity (2, low), precipitation (1, high)

<u>Climate and climate-driven changes that may benefit the species</u>: none identified

<u>Overall species sensitivity to climate and climate-driven factors</u>: Moderate-High

- Confidence of workshop participants: Moderate

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered. Corallines have been suggested to both benefit from future climate changes due to decreased competition from species more vulnerable, and to suffer from climate changes due to their own vulnerability to ocean acidification (Miklasz 2012). Though workshop participants characterized coralline algae as having only low-moderate sensitivity to climate and non-climate impacts, literature review conducted suggests this sensitivity may be higher.

[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.

Air Temperature

Though intertidal coralline algae are relatively resistant to desiccation and heat stress through moisture retention (Padilla 1984, Miklasz 2012), photosynthesis has been documented to abruptly stop in two species of articulate coralline algae during low tide (Guenther and Martone 2014). Bleaching (physiological stress that leads to complete loss of pigment) of entire intertidal areas has been observed (Harley 2008) and may become more frequent as the number of extreme heat days increases. Air temperature does not seem to be a leading factor in coralline bleaching, but interacts with both light and desiccation, causing a 50% reduction in pigmentation within 24 minutes of exposure (Martone et al. 2010). Increased air temperature, in combination with daytime low tides and enhanced winds, may have serious implications for intertidal coralline.

Sea Surface Temperature

Increased sea surface temperature has been shown to exacerbate the effects of elevated CO_2 in seawater, which effectively lowers net calcification rates for coralline algae (Koch et al. 2013). Martin and Gattuso (2009) documented death of a Mediterranean coralline alga under elevated water temperature (+3˚C), with a two- to three-fold increase in algal necrosis when combined with elevated CO_2. The authors suggest that net dissolution will likely exceed net calcification by the end of the century due to increased water temperature and decreased pH.

Ocean pH

As calcifying red algae, corallines are highly sensitive to changes in pH (Koch et al. 2013). Elevated CO_2 lowers net calcification and this effect is amplified by increased water temperature (Koch et al. 2013). Decreased pH also interrupts diffusion and transportation of hydrogen ions and dissolved inorganic carbon, which are vital in promoting calcification over dissolution (Koch et al. 2013). Koch et al. (2013) suggest that fleshy algae may become more dominant and out-compete calcifying species in a more acidic ocean. Supporting this idea, Kuffner et al. (2008) experimentally showed decreased recruitment and growth of crustose coralline algae in higher CO_2 conditions, along with increased growth of fleshy red algae.

II. Sensitivity to changes in disturbance regimes

Disturbance regimes identified: none identified by workshop participants, though storm activity has been identified by reviewers as a possible disturbance regime of importance.

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: rocky substrate of intertidal and subtidal kelp forest habitats

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: presence of grazers that feed on competing fleshy algae

- Degree of dependence: Moderate-High
- Confidence of workshop participants: High

Specialization of species (1=generalist; 5=specialist): 1

- Confidence of workshop participants: High

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution (2, moderate)

Overall species sensitivity to non-climate stressors: Low
- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Low-Moderate
- Confidence of workshop participants: High

Supporting literature

Nutrient Pollution

Nutrient pollution can cause decreased growth and abundance of coralline algae due to increased microalgal growth, increased sedimentation, decreased light availability and increased growth of fleshy algal competitors (Björk et al. 2009). Decreased calcification was documented in coralline algae when exposed to high phosphate levels (Björk et al. 2009), which may exacerbate the effect of decreased calcification due to decreasing pH.

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 5
- Confidence of workshop participants: High

Population status of the species (1=endangered; 5=robust): 5
- Confidence of workshop participants: Moderate

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 2
- Confidence of workshop participants: Moderate

Dispersal ability of the species: Low
- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: 1-5km
- Confidence of workshop participants: Moderate

Supporting literature

This species assemblage inhabits the world's oceans from the tropics to polar regions (Johansen 1981). Coralline algae have a low dispersal capability, as spores are able to attach to the bottom within hours of release, and often recruit near the parent alga (Miklasz 2012). This characteristic limits the dispersal distance, but enhances the potential for local adaptation (Hoffman et al. 2014).

[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.