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Climate Change Vulnerability Assessment for the North-central California Coast and Ocean

U.S. Department of Commerce
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Climate Change Vulnerability Assessment for the North-central California Coast and Ocean

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(left) Sea Palm; (top): North-central California coastline; (bottom, center): black oystercatcher; (bottom, right): California hydrocoral

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Abstract

This vulnerability assessment is a science-based effort to identify how and why focal resources (habitats, species, and ecosystem services) across the North-central California coast and ocean region are likely to be affected by future climate conditions. The goal of this assessment is to provide expert-driven, scientifically sound assessments to enable marine resource managers to respond to, plan, and manage for the impacts of climate change to habitats, species, and ecosystem services within the region. This information can help prioritize management actions, and can help managers understand why a given resource may or may not be vulnerable to a changing climate, enabling a more appropriate and effective management response. Climate change vulnerability of 44 focal resources, including eight habitats, populations of 31 species, and five ecosystem services was assessed by considering exposure and sensitivity to climate changes and non-climate stressors and adaptive capacity. The 44 focal resources were identified and assessed by representatives from federal and state agencies, non-governmental organizations and academic institutions. Coastal habitats in the study region, including beaches and dunes, estuaries, and the rocky intertidal, along with associated species and ecosystem services, were identified through this assessment as being most vulnerable, and will likely be prioritized for future management action.

Key Words

Climate change, climate-smart, adaptation, vulnerability assessment, Gulf of the Farallones National Marine Sanctuary, GFNMS, climate impact, focal resources, habitats, species, ecosystem services

Table of Contents

List of Figures and Tables

Figure/Table Number and Title **Page**

Executive Summary

Marine resource managers realize the immediate threats of climate change to the resilience, health, and ecosystem services of the coastal and ocean places they protect, yet the resources to develop appropriate management options to prepare for and respond to a changing environment are limited (Gregg et al. 2011). Adaptation planning techniques and processes are well developed, but there is a lack of application of these methods for marine systems (Gregg et al. 2011). This report is the first step in a process to enable marine resource managers to respond to, plan, and manage for the impacts of climate change to habitats, species, and ecosystem services within the North-central California coast and ocean region by utilizing expert-driven, scientifically sound assessments to provide prioritized, stakeholder-led climate-smart adaptation strategies.


Figure 1. Sea Palm, one of 44 focal resources assessed.

This vulnerability assessment is a science-based effort to identify how and why focal resources (habitats, species, and ecosystem services) across the North-central California coast and ocean region are likely to be affected by future climate conditions. This information can facilitate efficient allocation of limited resources by identifying priority areas for management action and responses, ultimately helping to sustain optimal conditions for the region’s resources. This information can also help managers understand why a given resource may or may not be vulnerable to a changing climate, enabling a more appropriate and effective management response.

Climate change vulnerability of 44 focal resources, including eight habitats, populations of 31 species, and five ecosystem services was assessed by considering exposure and sensitivity to climate changes and non-climate stressors and adaptive capacity. The 44 focal resources were identified and assessed by representatives from federal and state agencies, non-governmental organizations and academic institutions. Climate information used in this assessment was provided by the Climate Change Impacts Report, a joint working group report of the Cordell Bank and Gulf of the Farallones National Marine Sanctuary Advisory Councils. This assessment focuses on the North-central California coast and ocean region, from Point Año Nuevo, San Mateo County, in the south to Alder Creek, Mendocino County, in the north, including three national marine sanctuaries, two national parks, and one US Fish and Wildlife Refuge, and one National Monument (Figure 3). Most resources considered in this assessment were identified by workshop participants as moderately vulnerable to climate change, with a range from low-moderate


Figure 2. Rodeo Lagoon, estuarine habitat in the study region.

vulnerability to moderate-high vulnerability. Coastal habitats in the study region, including beaches and dunes, estuaries, and the rocky intertidal, along with associated species and ecosystem services, were identified through this assessment as being most vulnerable, and will likely be prioritized for future management action.

Vulnerability Assessment Report Section-by-Section

The introduction provides a brief overview of the study region and expected climate changes in the region, as well as an overview of the project, how the information from vulnerability assessments can be used, and a summary of assessment results. The methodology section describes in greater detail the methods used to select resources, as well as the development of the vulnerability assessment methodology and its application. The results section provides descriptive figures and tables, discusses assessment results, and is followed by the individual assessments for each focal resource, incorporating the scores received during the vulnerability assessment workshop with information from the scientific literature. Finally, conclusions and next steps are addressed. Appendices A and B provide information regarding the two decision-support workshops, including agendas and participants, and Appendix C lists contributors and reviewers of the individual assessment reports. Appendix D provides an overview of the vulnerability assessment component scores for each resource.

Introduction

Study Region

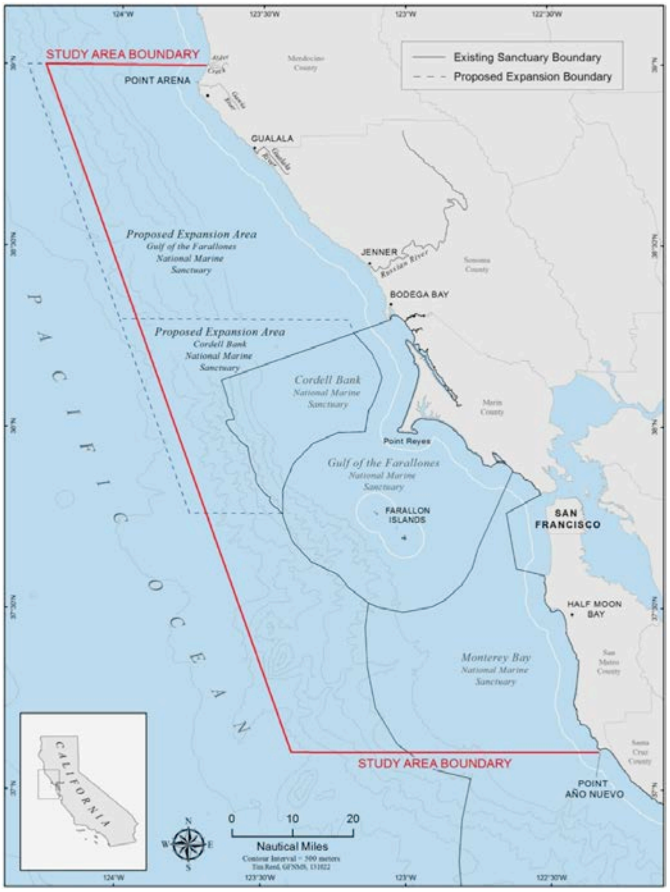

Figure 3. Map of study region (thick red lines), with related sanctuary boundaries (black solid lines) and proposed sanctuary expansion areas (black dashed lines).

The North-central California coast and ocean is a globally significant, highly diverse, productive marine and coastal ecosystem that is home to abundant wildlife, valuable fisheries, three national marine sanctuaries and two national parks. It is a treasured resource of the San Francisco Bay Area's seven million residents that rely on this unique marine ecosystem for their livelihoods and recreation. It provides breeding and feeding grounds for at least 25 endangered or threatened species, including blue, fin, sperm, and humpback whales and one of the southernmost U.S. populations of threatened Steller sea lions. This area is especially important to approximately 350,000 wintering shorebirds, seabirds, and waterbirds, and many fish species including sturgeon, halibut, endangered coho salmon, and the commercially important Pacific herring, that rely on creeks and extensive eelgrass beds to spawn. Significant coastal areas, including Tomales Bay, Bolinas Lagoon, Drakes Estero and Esteros Americano and San Antonio, support a diversity of habitats, including eelgrass beds, intertidal sand and mud flats, and salt and freshwater marshes that provide numerous ecosystem services such as carbon sequestration, flood control, and improved water quality (GFNMS 2008).

For this assessment, the study region (Figure 3), bound by Point Año Nuevo, San Mateo County, in the south and Alder Creek, Mendocino County, in the north, includes coastal land and waters managed by three national marine sanctuaries (Gulf of the Farallones, Cordell Bank, Monterey Bay), two national parks (Point Reyes National Seashore and Golden Gate National Recreation Area), the US Fish and Wildlife Service Farallon National Wildlife Refuge, and the Bureau of Land Management California Coastal National Monument. There are eight major habitat types in the region that were evaluated for this assessment:
<u>Beaches and dunes</u>: Located along the coastal border of the study region, including the Farallon Islands, beaches are composed of three distinct zones defined by the level of tidal inundation: the coastal strand and supra-littoral zone, which includes dunes, the middle intertidal zone, and the lower intertidal beach zone.
<u>Rocky intertidal:</u> Located along the coastal border of the study region, including the Farallon Isalnds, this habitat is rocky substrate found between high and low tide water levels.

Kelp forest: Located primarily at depths from 4 meters to 25 meters, dense forests of kelp inhabit the rocky nearshore environment. The bull kelp, *Nereocystis luetkeana*, is the dominant canopy-forming kelp, with an understory of other kelp species (e.g. *Pterygophora californica*, and other Laminarials).
Cliffs: Located along rocky portions of the coastline including the Farallon Islands, these are vertical or near-vertical rocky faces above the water line that provide habitat for pinnipeds, birds and rare native plants and are subject to erosion due to exposure to wave action, wind, and rain.
Nearshore: Including the water column and soft-bottom subtidal, the nearshore habitat extends from the surf out to waters that are approximately 30 meters deep (100 feet).
Estuaries: The estuarine habitat includes small and sandbar-built estuaries within the study region, such as Pescadero Marsh, Estero Americano and Estero de San Antonio, and moderately sized bays such as Tomales Bay, Bolinas Lagoon and Drakes Estero. San Francisco Bay is not included in this assessment.
Pelagic water column: Extending out from the nearshore habitat, the pelagic water column includes the sea surface to the seabed, and is a highly heterogeneous and dynamic environment.
Offshore rocky reefs: Including banks and seamounts, offshore rocky reefs are discrete features that provide complex and heterogeneous environments for colonization by deep-water corals, sponges, other invertebrates, and numerous fish species. The reefs considered in this assessment include Cordell Bank, Rittenburg Bank, and Fanny Shoals.

For a more detailed description of the study region and associated habitats, see *Appendix C: Gulf of the Farallones Regional Ecosystem Description* of the report, "Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region" (Duncan et al. 2013).

Climate-Smart Adaptation for the North-central California Coast

In 2009, the Gulf of the Farallones and Cordell Bank Sanctuary Advisory Councils recognized the importance of understanding climate change impacts to sanctuary resources, and called for the formation of a working group of local scientists from 16 agencies, organizations, and institutions to assess and downscale global climate change information into a regional climate change survey for north-central California coast and ocean ecosystems. The resulting Climate Change Impacts Report (Largier et al. 2010) documents recent observations and potential impacts, including: observed increase in surface ocean temperature offshore of the continental shelf; observed increase in extreme weather events (winds, waves, and storms); expected decrease in seawater pH due to uptake of carbon dioxide by the ocean; observed northward shift of key species (including Humboldt squid, volcano barnacle, gray whales, and bottlenose dolphins); possible shift in dominant phytoplankton (from diatom to dinoflagellate blooms); and the potential for effects of climate change to be compounded by parallel environmental changes associated with local human activities. This document serves as a robust, peer-reviewed, and scientifically sound foundation for climate adaptation planning. Recommendations from this report include the reduction of manageable stressors to enhance ecosystem resilience and the creation of policies and management strategies to minimize future impacts. In response to the recommendations and final report, the GFNMS established the Climate-Smart Conservation Program as an effort to integrate adaptation planning, monitoring, mitigation, and climate change communication, into sanctuary management. For a conceptual ecological model depicting climate change drivers and associated biological responses, see

Appendix D: Conceptual Ecological Model for North-central California Coast and Ocean of the report, "Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region" (Duncan et al. 2013).

Additionally, GFNMS, in partnership with USGS Western Ecological Research Center, led an effort to develop physical and biological ocean climate indicators for the study region. These indicators provide vital information about the presence and implications of climate change on the ecosystems within the region. The indicators were specifically developed to support science-based decision-making at local, state, and federal agencies, and they are the first regional ocean climate indicators developed by the National Marine Sanctuary System. A working group of the GFNMS Advisory Council also developed the report, "Ocean Climate Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-central California Coast and Ocean Region" (Duncan et al. 2013) that includes monitoring strategies and activities; the best available monitoring data identified; opportunities for improving or expanding existing monitoring, or for establishing new indicator monitoring; and case studies providing specific examples of the indicators' utility in a decision-making context.

As a next step to this foundational science, GFNMS, along with project partners, Bay Area Ecosystems Climate Change Consortium (BAECCC), California Landscape Conservation Cooperative (CA LCC), EcoAdapt, Farallones Marine Sanctuary Association (FMSA), Golden Gate National Recreation Area (GGNRA), National Park Service Pacific West Region, Point Blue Conservation Science, Point Reyes National Seashore, and the US Fish and Wildlife Service are collaborating on the Climate-Smart Adaptation Project for the North-central California Coast and Ocean. The goal of the project is to enable marine resource managers to respond to, plan, and manage for the impacts of climate change to habitats, species, and ecosystem services within the North-central California coast and ocean region by utilizing expert-driven, scientifically sound assessments to provide prioritized, stakeholder-led climate-smart adaptation strategies. Specifically, the project seeks to integrate climate-smart adaptation into existing management frameworks, and provide guidance to help ensure long-term viability of the habitats and resources that natural resource agencies are mandated to protect. To meet the project goal, the following overarching objectives will be achieved:

1) Produce scientifically sound vulnerability assessments of focal resources through expert elicitation and literature review.
2) Develop and prioritize climate change adaptation action recommendations that can be feasibly implemented by managers, while considering a range of plausible future climate scenarios that incorporate interdisciplinary collaborative input.
3) Develop an implementation plan for sanctuary management based on the approved adaptation actions.
4) Serve as a pilot climate-smart adaptation project for other marine protected areas, such as national marine sanctuaries, both nationally and within California.

The Climate-Smart Adaptation project consists of two phases: 1) Vulnerability Assessment, and 2) Adaptation Planning. This vulnerability assessment report is the product of Phase 1, which consisted of two workshops of scientists, natural resource managers, and policy experts to define focal resources and assess climate vulnerabilities of these resources, as well as an extensive literature review (see Vulnerability Assessment Project Overview). Phase 2 of the project, initiated in 2015, convenes a GFNMS Advisory Council working group of scientists and resource managers to define distinct future climate scenarios for the study region and develop prioritized adaptation action recommendations. These recommendations will be forwarded to the GFNMS Advisory Council for approval, and the approved recommendation will then be forwarded to the GFNMS superintendent, as well as other coastal resource management agencies in the region for consideration in their current or future adaptation planning efforts. GFNMS will then adopt a final set of climate-smart adaptation strategies based on the Sanctuary Advisory Council recommendations, and develop an adaptation implementation plan.

Climate-Smart Conservation

As outlined by Ellie Cohen, President and CEO of Point Blue Conservation Science, Climate-Smart Conservation addresses impacts of climate change in concert with existing threats and promotes nature-based solutions to:

1) Reduce greenhouse gas emissions and enhance carbon sinks;
2) Reduce climate change impacts on wildlife and people and enhance the ability to adapt; and
3) Sustain vibrant, diverse ecosystems

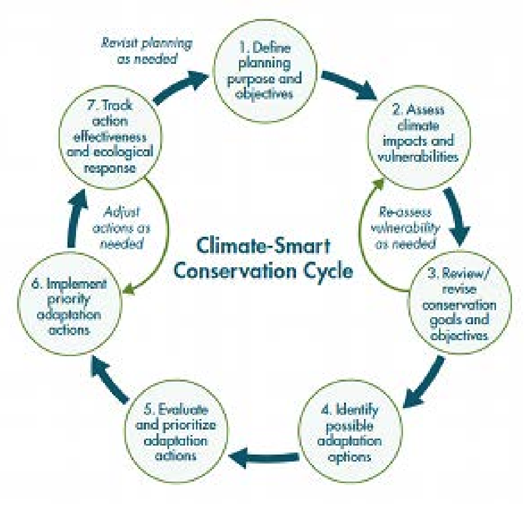

Figure 4. Steps of the "Climate-Smart Conservation Cycle" from the National Wildlife Federation's Quick Guide to Climate-Smart Conservation (Glick et al. 2011).

Climate-Smart Conservations principles guide an approach to conservation that: links actions to climate impacts; embraces forward-looking goals; considers broader landscape context; adopts strategies robust to uncertainty; employs agile and informed management; minimizes carbon footprint; accounts for climate influence on project success; safeguards people and nature; and avoids maladaptation (Stein et al. 2014). The National Wildlife Federation’s Climate-Smart Conservation Cycle (Figure 4) highlights the iterative steps involved with this process.

Vulnerability Assessment Overview

Marine resource managers realize the immediate threats of climate change to the resilience, health, and ecosystem services of the coastal and ocean places they protect, yet the resources to develop appropriate management options to prepare for and respond to a changing environment are limited (Gregg et al. 2011). Vulnerability assessments provide a foundation for understanding how and to what degree resources are threatened by climate change, and can help resource managers and conservation planners set management and planning priorities as well as enable more efficient and effective allocation of resources. This is the first step in developing adaptive management strategies to prepare for and respond to projected climate changes.

This vulnerability assessment is a science-based effort to identify how and why important resources across the North-central California coast and ocean region are likely to be affected by future climate conditions. In this context, vulnerability is a function of the sensitivity of the resource to climate change, its anticipated exposure to those changes, and its capacity to adapt to changes. Specifically, sensitivity is defined as a measure of whether and how a resource is likely to be affected by a given change in climate, or factors driven by climate; exposure is defined as the degree of change in climate or climate-driven factors a resource is likely to experience; and adaptive capacity is defined as the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011). This information can facilitate priority setting for management action and responses, and better characterize the cause of vulnerability for more effective management. The analyses and conclusions are based on available information and expert opinion.

Climate change vulnerability assessments provide two kinds of information that are critical in adaptation planning: (1) they identify which resources are likely to be most affected by changing climate conditions, and (2) they improve understanding as to why these resources are likely to be vulnerable. Knowing which resources are most vulnerable better enables managers to set priorities for conservation action, while understanding why provides a basis for developing appropriate climate-smart adaptation responses (Glick et al. 2011).

The overarching goal of this assessment is to provide vulnerability information and supporting tools and resources that will help coast and ocean managers plan their management of important resources in a changing climate. To meet this goal, the assessment has three main objectives:

1. Use the latest scientific knowledge and understanding of climate trends (current, historic, projected future) for the North-central California coast and ocean to evaluate the sensitivity, exposure, and adaptive capacity of selected habitats, species, and ecosystem services (termed focal resources).
2. Produce scientifically sound vulnerability assessments for focal resources through expert elicitation, regional modeling, and literature review.
3. Provide vulnerability assessment training, resources, support, and tools to participants to apply this process to similar efforts in their own work.

To achieve these objectives, a vulnerability assessment model was developed and applied consistently across the North-central California coast and ocean region that improves understanding of why resources may be vulnerable, how these vulnerabilities may vary across the region, and where and how management could intervene to reduce vulnerabilities. This report describes how this vulnerability methodology was developed, and summarizes the results that were obtained when the methodology was applied to the region.

Climate change vulnerability of North-central California coast and ocean resources was assessed by considering exposure to climate change, sensitivity to climate and non-climate stressors, and adaptive capacity. Proposed resources were identified during the Focal Resources Workshop, and the final 44 resources were decided by the assessment workshop participants and sanctuary staff. Climate exposure information for the region was provided to workshop participants through a Climate Change Impacts Report (Largier et al. 2010) that was developed by a joint working group of Gulf of the Farallones and Cordell Bank National Marine Sanctuary Advisory Councils, and by Tom Suchanek, USGS, during a presentation at the Vulnerability Assessment Workshop. These resources included information on potential climate change impacts to habitats and biological communities along the north-central California coast, with an emphasis on the most likely ecological impacts and the impacts that would be most severe if they occur.

The Vulnerability Assessment Workshop was convened to evaluate the vulnerability of each resource, and included participants from resource management agencies, academic institutions, and non-governmental conservation organizations from the surrounding region. Sensitivity, adaptive capacity, and exposure were assessed on a 1-5 scale (1 = low, 5 = high) based on participant expertise. Interpretation of questions likely varied among participants, and there was no standardization among participants. Each ranking also included a confidence evaluation (1-3 scale; 1 = low, 3 = high).

Climate Factors for the Study Region

The following climate factors (listed alphabetically) were identified by participants of the Vulnerability Assessment Workshop for North-central California coast and ocean resources. These factors were identified due to their importance in understanding future changes in climate that the region's resources may experience. For information regarding key factors identified for specific resources, see the vulnerability assessment results section.

Changes in **air temperature**

Air temperatures along the California coastline will likely exhibit high variability in the future (Largier et al. 2010). Lebassi et al. (2009) analyzed 253 California National Weather Stations from 1950-2005 and found that air temperature in low-elevation coastal areas cooled (-0.30°C/decade) and inland stations warmed (+0.16° C/decade). However, a gradual retraction of the North Pacific High could contribute to decreased formation of the marine layer with declines in coastal fog and increases in temperature (Johnstone and Dawson 2010). By the end of the century, extreme heat days are expected to increase dramatically for all areas in the Bay Area, but coastal areas (including San Francisco) are estimated to endure a much higher number of such events (Ekstrom and Moser 2012).

Increased **coastal erosion and run-off**

An enhanced potential for coastal erosion is expected across the study region due to rising sea level, enhanced storm intensity and frequency, and increased wave action (PWA 2009). Mendocino County is projected to lose the largest area of land (dunes and cliffs) to coastal erosion, and Marin County will be greatly impacted by dune erosion (PWA 2009). Rising air temperatures are expected to decrease Sierra snowpack and decrease the precipitation ratio of snowfall to rainfall (Knowles et al. 2004), which will likely lead to increased winter run-off, decreased summer run-off, and higher annual peak run-off, impacting the study area via San Francisco Bay. An anticipated increase in intensity and occurrence of fire may also increase run-off (Kiparsky and Gleick 2005). Overall, increased erosion and run-off are likely to occur in association with winter storms that bring large waves and heavy precipitation to the region (Largier et al. 2010).

Altered **currents and mixing**

Currents and mixing are heterogeneous along the California coastline, making projections of future climate-related impacts difficult to discern (Largier et al. 2010). In addition, natural interannual and interdecadal variability (i.e., due to El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) shifts) can exceed magnitudes caused by climate change (McPhaden and Zhang 2004, DiLorenzo et al. 2008). In general, the California Current is controlled by the North Pacific High pressure cell and the Aleutian Low pressure cell, and when the Aleutian Low is weaker than the North Pacific

High, the California Current exhibits a strong southerly flow and contributes to cooler surface waters, reduced stratification, stronger upwelling, and more productivity along the California coastline (Largier et al. 2010). Some climate models suggest that weakening atmospheric circulation could reduce the southerly flow of the California Current (Meehl and Teng 2007, Vecchi and Soden 2007), potentially decreasing regional ocean productivity. During the past 30 years, the California Current System (CCS) has experienced significant environmental shifts and subsequent impacts on marine productivity, including intensification of El Niño events (McGowan et al. 1998, Fiedler 2002) and of wind-driven upwelling (Sydeman et al. 2014). Future intensification of these events is expected (Snyder et al. 2003, Auad et al. 2006, Sydeman et al. 2014), which will likely continue to alter oceanographic conditions and primary productivity in the CCS, creating a diverse assortment of marine conditions (Wolf et al. 2010). The timing and magnitude of upwelling has become much more variable over the last six centuries (Black et al. 2014), and is projected to change significantly during the current century (Snyder et al. 2003, Auad et al. 2006, Sydeman et al. 2014), displaying greater spatial and temporal variability (Snyder et al. 2003, Black et al. 2014).

Decreased **dissolved oxygen (DO)**

Significant changes to dissolved oxygen can result from a number of physical and biological processes, including circulation, ventilation, air-sea exchange, large algal blooms, production and respiration (Keeling and Garcia 2002, Deutsch et al. 2005, Bograd et al. 2008). Models predict a decline in midwater oceanic DO, due to enhanced stratification and reduced ventilation (Sarmiento et al. 1998, Keeling and Garcia 2002). Weaker transport of the California Current could reduce dissolved oxygen levels in waters along the California coast (Bograd et al. 2008, Stramma et al. 2008). Low-DO waters are typically restricted to deeper environments, though shoaling of the oxygen minimum zone and the upwelling of low-DO waters may increase the likelihood of exposure to anoxia for nearshore resources (Largier et al. 2010), leading to high mortality of demersal fish and benthic invertebrate communities (Grantham et al. 2004, Chan et al. 2008). This expansion of the oxygen minimum zone could have cascading effects on benthic and pelagic communities (Largier et al. 2010), including range expansion of certain species (Humboldt squid, Gilly et al. 2006).

Changes in **El Niño events**

The number of El Niño events likely will not change, though the likelihood of super El Niños doubled from one every 20 years in the previous century to one every 10 years in the 21st century (Cai et al. 2013). Warm El Niño years have been intensifying (McGowan et al. 1998, Fiedler 2002), during which a 90% reduction in zooplankton biomass has been recorded (Rommich and McGowan 1995). The high waves during El Niño events will be more extreme when combined with the trend of increased wave height (Largier et al. 2010).

Increased **flooding**

Increased flooding of low-lying coastal areas is expected in the study region due to rising sea level, increased storm activity and intensity, and increased extreme precipitation events.

Decreased **pH**

Globally, average surface ocean pH has decreased by 0.1 units since pre-industrial times (Doney et al. 2009). Upwelled waters along the coast of California, including the CCS, have very low pH and strong upwelling events result in understaturation of calcite and aragonite, two common types of calcium carbonate secreted by marine organisms (Lischka et al. 2010), for the entire shelf (Feely et al. 2008, Largier et al. 2010, Alin et al. 2012). Using two emissions scenarios, the saturation state of aragonite is projected to drop rapidly in the CCS within the next 30 years, with much of the nearshore region developing summertime undersaturation in the top 60 meters (Gruber et al. 2012). By 2050, more than half of the waters in the CCS will be undersaturated year-round (Gruber et al. 2012), with impacts to shelled marine organisms, including pteropods (Hauri et al. 2013), and larval and juvenile fish (Munday et al. 2009, Hamilton et al. 2013).

Changes in **precipitation**

Precipitation has increased in California since the early 20th century (Groisman et al. 2001, Mote et al. 2005). Some models project a continued trend in increasing precipitation across California, with the greatest increase in northern California (Kim et al. 2002, Snyder et al. 2002), while others suggest no change or only a slight increase for northern California and a slight decrease for central California (DWR 2006). Future projections include increased variability of precipitation (drier dry years, wetter wet years) (DWR 2006, Largier et al. 2010), increased frequency of extreme winter precipitation events, and more rapid melting of spring snowpack, potentially causing more intense periods of river flow and freshwater discharge in winter and spring (DWR 2006).

Changes in **salinity**

Due to the expected increase in extreme precipitation events and extreme heat events, the California coast and ocean can expect greater fluctuations in salinity due to runoff and evaporation (Snyder and Sloan 2005, Largier et al. 2010). Salinity also fluctuates in accordance with upwelling, as increased stratification and/or wind reductions could lead to upwelling of shallower, less saline water (Largier et al. 2010). ENSO events and decreased mixing of deep saline waters (due to persistent heating of surface waters) have been implicated as causes of long-term freshening of surface waters in Southern California (McGowan et al. 1998, Gomez-Valdez and Jeronimo 2009). Salinity impacts the solubility of CO_2 in the ocean (Raven and Falkowski 1999), contributes to shifts in regional and large-scale circulation patterns (DiLorenzo et al. 2008), and impacts many habitats and species in the study region, including marsh community structure (Callaway et al. 2007).

Sea level rise

Sea level along the California coast has increased by about 15 centimeters over the last 100 years (CEC 2006), while the longest-running tide gauge in the nation, located in San Francisco Bay, indicates 2.01 millimeters of rise per year, or approximately 20.1 cm over the last 100 years (NOAA 2009). According to the National Research Council's 2012 sea level rise projections for North-central California, 12-61 cm of sea level rise is expected by 2050 and 42-167 cm is expected by 2100.

Changes in **sea surface temperature**

Global ocean temperatures have increased 0.11°C from 1971-2010 in the upper 75 meters (IPCC 2014), though warming is spatially variable (Largier et al. 2010). Sea surface temperatures have been increasing since 1955 at offshore and at shore monitoring stations along the Pacific Coast (McGowan et al. 1998, Enfield and Mestas-Nunes 1999, Sagarin et al. 1999, Mendelssohn et al.

2003, Palacios et al. 2004), though there has been local upwelling-driven cooling along the continental shelf in central California over the past 30 years (Mendelssohn and Schwing 2002, Garcia-Reyes and Largier 2010). Continued warming of nearshore and enclosed bay waters is expected, while water temperatures are expected to cool over the continental shelf (Largier et al. 2010). Sea surface temperature impacts stratification and ocean circulation patterns, influencing primary productivity.

Changes in **sediment supply**[1]

Sediment supply and movement affects a variety of coastal and marine habitats and is influenced by both natural variability (e.g., in precipitation, streamflow input, wind and current patterns, storm frequency and intensity, local erosion) and human activities (Barnard et al. 2013 and citations therein; Hein et al. 2013; Hestir et al. 2013). In North-central California, open coastal and marine ecosystem sediment dynamics are linked with anthropogenic activity within regional sediment-sheds (e.g., dredging, water diversion, development, restoration projects), underscoring the importance of exploring terrestrial, deltaic, coastal, and marine sediment transport connections during project planning and development (Hein et al. 2013). Although sediment supply has varied significantly among different North-central coast areas over the past two centuries (Barnard et al. 2013 and citations therein), it is estimated that the San Francisco Bay Coastal System lost 240 million cubic meters of sediment from 1965-2005 (Schoellhamer 2011). The study region has also experienced reduced ebb-tidal delta surface area and volume (Barnard et al. 2013 and citations therein) and accelerated erosion (Dallas and Barnard 2011), indicative of reduced sediment supply (Barnard et al. 2013). Future shifts in precipitation (e.g., snow to rain) will likely cause peak streamflow and sediment loads to occur earlier in the year (Ganju and Schoellhamer 2010), while extreme precipitation events and flooding can affect the timing and overall supply of sediment coming from smaller tributaries (Hestir et al. 2013). In general, continued or exacerbated reductions in sediment supply may threaten the persistence of some habitats in the face of sea level rise (Ganju and Shcoellhamer 2010; Knowles 2010; Callaway et al. 2012) and have additional implications for marine productivity and fish stocks (Barnard et al. 2013 and citations therein; Hestir et al. 2013 and citations therein).

Increased **storminess**

Winter storms (i.e., North Pacific winter cyclones/extra-tropical cyclones) have been increasing in frequency and intensity since 1948 (Graham and Diaz 2001, Zhang et al. 2004). Storms increase precipitation and wave height and can cause temporarily higher sea levels (e.g., wind-driven storm surge). Peak storm wave heights have been increasing along the Pacific Coast (i.e., Washington, Oregon, and Northern California), although there have not yet been statistically significant increases in Central California (Largier et al. 2010). Models suggest that the tracks of storms in the northeast Pacific Ocean are migrating poleward (Hartmann et al. 2013), with a decrease in the frequency of storms at mid latitudes (including the study region), but an increase in intensity of storms at both high and mid latitudes (McCabe et al. 2001). Additionally, the number of El Niño events is projected to likely not change, though the likelihood of super El

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[1] For more in-depth discussions of sediment supply and movement dynamics in the study region, please see: Barnard, P. L., B. E. Jaffe and D. H. Schoellhamer (eds). 2013. A multi-discipline approach for understanding sediment transport and geomorphic evolution in an estuarine-coastal system: San Francisco Bay. Marine Geology 345:1-326. Available online at http://www.sciencedirect.com/science/journal/00253227/345.

Niños doubled from one every 20 years in the previous century to one every 10 years in the 21st century (Cai et al. 2013).

Vulnerability Assessment Results Summary

The vulnerabilities for all 44 focal resources are presented in the figures, tables and individual assessment reports in the Results section. In general, most resources were assessed as having moderate vulnerability.

The eight habitats assessed were scored as having moderate to moderate-high adaptive capacity, but highly variable degrees of exposure and sensitivity, ranging from low-moderate to moderate-high. The most vulnerable habitats – beaches/dunes, estuaries, and rocky intertidal – exist at the land-sea interface. The 31 species assessed were scored as having highly variable adaptive capacity, from low to moderate-high, and highly variable exposure and sensitivity scores, from low-moderate to high. The majority of the ten species identified as being most vulnerable are those that use the three most vulnerable habitats –beaches/dunes, estuaries, and the rocky intertidal. The five ecosystem services assessed generally scored higher for exposure and sensitivity than species or habitats, ranging from moderate-high to high. Adaptive capacity was more variable, ranging from low-moderate to moderate-high. Those services that are provided primarily by the region's coastal habitats were identified as being most vulnerable – flood and erosion protection, which is provided by estuarine and beach/dune habitat, carbon storage and sequestration, which is provided by estuarine habitat, and water purification, which is provided by estuarine and beach habitat.

The adaptive capacity component of this vulnerability assessment considered potential management approaches for a given resource to facilitate adaptation to changing climate conditions. Most management approaches focused on alleviating current non-climate stressors (e.g., protecting upland habitat, restoration activities), but represent important management action considerations to enhance resource resilience to climate change. The information in this vulnerability assessment is intended to help managers develop and prioritize adaptation strategies to conserve resources by better integrating the effects of climate change.

Process and Methodology

Development of Collaborative Process

This project used a collaborative, expert elicitation-based approach that involved representatives from numerous federal and state agencies, non-profit organizations, and academic institutions (see Appendices A and B for full list of workshop participants and affiliations). Expert elicitation has a long history in conservation and regulation. These approaches are effective where there is greater uncertainty about resource function or future projections, but detailed knowledge and expertise from local stakeholders. Participants in this process had extensive knowledge about the ecology, management, and threats to north-central California coast and ocean habitats, species, and ecosystem services, and also comprise many of the professionals who will use the results of the project. A series of two invitational workshops were held in San Francisco: *Focal Resources Workshop* in February 2014, and *Vulnerability Assessment Workshop* in June 2014. Focal Resources Workshop participants were asked to apply their knowledge of the region's ecological resources to make recommendations for those species, habitats, and ecosystem services that are most vital to the region for which to assess vulnerability to climate impacts and non-climate stressors. Using the vulnerability assessment methodology described below as a guide, Vulnerability Assessment Workshop participants were asked to apply their knowledge and expertise about a selected resource (habitat, species, or ecosystem service) to evaluate its vulnerability to climate and non-climate stressors. Participants in this workshop provided both scores and confidence evaluations for resource assessments.

Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014).

Focal Resources Methodology

Selection Process

Gulf of the Farallones National Marine Sanctuary, in collaboration with project partners, convened the *Focal Resources Workshop* on February 11, 2014 at the California Academy of Sciences in San Francisco, CA (see Appendix A for agenda and participants). The goal of this workshop was to finalize a list of North-central California coast and ocean focal resources (species, habitats and ecosystem services) for use in vulnerability assessments. Information from the workshop such as a workshop summary, presentations, handouts, readings, and other resources can be found on the workshop support page.

Working in break-out groups, 30 scientists, managers, and policy experts representing 21 institutions, organizations, and agencies discussed and developed consensus recommendations for species, habitats and ecosystem services for inclusion in the vulnerability assessments. Given the time and resources available for the vulnerability assessments, it was not feasible to assess all 72 recommended focal resources individually. Therefore, the project planning committee finalized the smaller list of focal resources based on feedback received from the break-out groups using the following process. Further culling of this list took place at the *Vulnerability Assessment Workshop*, as participants prioritized the resources to be completed during and following the workshop based on available time and resources.

Species

Species that were suggested by a break-out group to be adequately assessed in one of the habitat assessments were removed from the final list (e.g. bull kelp may be adequately assessed via the kelp forest habitat assessment). Species that displayed similar life history characteristics as another listed species were removed (e.g. steelhead trout is similar to coho/Chinook salmon; humpback whale is similar to the blue whale). All species with multiple recommendations from break-out groups were retained in the final list. The recommended group of invertebrates remained very large, so the planning committee decided to base any further culling of this group on available expertise (certain species would not be assessed at the workshop if the required expertise was not available), and by the participants of the *Vulnerability Assessment Workshop*.

Habitats

The list of habitats was finalized by combining the dune and beach habitats and by combining offshore rocks with the rocky intertidal habitat. Islands were removed, and were assessed by a suite of other habitats (including rocky intertidal, beaches/dunes, and cliffs).

Ecosystem Services

The list of ecosystem services was finalized by combining protection from erosion and protection from flooding, and removing scientific discovery (it was determined by the planning committee this would be too difficult to assess).

Vulnerability Assessment Methodology

Vulnerability Assessment Methodology Overview

The vulnerability assessment methodology used in this process comprises three vulnerability components (sensitivity, adaptive capacity, and exposure), confidence evaluations for all components, and overall vulnerability and confidence scores for a resource (Figure 11). In this report, each component of vulnerability includes expert assigned scores as well as written summaries describing expert comments and information from the scientific literature. The aim of the summaries that accompany scores is to make transparent the rationales and assumptions underlying the scores and confidences assigned to each variable.

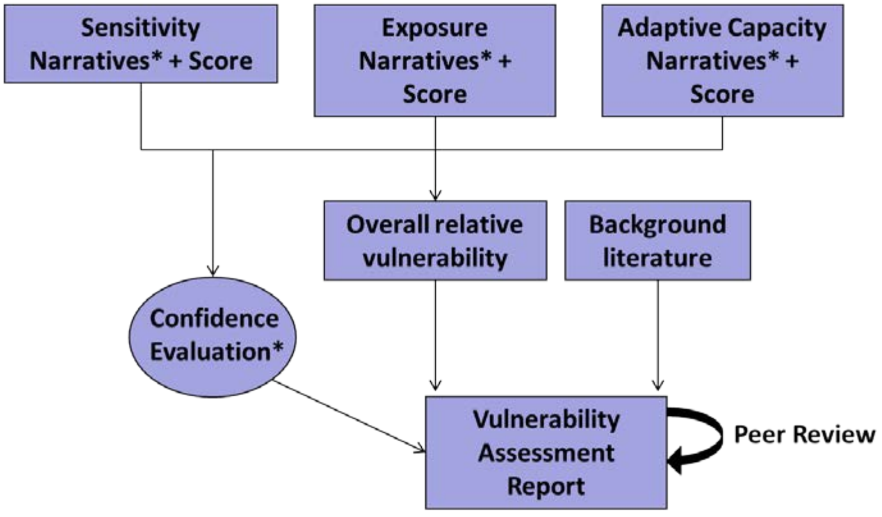
Sensitivity, adaptive capacity, and exposure components were broken down into specific elements better suited to assessing the vulnerability of particular resources for this assessment. For example, sensitivity comprises three main elements for habitats and ecosystem services, and five elements for species. Elements for each vulnerability component were delineated by EcoAdapt, and are described in more detail below.

Expert participants assigned one of five scores (High-5, Moderate-High-4, Moderate-3, Low-Moderate-2, or Low-1) for each component of vulnerability. Interpretation of questions likely varied among participants, and there was no standardization among participants. Expert-assigned scores for each component were then averaged (mean) to generate an overall score for that particular component. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for the exposure component of vulnerability were weighted less than scores for the sensitivity and adaptive capacity components of vulnerability by a factor of 0.5. Exposure was weighted lower than sensitivity and adaptive capacity due to uncertainty about the magnitude and rate of future change. Sensitivity, adaptive capacity, and exposure scores were then combined into an overall vulnerability score calculated as follows:

$$\textbf{Vulnerability} = \frac{\textbf{Climate Exposure (0.5) + Sensitivity}}{\textbf{Adaptive Capacity}}$$

Elements for each component of vulnerability were also assigned one of three confidence scores (High-3, Moderate-2, or Low-1). This ensured the degree of confidence that assessors had in scoring each variable was explicit. Confidence scores for each vulnerability component were averaged (mean) to generate an overall confidence score.

The user is encouraged to pay close attention to the summaries and individual scores for each resource. Familiarity with each vulnerability component in addition to a resource's overall score better informs *why* a particular resource is vulnerable and *what* management actions may reduce vulnerabilities given possible tradeoffs. Additionally, due to participant differences in question interpretation, users are encouraged to exercise caution when comparing results between resources; however, at this time they provide the best tool available to describe vulnerabilities.



*documenting uncertainty

Figure 5. Structure of the vulnerability assessment methodology used in this process.

Model Elements – Habitats

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for habitats.[2]

Habitat Sensitivity & Exposure

1. Climate and Climate-Driven Factors

There are two ways to consider habitat sensitivity to climate and climate-driven factors: (1) does the habitat exist in a relatively narrow climatic zone, and (2) does the habitat experience large changes in composition or structure due to small changes in climate or climate-driven factors? Habitats that exist in a narrow climatic zone and/or experience large changes in composition or structure in response to small changes in climate likely have higher sensitivity (Lawler 2010). Climate and climate-driven factors considered included air temperature, ocean temperature, precipitation, chemistry (i.e., salinity, oxygen, pH), sea level rise, wave action, currents/mixing/stratification, coastal erosion, and others. Habitat benefits from climate and climate-driven factors were also considered.

2. Disturbance Regimes

Habitats may be sensitive to particular disturbance regimes such as wind, flooding, diseases, or storms, among others. Habitats that experience larger changes in composition or structure due to small changes in disturbance regimes are likely more sensitive (Lawler 2010).

3. Future Climate Exposure

A number of climate and climate-driven changes may be important to consider for marine and coastal habitats. These factors may include, but are not limited to: increased air or ocean temperature, changes in precipitation, sea level rise, changes in salinity, decreased oxygen or pH, increased flooding, and others. In addition to ranking exposure, participants were asked to document any potential areas of refugia from a particular climate or climate-driven change.

4. Non-Climate Stressors

Non-climate stressors may have independent, synergistic, additive, or antagonistic effects with climate change (Hansen and Hoffman 2011). Habitats that have to endure multiple non-climate stressors may be more sensitive to climate changes. Non-climate stressors for marine and coastal habitats may include land use change, aquaculture, energy production, roads and armoring, overwater/underwater structures, dredging, harvest, invasive and other problematic species, recreation, or pollution and poisons, among others. Participants were asked to identify non-climate stressors most likely to increase sensitivity of the habitat to climate change, assess the degree to which the stressor affects sensitivity and degree of current exposure (both local and regional) to the stressor, and evaluate confidence.

Habitat Adaptive Capacity

1. Extent, Integrity and Continuity

Habitats that are currently widespread in their geographic extent, with high integrity and continuity may be better able to withstand and persist into the future despite climate and non-climate stressors. Habitats that are degraded, isolated, limited in extent, or currently declining due to climate and non-climate stressors will likely have lower adaptive capacity (Manomet Center for Conservation Sciences 2012). Geographic extent, structural and functional integrity, and continuity were considered for marine and coastal habitats.

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[2] Elements generated by EcoAdapt.

2. Resistance and Recovery

Some habitats may be more resistant to changes, stressors, or maladaptive human responses, or are able to recover more quickly from stressors once they do occur, resulting in greater adaptive capacity (Manomet Center for Conservation Sciences 2012). For example, some habitats may have more rapid regeneration times and/or are dominated by species with short generation times. Habitats with a shorter recovery period from the impacts of stressors (e.g., <20 years) may have greater intrinsic adaptive capacities than slower developing or recovering habitats, as these habitats may be more intrinsically vulnerable to the potential intervening effects of climate change.

3. Habitat Diversity

Habitats that include diverse physical and topographical characteristics (e.g., variety in aspects, sediment types) may be better able to persist under changing climate conditions than habitats that are less varied because they exist across widely differing conditions (Manomet Center for Conservation Sciences 2012). The level of diversity of component species and functional groups in a habitat may also affect its adaptive capacity (or sensitivity) to climate change impacts. For example, in habitats where each functional group is represented by multiple species, response to changes in climate varies among the species resulting in greater adaptive capacity (Glick et al. 2011). Dependency on a single keystone or foundation species can also affect the adaptive capacity of the habitat, contingent upon the species vulnerability to climate change.

4. Management Potential

Humans have the potential to intervene and change habitats in ways that reduce the impacts of climate change. Management potential reflects our ability to impact the adaptive capacity and resilience of a habitat to climate and climate-driven changes. Management potential can be evaluated in two ways: (1) Societal value - Is the habitat highly valued? Habitats with a high societal value likely have higher adaptive capacity, as people may have a greater interest in protecting and/or maintaining them; and (2) Managing or alleviating climate impacts - Can habitat impacts be managed or alleviated? If human intervention or management has a high likelihood of alleviating climate impacts, the adaptive capacity of the habitat is likely higher. The costs and benefits of management actions will vary among habitats. Actions will be most feasible when resources are culturally and economically valued and the costs of implementing new management strategies are low.

Model Elements – Species

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for species.[3]

Species Sensitivity & Exposure

1. Climate and Climate-Driven Factors

Species sensitivity to climate and climate-driven factors may be direct (e.g., physiological) or indirect (e.g., ecological relationships). Physiological sensitivity is directly related to a species' physiological ability to tolerate changes in climate or climate-driven factors that are higher or lower than the range that they currently experience. Species life history may also be affected by changes in climate or climate-driven factors. Species that are able to tolerate a wide range of variables are likely less sensitive to climate change (Glick et al. 2011). Ecological relationships (e.g., predator/prey, foraging, habitat, pollination, dispersal, competition) may also be affected

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[3] Elements generated by EcoAdapt.

by climate or climate-driven factors; those relationships significantly affected by small changes in climate likely have higher sensitivity. Climate and climate-driven factors considered included air temperature, ocean temperature, precipitation, chemistry (i.e., salinity, oxygen, pH), sea level rise, wave action, currents/mixing/ stratification, coastal erosion, and others. Species benefits from climate and climate-driven factors were also considered.

2. Disturbance Regimes

Species may be sensitive to particular disturbance regimes such as wind, flooding, diseases, or storms, among others. Species that experience larger changes in response to small changes in disturbance regimes are likely more sensitive (Lawler 2010).

3. Future Climate Exposure

A number of climate and climate-driven factors may be important to consider for marine and coastal species. These factors may include, but are not limited to: increased air or ocean temperature, changes in precipitation, sea level rise, changes in salinity, decreased oxygen or pH, increased flooding, and others. In addition to ranking exposure, participants were asked to document any potential areas of refugia from a particular climate or climate-driven change.

4. Life History[4]

Species reproductive strategy may influence sensitivity to climate change; for example, species with longer generation times and fewer offspring (K-selection) may be at increased extinction risk under long-term climate change. Species with a short generation time that produce many offspring (r-selection) may be better able to take advantage of climate changes (Glick et al. 2011).

5. Dependencies

Species that use multiple habitats or have multiple prey or forage species are likely less sensitive to climate change (generalist). Conversely, species with very narrow habitat needs, single prey or forage species, or dependence on another sensitive species or habitat for life history purposes likely have greater sensitivity to climate changes (specialist).

6. Non-Climate Stressors

Non-climate stressors may have independent, synergistic, additive, or antagonistic effects with climate change (Hansen and Hoffman 2011). Species that have to endure multiple non-climate stressors may be more sensitive to climate changes. Non-climate stressors for marine and coastal species may include land use change, aquaculture, energy production, roads and armoring, overwater/underwater structures, dredging, harvest, invasive and other problematic species, recreation, or pollution and poisons, among others. Participants were asked to identify non-climate stressors most likely to increase sensitivity of the species to climate change, assess the degree to which the stressor affects sensitivity and degree of current exposure (both local and regional) to the stressor, and evaluate confidence.

Species Adaptive Capacity

1. Extent, Status and Dispersal Ability

Species that are currently widespread in their geographic extent, with a robust population status, high connectivity, and a high ability to disperse may be better able to withstand and persist into the future despite climate and non-climate stressors. Species that are endemic, endangered, or with isolated or fragmented populations and/or limited ability to disperse will likely have lower

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[4] Though information regarding species life history was collected from workshop participants and included in the species assessment reports, this information was not included in analysis of vulnerability.

adaptive capacity (Manomet Center for Conservation Sciences 2012). Geographic extent, population status, population connectivity, and dispersal distance were considered for marine and coastal species.

2. Intraspecific/Life History Diversity
Species that demonstrate a diversity of life history strategies (e.g., variations in age at maturity, reproductive or nursery habitat use, or resource use) are likely to have greater adaptive capacity. Similarly, species able to express different and varying traits (e.g., phenology, behavior, physiology) in response to environmental variation have greater adaptive capacity than those that cannot modify their physiology or vary behavior to better cope with climate changes and its associated effects. Many species exhibit phenotypic plasticity in response to inter-annual variation in temperature. Some species and/or populations will be better able to adapt evolutionarily to climate change. For example, species may have greater adaptive capacity if they exhibit characteristics such as faster generation times, genetic diversity, heritability of traits, larger population size, or multiple populations with connectivity among them to allow for gene flow.

3. Management Potential
Humans have the potential to intervene in ways that reduce the impacts of climate change on a particular species. Management potential reflects our ability to impact the adaptive capacity and resilience of a species to climate and climate-driven changes. Management potential can be evaluated in two ways: (1) Societal value - Is the species highly valued? Species with a high societal value (e.g., commercial fish species) likely have higher adaptive capacity, as people may have a greater interest in protecting and/or maintaining their populations; and (2) Managing or alleviating climate impacts - Can impacts on the species be managed or alleviated? If human intervention or management has a high likelihood of alleviating climate impacts, the adaptive capacity of the species is likely higher. The costs and benefits of management actions will vary among species. Actions will be most feasible when resources are culturally and economically valued and the costs of implementing new management strategies are low.

Model Elements – Ecosystem Services

This section lists the elements that were considered in the expert elicitation-based vulnerability assessment model for ecosystem services.[5]

Ecosystem Service Sensitivity & Exposure

1. Climate and Climate-Driven Factors
The sensitivity of an ecosystem service may largely be determined by the sensitivities of those components (e.g., species, habitat, ecosystem process or function) that provide or support the service. Ecosystem services with components sensitive to climate or climate-driven factors are likely more sensitive. For example, the sensitivity of fisheries as an ecosystem service is largely determined by the sensitivity of the target fish species to climate changes. Climate and climate-driven factors considered included air temperature, ocean temperature, precipitation, chemistry (i.e., salinity, oxygen, pH), sea level rise, wave action, currents/mixing/stratification, coastal erosion, and others. Ecosystem service benefits from climate and climate-driven factors were also considered.

2. Disturbance Regimes

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[5] Elements generated by EcoAdapt.

Ecosystem services may be sensitive to particular disturbance regimes such as wind, flooding, diseases, or storms, among others. Services that experience larger changes in function (or ability to be provided) due to small changes in disturbance regimes are likely more sensitive.

3. Non-Climate Stressors
Non-climate stressors may have independent, synergistic, additive, or antagonistic effects with climate change. Ecosystem services that have to endure multiple non-climate stressors may be more sensitive to climate changes. Non-climate stressors for marine and coastal services may include land use change, aquaculture, energy production, roads and armoring, overwater/underwater structures, dredging, harvest, invasive and other problematic species, recreation, or pollution and poisons, among others. Participants were asked to identify non-climate stressors most likely to increase sensitivity of the service to climate change, assess the degree to which the stressor increases sensitivity of the service, evaluate the degree to which the stressor currently affects the service, and evaluate confidence.

4. Future Climate Exposure
A number of climate and climate-driven changes may be important to consider for marine and coastal ecosystem services. These factors may include, but are not limited to: increased air or ocean temperature, changes in precipitation, sea level rise, changes in salinity, decreased oxygen or pH, increased flooding, and others. In addition to ranking the degree to which the ecosystem service is likely to be affected by future climate changes, participants were asked to document any potential areas of refugia.

Ecosystem Service Adaptive Capacity

1. Intrinsic Value
Some ecosystem services may have higher intrinsic value than others (e.g., recreation or water quality). Because of this, people may be willing to change their behavior to continue to access the service, thus conferring greater adaptive capacity. However, economic drivers as well as service location (e.g., is it important that the service continue to be accessed in its current location?) may also need to be considered as they can influence adaptive capacity.

2. Management Potentia**l**
Management potential reflects our ability to impact the adaptive capacity and resilience of an ecosystem service to climate and climate-driven changes. Management potential can be evaluated in two ways: (1) Management guidelines - How rigid or specific are the rules governing the management of the service itself or the areas that provide the service. For example, does the service fall under specific management guidelines (e.g., water quality) or does it occur in an area with specific management rules (e.g., marine protected area)? and (2) Managing or alleviating climate impacts - Can climate impacts to the service be managed or alleviated? If human intervention or management has a high likelihood of alleviating climate impacts, the adaptive capacity of the service is likely higher. The costs and benefits of management actions will vary among services. Actions will be most feasible when services are culturally and economically valued and the costs of implementing new management strategies are low.

Confidence Evaluation

Each of the sensitivity, adaptive capacity, and exposure elements described above for resources were assigned a confidence score: High-3, Moderate-2, or Low-1. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report to avoid implying a greater level of certainty precision. This vulnerability assessment model not only evaluates the confidence associated with the individual element scores, but also uses these scores to estimate the overall level of confidence for each component of vulnerability by calculating mean confidence scores across elements.

Vulnerability Assessment Application

Methodology Application

Gulf of the Farallones National Marine Sanctuary, in collaboration with project partners, convened a 2-day workshop entitled *A Vulnerability Assessment Workshop for the North-central California Coast and Ocean*, held June 10-11, 2014 at Fort Mason in San Francisco, CA (see Appendix B for workshop agenda and participants). The main focus of the workshop was assessing the vulnerabilities of resources (habitats, species, and ecosystem services). Approximately 35 scientists and resource managers participated in this workshop, representing 25 agencies, organizations, and academic institutions. Information from the workshop such as the agenda, presentations, handouts, readings, and other resources can be found on the workshop support page.

This workshop was structured to provide participants with a foundation of information from which they could assess the vulnerabilities of selected resources. Participants were introduced to general vulnerability assessment theory and approaches, provided with past and projected climate trends in the north-central California coast region, and organized into several different small working group arrangements to discuss and evaluate the vulnerability of resources.

Workshop participants were directed to apply the vulnerability assessment methodology described above to the list of resources. As this was an expert elicitation process, participants were encouraged to make decisions based on their knowledge and expertise, and the workshop process and vulnerability assessment methods were designed to be flexible to support collaborative modification and improvement. Most of the 44 resources were assessed during this workshop; 11 species that were not assessed at the workshop but identified as important focal species for the region were assessed by regional experts outside of the workshop. See Appendix C for a list of contributors to these assessments.

Participant evaluations and comments were compiled and assembled into this vulnerability assessment report. As part of this report, individual resource vulnerability reports were created which synthesize participant comments and peer-review references for each resource. These vulnerability reports are detailed in the next section of this report.

Peer Review Process

Each species and habitat vulnerability assessment summary was reviewed by a local expert in the resource, and comments and revisions from these reviewers were incorporated into the summaries before the completion of the final draft report. Only changes in text were accepted; scores provided by workshop participants were not altered through the peer review process. Following this first round of reviews, the complete draft vulnerability assessment report was sent to members of the project planning committee, including scientists and resource managers, who also reviewed the ecosystem services summaries. Comments and revisions from these reviewers were incorporated into the final report. See Appendix C for a complete list of reviewers.

Results

The vulnerabilities for all 44 focal resources are summarized in Figures 6-11. These figures are arranged such that resources listed in the upper left region were judged to have less vulnerability than those listed in the lower right region. Tables 1-3 provide the calculated vulnerability and component scores for all focal resources by decreasing vulnerability score. Tables 4 and 5 present all climate and non-climate stressors that were identified in this assessment. Stressors are ranked from most impactful to least, based on the mean sensitivity score assigned for all species and habitats.

The scores presented are comparable only within the resources considered here, and are not standardized in any way to other climate change vulnerability assessments. The information supporting these scores and figures is available in the individual Vulnerability Assessment Reports and should be referred to before using the overview results in decision-making. This vulnerability assessment can be used as a foundation from which management and planning can be strengthened by better integrating the effects of climate change. However, it is also important to continue to gather information to better understand local climate, its interactions with non-climate stressors, and the impacts to resources. This assessment is intended to be updatable so that as new information becomes available on sensitivity, adaptive capacity, or exposure for a given resource, it can be integrated and used to re-evaluate vulnerability.

Habitats

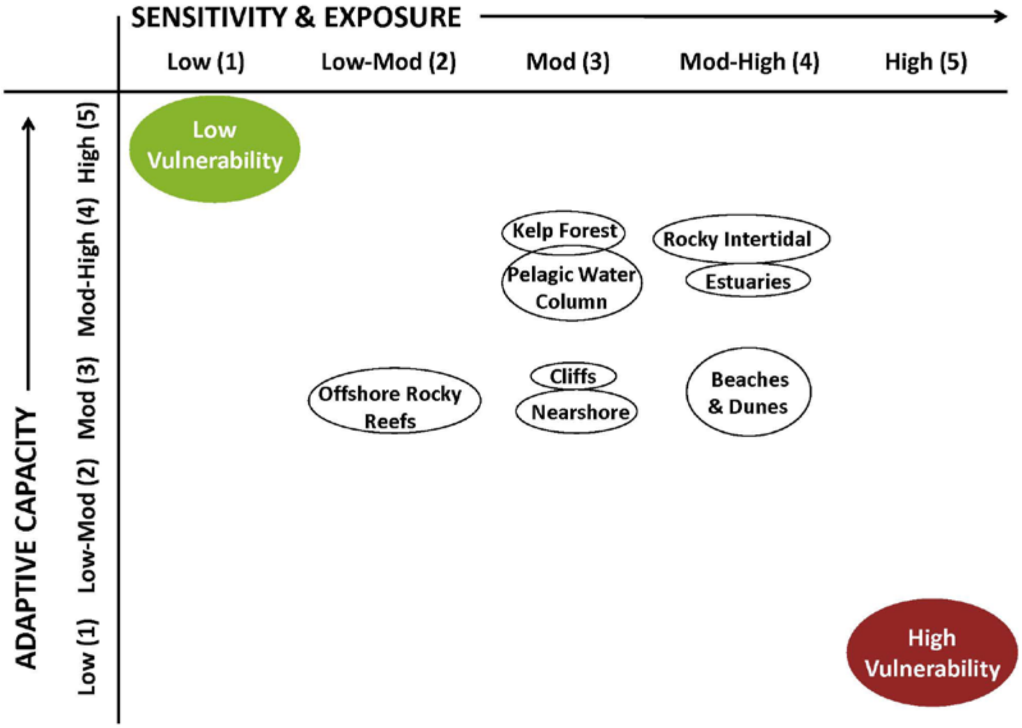

Figure 6. Overall vulnerabilities of eight habitats based on the climate change sensitivity, exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Habitats listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence ranged from moderate to high.

The eight habitats assessed were scored as having moderate to moderate-high adaptive capacity, but highly variable degrees of exposure and sensitivity, ranging from low-moderate to moderate-high (Figure 6).

The most vulnerable habitats (Table 1), beaches/dunes, estuaries, and rocky intertidal, exist at the land-sea interface. These habitats are expected to experience greater exposure and sensitivity to climate changes and non-climate stressors. Key climate-driven factors identified for the beach/dune, estuarine, and rocky intertidal habitats include sea level rise, wave action, and coastal erosion. Flooding and inundation of these habitats is a primary concern, as well as disturbance to the structural and functional integrity of the habitats due to increased storms, wind, and wave events. Key non-climate stressors identified for the three most vulnerable habitats include coastal armoring and invasive species. Coastal armoring inhibits the ability for a habitat to migrate inland or upland in response to rising sea level, and accelerated, localized loss of habitat may be expected in areas where the upland border of the habitat abuts roads, levees or other armored structures. Invasive species threaten the abundance and/or diversity of native species, disrupt ecosystem balance, threaten local marine-based economies and can even alter the habitat itself (for example, by altering dune morphology).

The least vulnerable habitats identified (Table 1) were offshore rocky reefs and kelp forests, but for different reasons. Offshore rocky reefs were evaluated to have overall low-moderate exposure to climate factors, and low-moderate sensitivity to climate and non-climate stressors, whereas kelp forests were evaluated to have a high adaptive capacity due to high habitat diversity and a moderate-high ability to recover from impacts. Offshore rocky reefs may be less vulnerable to climate change because they are less exposed and less sensitive to climate impacts, while kelp forests will likely experience greater exposure, but are predicted to be able to better adapt to those impacts.

Table 1. The calculated scores for overall vulnerability, exposure, sensitivity and adaptive capacity for the eight habitats assessed, ordered by decreasing vulnerability.

	Beaches and Dunes	**Estuaries**	**Rocky Intertidal**	**Cliffs**	**Nearshore**	**Pelagic Water Column**	**Offshore Rocky Reefs**	**Kelp Forest**
	SENSITIVITY							
Average	3.9	4.1	4.0	3.2	2.8	2.7	2.0	2.9
Rank	**Mod-High**	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**	**Moderate**	**Low-Mod**	**Moderate**
	EXPOSURE							
Average	4.5	4.3	4.1	2.3	4.0	4.1	2.3	2.5
Rank	**High**	**High**	**Mod-High**	**Low-Mod**	**Mod-High**	**Mod-High**	**Low-Mod**	**Low-Mod**
	ADAPTIVE CAPACITY							
Average	3.1	3.5	4.0	2.8	3.3	3.7	2.7	3.9
Rank	**Moderate**	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**	**Mod-High**	**Moderate**	**Mod-High**
	VULNERABILITY							

Weighted Score	3.1	2.8	2.0	1.5	1.5	1.1	0.5	0.3
Final Rank	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low-Mod**	**Low-Mod**

Species

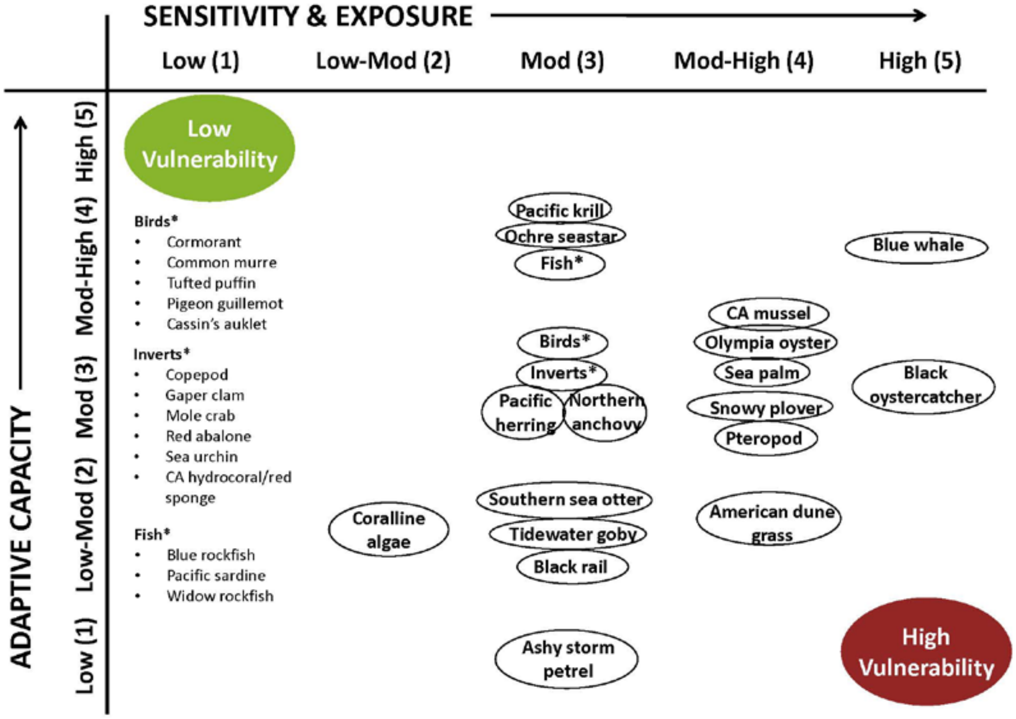

Figure 7. Overall vulnerabilities of all 31 species based on the climate change sensitivity, exposure, and adaptive capacity assessment. Due to space limitation in the figure, two groups of species with similar scores have been lumped. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Species listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence ranged from moderate to high.

Species were assessed as having wide-ranging adaptive capacity (Figure 7), from low adaptive capacity as seen in the ashy storm petrel, to moderate-high adaptive capacity, as seen in Pacific krill and the ochre sea star. Exposure and sensitivity were highly variable as well, ranging from low-moderate to high. With the exception of the pteropod and blue whale (which use the offshore pelagic habitat) and ashy storm petrel (which uses coastal cliff and offshore habitat), the majority of the top ten species identified as being most vulnerable (Table 2) are those that use the three most vulnerable habitats –beaches/dunes, estuaries, and the rocky intertidal.

Table 2. The calculated scores for overall vulnerability, exposure, sensitivity and adaptive capacity for the 31 species assessed, ordered by decreasing vulnerability.

	Black Oyster catcher	American Dune Grass	Pteropod	Black Rail	Western Snowy Plover	Sea Palm	Ashy Storm Petrel	Blue Whale	Tidewater Goby	Olympia Oyster
	SENSITIVITY									
Average	4.6	3.8	3.6	3.8	3.8	3.8	3.4	3.9	3.0	3.2
Rank	**High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Moderate**	**Mod-High**	**Moderate**	**Moderate**
	EXPOSURE									
Average	4.6	5.0	5.0	2.5	4.0	4.0	2.5	5.0	3.0	4.3
Rank	**High**	**High**	**High**	**Low-Mod**	**Mod-High**	**Mod-High**	**Low-Mod**	**High**	**Moderate**	**High**
	ADAPTIVE CAPACITY									
Average	2.9	2.5	2.7	2.0	2.8	2.9	1.8	3.8	2.0	2.9
Rank	**Moderate**	**Low-Mod**	**Moderate**	**Low-Mod**	**Moderate**	**Moderate**	**Low**	**Mod-High**	**Low-Mod**	**Moderate**
	VULNERABILITY									
Weighted Score	4.0	3.8	3.4	3.1	3.0	2.9	2.9	2.6	2.5	2.4
Final Rank	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**

	Red Abalone	Gaper Clam	Southern Sea Otter	Cassin's Auklet	Brandt's Cormorant Common Murre	California Mussel	Copepod	California Hydrocoral, Red Sponge	Pigeon Guillemot, Tufted Puffin	Ochre Sea Star
	SENSITIVITY									
Average	3.5	2.9	2.6	3.5	3.5	3.1	2.0	3.2	3.4	3.0
Rank	**Mod-High**	**Moderate**	**Low-Mod**	**Mod-High**	**Mod-High**	**Moderate**	**Low-Mod**	**Moderate**	**Moderate**	**Moderate**
	EXPOSURE									
Average	3.0	4.1	3.5	2.5	2.6	4.1	5.0	3.1	2.5	4.1
Rank	**Moderate**	**Mod-High**	**Mod-High**	**Low-Mod**	**Moderate**	**Mod-High**	**High**	**Moderate**	**Low-Mod**	**Mod-High**
	ADAPTIVE CAPACITY									
Average	2.8	2.7	2.5	2.9	3.0	3.4	2.9	3.2	3.2	3.5
Rank	**Moderate**	**Moderate**	**Low-Mod**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Mod-High**
	VULNERABILITY									
Weighted Score	2.3	2.3	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.5
Final Rank	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**

	Pacific Herring	Coralline Algae	Sea Urchin	Pacific Sardine	Widow Rockfish	Northern Anchovy	Mole Crab	Blue Rockfish	Pacific Krill
	SENSITIVITY								
Average	2.6	2.4	3.3	3.3	3.0	2.9	2.0	3.0	1.6
Rank	**Low-Mod**	**Low-Mod**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low-Mod**	**Moderate**	**Low**
	EXPOSURE								
Average	3.7	3.0	2.3	3.3	3.2	3.3	4.8	2.7	5.0
Rank	**Mod-High**	**Moderate**	**Low-Mod**	**Moderate**	**Moderate**	**Moderate**	**High**	**Moderate**	**High**
	ADAPTIVE CAPACITY								
Average	2.9	2.4	3.2	3.8	3.5	3.4	3.4	3.7	4.0
Rank	**Moderate**	**Low-Mod**	**Moderate**	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**	**Mod-High**	**Mod-High**
	VULNERABILITY								
Weighted Score	1.5	1.4	1.2	1.2	1.1	1.1	1.0	0.7	0.1
Final Rank	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Low-Mod**

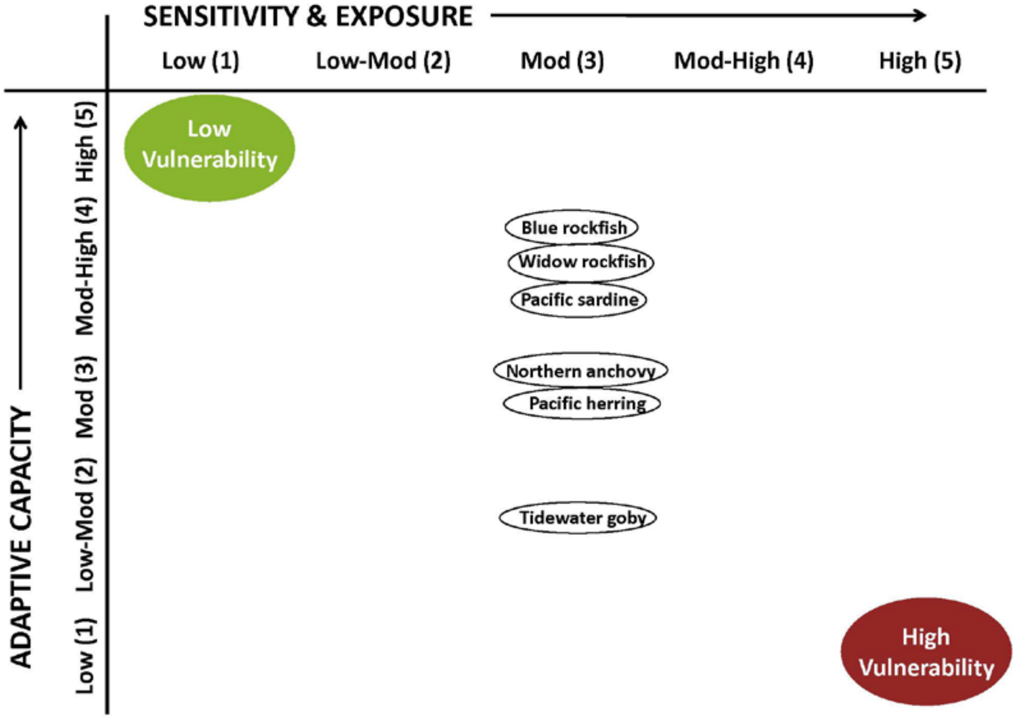

Figure 8. Overall vulnerabilities of all six fish species based on the climate change sensitivity, exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Species listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence ranged from moderate to high.

All six fish species considered in this assessment were identified as having moderate exposure and sensitivity to climate and non-climate stressors (Figure 8). The ability for the species to adapt to a changing climate is what determined the range in vulnerability. The tidewater goby was identified as being most vulnerable to climate change, and is the only fish species in the top ten most vulnerable of all species assessed (Table 2), primarily due to its limited geographic extent, fragmented habitat as a result of degradation from land use change, and limited dispersal. Blue rockfish was identified as being the least vulnerable of the fish species due to its robust, highly connected population, and great value to commercial and recreational fisheries, indicating that action would likely be taken to conserve the sustainability of the fishery. The most frequently identified climate sensitivities for fish species include pH, dissolved oxygen, salinity, and dynamic ocean conditions. Harvest and pollution were commonly identified non-climate stressors for all fish species.

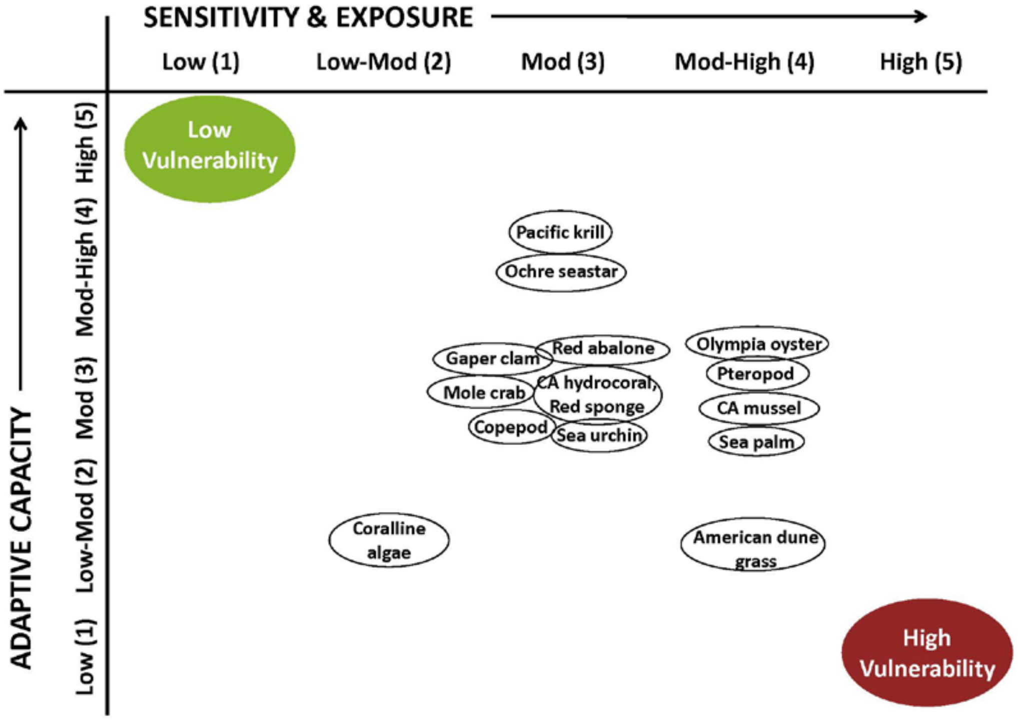

Figure 9. Overall vulnerabilities of all 14 invertebrate, plant and algal species based on the climate change sensitivity, exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Species listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence ranged from moderate to high.

The diverse grouping of invertebrate, plant and algal species exhibits diverse responses to the vulnerability assessments, with sensitivity, exposure and adaptive capacity ranging from low-moderate to moderate-high (Figure 9). American dune grass and sea palm, the only plant/algae species assessed, were identified as the most vulnerable of this group due to their relatively higher exposure and sensitivity and lower adaptive capacity, and are the only species of this group in the top ten most vulnerable of all species assessed (Table 2). Pacific krill, the least vulnerable species in this group and of all species assessed, was identified as having very low sensitivity to climate change, little to no sensitivity to non-climate stressors, and relatively high adaptive capacity. The species is not dependent on specific prey or a sensitive habitat, has a robust and highly connected population, and exhibits some degree of behavioral plasticity in response to changing environmental conditions. Generally, most invertebrate species ranked as having moderate exposure and sensitivity and moderate adaptive capacity.

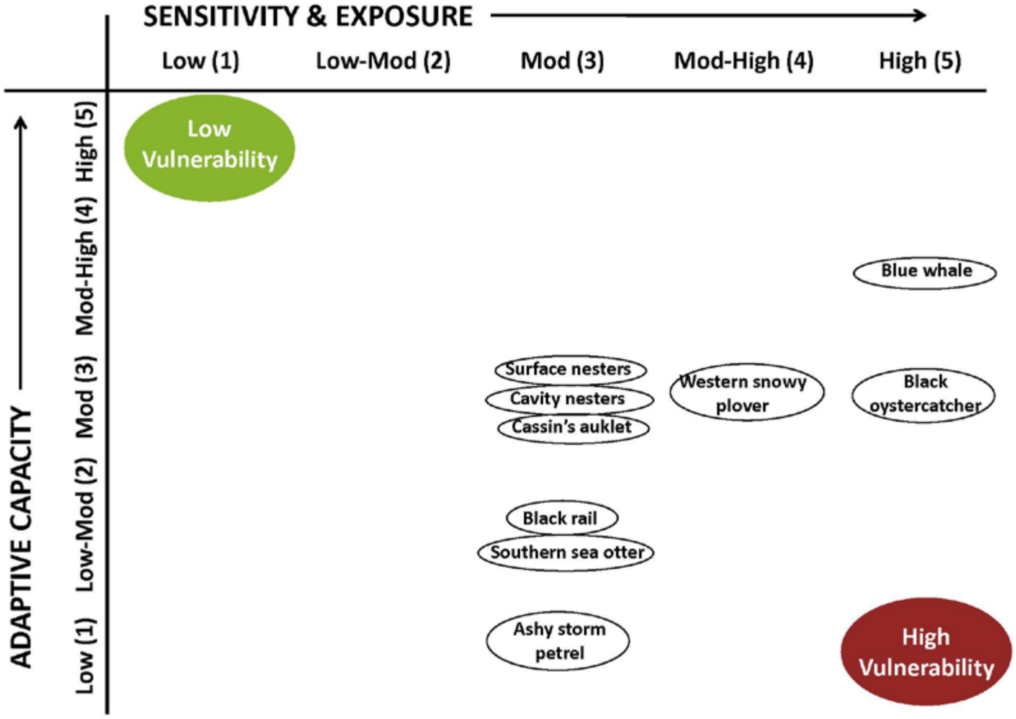

Figure 10. Overall vulnerabilities of all 11 bird and mammal species based on the climate change sensitivity, exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Species listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence ranged from moderate to high.

The bird and mammal species assessed cover a range of vulnerabilities (Figure 10), though in general were identified as being more vulnerable overall as compared to fish and invertebrate species; in fact, half of the species in this group are in the top ten most vulnerable of all species assessed (Table 2). The black oystercatcher received the highest vulnerability ranking, in part due to its high dependency on vulnerable habitats and high sensitivity and exposure to climate drivers and non-climate stressors like land use change and recreation. The other highly vulnerable bird species include ashy storm petrel, black rail, and Western snowy plover. The least vulnerable bird species identified are the tufted puffin and pigeon guillemot, which were grouped along with the ashy storm petrel as "cavity nesters" due to their similar characteristics; however, unlike the petrel, the puffin and guillemot have relatively greater adaptive capacity due to their more robust, widespread, and connected populations. The two mammal species assessed varied markedly in all components of vulnerability; the blue whale was identified as having overall moderate-high vulnerability with high sensitivity and exposure, whereas the Southern sea otter was moderately vulnerable, with moderate sensitivity and exposure. However, the blue whale was indicated as having a greater capacity to adapt to climate changes than the sea otter.

Ecosystem Services

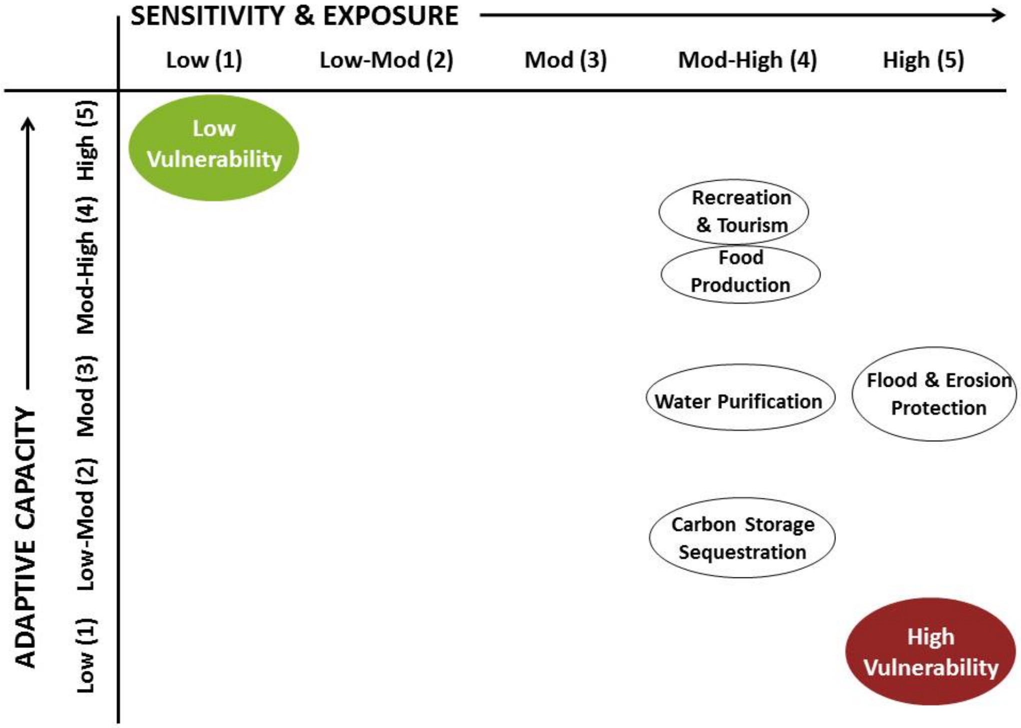

Figure 11. Overall vulnerabilities of five ecosystem services based on the climate change sensitivity, exposure, and adaptive capacity assessment. Overall vulnerability increases with increasing sensitivity and exposure, and decreasing adaptive capacity. Services listed in the upper left region were judged less vulnerable than those listed in the lower right region. Overall confidence was high for all ecosystem services.

The five ecosystem services assessed generally scored higher for exposure and sensitivity than species or habitats, ranging from moderate-high to high (Figure 11). Adaptive capacity was more variable, ranging from low-moderate to moderate-high. Those services that are provided primarily by the region’s coastal habitats were identified as being most vulnerable (Table 3) – flood and erosion protection, which is provided by estuarine and beach/dune habitat, carbon storage and sequestration, which is provided by estuarine habitat, and water quality, which is provided by estuarine and beach habitat.

The two most vulnerable ecosystem services were identified by workshop participants as being vulnerable for very different reasons. Habitats that protect human infrastructure from flooding and erosion are expected to experience relatively higher exposure and sensitivity to both climate-driven and non-climate stressors that will negatively impact sediment deposition and erosion, compromising the ability to provide this service. Alternatively, carbon storage and sequestration was identified as having a lower capability to adapt to climate change, primarily due to the lack of public support in protecting this ecosystem service which may make management of climate impacts challenging.

The least vulnerable ecosystem service category, recreation and tourism, was identified as having relatively high capacity to adapt to climate changes because the general public values recreation and tourism greatly, and will likely be willing to change behavior to retain these services, for example by modifying the location and extent of recreation and tourism activities. Also, local economies depend on this service category, so there will likely be strong support for protecting the provision of recreation and tourism locally.

Table 3. The calculated scores for overall vulnerability, exposure, sensitivity and adaptive capacity for the five ecosystem services assessed, ordered by decreasing vulnerability.

	Flood and Erosion Protection	Carbon Storage	Water Purification	Food Production	Recreation & Tourism
	SENSITIVITY				
Average	4.8	3.0	3.8	3.8	3.2
Rank	**High**	**Moderate**	**Mod-High**	**Mod-High**	**Moderate**
	EXPOSURE				
Average	5.0	5.0	4.0	4.0	4.0
Rank	**High**	**High**	**Mod-High**	**Mod-High**	**Mod-High**
	ADAPTIVE CAPACITY				
Average	3.3	2.3	3.3	3.8	4.0
Rank	**Moderate**	**Low-Mod**	**Moderate**	**Mod-High**	**Mod-High**
	VULNERABILITY				
Weighted Score	4.0	3.2	2.6	2.1	1.2
Final Rank	**Mod-High**	**Mod-High**	**Moderate**	**Moderate**	**Moderate**

Climate and Non-Climate Stressors

Tables 4 and 5 provide a ranked list of all climate and non-climate stressors identified by workshop participants during the sensitivity portion of the assessment for species and habitats. Stressors are ranked by decreasing mean sensitivity score; the number of resources that indicated each stressor as a sensitivity is also included. Stressors that scored a high mean sensitivity for many resources (e.g. wave action and invasive species) may represent priorities for managers to address because they apply to multiple resources in the study region and have a high overall impact. Managers may also want to consider developing climate-smart adaptation strategies and actions that address multiple high-ranking climate and non-climate stressors together. Some stressors are tightly linked and may be considered as consequences of the same climate stressor, such as wave action and coastal erosion, which are consequences of increasing storm severity and frequency.

Table 4. Climate stressors identified in the vulnerability assessment, listed by decreasing average sensitivity score for those species and habitats that identified the climate stressor as a sensitivity. Asterisk denotes those stressors identified by only 1 or 2 resources.

Climate Stressor	Average sensitivity score	Number of resources
Storm severity/frequency	4.67	6
Wave action	3.5	22
Coastal erosion	3.25	24
Salinity	3.23	26
pH	3.2	30
Sedimentation	3.17	4
Dynamic ocean conditions (currents/mixing/stratification)	3.14	29
Dissolved oxygen	3.08	24
Sea surface temperature	3.04	27
Sea level rise	2.94	18
Air temperature	2.81	21
Precipitation	2.54	26
Turbidity*	3	2
Upwelling*	5	1
Wind*	3	1
Pacific Decadal Oscillation*	4	1

Table 5. Non-climate stressors identified in the vulnerability assessment, listed by decreasing average sensitivity score for those species and habitats that identified the non-climate stressor as a sensitivity. Asterisk denotes those stressors identified by only 1 or 2 resources.

Non-Climate Stressor	Average sensitivity score	Number of resources
Roads/Armoring	3.88	8
Invasive and problematic species	3.78	17
Aircraft and vessels	3.67	3
Recreation	3.54	13
Pollution and poisons (including oil spills and run-off)	3.43	31
Land use change	3.33	14
Overwater/underwater structures	3.25	4
Harvest	3.07	20
Energy production	2	6
Natural predation*	4.5	2
Dredging *	4	2
Boat groundings *	3	2
Anthropogenic noise*	5	1
Disease*	5	1
Transportation *	2	1
Researcher disturbance*	1	1

Vulnerability Assessment Reports

The following section presents individual climate change vulnerability assessment reports for all 44 habitats, species, and ecosystem services considered as part of the Climate-Smart Adaptation Project for the North-central California Coast and Ocean. Reports are listed in alphabetical order within resource categories, with habitat reports presented first, followed by species reports, and ecosystem services reports. Four reports combine information for multiple species due to the similarities in most aspects of vulnerability: the Cavity Nesters report includes ashy storm petrel, tufted puffin, and pigeon guillemot; the Surface Nesters report includes Brandt's cormorant and common murre; Northern anchovy and Pacific sardine are combined in one report, as are California hydrocoral and red sponge.

Each individual assessment report is formatted in the same manner, with an executive summary that provides a brief introduction to the resource and its characteristics, as well as a summary score table that provides the vulnerability component scores and confidence levels. The reports are comprised of evaluations and comments from an expert-elicitation workshop, peer-review comments following the workshop, and relevant references from the literature. Supporting information was either gathered from available literature and cited as such, or was provided by workshop participants and cited as: Vulnerability Assessment Workshop, pers. comm., 2014. The sections titled "additional participant comments" include information supplied by participants that is supplementary.

During the workshop, participants assigned one of five rankings (5: High, 4: Moderate-High, 3: Moderate, 2: Low-Moderate, or 1: Low) to each finer resolution element of vulnerability components, and provided a corresponding confidence score to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for sensitivity, exposure and adaptive capacity. The resulting reports represent an evaluation of vulnerability based on existing information and expert input. These reports are intended to help managers develop and prioritize adaptation strategies to conserve these resources in the face of climate change, and are intended to be living documents that can be revised and expanded upon as new information becomes available.

Beaches and Dunes[1]

Executive Summary

Beaches and Dunes	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	4 Moderate-High	3 High

Beach and dune systems are formed from unconsolidated sand from coastal bluffs and watersheds, are shaped by a myriad of marine and terrestrial processes, and provide habitat for a variety of species, including pinnipeds, sea and shorebirds, and unique vegetation. Key climate sensitivities identified for this habitat by workshop participants include sea level rise, coastal erosion, wave action, and sediment supply and movement. Key non-climate sensitivities include coastal armoring and road construction, overwater/underwater structures, recreation, invasive species, and dredging. Beach and dune habitats are transcontinental in geographic extent, have moderate habitat connectivity, and have moderate structural and functional integrity due to impacts from coastal, inland, and watershed development. Beach and dune habitats have relatively low-moderate physical/topographical and functional group diversity, but moderate component species diversity, and feature key species such as sand crabs and talitrid amphipods. Overall, beach and dune habitats are highly valued and can recover quickly if they have space to migrate or have enough sediment supply to keep up with sea level rise and erosion. Potential management measures include beach nourishment and protection of retreat areas.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): sea level rise (5, high), wave action (5, high), coastal erosion (5, high), sediment supply and movement (5, high), wind (3, high), precipitation (2, moderate), pH (1, low)

Climate and climate-driven changes that may benefit the habitat: coastal erosion

- Description of benefits: Increased erosion of coastal cliffs and inland areas may prove beneficial to some beaches by increasing supplies of sediment that enable sediment deposition rates to keep up with rates of sea level rise.

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

- Confidence of workshop participants: High

Additional participant comments

Beaches and dunes are naturally very dynamic systems; if given room to migrate, they are likely to be resilient to climate and climate-driven changes, though much of their overall areal habitat extent might be lost

[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

Beach and dune systems are formed from unconsolidated sand from coastal bluffs and watersheds, and are shaped by a myriad of marine and terrestrial processes (Largier et al. 2010). Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered.

Sea Level Rise

Sea level rise can inundate current beach and dune systems and increase rates of shoreline erosion, potentially forcing upland retreat of beach and dune habitats (Feagin et al. 2005). Where development or other barriers (i.e., cliffs) block upland retreat, beach and dune habitats could suffer reduced areal extent and/or increased fragmentation, shifting from continuous habitat to narrower, steeper, and isolated pocket beaches (Largier et al. 2010). Reductions in beach and dune habitat could affect many species, including pinnipeds (e.g., elephant seals, harbor seals, sea lions) and nesting shore birds (e.g., western snowy plover). In addition, sea level rise can contribute to changes in relative proportions of the different ecological zones within beach habitats, which could lead to propagating changes in all levels of the food web (Dugan et al. 2008). Sea level rise can also disrupt successional dynamics and degrade habitat quality by preventing the formation of mature coastal dune vegetation communities (Feagin et al. 2005).

Wave Action

Wave action, which varies seasonally and according to local and more broad scale climatic processes, shapes beach and dune systems, contributes to erosion, and affects key species. Wave heights in winter can be in excess of 8 m and are driven by extra-tropical cyclones in the North Pacific, smaller, shorter period waves in summer are generated from winds stemming from the North Pacific High (Wingfield and Storlazzi 2007), and local winds affect wave heights throughout the year. Waves, particularly larger wave heights associated with late winter El Niño events, are often the main driver of beach and dune erosion, as these large, late winter waves coincide with when beaches are at their narrowest widths (Storlazzi and Griggs 2000; Wingfield and Storlazzi 2007). Waves can also increase coastal flooding (Storlazzi and Griggs 2000; Wingfield and Storlazzi 2007), potentially inundating dune and beach areas and forcing landward retreat of these habitats (Feagin et al. 2005). Waves can also shift distributions of sandy shorelines. For example, shifts in the Pacific Decadal Oscillation (PDO) can alter wave directions, exposing sheltered beaches to significant erosion and/or rotating sandy shoreline segments to the north and increasing erosion in southern ends of littoral cells (Sallenger et al. 2002). In addition, intense wave action during storms or larger wave heights coinciding with high tides can negatively affect key species such as sand crabs and talitrid amphipods, impacting larger food webs (Dugan et al. 2008) and nutrient cycling (Lastra et al. 2008).

Coastal Erosion

Coastal erosion can have varying impacts on beach and dune systems. For example, beach erosion combined with sea level rise can reduce beach and dune habitat, especially in areas where beaches are backed by coastal cliffs (i.e., a majority of beaches in the study area) (Largier et al. 2010). Reduction of beach and dune habitat can negatively impact component species such as sand crabs and wrack consumers, as well as species that depend on beach habitats for breeding and nesting (i.e., pinnipeds and seabirds) (Largier et al. 2010). Alternatively, erosion of coastal cliffs may help some beach and dune systems keep pace with sea level rise by increasing local sediment delivery and enhancing sandy beach habitat (Sarah Allen, pers. comm., 2014). In addition, erosion of upland or inland sediments can increase sediment transport and delivery to beach and dune areas (Sarah Allen, pers. comm., 2014).

Sediment Supply and Movement

Sediment supply and movement influences the areal extent of beach and dune systems, and is controlled by a variety of climate and climate-driven factors (i.e., wave action, coastal erosion, currents, precipitation), as well as by changes within the "sediment-shed" (i.e., changes in the watershed, coastal wetlands, or the littoral cell) (Revell et al. 2007; Largier et al. 2010; Vulnerability Assessment Workshop, pers. comm., 2014). Surpluses in local sediment budgets typically increase beach width and minimize shoreline erosion, while sediment deficits result in narrower beaches with significant rates of coastal erosion (Largier et al. 2010). Reductions in beach width can also expose dune habitats to increased wave exposure (Largier et al. 2010). Sediment supply will vary according to many factors. For example, short, heavy precipitation events can increase freshwater sediment discharge and bolster beach and dune systems, though this dynamic is mediated by inland water and sediment retention structures such as dams (Slagel and Griggs 2008; Largier et al. 2010). Alternatively, wave action can deliver or remove sediment, leading to dynamic changes in beach shape and size over the course of different seasons.

Beaches and dunes are also sensitive to precipitation and pH, but to a lesser extent than the afore-mentioned factors. For example, pH can affect sand crab shell formation and the foraging value of beach and dune habitat (Vulnerability Assessment Workshop, pers. comm., 2014), while precipitation and subsequent runoff can increase sediment delivery to beach and dune systems and/or contribute to shifting soil salinities in dune vegetation communities (Williams et al. 1999; Greaver and Sternberg 2007).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind and storms

Overall habitat sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

Wind, influenced by air and sea surface temperatures, affects sediment supply and movement, periodically adding, removing, and repositioning sand within beach and dune systems. Storms affect wave height, influence rates of erosion, and can alter sediment supply.

Supporting literature

Winds are typically stronger in spring and summer and weaker in fall and winter (Largier et al. 2010). Alongshore winds increased from 1940-1990 (Bakun 1990; Schwing and Mendelssohn 1997; Mendelssohn and Schwing 2002), and are expected to increase in all seasons in the future, particularly in summer and fall, due to increasing differences in land-ocean pressures and temperatures (Snyder et al. 2003; Auad et al. 2006; Largier et al. 2010). In addition to the impacts mentioned by workshop participants, winds may impact the delivery of cold, nutrient-rich water to beach habitat, impacting the availability of food for suspension feeders (Dan Robinette, pers. comm., 2014). Storms are typically more common in winter, and can vary in intensity, magnitude, and direction according to larger climate forcings such as the El Niño Southern Oscillation (ENSO) or the Pacific Decadal Oscillation.

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): coastal roads/armoring (5, high), overwater/underwater structures (4, high), recreation (3, high), invasive species (3, moderate), dredging (3, moderate)

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

- Confidence of workshop participants: High

Overall habitat exposure to non-climate stressors: Moderate

- Confidence of workshop participants: High

Additional participant comments

Shifting water storage demands could affect dam operations in the future, with further impacts on sediment delivery to beach and dune habitats. Recreation can have direct impacts on beach and dune systems, but is also a critical factor in maintaining stewardship support. Invasive and problem species outcompete native dune vegetation, can lock up foredune sand supply, and prevent upland migration of this system. Dredging can influence sediment supply for beach and dune systems by reducing supply if dredged sediment is disposed of outside the littoral cell, which can increase beach and dune sensitivity to climate changes. Alternatively, dredged materials can be used for beach nourishment, which could bolster beach and dune resilience (e.g., by offsetting erosion), though also negatively impact the infaunal community.

Supporting literature

Armoring/Roads

Coastal armoring and road construction prevent upland beach and dune migration in response to sea level rise and increased passive erosion, increasing the sensitivity of beach and dune systems. Passive erosion related to armoring or road structures can shift habitat zones downward on the beach profile by "drowning" upper beach areas, disproportionally degrading upper and mid beach habitat (Dugan et al. 2008). These effects will only become more pronounced with sea level rise as these structures interact with waves and tides (Dugan et al. 2008). In addition, armoring can replace beach habitat, reducing beach extent and negatively impacting bird species (Dugan et al. 2008). Armoring is projected to increase, although beach nourishment is now being used more frequently as an alternative (Defeo et al. 2009).

Overwater/Underwater Structures

Overwater and underwater structures can alter sediment supply and delivery and impair the resiliency of beach and dune habitats. Dams and debris basins in watersheds can trap sediments and alter peak flows, effectively reducing sediment transport to beach and dune systems which increases littoral cell sediment deficits and the potential for erosion (Willis and Griggs 2003; Slagel and Griggs 2008; Largier et al. 2010). For example, multiple dam projects on the Russian

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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.

River reduced annual coarse-grained sediment supplies by more than 30% (Slagel and Griggs 2008).

Recreation
Recreational use can lead to trampling of vegetation or sensitive habitat areas, as well as to behavioral modifications in beach and dune wildlife (e.g., bird nest abandonment and seal beach abandonment) (Grigg et al. 2002; Schlacher et al. 2007; Largier et al. 2010). The accumulation of plastics and other human trash as a result of recreation and use can negatively impact beach and dune systems through direct impacts to species (entanglement, ingestion, smothering) and indirect impacts to the habitat itself (clean-up efforts and introduction of invasive species) (EPA 2012). Coastal recreational pressure could increase as a result of population growth and increased inland temperatures (Vulnerability Assessment Workshop, pers. comm., 2014).

Invasive and problem species
Many dunes have been invaded by European beachgrass (*Ammophilia arenaria*), resulting in reduced species richness (Barbour et al. 1976), changes in dune shape and orientation relative to the ocean (Barbour and Johnson 1988), and degradation of the habitats that back dunes, such as swales (Randall and Hoshovosky 2000). Iceplant/hottentot fig (*Carpobrotus edulis*), another harmful non-native plant, creates deep mats that exclude native vegetation (California State Parks 2009). Additionally, non-native species such as the sea fig (*Carpobrotus chilensis*) and the Uruguayan pampas grass (*Cortaderia selloana*) could also negatively impact dune systems in the study region (ONMS 2014). Non-invasive, problem species, such as gulls, ravens, foxes, coyotes, dogs, feral cats, skunks and racoons often follow human activity into beach and dune habitat, negatively impacting shorebird species, such as the snowy plover, and altering ecological dynamics (Campbell 2013; Dan Robinette, pers. comm., 2014).

IV. Other sensitivities: none identified

Additional participant comments

Increasing pressure for more water storage projects may result in impacts to the supply and transport of replenishing sediments to beach and dune habitats. Additionally, a growing population and increased inland air temperatures may result in increased pressure on beach and dune habitats. Because of their dynamic nature beach and dune habitats that have sufficient room to migrate will probably be fairly resilient to climate change impacts. However, much of the areal extent of these habitats may be lost.

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 3 (Altered but not degraded)

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Supporting literature

Sandy beaches are a small but important component of the North-central California coastline (SIMoN 2014), and occur in varying forms, primarily pocket beaches tucked amongst the rocky coastline and narrow beaches that front cliffs, as well as occasional linear beaches backed by dunes (Hapke et al. 2006). The largest beaches occur near the Gualala and Russian Rivers, and beach/dune systems occur near Bodega Head and Point Reyes (Largier et al. 2010). The structural and functional integrity of dunes is undermined by beach front development, which prevents natural adaptation to changes in shoreline stability (Clark 1996), erosion, and sea level rise (Nordstrom 2000; Schlacher et al. 2007). Other factors, such as altered sediment dynamics and coastal and watershed perturbations, also decrease the integrity of this ecosystem.

II. Resistance and recovery

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

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Additional participant comments

Beach and dune habitats are naturally very dynamic, and with sufficient room to migrate, may prove to be resilient to climate change impacts. However, coastal development and coastal roads/armoring may adversely impact the ability of beach and dune habitats to recover from and adapt to rising sea levels and increased coastal erosion.

III. Habitat diversity

Physical and topographical diversity of the habitat: Low-Moderate

- Confidence of workshop participants: Moderate

Diversity of component species within the habitat: Moderate

- Confidence of workshop participants: Moderate

Diversity of functional groups within the habitat: Low-Moderate

- Confidence of workshop participants: Moderate

Keystone or foundational species within the habitat: Beach and dune habitat quality depends on some key species, such as sand crabs (*Emerita analoga*) that are critical to the food web, and talitrid amphipods (family *Talitridae*) for wrack processing.

Additional participant comments

Other diversity factors important to consider are landscape-level diversity and an intact habitat mosaic, as these are important factors in determining the functionality and value of beach and dune habitats.

Supporting literature

Beaches and dunes are formed from unconsolidated sand from watersheds and coastal bluffs, and are constantly being shaped by wind, waves, and tides. Dune habitats are found in the supralittoral zone, while beach habitats feature three ecological zones: supra-littoral at or above the drift line, middle intertidal, and lower intertidal (Largier et al. 2010). Landscape level diversity and intact habitat mosaics determine the functional and habitat value of beach and dune systems. (Peter Baye, pers. comm., 2014). Beaches and dunes provide key habitat for a variety of species. For example, dunes are home to many unique and threatened plants, while the uppermost intertidal zones of sandy beaches are important for California grunion (*Leuresthes tenuis*) and smelt spawning (Thompson 1919) and pinniped pup rearing. Open beach and dune habitats also provide feeding and nesting habitat for shorebirds, including the threatened western snowy plover (*Charadrius alexandrines nivosus*), which nests in the dry sand zone. Sand crabs are the most abundant invertebrate in beach and dune habitats, acting as a critical component of the food web by filter-feeding plankton from the ocean and acting as a food source for shorebirds, gulls and sea otters (Largier et al. 2010; SIMoN 2014). Talitrid amphipods play a key role in wrack processing and nutrient cycling (Lastra et al. 2008). Both of these groups are highly sensitive to changes in erosion and storms, among other factors (Largier et al. 2010).

IV. Management potential

Value of habitat to people: High

- Confidence of workshop participants: High
- Description of value: Humans value beach and dune habitats for their natural storm protection, aesthetics, and for the recreational opportunities that they provide, such as surfing, fishing, vacations, and driving of off-road vehicles.

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

- Confidence of workshop participants: High
- Description of potential management options: Management likelihood varies by location. For example, some beaches and dunes will likely be prioritized for beach nourishment, especially those that are of high recreational or ecological value. Protected areas also provide opportunities for beach and dune systems to retreat in the face of sea level rise and erosion. In comparison, beach and dune areas that are backed by development or natural barriers (i.e., cliffs) that prevent migration or prevent natural beach nourishment are likely to disappear. For many of these threatened locations, there is no economic justification for nourishment intervention based on their perceived level of use. Beach nourishment or near-shore disposal sites for dredged materials are available management steps to bolster the adaptive capacity of beach and dune systems.

Supporting literature

Beach clean-ups are a means of both improving quality of habitat and building public support and investment in beach health (Dan Robinette, pers. comm., 2014).

V. Other adaptive capacities:

Critical factors not addressed that may affect habitat's adaptive capacity: sediment supply and transport

- Degree to which these factors affect the habitat's adaptive capacity: High
- Confidence of workshop participants: High

Additional participant comments

Sediment supply and transport are critical to beach and dune habitats, and are impacted by both climate change impacts and human disturbances.

Exposure

I. Future climate exposure[6]

Future climate and climate-driven factors identified (score[7], confidence[8]): sea level rise (5, high), increased storminess (5, high), increased coastal erosion and runoff (5, high), increased flooding (3, low)

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

- Confidence of workshop participants: High

Additional participant comments

Potential refugia areas include beaches and dunes that are very wide and/or those that have room to migrate inland (i.e., are not back by development or natural barriers), which may represent only a small percentage of habitat area within the study region. Beach and dune systems are sensitive to extreme increases in the duration or frequency of flooding.

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

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

[8] Confidence level indicated by workshop participants.

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Cliffs[1]

Executive Summary

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

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

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

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

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

- Confidence of workshop participants: High

Additional participant comments

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

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

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

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

[4] Confidence level indicated by workshop participants.

Supporting literature

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

Extreme Weather Events

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

Wave Action

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

Coastal Erosion

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

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

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

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

II. Sensitivities to disturbance regimes

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

Overall habitat sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Supporting literature

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

III. Sensitivity and current exposure to non-climate stressors

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

Overall habitat sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: High

Overall habitat exposure to non-climate stressors: Low

- Confidence of workshop participants: High

Additional participant comments

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

Supporting literature

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

Land Use Changes

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

Roads and Armoring

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

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

[6] Confidence level indicated by workshop participants.

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

Urban Runoff

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

IV. Other sensitivities identified by workshop participants

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

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

Supporting literature

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

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 4 (Minor to moderate alterations)

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Supporting literature

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

II. Resistance and recovery

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

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Supporting literature

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

III. Habitat diversity

Physical and topographical diversity of the habitat: Low-Moderate

- Confidence of workshop participants: High

Diversity of component species within the habitat: Low

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Low

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: none identified

Supporting literature

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

IV. Management potential

Value of habitat to people: Moderate-High

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

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

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

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[7]

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

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

- Confidence of workshop participants: Moderate

Supporting literature

Increased coastal erosion and runoff

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

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

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

[9] Confidence level indicated by workshop participants.

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

Precipitation

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

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Estuaries: ephemeral and year-round[1]

Executive Summary

Estuaries	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	5 High	3 High
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	4 Moderate-High	3 High

The estuarine habitat includes small and sandbar-built estuaries within the study region, such as Pescadero Marsh, Estero Americano and Estero de San Antonio, and moderately sized bays such as Tomales Bay, Drakes Estero, and Bolinas Lagoon. Key climate sensitivities identified for this habitat by workshop participants include sea level rise, sea surface temperature, precipitation, and wave action. Key non-climate sensitivities include land use change, overwater/underwater structures, roads and armoring and invasive species. This habitat has a transcontinental geographic extent, is patchily distributed throughout the study region, and is considered to be in a somewhat degraded condition, due to land use pressures, water diversion, pollutants and sedimentation. A diverse range of coastal formations and the interplay of terrestrial, freshwater and marine influences result in a highly diverse and productive community that supports multiple commercial and recreational fisheries and provides protection from coastal erosion that may impact populated coastal communities. Resistance to stressors is low, though recovery from stressors may be possible with appropriate conservation efforts and ongoing management activities.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

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

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

- Confidence of workshop participants: High

Supporting literature

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

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

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

[3] Confidence level indicated by workshop participants.

Sea Level Rise

Sea level rise will exacerbate shoreline erosion and cause saltwater intrusion, possibly increasing salinity by as much as 9 practical salinity units in the region's estuaries (Knowles and Cayan 2002). Unless there is a comparable increase in elevation of the land surface due to sediment delivery and availability, estuarine habitat will not be able to adjust to rising sea levels, and flooding will also be expected (Largier et al. 2010, Ackerly et al. 2012). Tidal flux may be altered, including the timing and extent of the rise and fall of the tide (Largier et al. 2010). Estuarine habitats more dependent on organic deposition (microtidal) rather than inorganic sediment deposition (mesotidal) will likely be more impacted by changes in sea level (Stevenson et al. 1986, Stevenson and Kearney 2009).

Sea Surface Temperature

Increasing water and air temperatures are magnified in estuaries relative to the outer coast and are important drivers of community and ecosystem responses in estuaries. Increasing water temperatures can result in the range expansion of both native and non-native species into new areas (Williams and Grosholz 2008), and can have significant demographic effects as well. Water temperatures may also impact the incidence of disease in estuarine species, estuarine circulation, the amount of oxygen that can dissolve in the water (which is critical for the survival of estuarine species), and key physiological processes in estuarine species that are temperature-dependent (NOAA Ocean Service Education 2008).

Precipitation

Changing patterns in precipitation may have consequences for the impact of invasive species, sediment deposition, erosion, flooding, river flow (which may impact the timing of mouth opening and closure of some estuaries), water chemistry and run-off. The seasonality of estuarine hydrology, including rainfall and water flow from rivers into estuaries will influence the transport and deposition of sediments with long-term consequences for estuarine physical structure. Increase in storm and precipitation intensity will likely lead to more frequent and severe flooding of estuaries and will greatly impact river flow, which will likely alter the timing of estuarine mouth opening and closing (Largier et al. 2010).

Wave Action

Increased storm activity, including wave action, will have important implications for flooding of estuarine habitat, the state of the estuarine mouth, and the timing of estuarine mouth opening and closing (Largier et al. 2010). The mouths of estuaries will tend to close with stronger wave energy, and may close earlier or later than usual depending on the interaction with river flow.

II. Sensitivities to disturbance regimes

Disturbance regimes considered: storms, flooding, and disease

Overall habitat sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Flooding

Increased flooding is expected with sea level rise and more intense precipitation events (see above). The estuarine habitat is highly sensitive to flooding because of the critical habitat that may be inundated, including mud flats for shorebird foraging (Stralberg et al. 2008) and pinniped resting and breeding (Sarah Allen, pers. comm., 2014). Landward migration of intertidal habitat may be restricted due to armoring, roads, and other structures.

Storms

Models suggest that the tracks of storms in the northeast Pacific Ocean will experience an increase in occurrence of extreme conditions, though the number of extreme events may not change (Largier et al. 2010). Increased storm intensity will impact both wave energy and the timing and intensity of precipitation events, with major consequences for estuarine habitat (see *Wave Action* and *Precipitation* sections above).

III. Sensitivity and current exposure to non-climate stressors

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

Overall habitat sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Supporting literature

Land Use Change

Land use pressures have impacted water quality in some of the region's estuaries, resulting in changes to sediment and freshwater regimes (ONMS 2010). Increased sedimentation can result from land use, causing the burying of oyster and eelgrass habitat and increasing the duration of mouth closure. Livestock grazing and agricultural runoff (primarily animal waste from dairies and rangelands) can result in high coliform and bacterial contamination, increased sedimentation and contamination with toxic materials (e.g., high mercury levels) in estuary waters (ONMS 2010). Freshwater diversions for agriculture and other human uses cause hypersaline conditions, slow circulation, and may result in the persistent closing of estuarine mouths due to reduced tidal prism (ONMS 2010).

Overwater/Underwater Structures

Fishing activities can impact eelgrass and oyster beds, and mariculture of several bivalve species in Tomales Bay has potential negative impacts, including the presence of mariculture-farming equipment that can reduce eelgrass cover, alter sediment deposition patterns, and provide large amounts of hard substrate that is not naturally present, thus altering species communities, and maintenance operations that trample sediments and damage eelgrass beds (Carr et al. 2008). Substantial loss of native oyster beds in Tomales Bay has resulted from increased moorings and anchored and abandoned vessels that impact the benthos. Vessel propellers, anchors, and moorings can damage the underground root and rhizome system of eelgrass and impact oyster beds (ONMS 2010).

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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.

Roads/Armoring

An important factor that will influence estuarine response to sea level rise is the ability of estuaries to migrate inland. Where the upland border abuts roads, levees or other armored structures, an accelerated loss of habitat may be expected (Fletcher et al. 1997, Dugan et al. 2008). Road construction and coastal armoring continues to be a problem in the study region, specifically Bolinas Lagoon and Tomales Bay, and in other areas of coastal development. Although localized, these activities can have a high impact as they can convert habitat type, increase erosion rates, and have the potential to result in large-scale debris (ONMS 2010).

Invasive species and other problematic 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. It is estimated that about 143 species of invasives are present in the region, most of which exist in the estuarine zone (Byrnes et al. 2007), including European green crabs (*Carcinus maenas*) which prey on and compete with native crabs, Japanese mud snails (*Batillaria attramentaria*) whose dense aggregations impact mudflat communities (Dewar et al. 2008), and smooth cordgrass (*Spartina alterniflora*) and its hybridization with the native cordgrass (*Spartina foliosa),* resulting in loss of habitat for salmon and oysters, and economic losses for those who rely on these species (Brusati 2008, ONMS 2010). Invasive species threaten the abundance and/or diversity of native species, disrupt ecosystem balance and threaten local marine-based economies (SIMoN 2014). Climate change is likely to enhance the negative impacts of coastal invaders. Stachowicz et al. (2002) documented earlier and greater recruitment of invasive tunicates as well as increased growth under warmer sea surface temperatures, and predicted that increasing temperatures will ultimately lead to more successful invasive species.

IV. Other sensitivities

Other critical factors likely to influence habitat sensitivity to climate change: restoration potential, resilience, and public awareness

Degree to which these factors influence habitat sensitivity to climate change: High

- Confidence of workshop participants: High

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 2 (somewhat degraded)

- Confidence of workshop participants: High

Continuity of habitat: 2 (somewhat isolated and/or fragmented, i.e. patchy)

- Confidence of workshop participants: High

Supporting literature

Estuaries occur worldwide along the coastal zone wherever rivers meet the ocean; they cover a global area of around 106 km^2 and encompass around 4% of the world's continental shelf. Major estuaries found in the study region include Tomales Bay, Bolinas Lagoon, Estero Americano and Estero de San Antonio, Drakes and Limantour Esteros, and Abbotts Lagoon. Pescadero and Scott's Creek marshes are also in the study region. The 2010 GFNMS Condition Report rates the region's estuaries and lagoons as good/fair to fair/poor condition due to land use pressures, water diversion, pollutants and sedimentation. The state has listed Tomales Bay, Estero Americano and Estero de San Antonio as impaired bodies of water under the 303(d) listing (SWRCB 2006) due to a broad range of impacts, including high nutrient loading, increased siltation and bacteria. Biodiversity in the region's estuaries is rated as fair/poor to declining, due to loss and alteration of eelgrass habitat, a key habitat for estuarine species, particularly in Bolinas Lagoon (T. Moore, pers. comm., as cited in ONMS 2010).

II. Resistance and recovery

<u>Habitat resistance to stressors/maladaptive human responses</u>: Low

- Confidence of workshop participants: High

<u>Ability of habitat to recover from stressor/maladaptive human response impacts</u>: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Conservation efforts may help achieve partial recovery of upper trophic levels, but have failed thus far to restore ecosystem structure and function (Lotze et al. 2006). In a comprehensive review of estuarine and coastal recovery, Borja et al. (2010) concluded that, though estuaries do respond well to restoration efforts, full recovery of an estuarine system may take a minimum of 15-25 years, with biodiversity of the system lagging behind. Recommendations for climate-smart restoration solutions include raising infrastructure off the marsh to allow for flooding and movement, allowing estuaries to open and close as conditions change, embrace resiliency and restore living shorelines (Ross Clark, pers. comm., Headwaters to Ocean Conference, 2014).

III. Habitat diversity

<u>Physical and topographical diversity of the habitat</u>: High

- Confidence of workshop participants: High

<u>Diversity of component species within the habitat</u>: High

- Confidence of workshop participants: High

<u>Diversity of functional groups within the habitat</u>: Moderate-High

- Confidence of workshop participants: Moderate

<u>Keystone or foundational species within the habitat</u>: none identified

Supporting literature

A diverse range of coastal formations is included in the estuary designation, including bays, inlets, lagoons, wetlands, marshes and esteros. Estuaries may be bar-built and ephemeral, year-round open river mouths, or perennially tidal (SWRCB 2006). Because of this diversity in terrestrial, freshwater and marine influences, estuaries support highly diverse communities, including eelgrass nursery habitat for commercially and recreationally important fish species, shorebirds, waterfowl, crabs, shrimp and many other invertebrates (Largier et al. 2010, SIMoN 2014). Eelgrass (*Zostera marina)* is a keystone species in the estuarine habitat; 10 to 100 times more animals can be found in eelgrass beds compared to adjacent sandy and muddy habitats (Olyarnik 2007). This species has shown signs of decline in some estuaries, including nearly extinct levels in Bolinas Lagoon (Leet et al. 2001, GFNMS 2008). A key factor for eelgrass health is water clarity and quality, which is greatly impacted by human activities and land use. An additional component of estuarine habitat is sand bars that are exposed at low tides and provide important habitat to shorebirds, waterbirds and pinnipeds (Sarah Allen, pers. comm., 2015).

IV. Management potential

Value of habitat to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: no information provided

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

- Confidence of workshop participants: Low
- Description of likelihood of managing or alleviating climate change impacts: The likelihood of managing or alleviating climate change impacts will depend on the extent of existing habitat and the value of the habitat.

Supporting literature

Estuaries are valued, in part, due to the fisheries that are supported by nursery grounds, including commercial harvest of oysters in aquaculture facilities, sport take of clams, and some fishing for herring, rock crab, perch and halibut (ONMS 2010). Estuaries are also recognized as providing a buffer from coastal erosion and inundation for populated communities along the coast. Past and ongoing management activities that have reduced impacts to the region's estuaries include implementation of best management practices to reduce runoff, the closure and restoration of a mercury mine, the development of a vessel management plan to address illegal moorings in eelgrass, and the removal of abandoned vessels from Tomales Bay (ONMS 2010). Information on current management activities can be found for Bolinas Lagoon (http://farallones.noaa.gov/eco/bolinas/bolinas.html) and Tomales Bay (http://farallones.noaa.gov/eco/tomales/tomales.html).

V. Other adaptive capacity factors

Other critical factors that may affect habitat's adaptive capacity: room to migrate

Degree to which factors affect habitat's adaptive capacity: High

- Confidence of workshop participants: High

Additional participant comments

Beach and dune habitats that are bound by natural or human built structures will have a low adaptive capacity to climate change impacts.

Exposure

I. Future climate exposure[6]

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

Exposure of habitat to future climate and climate-driven changes: High

- Confidence of workshop participants: High

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

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

[8] Confidence level indicated by workshop participants.

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Kelp Forest[1]

Executive Summary

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

The rocky nearshore environment in the study region is characterized by dense forests of kelp that occur at varying depths (approximately 4 to 25 meters). The bull kelp, *Nereocystis luetkeana*, is the dominant canopy-forming kelp and tolerates high wave action. Kelp forest habitats can also feature sub-canopies of feather boa kelp, *Egregia menziesii*, and understories of other kelp species (e.g. *Pterygophora californica*, and other Laminariales). Key climate sensitivities identified for this habitat by workshop participants include dissolved oxygen, salinity, wave action, sea surface temperature, and dynamic ocean conditions. Key non-climate sensitivities include pollution and oil spills. Kelp forest habitat has a broad geographic extent, is patchy in its distribution, and considered to have moderate to high structural and functional integrity. This habitat has a high degree of topographical and biological diversity, which supports recreational activities, multiple fisheries, and, to a lesser extent, kelp harvesting. As the dominant canopy-forming kelp in the study region, bull kelp is able to rapidly colonize new areas, though only under certain environmental conditions that favor it over other competitors (including giant kelp). Community dynamics between bull kelp, its grazers, and their predators is important in structuring the distribution of the kelp forest habitat. Potential management measures include alterations to the allowable urchin harvest to limit their grazing impact.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): salinity (5, high), dissolved oxygen levels (5, high), wave action (5, high), sea surface temperature (4, high), pH (3, moderate), dynamic ocean conditions (currents/mixing/stratification) (3, moderate), sea level rise (2, low), precipitation (2, moderate), coastal erosion (1.5, moderate), air temperature (1, high)

Climate and climate-driven changes that may benefit the habitat: pH, dynamic ocean conditions, and sea surface temperature

- Description of benefits: Potential benefits to this habitat include the expected decrease in pH and associated increase in dissolved carbon dioxide, enhanced larval and nutrient transport that may result from altered currents and mixing, and decreased sea surface temperature due to enhanced upwelling that would benefit bull kelp and recruitment success for nearshore rockfishes.

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

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

[3] Confidence level indicated by workshop participants.

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

- Confidence of workshop participants: High

Additional participant comments

Nereocystis luetkeana, the bull kelp, is the central component of kelp forests in the North-central California region; sensitivity to change in the kelp forest habitat is directly linked to the sensitivity of this species.

Supporting literature

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

Salinity

The role of salinity in impacting and structuring kelp forest ecosystems has received little attention (Dayton 1985), though adverse effects of diluted salinity have been documented on two species of laminarian algae (Norton and South 1969) and on the germination of the Arctic kelp *Alaria esculenta* (Fredersdorf et al. 2009). Hurd (1919) demonstrated that bull kelp sporophytes develop blisters and wilt when subjected to rapid reductions in environmental salinity. Alternatively, healthy kelp forests have been observed growing in freshwater lenses in the Pacific Northwest (Dayton 1985).

Dissolved Oxygen

During strong spring upwelling events, kelp forest habitat may be exposed to low-oxygen waters, though hypoxic conditions are generally limited to greater depths (Largier et al. 2010). Grantham et al. (2004) documented mass die-offs of fish and invertebrates inshore of the 70m isobath during a severe hypoxic event in coastal Oregon in 2002, suggesting that extreme shoaling of the oxygen minimum zone to kelp forest depths would be catastrophic to the ecological community. However, kelp forest habitat may more likely act as a refuge during deeper hypoxic events due to the shallow depths of the habitat (abnormal fish aggregations observed <25m in Oregon, Grantham et al. 2004) and the high production of oxygen by the algal community (Frieder et al. 2012).

Wave action

Increasing significant wave heights will have a much greater impact on the southern-most kelp species in the region, the giant kelp, than it will on the dominant species in the region, the bull kelp, due to bull kelp's great adaptability to extreme physical forces. However, increased wave action may impact sediment redistribution and alter sand scour dynamics within reef communities, and may also force the movement of nearshore kelp forests into deeper water (Graham 1997) and create greater intra-annual variability in kelp productivity and abundance (Graham et al. 1997).

Sea Surface Temperature

In California, nearshore waters have shown an increasing temperature trend since 1955 (Mendelssohn et al. 2003), though water temperature over the continental shelf has cooled over the last 30 years (by as much as 1°C in some locations) due to stronger seasonal upwelling (Mendelssohn and Schwing 2002; Garcia-Reyes and Largier 2010). Continued warming of nearshore and enclosed bay waters is expected, while water temperatures are expected to cool over the continental shelf (Largier et al. 2010). Schiel et al. (2004) documented the effect of a

3.5°C increase in temperature in San Luis Obispo county caused by the thermal outfall of a nuclear power plant on kelp forest habitat dominated by a canopy of bull kelp and an understory mostly comprised of *Pterygophora californica* and *Laminaria setchellii*. After initiation of the thermal outfall, bull kelp was replaced by the giant kelp *Macrocystis pyrifera* and subcanopy kelps decreased while foliose red algae increased in abundance. Within the study region, this highlights the potential for bull kelp to be negatively affected by increased water temperatures and replaced by better-adapted competitors, although potential competitors (e.g., giant kelp) may also be sensitive to increased water temperatures, among other factors (Edwards and Hernández-Carmona 2005, Edwards and Estes 2006). A sustained sea temperature increase of 3°C is projected to greatly reduce kelp forests, which were temporarily damaged by the 1998 El Niño. Culture studies with bull kelp show that the thermal conditions allowing reproduction of the microscopic stages range from 3°C to 17°C (Vadas 1972).

Dynamic ocean conditions (currents/mixing/stratification)
At a local scale, kelp forest habitat is less sensitive to this factor than at a large, regional scale. Nutrient delivery and offshore transport of larvae and spores may be enhanced by intensified upwelling, which would be beneficial to bull kelp, benthic macroalgae, and phytoplankton (but may also disturb food particle concentration, which is critical to larval survival). However, in nearshore regions sheltered from the direct effects of upwelling, these factors may be reduced (Bakun 1990, Largier et al. 2010). In Southern California, where stratification is observed during summer, nitrate availability limits kelp forest productivity (Zimmerman and Kremer 1984, 1986; Zimmerman and Robertson 1985), which could occur in sheltered northern waters, bringing significant change to these habitats.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease and storms

Overall habitat sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

Invertebrate diseases may impact trophic interactions. Storms increase turbulence that exacerbates kelp dislodgement and sedimentation that may reduce the recovery of storm-damaged forests.

Supporting literature

Disease
Kelp forests are indirectly affected by disease; impacts of a sea otter or sea star disease may result in increased grazing by urchins (Conrad et al. 2005), and disease presence in local urchin populations may limit the grazing impact on kelp (Behrens and Lafferty 2004). The only known parasite that commonly infects bull kelp is *Streblonema* sp., a brown alga that causes distortions of the stipe including abnormal outgrowths and extended rugose areas. These deformations can weaken the stipe and may result in breakage during exposure to strong surge or storm conditions (CEQA 2001).

Storms
Increasingly intense run-off during extreme storm events may cause increased sedimentation that may negatively impact understory growth due to sand scour, and increased freshwater input to

the nearshore subtidal that may lead to higher resuspension of sediment resulting in increased turbidity and light attenuation. Increased turbidity will compromise kelp growth, and culture experiments indicate that total light quantity is the single most important factor in the development of the microscopic stages of bull kelp (Vadas 1972).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution (5, high), oil spills (3, low), harvest (grazers) (2, moderate), harvest (algae/kelp) (1, high), harvest (mid-trophic level species) (1, high)

Overall habitat sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Additional participant comments

Workshop participants expressed that they were not confident in their knowledge about the combined effects/interactions of non-climate stressors on kelp forest habitats because of a lack of data.

Supporting literature

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

Pollution and oil spills

Pollutants, including agricultural and livestock waste, wastewater, sewage outfalls, historic mining and industrial wastes, can be carried into the study region via the freshwater outflow from San Francisco Bay (Largier et al. 2010), significantly reducing water clarity and negatively impacting the survival and growth of bull kelp (Springer et al. 2006). High sedimentation from coastal run-off may bury new plant shoots. Studies on microscopic stages of kelp suggest that kelp is sensitive to sewage, industrial waste discharges, and other causes of poor water and sediment quality (NOAA 2013). Falkenburg et al. (2013) demonstrated that for kelp forest turf algae, whose expansion can restrict recruitment for kelp canopy species, the combined effect of increased CO_2 and increased nutrients is greater than the sum of the individual impacts, and that by limiting the nutrient input to kelp forest habitat, managers can substantially mitigate the potential for enhanced competitive interaction between turfing algae and kelp canopy species.

IV. Other sensitivities identified by workshop participants

Other critical factors likely to influence the sensitivity of the habitat: human population growth along the coast and the interactions between climate and non-climate factors

- Degree to which these factors affect the habitat's sensitivity: Moderate-High

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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.

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

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Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 4 (Minor to moderate alterations)

- Confidence of workshop participants: High

Continuity of habitat: 2 (Somewhat isolated and/or fragmented, i.e. patchy)

- Confidence of workshop participants: High

Supporting literature

Forests of bull kelp exist primarily along the Pacific coast of North America and are the dominant kelp forest north of Santa Cruz, California. Extensive beds of bull kelp can be found from Point Conception, CA to Unmak Island, AK (Abbott and Hollenberg 1976). When it grows alongside giant kelp, bull kelp will form a forest understory.

II. Resistance and recovery

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

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Supporting literature

Bull kelp can rapidly colonize a newly cleared or scoured location, though its longevity as the dominant canopy-forming kelp among other competitors is dependent upon favorable environmental conditions (Kalvass and Larson 2001).

III. Habitat diversity

Physical and topographical diversity of the habitat: High

- Confidence of workshop participants: High

Diversity of component species within the habitat: High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: High

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: Kelp, urchin, and sea otters

Supporting literature

Kelp forest habitats harbor high diversity, including diverse fish, algae, and invertebrate taxa (Carr et al. 2013). However, the functional redundancy of habitat-forming kelp species is very low, and kelp forests in the North-central California region are reliant on the abundance of the bull kelp species. This species alone supports a very diverse community of invertebrates, fishes and understory algae that rely on its presence. Sea urchins (*Strongylocentrotus* spp.) and their predators (large fishes, birds, crabs, sunflower stars, commercial/recreational fishing, and sea otters only in the very southern stretch of the study area) play critical roles in the stable equilibrium ecosystem. Sea urchins graze kelp and may reach population densities large enough to destroy kelp forests at a rate of 30 feet per month (NOAA 2013). Urchins move in "herds," and enough urchins may remain in the "barrens" of a former kelp forest to negate any attempt at regrowth. Sea urchin predators, playing a critical role in containing the urchin populations, prey on urchins and thus control the numbers of kelp grazers (NOAA 2013).

IV. Management potential

Value of habitat to people: High

- Confidence of workshop participants: High
- Description of value: Kelp forests are valued for their aesthetics, cultural value, and for the recreational (scuba, kayaking) and fishing opportunities they provide (rockfish).

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

- Confidence of workshop participants: Moderate
- Description of potential management options: Managers may be able to modify the allowable urchin harvest to better manage grazers and predators in the system.

V. Other adaptive capacity factors identified by workshop participants

Critical factors not addressed that may affect habitat's adaptive capacity: nutrients

- Degree to which these factors affect the habitat's adaptive capacity: Moderate
- Confidence of workshop participants: Low

Exposure[6]

I. Future climate exposure

Future climate and climate-driven factors identified (score[7], confidence[8]): increased storminess (5, high), decreased pH (5, high), sea level rise (5, high), altered currents and mixing (4, moderate), El Niño (2, low), decreased dissolved oxygen levels (2, low), changes in salinity (1, high), changes in precipitation (1, high), increased flooding (1, high), increased coastal erosion and runoff (1, high), changes in sea surface temperature (1, moderate)

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

- Confidence of workshop participants: High

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

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

[8] Confidence level indicated by workshop participants.

Supporting literature

Sea level rise will affect kelp forest communities through decreased light availability to sessile macroalgae and a forced shoreward migration, which will depend on available rocky substrate at shallower depths (Graham et al. 2003, 2008). Sea level rise may also change the shape of the coastline and substrate composition (i.e., rocky vs. sandy shores; Graham 2007), and thus impact the availability and living conditions of macroalgae and their associated species. The associated elevation of dissolved CO_2 with decreasing pH may benefit bull kelp and other noncalcareous macroalgae by increasing growth and production (Hepburn et al. 2011), but this could also lead to competitive interactions between canopy kelp species and turfing algae (Falkenberg et al. 2013).

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Nearshore soft-bottom[1]

Executive Summary

Nearshore soft-bottom	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	4 Moderate-High	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

The nearshore zone extends from the surf out to waters that are approximately 30 meters deep (100 feet). This habitat lacks hard substrate and is greatly impacted by waves and currents. Key climate sensitivities identified for this habitat by workshop participants include coastal erosion, pH, wave action and turbidity. Key non-climate sensitivities include pollution and land use change. The nearshore soft-bottom habitat has a wide-ranging and continuous distribution and is considered to have moderate-high functional integrity, with only minor to moderate alterations, likely a result of compromised water quality. This habitat has moderate-high potential to resist climate impacts due to these characteristics, and may be able to recover moderately well due to the extensive dispersal capabilities of macroinvertebrate larvae. The habitat itself is rather homogenous, and there is moderate diversity in species and functional groups, with two major biological communities organized along a wave gradient. Societal value and management potential for this habitat are considered low-moderate.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

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

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

- Confidence of workshop participants: Moderate

Supporting literature

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

Coastal Erosion

Nearshore habitats may be directly impacted by coastal erosion or indirectly via human responses such as armoring and beach nourishment that will impact sediment supply and run-off (Largier et al. 2010). Erosion transports sediment into nearshore waters, which does help to

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

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

[3] Confidence level indicated by workshop participants.

maintain soft-bottom habitat. However, if sedimentation is excessive, negative impacts can include smothering of benthic invertebrates, reduced survival of fish eggs, oxygen depletion and increased turbidity (Schueler 1997).

Turbidity

Turbidity has been shown to negatively impact soft-bottom invertebrates, including mass die-offs of mole crabs in Atlantic Beach (Reilly and Bellis 1983), significantly reduced growth of clams (Lindquist and Manning 2001), and reduced feeding success of filter feeders due to gill clogging. A reduction in filter feeding invertebrates may further reduce water clarity and water clearing capacity (Auster and Langton 1999). Increased turbidity also reduces light penetration which reduces primary productivity of benthic microflora and phytoplankton (Auster and Langton 1999). Decreased primary productivity will affect demersal zooplankton that support higher trophic level organisms.

pH

Nearshore habitat of the north-central California coast is vulnerable to exposure of future acidification from seasonal upwelling, which transports acidified waters that are under-saturated with respect to aragonite from offshore onto the continental shelf (Feely et al. 2008; Gruber et al. 2012). However, carbonate chemistry in nearshore coastal areas can also vary according to localized freshwater inputs and/or other factors (e.g., acid-base reactions), which can compound or ameliorate acidification trends at various time scales and affect both the benthic and pelagic habitats critical for marine invertebrates (Waldbusser and Salisbury 2014). Acidified upwelled water may negatively impact calcifying organisms by making it more difficult to calcify and by potentially dissolving calcified structures (Gazeau et al. 2007, Doney et al. 2009, Doney 2010, Gruber et al. 2012, Bednarsek et al. 2014), which can affect marine food webs (Sydeman and Thompson 2013 and citations therein) and can lead to changes in population abundances due to altered predation dynamics (Dixson et al. 2010).

Wave action

Waves are a critical feature of disturbance to the nearshore habitat, removing as much as a meter of sediment at depths greater than 10 meters (Hodgson and Nybakken 1973). Sediment redistribution and the topography of the habitat are both highly impacted by increased significant wave heights (Largier et al. 2010). Biological communities in the nearshore soft-bottom are organized along a wave-induced gradient (crustaceans inhabiting the more wave-impacted zone, and polychaetes dominating the deeper, more stable, fine-sand and mud zone, Oliver and Kvitek 1996). Changes in the magnitude and frequency of wave activity may impact the composition and depth range of these communities.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind, storms, and disease

Overall habitat sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: High

Supporting literature

Wind

Wind plays a critical role in the delivery of cold, nutrient-rich upwelled waters to the nearshore habitat. Increased nutrient delivery may benefit macroalgae and phytoplankton (Largier et al.

2010), as well as increase productivity, which is associated with enhanced seabird breeding success (Ainley et al. 1995, Abraham and Sydeman 2004, Sydeman et al. 2006, Jahncke et al. 2008). However, intensification of upwelling, and subsequent enhanced offshore transport, may also lead to increased dispersion of larvae and spores, and enhanced turbulent mixing that may negatively impact food particle availability necessary for larval survival (Bakun 1990).

Storms
Storms also enhance turbulence in the nearshore region and lead to increasingly intense run-off that may cause increased sedimentation and higher resuspension of sediment, resulting in increased turbidity and light attenuation (Largier et al. 2010). Increased runoff and sedimentation associated with storms can alter water quality and quantity at river mouths and in open coastal habitat (Gibson et al. 2003), affecting delta formation and the quality of soft-bottom habitats in these areas (Sarah Allen, pers. comm., 2014). Storm waves are a critical feature of nearshore dynamics (see wave action section above), but severe storm events may reduce planktonic food sources and negatively impact local populations of fish and invertebrates (McGowan et al. 1998).

Disease
The prevalence of disease in marine organisms is expected to increase in response to warming water temperatures (Harvell et al. 2002), and has been documented in seagrasses, sea urchins and sea stars (Harvell et al. 1999, Hewson et al. 2014). Increased water temperature both increases organism susceptibility to infection, and also enhances the virulence and success of pathogens (Largier et al. 2010).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution and poisons (4, high), land use changes (4, high), transportation (2, high), energy production (1, high),

Overall habitat sensitivity to non-climate stressors: Moderate
- Confidence of workshop participants: High

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

Supporting literature

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

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), significantly reducing water clarity. The release of pollutants during dredging of soft bottom habitats has been documented, and may potentially expose species to additional pollutants (Sarah Allen, pers. comm., 2014). Increased extreme precipitation events will impact the timing and intensity of runoff of terrestrial pollutants, which

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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.

will have important consequences for the timing and intensity of harmful algal blooms (Anderson et al. 2008, Kudela et al. 2008).

Land Use Change

Land use pressures, such as agriculture, ranching, mining and coastal development, impact nearshore water quality by increasing sedimentation, turbidity and run-off of pollutants (Gibson et al. 2003, ONMS 2010). Land use changes can also drive shifts in freshwater delivery (volume and timing) to river mouths and open coastal environments; both water pulses and water reductions can affect habitat structure and quality and the health of component species (Gibson et al. 2003) in nearshore soft-bottom habitats.

IV. Other sensitivities

Other critical factors likely to influence the sensitivity of the habitat: ocean temperatures at depth and in the mid-water column

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

Supporting literature

Water temperature at depth and throughout the water column may increase during more frequent and intense El Niño events and decrease during more intense seasonal upwelling events. Low reproductive success in seabirds (Ainley et al. 1995, Abraham and Sydeman 2004, Sydeman et al. 2006, Jahncke et al. 2008) and low productivity/survival in pinnipeds (Sydeman and Allen 1999) have been correlated with increased water temperatures, especially during El Niño events.

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 4 (Minor to moderate alterations, likely a result of compromised water quality)

- Confidence of workshop participants: High

Continuity of habitat: 5 (Continuous)

- Confidence of workshop participants: High

Supporting literature

Soft-bottom subtidal habitat accounts for roughly 80% of the nearshore zone in the southern portion of the study region (SIMoN 2014). On-going monitoring studies in Monterey Bay National Marine Sanctuary indicate that large, structural sessile habitat-forming invertebrates (e.g., sponges, anemones, tube worms) appear to be healthy and no major perturbations have been observed (SIMoN 2014).

II. Resistance and recovery

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

- Confidence of workshop participants: High

Ability of habitat to recover from stressor/maladaptive human response impacts: no answer provided

Supporting literature

No rating for recovery from disturbance and impacts was provided by workshop participants, though nearshore soft-bottom macroinvertebrate larvae were found to have the greatest potential for extensive dispersal relative to other habitats (Grantham et al. 2003), suggesting that many species in this habitat may be able to colonize new areas or move to more suitable conditions if necessary.

III. Habitat diversity

Physical and topographical diversity of the habitat: Low-Moderate

- Confidence of workshop participants: High

Diversity of component species within the habitat: Moderate

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Moderate

- Confidence of workshop participants: Moderate

Keystone or foundational species within the habitat: none identified

Supporting literature

The homogenous soft-bottom habitat is composed exclusively of soft sediments such as sand and mud; however, at the mouth of the San Francisco Bay are the largest sand waves on the west coast (6 m in height, 80 m from crest to crest) that offer a very distinct and unique habitat (Gibbons and Barnard, 2007). Two major biological communities exist in this habitat along a wave-induced gradient: a crustacean zone of small, mobile, deposit-feeding crustaceans, including the sand-burrowing amphipods and surface-active cumaceans and ostracods, and the polychaete zone, dominated by worms that inhabit fairly permanent tubes/burrows and other sessile and suspension-feeding organisms (Oakden 1981, Slattery 1980, Slattery 1985). Fish diversity in this habitat is relatively low compared to adjacent reefs, but abundance can be very high and serve as important forage for predatory fish, seabirds and marine mammals (SIMoN 2014).

Gray whales may be considered a keystone species because they are recognized as ecological engineers for their foraging behavior. They have a dramatic effect on bottom sediments, as one whale can plow 100 acres in one summer while foraging in the soft bottom sediments of Alaska. Resident whales that over-summer in central California are becoming more frequent (Sarah Allen, pers. comm., 2014).

IV. Management potential

Value of habitat to people: Low-Moderate

- Confidence of workshop participants: High
- Description of value: most of the general public does not interact with the soft-bottom subtidal, and value lies in the use of this habitat for commercial and recreational fishing (including halibut, anchovy, sardine, Dungeness crab).

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

- Confidence of workshop participants: High
- Description of potential management actions: to limit human impacts such as dredging and bottom-tending fishing gear that may exacerbate climate impacts.

Supporting literature

Resource managers may value this habitat for its role in nutrient cycling and abundance of forage organisms that support birds, fish and marine mammals (Oregon DFW 2014).

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven factors identified (score[7], confidence[8]): increased coastal erosion and runoff (5, high), decreased pH (5, high), changes in sea surface temperature (4, moderate), increased storminess (4, high), altered currents and mixing (2, moderate)

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

- Confidence of workshop participants: High

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

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

[8] Confidence level indicated by workshop participants.

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Offshore rocky reefs[1]

Executive Summary

Offshore rocky reefs	Score	Confidence
Sensitivity	2 Low-Moderate	2 Moderate
Exposure	2 Low-Moderate	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	2 Low-Moderate	2 Moderate

Offshore rocky reefs, including banks and seamounts, are generally discrete features that provide complex and heterogeneous environments for colonization by deep-water corals, sponges, other invertebrates, and numerous fish species. Key climate sensitivities identified for this habitat by workshop participants include dissolved oxygen, dynamic ocean conditions (currents/mixing/stratification), and pH. The key non-climate sensitivity identified as a potential future threat that currently is not impacting the study region is invasive tunicates. Benthic shallow banks are an isolated and patchy habitat type, and exhibit moderate to moderate-high structural and functional integrity. This habitat has a low-moderate to moderate level of physical diversity but a moderate-high level of diversity of component species and functional groups. Hydrocorals and sponges provide an important role in benthic shallow banks by forming habitat features for benthic communities. Potential management measures include reducing human stressors, as it is unlikely climate stressors can be alleviated.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): dissolved oxygen levels (5, high), pH (3, low), dynamic ocean conditions (currents/mixing/stratification) (3, moderate), sea surface temperature (1, low)

Climate and climate-driven changes that may benefit the habitat: dynamic ocean conditions (currents/mixing/stratification)

- Description of benefits: enhanced wind-driven upwelling that brings cold, nutrient rich water to the area may occur in response to changes in wind patterns and dynamic ocean conditions and may have beneficial effects on benthic shallow bank habitats.

Overall habitat sensitivity to climate and climate-driven changes: Low-Moderate

- Confidence of workshop participants: High

Additional participant comments

Benthic species with a center of distribution in higher latitudes may have a more difficult time adapting to warming temperatures, as these species are at the southern end of their distribution and likely close to their thermal tolerance limits. In contrast, benthic species with a center of distribution in lower latitudes may expand their distribution north as ocean temperatures warm.

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

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

[3] Confidence level indicated by workshop participants.

However, there are complex interactions between temperature and other physical parameters that will have synergistic and unpredictable effects on benthic communities. For example, if increased sea surface temperature leads to decreased productivity, it would likely have a significant impact on benthic communities.

Supporting literature

Dissolved Oxygen

Areas adjacent to upwelling centers (e.g., Point Arena) are particularly susceptible to low dissolved oxygen, as the upwelling process naturally delivers low oxygen water from the deep ocean. An extensive Oxygen Minimum Zone (OMZ) exists along the continental margin of the northeast Pacific Ocean (Kamykowski and Zentara 1990), although the current source for upwelled water is shallower than this zone (Grantham et al. 2004). Recent work indicates that in the vicinity of Point Conception, the OMZ has shoaled by up to 90 meters (Bograd et al. 2008). If the OMZ were to migrate shallow enough to provide the source water for coastal upwelling, hypoxic events may be observed with significant and complex ecological changes and impacts (Bograd et al. 2008). For example, shoaling of the OMZ could lead to direct hypoxia-related effects on benthic organisms where the OMZ contacts the continental margin (Levin 2003).

pH

pH is very low in upwelled waters along the coast of western North America, including in this study region (Feely et al. 2008). Low pH (i.e., “ocean acidification”) water can be corrosive to a wide variety of organisms including corals, sea urchins, and mollusks (Guinotte and Fabry 2008), with possible declines in calcification rates (Gazeau et al. 2007). Larval and juvenile stages of benthic organisms, which spend the developmental phase of their early life history in the water column, may be impacted by ocean acidification (Kurihara et al. 2007), and declines in pH will likely add cumulatively to the stress of benthic organisms. Declines in the biomass of plankton will likely affect benthic communities.

Dynamic ocean conditions (currents/mixing/stratification)

Because sessile benthic organisms rely on the movement of currents to deliver suspended particulate food, “any significant disruption to the timing or intensity of seasonal upwelling winds resulting in reduced productivity over time would likely have negative impacts” (e.g., survival, recruitment success) on benthic organisms (Largier et al. 2010). This climate factor also impacts the habitat’s exposure to sea surface temperature, dissolved oxygen and pH.

Ocean temperature

Increased water temperature will likely have a negative effect on benthic communities if it leads to less productive conditions (Vulnerability assessment workshop, pers. comm., 2014). Warm water conditions have also been shown to affect juvenile rockfish, with subsequent impacts on seabirds. For example, trawl data from NOAA National Marine Fisheries Service shows a sharp decline in juvenile rockfish in response to warm water conditions observed in the central California Current region in 2005. Similarly, diet studies on common murres have shown a decrease in juvenile rockfish during years with warm sea surface temperatures and/or warm PDO periods (Miller and Sydeman 2004). Conversely, the appearance of juvenile rockfish in the diet of rhinoceros auklet was higher in years with low sea surface temperatures (Thayer and Sydeman 2007).

II. Sensitivities to disturbance regimes:

Disease was identified as one possible disturbance regime that may be a source of sensitivity for benthic shallow banks, however the potential impact is unknown.

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): invasive species (3, moderate), pollution (1, moderate), harvest (gear) (1, moderate)

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

- Confidence of workshop participants: Moderate

Overall habitat exposure to non-climate stressors: Low

- Confidence of workshop participants: Moderate

Supporting literature

Although not identified by workshop participants, new cables and pipelines would represent an additional non-climate threat to benthic shallow banks due to their significant impact on benthic habitat during construction and placement of cables (ONMS 2009).

Invasive species

Though not currently impacting the study region, there is some concern regarding an invasive tunicate, *Didemnum* sp., that has been observed in nearby coastal areas 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 sampling will be necessary to elucidate which species is present on Cordell Bank (ONMS 2009) and other offshore reefs in the study region.

Pollution and poisons

Due to the offshore nature of this habitat type, and the distance from population centers on the mainland, water quality is considered to be in fairly good condition (ONMS 2009). However, oil spills and dispersants are a threat to the health of this ecosystem, and there have been several large spills in the region over the last decade.

Harvest (gear)

Significant amounts of derelict fishing gear have been documented in rocky areas of Cordell Bank (ONMS 2009). The most common gear types observed are long-lines and gill nets; most of this gear is entangled among boulders or on high relief rock. Entanglement can lead to damage of sensitive habitats that provide food and shelter for invertebrates and fishes, including structure-forming hydrocorals and sponges (Barnes and Thomas 2005). Many areas in the sanctuary (~86%) are now closed to the use of some type of bottom contact gear and bottom trawling, and the condition of biologically structured habitats is likely to improve. However, recovery may be slow due to the slow growth of some habitat-forming organisms (e.g., cold water corals). Workshop participants also noted that it is difficult to assess the affects of harvest gear on benthic shallow banks, and that the impact of harvest gear is dependent on location.

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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.

IV. Other sensitivities: none identified

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 3 (Distribution within single state to two states)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 3 (Altered but not degraded)

- Confidence of workshop participants: High

Continuity of habitat: 1 (Isolated and/or fragmented)

- Confidence of workshop participants: High

Additional participant comments

Although offshore rocky reefs, including banks and seamounts, are ubiquitous worldwide, they are patchy in their distribution and may act as "stepping stones" for the dispersal of species. In this study region, benthic shallow banks occur as discrete rocky reef banks that are isolated in space and have higher elevations and a different substrate than the surrounding seabed of the continental shelf. Benthic shallow banks exhibit moderate to moderate-high structural and functional integrity, due to relatively good water quality conditions but some degradation due to derelict fishing gear.

II. Resistance and recovery

Degree of habitat's resistance to the impacts of stressors/maladaptive human responses: no answer provided

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

- Confidence of workshop participants: High

Additional participant comments

Benthic habitat overall is fairly resilient, but species assemblage might change in response to climate change.

III. Habitat diversity

Physical and topographical diversity of the habitat: Low-Moderate

- Confidence of workshop participants: High

Diversity of component species within the habitat: Moderate-High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Moderate-High

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: none provided

Supporting literature

Much of Cordell Bank, Rittenberg Bank, and Fanny Shoal is granite reef with a mixture of boulders, smaller rocks, sand, and mud. The bathymetry and location of Cordell Bank (e.g., nearness to upwelling centers) combine to make it a very productive marine habitat. The vertical structure, habitat complexity, and rocky substrate of benthic shallow banks provide ideal habitat for colonization by deep-water corals, sponges, other invertebrates, and numerous fish species. Hydrocorals and sponges are important components of benthic shallow banks as they form habitat for benthic communities. Diversity in the water surrounding Cordell Bank as well as the bank itself includes 246 species of fish, 26 species of marine mammal, 59 species of bird, and numerous benthic algae and invertebrates. In 2012, 23 taxa of managed fish species, 113 coral colonies, 322 seapens and seawhips, and 2,628 sponges were observed on Rittenberg Bank. The banks serve as critical habitat for young of the year, juvenile, and adult rockfish, as well as for settlement of larvae from the water column (ONMS 2009).

IV. Management potential

Value of habitat to people: Moderate-High

- Confidence of workshop participants: Low-Moderate
- Description of value: This habitat is valued because of the inclusion of banks and seamounts in national marine sanctuaries on the west coast, in particular a sanctuary focused on Cordell Bank and the expansion of Monterey Bay National Marine Sanctuary for the purpose of including Davidson Seamount. Another example of societal value is that Cordell Bank is known as a historically good fishing spot and an area where whales and seabirds congregate.

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

- Confidence of workshop participants: High
- Description of potential management options: It is difficult to manage climate changes in deep water; managers may be better able to minimize other human stressors on this habitat type.

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): decreased pH (4, high), decreased dissolved oxygen levels (2, low), altered currents and mixing (2, moderate), changes in sea surface temperature (1, low)

Exposure to future climate and climate-driven changes: Low-Moderate

- Confidence of workshop participants: Moderate

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

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

[8] Confidence level indicated by workshop participants.

Additional participant comments

Potential areas of refugia may include deep reefs, possibly protected from decreased oxygen if the event is localized and from temperature increases that occur at shallower depths, and areas located outside of upwelling centers. Workshop participants also noted that increases in ocean temperature are also important to consider for this habitat type, and there are likely no potential areas of refugia from this factor.

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Pelagic Water Column[1]

Executive Summary

Pelagic Water Column	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	4 Moderate-High	3 High
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

The pelagic water column in the study region includes the sea surface to seabed, and is a highly heterogeneous and dynamic environment. Light and nutrient availability are the principal factors that determine the abundance and distribution of organisms in this habitat type. Biological activity is controlled by a balance between wind-driven upwelling and stratification of the water column. Key climate sensitivities identified for this habitat by workshop participants include upwelling, ocean temperature, dissolved oxygen, pH, and dynamic ocean conditions, and no key non-climate sensitivities were identified. The pelagic water column is a continuous, transboundary habitat type, and exhibits moderate-high structural and functional integrity. This habitat has a low degree of physical diversity but a moderate-high degree of diversity of component species and functional groups. This is a bottom-up driven system, where krill are considered keystone species and large changes in population size are related to changing oceanic conditions. Declines in krill abundance have negative impacts on higher trophic levels that depend upon them. Potential management measures include reducing human stressors, as it is unlikely climate stressors can be alleviated.

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) (5, high), upwelling (5, high), dissolved oxygen levels (4, high), pH (4, moderate), sea surface temperature (3, high), precipitation (3, high), air temperature (2, moderate), salinity (1, moderate)

Climate and climate-driven changes that may benefit the habitat: upwelling

- Description of benefits: Changes in ocean pH and sea surface temperature may be beneficial to kelp and changes in dynamic ocean conditions may increase nutrient and larval transport.

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

- Confidence of workshop participants: High

Additional participant comments

Potential benefits to this habitat include increased production that may result from enhanced wind-driven upwelling that brings cold, nutrient rich water to the surface. There may be both

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

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

[3] Confidence level indicated by workshop participants.

winners and losers as a result of changing conditions, as different species will be impacted differently. The impacts of changes in sea surface temperature and ocean temperature, which impact ocean stratification, and prevailing wind patterns, which drives upwelling, are unknown. It is possible that increased upwelling could counter the impacts of increased stratification.

Supporting literature

Although not identified by workshop participants, species range shifts such as the jumbo squid – which has already expanded into the region and persisted – have the potential to significantly impact the biodiversity and community composition within Cordell Bank National Marine Sanctuary (ONMS 2009).

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

Dynamic ocean conditions (currents/mixing/stratification)

Thermoclines have become stronger and deeper in offshore waters of the region (Palacios et al. 2004), and stratification due to climate change has already been reported to alter zooplankton communities in offshore waters (Roemmich and McGowan 1995). Similarly, in the Bering Sea, warmer and more stratified waters have led to increased numbers of gelatinous zooplankton (Brodeur and Terazaki 1999).

Upwelling

Seasonal variations in upwelling can affect phytoplankton and zooplankton abundances, with subsequent impacts on higher trophic levels. For example, years with strong, early alongshore winds led to strong and early upwelling, resulting in increased abundance of important zooplankton species (e.g., euphausiids and copepods) and above-average breeding success of Cassin’s auklet. Strong upwelling is generally associated with high seabird reproductive success because of its positive effect on ocean productivity (Ainley et al. 1995, Abraham and Sydeman 2004, Sydeman et al. 2006, Jahncke et al. 2008). Conversely, in 2005 and 2006, the opposite scenario occurred where a later spring upwelling was observed due to weak and/or delayed alongshore winds. Significant bottom-up effects in the ecosystem were observed and documented as a result of this delayed upwelling, including low primary production, low krill abundance, shifts in the zooplankton community (e.g., decreased abundance of adult krill and copepods and increased abundance of gelatinous zooplankton), a decline in at-sea seabird abundance, late and reduced reproductive success in seabirds (e.g., Cassin’s auklets abandoned nests and failed to breed due to lack of available adult krill) (Jahncke et al. 2008), and declines in blue whale (another krill predator) sightings (PRBO unpublished data *cited in* Largier et al. 2010). The decline in adult krill in 2005 may also be related to decreased survival of Chinook salmon entering the ocean that year and low salmon returns in 2008.

Dissolved Oxygen

Areas adjacent to upwelling centers (e.g., Point Arena) are particularly susceptible to low dissolved oxygen, as the upwelling process naturally delivers low oxygen water from the deep ocean. An extensive Oxygen Minimum Zone (OMZ) exists along the continental margin of the northeast Pacific Ocean (Kamykowski and Zentara 1990), although the current source for upwelled water is shallower than this zone (Grantham et al. 2004). Recent work indicates that in the vicinity of Point Conception, the OMZ has shoaled by up to 90 meters (Bograd et al. 2008).

If the OMZ were to migrate shallow enough to provide the source water for coastal upwelling, hypoxic events may be observed with significant and complex ecological changes and impacts (Bograd et al. 2008).

pH

Feely et al. (2008) show that pH is very low in upwelled waters along the coast of western North America, including in this study region. Large-scale increases in CO_2 and pH and localized upwelling that brings low dissolved oxygen and high CO_2 water will likely affect the pelagic water column (Vulnerability Assessment Workshop, pers. comm., 2014). Low pH water becomes corrosive to a wide variety of organisms, and calcification rates are likely to decline (Gazeau et al. 2007). Shell-building pteropods and foraminiferans that form the base of ocean food webs will be adversely impacted by increasing acidity (Spero et al. 1997, Fabry et al. 2008). Larval and juvenile stages of benthic organisms, which spend the developmental phase of their early life history in the water column, may also be impacted by ocean acidification (Kurihara et al. 2007).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind and storms

Overall habitat sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

Wind drives upwelling, with subsequent impacts on ocean temperature, salinity, nutrients, and production.

Supporting literature

Regional models (Snyder et al. 2003, Auad et al. 2006) have found that increased global temperatures lead to stronger wind stress along the California Coast, and analysis of wind data in the region show an enhancement in alongshore winds between 1982-2007 (Garcia-Reyes and Largier 2010), particularly during the summer and early fall. Studies have also observed an increase in the occurrence of extreme conditions; for example, extreme wind speeds have increased in North Pacific winter cyclones since 1948. Winter storms have also increased in intensity since 1950 (Bromirski et al. 2003). Models suggest that the tracks of storms in the northeast Pacific will migrate, on average, further north and experience an increase in the occurrence of extreme conditions. For example, the likelihood of super El Niños doubles from every 20 years in the previous century to one every 10 years in the 21st century (Cai et al. 2013). High waves that occur during El Niño events are likely to be more extreme when combined with higher sea level and increased wave heights due to climate change. For more on wind, please see the Upwelling sections in Sensitivity and Future Climate Exposure.

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): harvest (1, moderate), pollution (oil spills and dispersants) (1, moderate)

Overall habitat sensitivity to non-climate stressors: Low
- Confidence of workshop participants: Moderate

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

Additional participant comments

Due to the offshore nature of this habitat type, and the distance from population centers on the mainland, water quality is considered to be in fairly good condition. However, oil spills and dispersants are a threat to the health of this ecosystem, and there have been several large spills in the region over the last decade.

Supporting literature

Although not identified by workshop participants, invasive species and harmful algal blooms may represent additional non-climate threats to the pelagic water column. Shifts in the size, frequency, or timing of gelatinous zooplankton blooms in response to climate change have become a concern in many coastal marine ecosystems worldwide, as abundant, gelatinous zooplankton can induce trophic cascades as well as alter energy flows to upper-level consumers (Robinson and Graham 2014). At least one invasive species of gelatinous zooplankton, the moon jelly, is found in nearshore and offshore waters of California. Increases in harmful algal blooms (HABs) may be an indirect effect of warming ocean temperature (Van Dolah 2005). Currently there have been no indications to suggest that water quality in the region is compromised due to HABs (ONMS 2009), although with the possible rise in ocean temperature the emergence and spread of HABs and other diseases may increase (Largier et al. 2010).

IV. Other sensitivities

Other critical factors likely to influence the sensitivity of the habitat: noise
- Confidence of workshop participants: Moderate
- Confidence of workshop participants in the degree to which these factors influence habitat sensitivity: Low

Additional participant comments

Noise pollution decreases the quality of the habitat for many species. The amount of noise in the pelagic water column will likely be impacted by local ocean conditions, such as temperature and salinity. Increasing use of the ocean environment will likely result in increased noise in the pelagic water column.

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

[5] Confidence level indicated by workshop participants.

Supporting literature

Around 2,000 large commercial vessels transit through Cordell Bank NMS every year. While vessel numbers transiting the sanctuary do not appear to be increasing (1999-2005, United States Coast Guard, Automatic Identification System, unpublished data *cited in* ONMS 2009), it is unknown to what extent vessel traffic (including discharge, noise, collision) has on marine species or how this has changed through time. Documented ship strikes of humpback, blue and fin whales have occurred throughout the coastal waters of California.

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 4 (Minor to moderate alterations)

- Confidence of workshop participants: High

Continuity of habitat: 5 (Continuous)

- Confidence of workshop participants: High

Additional participant comments

Due to its offshore nature, most water quality parameters for the pelagic water column suggest relatively good conditions.

II. Resistance and recovery

Habitat resistance to the impacts of stressors/maladaptive human responses: no answer provided

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

- Confidence of workshop participants: High

III. Habitat diversity

Physical and topographical diversity of the habitat: Low

- Confidence of workshop participants: High

Diversity of component species within the habitat: Moderate-High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Moderate-High

- Confidence of workshop participants: High

Keystone or foundational species within the habitat: copepod, krill, and rockfish (bottom-up driven system)

Supporting literature

Diversity in the pelagic water surrounding Cordell Bank as well as the bank itself includes over 180 species of fish, 28 species of marine mammal, over 50 species of bird, and numerous benthic algae and invertebrates (CBNMS 2010). Krill are considered keystone species, and large changes in population size are related to changing oceanic conditions. For example, in 2005, anomalous atmospheric conditions delayed upwelling and affected primary productivity, with subsequent impacts on krill population growth and the condition of higher trophic levels dependent upon krill (Sydeman et al. 2006, Jahncke et al. 2008).

IV. Management potential

Value of habitat to people: High

- Confidence of workshop participants: High
- Description of value: The pelagic water column is valued for its recreational and commercial value.

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

- Confidence of workshop participants: High
- Description of potential management options: It is difficult to manage changes in temperature, pH, or upwelling in the pelagic water column, so managers may be better able to manage human stressors on this habitat type.

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven factors identified (score[7], confidence[8]): air temperature (5, high), sea surface temperature (5, high), dissolved oxygen levels (5, high), ocean pH (5, high), upwelling (5, high), altered currents and mixing (5, high), precipitation (2, high), salinity (1, high)

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

- Confidence of workshop participants: High

Upwelling

The effect of a long-term increase in upwelling intensity is difficult to predict; increased upwelling may mitigate the negative consequences of rising sea surface temperature to some extent by cooling surface temperature and increasing productivity in the system. Enhanced upwelling that is more persistent may result in a greater but more diffuse supply of phytoplankton to waters over the outer shelf and slope; however, enhanced surface heating may reduce phytoplankton availability further offshore due to increased stratification (Largier et al. 2010). Changes in the timing or magnitude of seasonal winds driving coastal upwelling could reduce larval survival for many resident species, as a number of offshore benthic organisms that live in the California Current have early life histories linked to an annual production cycle driven by coastal upwelling. Upwelling that occurs too early in the year or is too intense and lacks in periodic relaxation events may disrupt the zooplankton food supply that seabirds rely on. Similarly, any significant disruption to the timing or intensity of seasonal upwelling winds

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

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

[8] Confidence level indicated by workshop participants.

resulting in reduced productivity over time would likely have negative impacts on long-term survival of benthic organisms.

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Rocky Intertidal[1]

Executive Summary

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

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

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

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

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

- Confidence of workshop participants: Moderate

Additional participant comments

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

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

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

Air Temperature

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

Salinity

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

pH

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

Wave Action and Erosion

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

II. Sensitivities to disturbance regimes

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

Overall habitat sensitivity to disturbance regimes: High

- Confidence of workshop participants: Moderate

Supporting literature

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

III. Sensitivity and current exposure to non-climate stressors

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

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

- Confidence of workshop participants: Low

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

- Confidence of workshop participants: Moderate

Additional participant comments

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

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

[5] Confidence level indicated by workshop participants.

Supporting literature

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

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

Armoring

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

Pollution and oil spills

Pollutants, including agricultural and livestock waste, wastewater, sewage outfalls, historic mining, and industrial wastes, can be carried into the study region via the freshwater outflow from San Francisco Bay (Largier et al. 2010), inhibiting the resilience of intertidal habitat and stimulating phytoplankton growth. This habitat is also sensitive to oil spills, with over 6,000 commercial vessels using the San Francisco Bay every year (Largier et al. 2010).

Recreation and trampling

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

Invasive species and species range expansions

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

IV. Other sensitivities: none identified

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 5 (Pristine)

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Supporting literature

Rocky intertidal habitat accounts for 39% of the shoreline in the southern portion of the study region (SIMoN 2014a), and is a dominant feature along the coastline. Intertidal habitat is interrupted by coastal cliffs, sandy beaches, and estuaries and lagoons but biologically connected through larval transport (SIMoN 2014b). Rocky shore habitat within the study region includes areas such as Bodega Head, Duxbury Reef, the Point Reyes Headlands, the rocky shores of Tomales Bay and the intertidal shores of the Farallon Islands (SIMoN 2014b).

II. Resistance and recovery

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

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: High

Additional participant comments

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

Supporting literature

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

III. Habitat diversity

Physical and topographical diversity of the habitat: Moderate-High

- Confidence of workshop participants: High

Diversity of component species within the habitat: High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: High

- Confidence of workshop participants: High

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

Additional participant comments

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

Supporting literature

More than 320 invertebrate species and 250 algal species have been identified by various surveys and monitoring programs in the southern portion of the study region's boundaries. High species diversity in the rocky intertidal in this region may be attributed, in part, to "the unusual mix of substrate – such as the soft shale at Duxbury Reef and hard shale at Estero de San Antonio – and the alternating estuaries and lagoons that line the sanctuary's shores" (SIMoN 2014b).

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

IV. Management potential

Value of habitat to people: Moderate-High

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

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

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

V. Other adaptive capacities: none identified

Exposure

I. Future climate exposure[6]

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

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

- Confidence of workshop participants: Moderate

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

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

[8] Confidence level indicated by workshop participants.

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American Dune Grass (*Elymus mollis*)[1]

Executive Summary

American Dune Grass	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	5 High	3 High
Adaptive Capacity	2 Low-Moderate	2 Moderate
Vulnerability	4 Moderate-High	3 High

American dune grass is a rhizomatous perennial that is an important pioneer and sand stabilizing species in dune habitats along the United States and Canadian Pacific coasts. Key climate sensitivities identified by workshop participants include sea level rise, wave action, coastal erosion and sediment supply and key non-climate sensitivities include roads/armoring, recreation, and invasive species. American dune grass exhibits a broad geographic extent, and a stable but diminished population that is fragmented. Overall, the species has low-moderate diversity/plasticity, though it is known to hybridize with other species, employs both sexual and asexual reproduction, and displays variable ecophysiological phenotypes based on environmental variability. Value for this species is generally low, with some preference given to the more effective sand-stabilizing invasive beach grass, and management potential is moderate, with invasive removal and upland habitat protection as viable options. The greatest threat to American dune grass is the invasive European beach grass, and dunes that are dominated by native, rather than invasive, species, including American dune grass, will likely be more resilient to climate impacts.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): sea level rise (4, high), wave action (4, high), sediment supply (4, high), coastal erosion (4, high), precipitation (2, moderate), air temperature (1, low)

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

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

- Confidence of workshop participants: High

Additional participant comments

The sensitivity of dune grass to climate factors is primarily due to the sensitivity of the dune habitat; however, if there is sufficient room to migrate inland, the species may be able to adapt and persist. Potential areas of refugia from climate impacts include seeps and drainages in coastal bluffs behind dunes, and moist hollows on sloping terraces (Peter Baye, pers. comm., 2014).

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

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

Sea Level Rise

Sea level rise can inundate dune systems and increase rates of shoreline erosion, potentially forcing upland retreat of beach and dune habitats (Feagin et al. 2005). Where development or other barriers (i.e., cliffs) block upland retreat, dune habitats may suffer reduced areal extent and/or increased fragmentation, shifting from continuous habitat to narrower, steeper, and isolated pockets (Largier et al. 2010). In addition, sea level rise can contribute to changes in relative proportions of the different ecological zones within dune habitats, which could lead to propagating changes in all levels of the food web (Dugan et al. 2008). In a high sea level rise scenario of 0.88m, complete breakdown of the dune plant successional process occurred in an experimental plot in Texas, with only early colonizers able to take root but not able to provide enough ameliorative force for the further development of the plant community, indicating that sea level rise may disrupt successional dynamics and degrade habitat quality by preventing the formation of mature coastal dune vegetation communities (Feagin et al. 2005).

Wave Action

Wave action, which varies seasonally and according to local and more broad-scale climatic processes, shapes dune systems, contributes to dune erosion, and affects key species. Waves, particularly larger wave heights associated with late winter El Niño events, are often the main driver of beach and dune erosion (Storlazzi and Griggs 2000, Wingfield and Storlazzi 2007), increase coastal flooding (Storlazzi and Griggs 2000, Wingfield and Storlazzi 2007), potentially inundating dune areas and forcing landward retreat (Feagin et al. 2005), and shift distributions of sandy shorelines. For example, shifts in the Pacific Decadal Oscillation (PDO) can alter wave directions, exposing sheltered beaches and dunes to significant erosion and/or rotating sandy shoreline segments to the north and increasing erosion in southern ends of littoral cells (Sallenger et al. 2002).

Coastal Erosion

American dune grass is an important part of dune ecology, as it is often one of the first plants to colonize during the early stages of dune development (Imbert and Houle 2000) and is an important sand stabilizer due to its rhizomatous growth, preventing erosion of coastal dunes (Gagné and Houle 2002). The invasive European beach grass, which is now more abundant, is also an effective sand stabilizer, but forms tall dunes that prevent inland movement of sand, potentially exacerbating coastal erosion and preventing the inland movement of dunes in response to sea level rise (UW 2013). Erosion combined with sea level rise will likely reduce dune habitat, especially in areas where dunes are backed by coastal cliffs (i.e., a majority of beaches in the study area) (Largier et al. 2010). Alternatively, erosion of coastal cliffs may help some beach and dune systems keep pace with sea level rise by increasing local sediment delivery and enhancing dune habitat (Sarah Allen, pers. comm., 2014). In addition, erosion of upland or inland sediments can increase sediment transport and delivery to beach and dune areas (Sarah Allen, pers. comm., 2014).

Sediment Supply

Sediment supply and movement influences the areal extent of dune systems, and is controlled by a variety of climate and climate-driven factors (i.e., wave action, coastal erosion, currents, precipitation), as well as by changes within the “sediment-shed” (i.e., changes in the watershed, coastal wetlands, or the littoral cell) (Revell et al. 2007, Largier et al. 2010, Vulnerability Assessment Workshop, pers. comm., 2014). Surpluses in local sediment budgets typically increase beach and dune width and minimize shoreline erosion, while sediment deficits result in narrower beaches and dunes with significant rates of coastal erosion (Largier et al. 2010). Reductions in beach width expose dune habitats to increased wave exposure (Largier et al. 2010). Sediment supply will vary according to many factors. For example, short, heavy precipitation events can increase freshwater sediment discharge and bolster beach and dune systems, though this dynamic is mediated by inland water and sediment retention structures such as dams (Slagel and Griggs 2008, Largier et al. 2010). Alternatively, wave action can deliver or remove sediment, leading to dynamic changes in beach shape and size over the course of different seasons.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

Although storms can damage the structure of dune habitats, they can quickly recover.

III. Dependencies

Species dependence on one or more sensitive habitat types: High

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

Species dependence on specific prey or forage species: low

- Confidence of workshop participants: High

Other critical dependencies: sediment supply to keep pace with sea level rise

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

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

- Confidence of workshop participants: High

Supporting literature

The species may also be somewhat dependent on restoration efforts due to its inability to compete with the invasive European beach grass (Bennett 2005). Because of these generally high dependencies, this species is considered a specialist, and therefore may have limited flexibility to adapt to environmental changes.

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): invasive species (5, high), coastal roads/armoring (4, high), recreation (3, moderate)

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

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Additional participant comments

Coastal roads and armoring can prevent the migration of American dune grass in response to rising sea levels, and invasive species may be able to spread faster in new dune habitat areas. Coastal recreational pressure could increase as a result of population growth and increased inland temperatures. European beach grass is more aggressive and dominant, and therefore is able to spread faster and colonize new areas more quickly than American dune grass.

Supporting literature

Invasive Species

The invasive European beach grass, which is now the most abundant dune grass species (Pojar and MacKinnon 1994), is considered the most pervasive exotic species currently threatening coastal dunes (Pickart 1997). European beach grass was first planted in California in the 1800s for sand stabilization purposes (Bennett 2005), and was generally preferred by nearby landowners because it is more efficient than native species at effectively trapping shifting sands (Vulnerability Assessment Workshop, pers. comm., 2014), though this preference has recently declined (Peter Baye, pers. comm., 2014). However, the efficient trapping of sand by European beach grass significantly alters dune morphology, threatening the federally listed Western Snowy Plover and displacing entire native plant communities, including the American dune grass (Pickart 1997, Bennett 2005). Dunes become very tall (up to 10m) when colonized by European beach grass, which prevents the inland movement of sand, potentially exacerbating coastal erosion and preventing the inland migration of the dune in response to sea level rise (UW 2013).

Roads/Armoring

Coastal armoring and road construction limits the ability of dune habitat and associated species, including American dune grass, to migrate upland or inland with rising sea level (Largier et al. 2010, Vulnerability Assessment Workshop, pers. comm., 2014). Passive erosion can also result from armoring, with habitat zones shifting downward on the beach/dune profile, disproportionally degrading upper and mid beach habitat (Dugan et al. 2008). Armoring is projected to increase in response to rising sea level and increased coastal erosion, although beach nourishment is now being used more frequently as an alternative (Defeo et al. 2009).

Recreation

Trampling of small pioneer colonies from regenerating vegetative fragments may have a significant impact on post-storm recovery of small populations, particularly where European

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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.

beachgrass is more abundant (Peter Baye, pers. comm., 2014). Recreational use can lead to trampling of vegetation or sensitive habitat areas, as well as to behavioral modifications in beach and dune wildlife (e.g., bird nest abandonment) (Grigg et al. 2002, Schlacher et al. 2008, 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): 5

- 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): 1

- Confidence of workshop participants: High

Dispersal ability of the species: Low-Moderate

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: <1km

- Confidence of workshop participants: Low

Additional participant comments

As a foredune species, American dune grass does have slightly greater adaptive capacity than other dune species and will be able to withstand a greater amount of sea level rise than species closer to mean high tide.

Supporting literature

This species exhibits a broad geographic extent along the US West coast, from Alaska to California (MBA 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: no answer provided

Behavioral plasticity: n/a

Phenotypic plasticity: Moderate

- Confidence of workshop participants: Low

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: Low

Additional participant comments

The species is capable of reproducing both sexually and asexually, can alter its phenology, and can allocate energy derived from photosynthesis either to reproduction or biomass accumulation in response to environmental conditions (Vulnerability Assessment Workshop, pers. comm., 2014). American dune grass reproduces in successive cycles, takes around one year to reach reproductive maturity, and reproduces sexually once per year with more frequent asexual, vegetative reproduction (Vulnerability Assessment Workshop, pers. comm., 2014).

Supporting literature

Genetic diversity of the species is unknown, though it does hybridize readily with multiple other species (Wang and Hsaio 1984). Dune grass also demonstrates phenotypic variation of some ecophysiological traits, including carbon assimilation rate and water use efficiency, based on its location on a dune, enabling the species to be present throughout all stages of dune succession (Imbert and Houle 2000). A reviewer of this document noted that the species exhibits high phenotypic plasticity, as it is able to "grow in dune systems from nutrient-rich macroalgal drift-lines of beaches (productive, luxuriant growth), to stressful high dune crests with high moisture deficits in summer, where it grows at low density, small size, and slow rates. Its ability to regenerate from winter storm-eroded vegetative fragments after immersion in full strength seawater, and establish in beach sand, and grow through multiple annual deposits of sand, indicates a high degree of phenotypic plasticity and a very wide ecological amplitude, compared with associated native species. High phenotypic plasticity is also consistent with its circumboreal distribution and latitudinal range from arctic to Central California beaches." (Peter Baye, pers. comm., 2014).

III. Management potential

Value of species to people: Low

- Confidence of workshop participants: High
- Description of value: some aesthetic value

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

- Confidence of workshop participants: Moderate
- Description of potential management options: protect inland dune areas to allow for migration and maintain sediment supply to keep pace with sea level rise.

Additional participant comments

The societal value for this species was rated as low due to the increased value that the invasive species, European beach grass, has with landowners and road users because of its superior ability to accumulate and retain sand and sediment (though this sentiment is likely outdated and applies only to the northern reaches of the species range, where more of the coastal land is privately owned, Peter Baye, pers. comm., 2014). The primary driver for American dune grass abundance, however, seems to be the non-climate threat of the invasive European beach grass. If management efforts can focus on the removal of beach grass, dune grass will likely be much more resilient. Identifying persistent populations that provide vegetative propagules to adjacent beaches during storm erosion events may be an important local strategy for conservation of refugia (Peter Baye, pers. comm., 2014).

V. Other adaptive capacities: none identified

Supporting literature

Though no additional adaptive capacities were identified for the species, Peter Baye, a coastal plant ecologist, noted that American dune grass has many adaptive qualities that may enable it to exploit the increase in storm wave overwash and disturbance to dune systems expected with climate change, especially as compared to the invasive European beach grass. Dune grass "allocates more growth to horizontal rhizome spread, and has higher tolerance to substrate salinity and flooding than European beach grass". He continues, "where barrier beaches undergo rapid transgression, dune development and accretion rates are likely to be reduced, and the extent of washover fans, and frequency of winter overwash, are likely to increase as beaches retreat under conditions of limited littoral sand supply. These geomorphic conditions may be conducive to either recovery of American dune grass, or a favorable opportunity for managing it over European beach grass."

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): increased coastal erosion (5, high), increased storminess (5, high), sea level rise (5, high), changes in sediment supply (5, high)

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

- Confidence of workshop participants: High

Additional participant comments

Potential areas of refugia exist for all of these factors if there is adequate room for dune habitat to migrate inland.

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

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

[8] Confidence level indicated by workshop participants.

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California Black Rail (*Laterallus jamaicensis coturniculus*)[1]

Executive Summary

Black Rail	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	2 Low-Moderate	3 High
Adaptive Capacity	2 Low-Moderate	3 High
Vulnerability	4 Moderate-High	3 High

The black rail is a small and inconspicuous bird that inhabits high portions of salt marshes, shallow freshwater marshes, wet meadows, and flooded grassy vegetation in isolated pockets across North, Central and South America and the Caribbean, including a subspecies that inhabits a small portion of California. Key climate sensitivities identified by workshop participants include sea level rise, salinity and storm severity/frequency and key non-climate sensitivities include predation, land use change/habitat loss, pollution and poisons, and invasive species. California's breeding population of black rails is fragmented and isolated, and listed as threatened in the state, with the species overall considered "near-threatened" by the IUCN. The majority of California's breeding population of black rails occurs in the northern San Francisco Bay region, with a smaller population along the outer coast of Marin County, estimated at 280 individuals, and some documented sightings in the south bay near coyote creek and alviso slough. The black rail has low-moderate dispersal capabilities, a low degree of diversity/plasticity, and low-moderate societal value due to its inconspicuous and secretive nature. The likelihood of managing this species in the face of climate change is considered moderate-high, with management actions such as habitat restoration and predator control considered to have multiple habitat-level benefits and garnering great support in the conservation and management communities.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): sea level rise (5, high), salinity (4, high), storm intensity (4, high), precipitation (3, moderate), wave action (2, high)

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

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

- Confidence of participant: Moderate

Supporting literature

The black rail is highly sensitive to climate change because of its dependency on tidal marsh habitat which itself is highly sensitive to sea level rise and salinity changes, and to extreme weather events, especially in areas with less vegetative cover and less or distant marsh-upland refugia (Julian Wood, pers. comm., 2014).

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

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

[3] Confidence level indicated by workshop participants.

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

Sea Level Rise
Unless there is a comparable increase in elevation of the land surface due to sediment delivery and availability, estuarine and tidal marsh habitat will not be able to adjust to rising sea levels, and more frequent and intense flooding will be expected (Largier et al. 2010, Ackerly et al. 2012). Black rails are extremely vulnerable to predation when forced out of their dense coastal marsh habitat at extreme high tide (Evens and Page 1986, Evens 1999, BirdLife International 2012), which occurs rarely now, but will likely increase as the combined effects of sea level rise and subsidence exacerbate periodic flooding of tidal marsh habitat (Evens 1999). Increased flooding also destroys black rail nests, which are constructed in clumps of vegetation on the ground (Evens and Page 1986).

Salinity
Though salinity was identified as a potential sensitivity for the black rail, the literature does not indicate that it is a major factor affecting distribution of the species. Manolis (1978) found black rails existing in marshes with salinities ranging from low (Olema Marsh, Marin County) to high (San Pablo Bay marshes), and population surveys indicated that black rails prefer marshes that range from saline to brackish (Spautz et al. 2005). Salinity may impact black rails, however, through the alteration of the estuarine and tidal marsh biota (Largier et al. 2010). Changing precipitation patterns and saltwater intrusion due to sea level rise will likely result in greater salinity variation and may change the abundance and distribution of marsh vegetation (Largier et al. 2010). However, the composition of marsh biota does not seem to impact black rail presence as much as the density of the vegetation (Spautz et al. 2005).

Storm Intensity
Increased storm intensity will impact both wave energy and the timing and intensity of precipitation events, with major consequences for flooding and salinity in tidal marsh habitat (Largier et al. 2010). The black rail is sensitive to extreme weather events, especially in areas with less vegetative cover and less or distant upland refugia (Julian Wood, pers. comm., 2014).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms and flooding

Overall species sensitivity to disturbance regimes: High

- Confidence of participant: Moderate

Additional participant comments

Storms and flooding can increase adult mortality and reduce nest survival as a result of increased exposure to the elements and predation.

Supporting literature

When their preferred habitat is flooded, the black rail is forced out of the protective cover of marsh vegetation and is highly vulnerable to predation (Evens 1999). Flooding of black rail habitat occurs now during extremely high tides, but will likely increase in frequency due to rising sea levels, subsidence, heavy rainfall during El Niño events, and increased water retention due to development. Models suggest that the number of El Niño events likely will not change, though the likelihood of super El Niños doubles from one every 20 years in the previous century to one every 10 years in the 21st century (Cai et al. 2013). The high waves during El Niño events will be more extreme when combined with the trend of increased wave height (Largier et al. 2010), resulting in more frequent flooding of black rail habitat.

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: tidal marsh

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

- Confidence of workshop participants: Moderate

Other critical dependencies: no answer provided

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

- Confidence of workshop participants: Moderate

Supporting literature

The black rail may be considered a habitat specialist and a diet generalist (Laurie Hall, pers. comm., 2014). It is highly dependent on tidal marsh habitat which itself is highly sensitive to sea level rise and salinity changes (Julian Wood, pers. comm., 2014), and has a low-moderate dependency on specific prey, probing for a variety of insects, spiders, small crustaceans, snails, and seeds on the ground or in shallow water (Eddleman et al. 1994). Population surveys indicate that black rails prefer marshes that are close to water (bay or river), large, away from urban areas, and saline to brackish with a high proportion of low and dense marsh vegetation (Spautz et al. 2005).

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): predation (5, high), land use change (5, high), pollution (4, moderate), invasive species (4, high), coastal roads and armoring (3, high)

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

- Confidence of participant: High

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

- Confidence of participant: High

Supporting literature

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

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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 participant.

Predation

Habitat loss and increased flooding have worked in concert to increase the black rail's susceptibility and exposure to predation by herons, egrets and raptors (Evens and Page 1986). As black rails are forced to retreat from the protective cover of marsh vegetation at high tides and during flooding events, avian predators, as well as foxes, rats and domesticated cats, have easy access to the typically hidden birds (Evens and Page 1986, Evens 1999). Marshes that are surrounded by development are more susceptible to mammalian predators due to the presence of people that often attract them to the area.

Land Use Change/Habitat Loss

The black rail thrives in extensive "high" marsh, areas which usually occur between the high tideline and the dry upland (Eddleman et al. 1994, Evens 1999). Population surveys in San Francisco Bay in the 1980s indicated that the species breeds almost exclusively in the North Bay (Evens 1999), though since this work, many birds have been captured in the South Bay, with a breeding population at Coyote Creek and possibly in the Eden Landing Ecological Reserve in Hayward (Laurie Hall, pers. comm., 2014). Subsidence, development, and the construction of levees and roads have effectively eliminated most of the higher marsh habitat in the South Bay region (Evens 1999). The loss of habitat along the outer coast of Marin County due to conversion to agriculture is cited as the primary cause for losses in Tomales Bay and Bolinas Lagoon (Evens et al. 1991), though recent restoration of portions of the Giacomini Marsh has resulted in black rail sightings in Tomales Bay (Laurie Hall, pers. comm., 2014). High marsh habitat is critical to the black rail for protection from predation at high tide and as refugia from flooding due to rising sea levels (Eddleman et al. 1994; BirdLife International 2012; Julian Wood, pers. comm., 2014).

Pollution/Poisons

Toxic contamination, including oil spills, has been shown to have adverse biological effects on estuarine birds in the San Francisco Bay region, including population declines associated with organochlorine contamination and impaired reproduction associated with selenium and heavy metals (Ohlendorf et al. 1986, Ohlendorf and Flemming 1988). Methylmercury levels were found to be above the "no observed adverse effect" levels for a majority of black rails tested from San Francisco Bay, putting the population at risk for reproductive effects (Tsao et al. 2009)

Invasive Species

Invasive species effectively out-compete native species and decrease native species diversity and abundance. It is estimated that about 143 species of invasives are present in the region, most of which exist in the estuarine zone (Byrnes et al. 2007), greatly altering the structure and function of marsh and estuarine habitats, impacting the black rail. For example, the invasive Phragmite reed on the east coast of the United States has aggressively colonized the narrow transition zone between high marsh and upland habitat, creating a monoculture that differs markedly from the natural breeding habitat of the black rail (CCD 2014).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 2

- Confidence of participant: High

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

- Confidence of participant: High

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

- Confidence of participant: High

Dispersal ability of the species: Low-Moderate

- Confidence of participant: Moderate

Maximum annual dispersal distance: no answer provided

Supporting literature

The majority of the breeding population of the black rail is in northern San Francisco Bay, but also along the outer coast of Marin County in Bolinas Lagoon and Tomales Bay (Evens et al. 1991, Spautz et al. 2005) and in South Bay near Coyote Creek and Alviso Slough (Laurie Hall, pers. comm., 2014). The species is considered "near threatened" on the IUCN Red List of Threatened Species due to the moderately rapid decline across its range (BirdLife International 2012) and is listed as threatened in the state of California (Spautz et al. 2005). Though dispersal was rated as low-moderate by workshop participants, genetic work by local researchers demonstrates frequent gene flow among bay area marshes, indicating that the species is capable of sustaining long-distance travel (Laurie Hall, pers. comm., 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low

- Confidence of workshop participants: Moderate

Genetic diversity: no answer provided

Behavioral plasticity: no answer provided

Phenotypic plasticity: no answer provided

Overall degree of diversity/plasticity of the species: Low

- Confidence of workshop participants: low

Supporting literature

The black rail likely has low behavioral plasticity, as it relies on thick marsh vegetation for protection from predation (BirdLife International 2012). Strong genetic divergence exists among black rail subspecies, but there is evidence of substantial gene flow among distinct geographic populations within California (Girard et al. 2010).

The black rail takes about a year to reach sexual maturity, experiences two reproductive events in a single year, and lives to be around 5-9 years in age (Julian Wood, pers. comm., 2014). The reproductive biology of this species is poorly known; males and females vocalize in breeding grounds and form mating pairs that incubate 6-8 eggs together in ground nests (Eddleman et al. 1994). The chicks hatch after 17-20 days and are semi-precocious, requiring feeding by the parents (Eddleman et al. 1984).

III. Management potential

Value of species to people: Low-Moderate

- Confidence of workshop participants: Moderate
- Description of value: some value for birders

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

- Confidence of workshop participants: Moderate
- Description of potential management options: habitat restoration and predator control, having multiple benefits for tidal marsh habitat and wildlife, are more likely to be pursued and supported (Julian Wood, pers. comm., 2014).

Supporting literature

An example of successful restoration of black rail habitat can be found in the Sierra foothills, where the Department of Fish and Wildlife creates black rail habitat by running irrigation water down small slopes to create wetlands. The birds colonize them quickly and use them for breeding (Laurie Hall, pers. comm., 2014).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified: increased flooding (3, high), sea level rise (3, high), changes in salinity (2, high), changes in precipitation (1, moderate)

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

- Confidence of workshop participants: High

Additional participant comments

Potential areas of refugia identified for these factors include high marsh habitat and marsh-upland transition zone.

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

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Black Oystercatcher (*Haematopus bachmani)*[1]

Executive Summary

California Mussel	Score	Confidence
Sensitivity	5 High	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	4 Moderate-High	3 High

The black oystercatcher is a large, conspicuous, non-migratory rocky shore bird with a distinctive bill that enables the animal to pry open intertidal invertebrates. The species ranges from Alaska to Baja California. Key climate sensitivities identified by workshop participants for the black oystercatcher include sea level rise, wave action, precipitation, and erosion, and key non-climate sensitivities include land use change, pollution/poisons, and recreation. The black oystercatcher exhibits a transcontinental geographic extent and a somewhat fragmented and diminished, though fairly stable, population that predominantly resides in the northern stretches of its range. The population in California is thought to number around 800 individuals, and the degree of dispersal is fairly limited, though dispersal to some extent by juveniles is critical in maintaining genetic diversity. The societal value for this species is high due to its aesthetic value to the general public and its value as an indicator of ecosystem health for the rocky intertidal. Management potential is considered to be moderate, with some possibility to better manage disturbance from public visitation and to better protect the few meters of land above the beach that may serve as climate refugia for nesting habitat.

Sensitivity

I. Sensitivity to climate and climate driven changes

Climate and climate-driven changes identified (score[2], confidence[3]): sea level rise (5, high), wave action (5, high), precipitation (4, high), coastal erosion (4, moderate), air temperature (1, moderate)

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

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

- Confidence of workshop participants: Moderate

Additional participant comments

It is expected that sea level rise and coastal erosion will lead to habitat loss, and increased storm frequency and intensity would be expected to increase reproductive disturbance. Loss of breeding and nesting habitat is also expected with increased erosion, as is the loss of pre-existing nests to burying from eroded sediment.

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered. Sea level rise and wave action negatively impact the species through the same mechanism of coastal flooding, so these stressors are discussed together.

Sea Level Rise and Wave Action

The impact of sea level rise and enhanced wave action to oystercatchers is primarily through the exacerbation of flooding at high tide. In the long-term, sea level rise will reduce the availability of nesting and breeding habitat (Vulnerability Assessment Workshop, pers. comm., 2014), but acute flooding events, due to the combination of sea level rise, wave activity and high tide, can result in nest loss and an overall decline in reproductive success (Tessler et al. 2007). Clutches are regularly lost to flooding of nesting sites; a study of Alaskan nesting sites attributed 32% of nest losses to flooding events (Tessler et al. 2007).

Precipitation

Also a contributor to flooding, heavy precipitation events can negatively impact breeding success of black oystercatchers by inundating nesting sites that are built into depressions (Tessler et al. 2007).

Erosion

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

II. Sensitivity to changes in disturbance regimes

Disturbance regimes identified: wind, storms, and flooding

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

The identified disturbance regimes would greatly impact the breeding success of the black oystercatcher, but not the survival of adults.

Supporting literature

As storms are predicted to become more frequent and more severe, winter survival of adult and juvenile oystercatchers is expected to decline (Tessler et al. 2007) and reproductive disturbance will likely occur due to increased flooding from wave action and precipitation (see climate sensitivities above). Severe weather events, including high wind events and enhanced flooding, impact seabirds directly through the loss of nests and/or chicks (Hennicke and Flachsbarth 2009), and indirectly, by inhibiting adult feeding which reduces chick provisioning (Schreiber 2002).

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: rocky intertidal habitat for foraging and the narrow band of rocky and mixed substrate headland and island habitat above mean high tide for breeding and nesting

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

- Confidence of workshop participants: Moderate

Other critical dependencies: none identified

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

- Confidence of workshop participants: High

Additional participant comments

The black oystercatcher would likely not be able to quickly adapt to another breeding habitat, so if the narrow band of rocky and mixed substrate habitat above mean high tide is negatively affected by sea level rise, development, erosion, or other stressors, the species would be highly impacted.

Supporting literature

The species feeds exclusively on intertidal invertebrates such as limpets and mussels (SIMoN 2014a).

IV. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): land use change (5, moderate), recreation (5, moderate), pollution and poisons (4, moderate)

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

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: no answer provided

Additional participant comments

Land Use Change

How land is used in and near oystercatcher habitat (especially breeding/nesting habitat upland of rocky intertidal habitat) and how this use may change has real repercussions for the species through possible changes to the severity and frequency of disturbance from humans, coastal erosion, and nutrient run-off.

Recreation

The presence and activity of humans and dogs in oystercatcher habitat causes disturbance and can decrease nesting, or increase predation through the attraction of dogs or ravens to high human use zones.

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

[5] Confidence level indicated by workshop participants.

Supporting literature

Recreation

A study in Oregon found that the majority of nests that were accessible to humans failed, presumably a result of increased disturbance (Tessler et al. 2007). Also, because nesting sites are highly vulnerable to flooding, increased boating activity and visitation to nesting areas increases the probability that nests may be flooded by boat wakes, especially when visitation coincides with high tide (Tessler et al. 2007).

Pollution/Poisons

Poor water quality due to pollution can affect California mussels, which are a primary food source for oystercatchers. Because mussels are highly efficient filter feeders, heavy metals and organic pollutants can accumulate in their tissues (SIMoN 2014b), negatively impacting oystercatchers as they are consumed. Oil spills are also a threat to oystercatchers; up to 20% of the population in Prince William Sound was killed by the 1989 Exxon Valdez spill, breeding activity was disrupted, and chick survival was reduced (Andres 1994, 1997).

V. Other sensitivities: none identified

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): 3

- Confidence of workshop participants: Moderate

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 2-3

- Confidence of workshop participants: Moderate

Dispersal ability of the species: unknown

- Confidence of workshop participants: Low

Maximum annual dispersal distance: no answer provided

Supporting literature

This species exhibits a transcontinental geographic extent, from the Aleutian Islands, Alaska to Baja California, Mexico (SIMoN 2014a), and a population numbering approximately 10,000 individuals with only around 800 in California (Tessler et al. 2007). The black oystercatcher is considered a USFWS Focal Species for priority conservation action and a species of special concern within multiple jurisdictions, and is the least abundant shorebird species in North America (Tessler et al. 2007). Southern populations (including the study region) are thought to have very little migratory movement away from nesting sites, though some movement does occur, especially in juveniles and subadults (Tessler et al. 2007).

II. Intraspecific/Life History Diversity

Diversity of life history strategies: Low

- Confidence of workshop participants: Low

Genetic diversity: unknown

- Confidence of workshop participants: n/a

Behavioral plasticity: Low

- Confidence of workshop participants: Moderate

Phenotypic plasticity: no answer provided

Overall degree of diversity/plasticity of the species: Low

- Confidence of workshop participants: Low-Moderate

Additional participant comments

The black oystercatcher is long-lived, breeds once per year (or maybe twice, in the case of a failed brood), and may produce 1-2 chicks each successful breeding event.

Supporting literature

Little is known of the genetic diversity of the species, though it is hypothesized that juvenile dispersal is critical to maintaining genetic diversity in light of high site fidelity and a vast geographic range (Tessler et al. 2007).

III. Management Potential

Value of species to people: High

- Confidence of workshop participants: Moderate
- Description of value: value to the general public as an easily recognizable, charismatic and aesthetic species of the California coast

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

- Confidence of workshop participants: Moderate
- Description of potential management options: protect habitat from public (recreational) use that may serve as climate refugia (higher elevation areas that are more protected from big storms)

Supporting literature

The black oystercatcher is valued by the scientific community as a key indicator of ecosystem health for the rocky intertidal (Tessler et al. 2007).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): increased flooding (5, high), sea level rise (5, high), increased storminess (5, high), changes in precipitation (4, moderate), increased coastal erosion and runoff (4, moderate)

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

- Confidence of workshop participants: Moderate

Additional participant comments

Increased flooding of low-lying coastal areas, including oystercatcher feeding and nesting habitat, is expected in the study region due to rising sea level, increased storm activity and intensity, and increased extreme precipitation events.

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

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

[8] Confidence level indicated by workshop participants.

Blue Whale (*Balaenoptera musculus)* [1]

Executive Summary

Blue Whale	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	5 High	2 Moderate
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	4 Moderate-High	3 High

Blue whales are filter-feeding baleen whales that concentrate in areas downstream from upwelling centers where krill are concentrated into large swarms. In the study region, blue whales are often sighted near Cordell Bank and the broad shelf and shelf break in the Gulf of the Farallones. The Eastern North Pacific stock ranges from the Gulf of Alaska to Southern California in the summer and fall to feed and between Mexico and Panama in the winter and spring to breed. Key climate sensitivities identified by workshop participants for this species include sea surface temperature and dynamic ocean conditions (currents/mixing/stratification) and key non-climate sensitivities include pollution and poisons, human interactions, and anthropogenic noise. Blue whales exhibit a transcontinental geographic extent and an endangered population due to extensive whaling, though the Eastern North Pacific stock is recovering and growing. The species has high dispersal capability, with adults traveling great distances to access breeding and feeding grounds, and exhibits behavioral adaptation to anthropogenic noise, variable morphology and genetics among subspecies, and variable genetic structure due to hybridization among subspecies and with the related fin whale. The societal value for blue whales is high due to value to the tourism industry as charismatic megafauna. The challenge in managing this species is due to its cosmopolitan distribution, though human impacts (including noise, entanglement and vessel strikes) are currently managed for the Eastern North Pacific stock that occurs in the study region.

Sensitivity

I. Sensitivities to climate and climate-driven factors

<u>Climate and climate-driven changes identified (score[2], confidence[3])</u>: sea surface temperature (2, moderate) and dynamic ocean conditions (currents/mixing/stratification) (2, low)

<u>Climate and climate-driven changes that may benefit the species</u>: no answer provided

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

- Confidence of workshop participants: Low

Supporting literature

Though the only climate-driven factors identified for this species received low-moderate sensitivity scores, literature review was conducted on these factors in order to provide some information on their impact. However, it should be noted that the blue whale is likely more sensitive to direct impacts from human activity rather than from climate change.

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

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

[3] Confidence level indicated by workshop participants.

Sea Surface Temperature

Modeling based on ten years of data collected by Applied California Current Ecosystem Studies (ACCESS) cruises indicate that two climate indices are critical factors in predicting blue whale presence in the region (Vulnerability Assessment Workshop, pers. comm., 2014). These climate indices, which also impact sea surface temperature in the study region, are the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). The PDO is a long-term fluctuation in ocean climate that changes state every 20-40 years (Trenberth 1990, Trenberth and Hurell 1994), with warmer ocean temperatures observed during the positive phase, and cooler temperatures during the negative phase. The NPGO describes decadal scale fluctuations in sea surface temperature when paired with the PDO, as well as in salinity, chlorophyll, and thermocline depth, which has important implications for upwelling (DiLorenzo et al. 2008, Largier et al. 2010). A positive PDO and a negative NPGO indicate less productive ocean conditions, as was observed in 2005 and 2006, along with weak upwelling and low blue whale sightings (Elliott and Jahncke 2014). Further, abundance of North Pacific krill (*Euphausia pacifica*), the primary prey for blue whales, is thought to be negatively correlated with the PDO and sea surface temperature, declining during warm ocean periods (Brinton and Townsend 2003).

Dynamic ocean conditions (currents/mixing/stratification)

There is not yet enough data to support the direct impact of oceanographic conditions such as upwelling on blue whale presence and abundance, but given that upwelling has a significant impact on krill distribution, there is likely a strong indirect effect of upwelling on blue whales (Vulnerability Assessment Workshop, pers. comm., 2014). Krill are more abundant with earlier and stronger upwelling events and less abundant in years that experience weaker and/or later upwelling. Associated blue whale sightings have been correlated with these events, including decreased blue whale sightings in 2005 and 2006 in association with weak upwelling and a decline in krill (Jahncke et al. 2008).

II. Sensitivities to disturbance regimes: none identified

III. Dependencies

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

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: continental shelf to provide krill concentrations

Species dependence on specific prey or forage species: High (krill)

- Confidence of workshop participants: High

Other critical dependencies: upwelling and favorable oceanographic conditions for reproductive success due to the availability of krill

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

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

- Confidence of workshop participants: High

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution and poisons (5, high), human interactions (5, high), anthropogenic noise (5, high)

Overall species sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: High

- Confidence of workshop participants: High

Additional participant comments

Exposure to pollutants may contribute to acute impacts, such as pregnancy termination, and chronic impacts, such as promoting growth of cancerous tumors.

Supporting literature

Pollution and Poisons

Though it is difficult to establish a link between observed levels of contamination and direct health impacts in wild populations of cetaceans (Elfes 2008), exposure to pollutants may negatively impact reproduction (Steiger and Calambokidis 2000). The pollutants most often associated with these impacts include PCBs and synthetic organochlorine pesticides (including DDT), both of which bioaccumulate in the fatty tissues of marine mammals and are transferred from female whales to calves during gestation and lactation (Trumble et al. 2013). However, much more research is needed to fully understand the effects of pollutants on blue whales, as the effect may not be significant considering the successful recovery of the Eastern Pacific stock (Sarah Allen, pers. comm., 2014).

Human Interaction

Blue whales in central California are affected by multiple factors due to interactions with humans, including whale watching disturbances, shipping vessel strikes, and fisheries interactions (Vulnerability Assessment Workshop, pers. comm., 2014). Whale watching boats seek out blue whales, and there is some evidence that closely-approaching boats cause behavioral responses such as avoidance and alteration of diving behavior (Calambokidis et al. 2004). Vessel strikes have been identified as a threat to the recovery of the blue whale population (NMFS 1998) and the West Coast Region of the Office of National Marine Sanctuaries identified the issue of vessel strikes as a regional management priority. This region has one of the busiest ports for large shipping vessels on the west coast, with over 6,000 commercial vessels transiting in and out of San Francisco Bay every year (GFNMS 2008), whose routes often overlap with prime feeding grounds and transiting zones for large whales (Joint Working Group on Vessel Strikes and Acoustic Impacts 2012). Approximately four blue whales are killed by vessel strike every year, and this figure may be much higher due to unreported or unnoticed collisions (Joint Working Group on Vessel Strikes and Acoustic Impacts 2012). Fishing activity may cause harm to blue whales through entanglement in fishing gear, which can cause impaired foraging, increased drag, and tissue damage, including infection and hemorrhage, which can all lead to death of an individual (Moore and van der Hoop 2012). Though direct observation of blue whale

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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.

mortality due to entanglement is rare, with two documented cases, entanglement rates are likely underestimated because of lack of detection (NMFS 2014).

Anthropogenic Noise
Noise from ships, aircraft, and industry and military activity (NRC 2005) can mask communication among blue whales and limit prey detection (Clark et al. 2009), cause direct physiological damage, and disrupt feeding, breeding and traveling behaviors, leading to chronic stress and population-level impacts (CBD 2012, Rolland et al. 2012). Noise has increased exponentially in the region over the past 60 years, largely due to an increased commercial fleet (NRC 2003, McDonald et al. 2006).

V. Other sensitivities: none identified

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): 1
- Confidence of workshop participants: High

Population connectivity of the species (1=isolated/fragmented; 5=continuous): no answer provided

Dispersal ability of the species: High
- Confidence of workshop participants: High

Maximum annual dispersal distance: >100km
- Confidence of workshop participants: no answer provided

Supporting literature

Blue whales exhibit a transcontinental geographic extent, but an endangered population status due to extensive commercial whaling that drastically reduced populations worldwide (SIMoN 2006). The Eastern North Pacific stock was reduced from approximately 4,900 individuals to less than 2,000 when whaling ceased in 1966 (Braham 1984). This stock is currently one of the more healthy and growing populations worldwide, and current estimates based on mark-recapture studies number the population at around 2,500 individuals, potentially reaching carrying capacity (Calambokidis et al. 2010, NMFS 2011). Dispersal capability is high, with individuals traveling greater than 100 km between feeding and breeding grounds (Vulnerability Assessment Workshop, pers. comm., 2014). Though individuals are fairly solitary, they do loosely aggregate in prime feeding grounds (SIMoN 2006, Vulnerability Assessment Workshop, pers. comm., 2014).

II. Intraspecific/Life history diversity

No information regarding blue whale diversity and plasticity was provided by workshop participants.

Supporting literature

There are thought to be between six and twelve distinct populations of blue whales around the world based both on different song types as well as genetics, and in the North Pacific, at least two populations exist based on these song types (Calambokidis 2011). Variation in phenotypic plasticity is observed among these distinct populations, suggesting that selective pressure on geographically widespread populations from varying environmental conditions results in variable morphologies, including size and proportions (Gilpatrick and Perryman 2008). The size of the whales in the eastern Pacific population is smaller, for example than that those in the Southern Hemisphere. Hybridization has been observed in at least 5 cases between blue and fin whales (Bérubé and Aguilar 1998) and between two distinct Southern Hemisphere blue whale subspecies (Attard et al. 2012), potentially suggesting an enhanced capacity for genetic variation and adaptation. Behavioral plasticity has been observed in right whales in response to noise pollution from vessels and human activities through alteration of their communication by changing the frequency, source level, redundancy, and timing of their communications (Parks et al. 2007, Rolland et al. 2012). Blue whales reproduce in successive cycles (iteroparous), become sexually mature around 10 years of age, and can have up to 1 calf every 2-3 years, with a 12-month gestation (Vulnerability Assessment Workshop, pers. comm., 2014).

III. Management potential

Value of species to people: High

- Confidence of workshop participants: High
- Description of value: value to the tourism industry as charismatic megafauna

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

- Confidence of workshop participants: Moderate
- Description of potential management options: None provided, as there is difficulty in managing such a cosmopolitan species that occurs throughout the Eastern Pacific

Supporting literature

Management authority for the blue whale falls to the National Marine Fisheries Service, which has produced the Pacific Offshore Cetacean Take Reduction Plan[6] to reduce negative impacts from commercial fishing and a recovery plan[7] for the North Pacific population. Efforts to limit the degree of human interactions have become a management priority for the sanctuary program as well through the use of dynamic shipping lane restrictions (Joint Working Group on Vessel Strikes and Acoustic Impacts 2012).

IV. Other adaptive capacity factors: none identified

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[6] http://www.nmfs.noaa.gov/pr/interactions/trt/poctrp.htm

[7] http://www.nmfs.noaa.gov/pr/pdfs/recovery/whale_blue.pdf

Exposure

I. Future climate exposure[8]

Future climate and climate-driven changes identified (score[9], confidence[10]): changes in sea surface temperature (5, high) and altered currents and mixing (5, low)

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

- Confidence of workshop participants: Moderate

Supporting literature

Potential areas of refugia include areas with topographic upwelling rather than along the continental shelf where cool waters occur, for example Cape Mendocino and Point Arena (Sarah Allen, pers. comm., 2014).

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

[9] 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.

[10] Confidence level indicated by workshop participants.

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Blue Rockfish (*Sebastes mystinus*)[1]

Executive Summary

Blue Rockfish	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	3 Moderate	2 Moderate
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

Blue rockfish is a medium-sized, midwater rockfish important in both the recreational and commercial catches in California, and is the most abundant rockfish in central California kelp forests (CDFG 2010). The species occurs from Alaska to Baja California, from surface waters to a maximum depth of 600 meters. Key climate sensitivities identified by workshop participants for the blue rockfish include dissolved oxygen, pH, salinity, and the Pacific Decadal Oscillation, and key non-climate sensitivities include harvest, energy production, and oil spills. Blue rockfish exhibit a transcontinental geographic extent and a stable, continuous population that is at abundant levels. The species has a relatively high dispersal capability for both the larval and adult stages, and exhibits relatively moderate-high diversity in life history strategies, genetics, and phenotypic/behavioral plasticity. The societal value for blue rockfish is moderate-high due to its value for harvest, recreational diving and tourism, but managers may have difficulty in managing this species due to the inability to control the impacts expected from climate change, which will likely outweigh any manageable impacts such as harvest and pollution.

Sensitivity

I. Sensitivity to climate and climate driven changes

Climate and climate-driven changes identified (score[2], confidence[3]): dissolved oxygen (DO) levels (5, high), ocean pH (4, low), salinity (4, moderate), Pacific Decadal Oscillation (PDO) (4, high), sea surface temperature (3, moderate), dynamic ocean conditions (currents/mixing/stratification) (2, moderate-high)

Climate and climate-driven changes that may benefit the species: sea surface temperature
Description of benefit: Increased sea surface temperatures may promote more jellyfish production, which are prey for blue rockfish, increasing food supplies. Increasing sea surface temperatures may also result in increased distribution of blue rockfish.

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

- Confidence of workshop participants: Moderate

Supporting literature

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

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

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

[3] Confidence level indicated by workshop participants.

Sea surface temperature

Enhanced ocean temperatures impact fish physiology by increasing the organism's oxygen demands (Portner and Knust 2007), reducing oxygen solubility in seawater, reducing the performance of energy metabolism proteins (Fields et al. 1999) and negatively impacting growth and respiration (Largier et al. 2010). Changes in temperature can also impact rockfish age to maturity and consumption (Harvey 2009). Shifts in the latitudinal and depth distribution of fishes are also expected as water temperature increases, depending on species tolerance (Largier et al. 2010). Warmer water temperature, due to El Niño conditions, have been shown to negatively impact female rockfish fecundity and growth rates, and repeated exposure to El Niño events may result in delay of maturation age, which can result in the reduction of lifetime egg production (Harvey 2005).

Salinity

In a salinity study in southern California, varying salinity levels were found to have no affect on juvenile and adult rockfish (various species) (Weston Solutions 2012). However, as non-migratory residents of kelp and rocky reef habitats during juvenile and adult life stages (Burford et al. 2011), blue rockfish may be indirectly affected by salinity changes that affect habitat structure, ecosystem processes, or marine food webs (Bodkin et al. 1987).[4]

Dissolved oxygen (DO) levels

Significant changes to dissolved oxygen (DO) can result from a number of physical and biological processes, including circulation, ventilation, air-sea exchange, production and respiration (Keeling and Garcia 2002, Deutsch et al. 2005, Bograd et al. 2008). A decline in midwater oceanic DO is predicted due to enhanced stratification and reduced ventilation (Sarmiento et al. 1998, Keeling and Garcia 2002). 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). DO levels under 2 mg/L have been observed to negatively impact rockfish prey sources (NMFS 2013), lead to mass mortality events (Palsson et al. 2008), and alter rockfish behavior and habitat use through movement to more tolerable conditions at shallower depths (Palsson et al. 2005). Though there is little information regarding habitat requirements of rockfish larvae, the larval stages of many other fish species are vulnerable to low DO (Boehlert and Morgan 1980, NMFS 2013).

Ocean pH

The direct effects of decreased pH on fishes within the study region are not well understood (Largier et al. 2010), though one study outside of the region documented the impact of lower pH levels on larval clownfish olfactory cues, which caused disorientation (Munday et al. 2009). Altered behavioral responses, in the form of increased time spent seeking refuge, have recently been documented in juvenile rockfish when exposed to lower pH waters (7.75; projected for the next century in California) for one week, with recovery of normal behavior taking 12 days after a return to seawater at a normal pH level. The cause was traced to altered ion concentration in the blood, which impacts the fish's sensory system (Hamilton et al. 2013).

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[4] For more information on salinity impacts in relevant habitats, please see the Kelp Forest, Nearshore, and/or the Offshore Rocky Reef habitat summaries.

Pacific Decadal Oscillation (PDO)

The PDO is a longer-term fluctuation (20-40 years) in ocean climate (Trenberth 1990). During the warm (positive) PDO phase, climate change impacts are expected to be exacerbated, including enhanced warming of surface waters, increased rainfall, erosion and run-off, and reduced upwelling (Largier et al. 2010). Seabird diet studies have shown a decrease in the availability of juvenile rockfish during warm (positive) PDO periods (Miller and Sydeman 2004), and reduced fecundity of female rockfish (as well as reduced growth rate) was correlated with changes in ocean circulation and temperature, likely a result of reduced food supply (Harvey 2005).

II. Sensitivity to disturbance regimes

Disturbance regimes identified: disease and storms

Overall species sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Storms may cause loss of prime habitat (kelp forests) which will impact blue rockfish recruitment and survival, and increase turbulence that exacerbates kelp dislodgement and sedimentation that may reduce the recovery of storm-damaged forests.

Supporting literature

Disease

Disease is projected to increase with warming water temperatures, due to enhanced pathogen development and survival, as well as host susceptibility (Harvell et al. 2002). Blue rockfish have no known diseases, but may be indirectly impacted by disease through their dependence on the kelp forest habitat.

III. Dependencies

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

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: kelp forest and nearshore habitat

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

- Confidence of workshop participants: High

Other critical dependencies: oceanographic conditions

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

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

- Confidence of workshop participants: High

Additional participant comments

Blue rockfish are dependent on productive oceanographic conditions, including upwelling and cool surface waters for reproductive success. This species does not recruit well with poor upwelling and during El Niño events.

Supporting literature

Blue rockfish are dependent on kelp forest and nearshore habitat for recruitment of young-of-year fish and for protection and abundant food for adults (CDFG 2010). The species is less dependent on a specific food source, feeding on a variety of jellyfish, tunicates, algae, and small fish (CDFG 2010).

IV. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified (score[5], confidence[6]): harvest (4, high), energy production (3, moderate), and pollution (oil spills) (3, moderate)

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Low

Additional participant comments

Although currently well-managed, including the use of marine protected areas to protect some stocks, blue rockfish are vulnerable to management error via poor recruitment. Oil spills would have direct impacts to the species and indirect impacts to the habitat and ecological relationships of blue rockfish.

Supporting literature

Harvest

Although well managed in marine protected areas, blue rockfish may become more vulnerable to fishing pressure as climate impacts alter their basic physiology, including age to maturity, fecundity and growth rate (Helmuth et al. 2010). Managers will need to take into account the diverse and complex impacts of climate stressors on blue rockfish when assessing stocks (Helmuth et al. 2010).

Energy production

An emerging potential issue in the region is the production of wave energy conversion devices (Largier et al. 2010). These structures may impact nearshore wave energy and wave-driven processes, which could impact species zonation, distribution and abundance in the nearshore environment of the study region (Largier et al. 2010). Construction and maintenance of energy production devices, including associated cables to shore, could also have direct impacts on the region through entrainment of organisms such as young-of-year rockfish, increased turbidity, and disturbance to the seafloor (Nelson et al. 2008).

Pollution (oil spills)

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 resources in the region (Largier et al. 2010). After the 1989

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

[6] Confidence level indicated by workshop participants.

Exxon Valdez oil spill in Prince William Sound, Alaska, demersal rockfish species were the only fish species found dead in significant numbers, likely due to elevated hydrocarbon metabolites (Marty et al. 2003).

V. Other sensitivities: none identified

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): 4

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Dispersal ability of the species: Moderate-High

- Confidence of workshop participants: High

Maximum annual dispersal distance: Larval dispersal 75-100km; adult dispersal 5-25km

- Confidence of workshop participants: Moderate

Supporting literature

The blue rockfish is the most common species of nearshore rockfish in California (SIMoN 2014); however, the southern population (south of Cape Mendocino) is less stable and likely decreasing as compared to the northern population, due to fishing pressure and environmental variability (Cope 2004). The species has a moderate-high dispersal capability, with most research indicating adult movement of less than 6 miles (CDFG 2010).

II. Intraspecific/Life History Diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: High

Genetic diversity: Moderate-High

- Confidence of workshop participants: Moderate-High

Behavioral plasticity: Moderate

- Confidence of workshop participants: Low

Phenotypic plasticity: Moderate

- Confidence of workshop participants: Moderate

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: Moderate

Supporting literature

Blue rockfish spawn once per year, take two to five years to reach sexual maturity, produce relatively few offspring and have high parental investment (Vulnerability Assessment Workshop, pers. comm., 2014; CDFG 2010). One of the faster growing species of rockfish, blue rockfish have been aged to a maximum of 44 years (CDFG 2010). High levels of population differentiation have been detected throughout the species' range, with a distinct break in genetic differentiation at Cape Mendocino (Cope 2004). Subpopulations north and south of this biogeographic barrier have had little contact for thousands of years, suggesting that repopulation of the more heavily fished southern population may not be possible from the less-fished northern population (Cope 2004). Recent genetic evidence suggests that blue rockfish are actually composed of two closely-related species that overlap in range but are behaviorally and reproductively isolated, currently described as "blue-sided" and "blue-blotched" (Peterson et. al, *in review*).

III. Management Potential

Value of species to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: Blue rockfish is valued as a food source by commercial and recreational fisheries, and for its aesthetics by recreational divers and tourists

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

- Confidence of workshop participants: Low
- Description of potential management options: None provided. Climate factors will primarily drive the success of this species, not necessarily the more manageable non-climate factors of harvest and pollution.

Supporting literature

Blue rockfish is often identified as an important recreational species in California for anglers, and is usually the most frequently caught rockfish north of Point Conception (CDFG 2010).

IV. Other adaptive capacity factors: none identified

Additional participant comments

The overall success of the species will depend on successful recruitment of the species in the future.

Exposure

I. Future climate exposure[7]

Future climate and climate-driven changes identified (score[8], confidence[9]): Changes in El Niño events (5, moderate), increased storminess (4, high), decreased pH (3, high), changes in sea

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

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

[9] Confidence level indicated by workshop participants.

surface temperature (2, moderate), changes in salinity (1, moderate), decreased dissolved oxygen (DO) levels (1, moderate)

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

- Confidence of workshop participants: Low-Moderate

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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.

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

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

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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.

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

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

[3] Confidence level indicated by workshop participants.

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.

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

[5] Confidence level indicated by workshop participants.

Supporting literature

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]

Future climate and climate-driven changes identified (score[7], confidence[8]): 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)

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

- Confidence of workshop participants: Moderate

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

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

[8] Confidence level indicated by workshop participants.

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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

Climate and climate-driven changes identified (score[2], confidence[3]): 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)

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

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

- Confidence of participants: Moderate

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

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

[3] Confidence level indicated by 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

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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 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),

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

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

[8] Confidence level indicated by 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

<u>Climate and climate-driven changes identified (score[2], confidence[3])</u>: 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)

<u>Climate and climate-driven changes that may benefit the species</u>: no answer provided

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

- Confidence of workshop participants: Moderate

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

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

[3] Confidence level indicated by workshop participants.

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).

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[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

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

[6] Confidence level indicated by workshop participants.

[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

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[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

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[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

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[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.

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

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

[5] Confidence level indicated by workshop participants.

Supporting literature

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

Value of species to people: 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.

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

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

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

- Confidence of workshop participants: no answer provided

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

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

[8] Confidence level indicated by workshop participants.

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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.

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

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

[3] Confidence level indicated by workshop participants.

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).

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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.

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: no answer provided

Behavioral plasticity: Low

- Confidence of workshop participants: High

Phenotypic plasticity: Low-Moderate

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Supporting literature

In general, the literature indicates that coralline algae exhibit a great diversity in morphology and reproduction. The high morphological diversity in this family of algae enables multiple adaptation strategies that fill multiple ecological niches (Miklasz 2012). More finely branched articulate species excel at resisting desiccation stress and maintaining photosynthesis, while more stout species inhibit the movement of grazers (Padilla 1984). Crustose forms are best adapted for space competition, and often overgrow each other (Padilla 1984), with one species documented to be able to change its morphology depending on water motion and light (Steneck 1986). Some morphological diversity can be attributed to an herbivory response, including protuberances and especially thick epithalli (Miklasz 2012). Additionally, the reproductive strategies of coralline algae are plastic, adjusting to environmental conditions, including stress and disturbance. Some coralline are long-lived (up to 100 years, Halfar et al. 2007) and some are considered "ephemeral weeds" that can reach reproductive maturity in as little as a few weeks after settlement (Morcom et al. 1997). Like most red algae, coralline alternate between asexual and sexual reproduction (Miklasz 2012). Coralline algae reproduce intermittently throughout their lifespan (polycyclic) and are able to reproduce many times in a year, given optimal environmental conditions. There is a great diversity in reproductive timing and frequency in this family of algae – from constant reproduction in most articulate corallines, to seasonal reproduction in most crustose species, and for some, restricted to a few months of a year, and for others, occurring most of the year except a few months (Miklasz 2012). All of this indicates that coralline algae, as a species assemblage, are very successful at responding to their environment, and may have greater diversity and plasticity than indicated by workshop participants.

III. Management potential

Value of species to people: Low

- Confidence of workshop participants: High
- Description of value: no answer provided

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

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

Supporting literature

The societal value for this species assemblage was rated as low, though scientists recognize the importance of coralline algae as the dominant assemblage in intertidal systems (Largier et al. 2010), and in providing habitat and settlement cues for invertebrate larvae (Johansen 1981) and kelp zoospores (Hutto 2011).

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): reduced pH (5, high), changes in sea surface temperature (3, moderate), changes in air temperature (1, high)

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

- Confidence of workshop participants: High

Additional participant comments

Potential areas of refugia from increased air temperature include low intertidal, subtidal, and tidepool habitats, and refugia from increased sea surface temperature include deeper subtidal zones, as water may be expected to cool in these areas due to enhanced upwelling. No potential areas of refugia were identified for increased pH.

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

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

[8] Confidence level indicated by workshop participants.

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Gaper Clam (*Tresus nuttalli* and *Tresus capax*)[1]

Executive Summary

Gaper Clam	Score	Confidence
Sensitivity	3 Moderate	2 Moderate
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	2 Moderate

The gaper clam, also referred to as horse or horseneck clam, is a bivalve filter-feeder that inhabits lower intertidal and subtidal zones (to depths of 150 feet) in mud, sand and gravel substrate from Alaska to Baja California. *T. nuttalli* is more common to the south, and *T. capax* is more common to the north. Key climate sensitivities identified for these species by participants include sea surface temperature, precipitation, pH, and coastal erosion and key non-climate sensitivities include pollution and poisons. This species exhibits a transcontinental geographic extent and a stable population at abundant levels that supports a sustainable recreational fishery. Dispersal capability is likely relatively low due to the species' short planktonic larval stage. The gaper clam exhibits overall low diversity due to low-moderate life history strategy diversity, moderate genetic diversity, low behavioral plasticity, and low phenotypic plasticity. Gaper clams are residents of nearshore, subtidal and intertidal estuarine habitat, so this species is adapted to a wide range of environmental variation. However, sessile, benthic species have no way to avoid exposure brought on by future climate change scenarios and other anthropogenic effects, with siphon retraction as the only behavioral modification available. The gaper clam holds moderate societal value due to the popular sport fishery that exists in some parts of the region, including Tomales and Bodega Bays, but management potential for this species is considered low-moderate due to the inability to manage for climate impacts.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

Climate and climate-driven changes that may benefit the species: sea level rise

- Description of benefit: Sea level rise may decrease the amount of time clams are exposed to predation from shorebirds during low tides and increase the amount of time clams can feed while they are submerged.

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

- Confidence of participants: Moderate

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

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

[3] Confidence level indicated by participants.

Additional participant comments

In general, because of the nature of estuarine habitats, clams have the ability to withstand changes in temperature and salinity as well as periods of anoxia; however, laboratory studies have shown that early life stages of related clams are sensitive to lower pH, increased temperature and hypoxia as well as a combination of these factors.

Supporting literature

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

Sea Surface Temperature

Increasing water and air temperatures are magnified in estuaries relative to the outer coast and are important drivers of community and ecosystem responses, potentially resulting in range expansions of both native and non-native species (Williams and Grosholz 2008), enhancing the incidence of disease in estuarine species, and impacting estuarine circulation and dissolved oxygen (which is critical for the survival of the gaper clam, NOAA Ocean Service Education 2008). Descriptions of gaper clam characteristics indicate that adult and juvenile life stages can withstand temperatures ranging between 2-20˚C (Lauzier et al. 1998). Literature specific to the gaper clam and related bivalves indicates significant impacts to the species' larval stages. Larvae experienced 100% mortality at 20˚C (68˚F) and no significant difference in mortality among the 15, 10 and 5˚C treatments, though larval metamorphosis took significantly longer in the colder treatments (Bourne and Smith 1972). In another study on related clam species, increased temperature (24 and 28˚C) significantly depressed survival, development, growth, and lipid synthesis in larvae (Talmage and Gobler 2011).

Precipitation

Changing patterns in precipitation may have consequences for the impact of invasive species, sediment deposition, erosion, flooding, river flow (which may impact the timing of mouth opening and closure of some estuaries), water chemistry and run-off. Increases in storm and precipitation intensity will likely lead to more frequent and severe flooding of intertidal gaper clam habitat (Largier et al. 2010). Gaper clams have been identified to tolerate salinities ranging between 27-33ppt (Lauzier et al. 1998).

pH

Currently, there are large gaps in the scientific understanding of the impact of low pH on estuarine molluscs, including the additive effects of multiple oceanographic changes and the capacity for species to acclimate and/or adapt to these changes (Gazeau et al. 2013). We can, however, generally expect species such as the gaper clam to suffer negative effects to the production and growth of their shells. In a study on related clam species, increased CO_2 concentrations (~250, 390, and 750 ppm, representative of past, present, and future summer conditions in temperate estuaries) significantly depressed survival, development, growth and lipid synthesis in larvae, which were much more vulnerable to increased CO_2 than juveniles (Talmage and Gobler 2011). Because acidified water is often also low in dissolved oxygen, the combined effect of acidified and hypoxic water were tested on two bivalve species (bay scallop and hard clam) and found to have synergistic negative effects on both species, with reduced survivorship, growth and metamorphosis documented for larval stages, and reduced growth documented for later stages (Gobler et al. 2014).

Coastal erosion

Gaper clams may be directly impacted by coastal erosion or indirectly via human responses such as armoring and beach nourishment that will impact sediment supply and run-off (Largier et al. 2010). Erosion transports sediment into nearshore waters, which does help to maintain soft-bottom habitat. However, if sedimentation is excessive, negative impacts can include smothering of gaper clams, oxygen depletion and increased turbidity (Schueler 1997).
An increased tidal prism is thought to have contributed to the conversion of a few dominant habitat types to a patchwork of habitat types and the formation of subtidal channels in Elkhorn Slough, an estuary located just south of the study region (Ritter et al. 2008). The subsequent loss of fine sediment due to the increased tidal prism resulted in a shift from gaper clams to boring clams (ESTWPT 2007).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease, storms, and flooding

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Low

Supporting literature

Disease

Increase in disease is often linked to increase in water temperature, as both pathogen survival and host susceptibility are enhanced (Friedman et al. 1997, Harvell et al. 1999, Raimondi et al. 2002, Largier et al. 2010). Infection of gaper clams by a haplosporidan parasite was documented in Yaquina bay, Oregon in the 1970s, with a 43% infection rate. Twenty percent of those infected were emaciated and sluggish in response to prodding, and had a watery and transparent mantle and underdeveloped gonads (Armstrong and Armstrong 1973). Mass mortality in related clams has been attributed to similar parasites. Other parasites reported in gaper clams are cyclopoid copepods that infect the gill and a larval tapeworm (*Echeneibothrium sp*) that completes its adult cycle in the bat ray (*Myliobatis californicus*) (Katansky et al. 1969, Lauzier et al. 1998).

Flooding

Increased flooding is expected with sea level rise and more intense precipitation events (see climate sensitivities above). The estuarine habitat is highly sensitive to flooding because of inundation and restricted landward migration due to armoring, roads and other structures (Largier et al. 2010).

Storms

Models suggest that the tracks of storms in the northeast Pacific Ocean will experience an increase in occurrence of extreme conditions, though the number of extreme events may not change (Largier et al. 2010). Increased storm intensity will impact both wave energy and the timing and intensity of precipitation events, with major consequences for estuarine habitat (see *Precipitation* and *Erosion* sections above).

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: soft-bottom subtidal areas and estuaries

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: no answer provided

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

- Confidence of workshop participants: High

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution and poisons (5, moderate), harvest (3, low), dredging (3, low), overwater/underwater structures (3, low), recreation (2, low)

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: Low

Overall current exposure to non-climate stressors: Moderate

- Confidence of workshop participants: Low

Supporting literature

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

Pollution/Poisons:

Though there are no direct studies of the impact of pollutants on the gaper clam, exposure to agricultural and livestock waste, wastewater, sewage outfalls, historic mining, and industrial wastes (Largier et al. 2010) will likely cause the accumulation of toxins and heavy metals in the tissues of gaper clams, potentially impacting individual health and population abundance, as has been documented in other bivalve species (Pacific Biodiversity Institute, SIMoN 2014). This exposure to pollutants may potentially lower the fitness of clams in combination with other environmental stressors (Christy Juhasz, pers. comm., 2014). Toxin exposure has been shown to lower survival under laboratory conditions in a similar clam species when exposed to the pollutant cadmium and anoxic conditions (de Zwaan et al. 1995). The release of pollutants during dredging of soft bottom habitats has been documented, and may potentially expose species to additional pollutants (pers. comm. Sarah Allen, NPS). Increased extreme precipitation events will impact the timing and intensity of runoff of terrestrial pollutants, which will have important consequences for the timing and intensity of harmful algal blooms (Anderson et al. 2008; Kudela et al. 2008).

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): 5

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Moderate

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 4

- Confidence of workshop participants: Moderate

Dispersal ability of the species: Low-Moderate

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: 5-25km

- Confidence of workshop participants: Low

Supporting literature

Though the species is harvested recreationally, both intertidal and subtidal populations seem to be at sustainable levels, with subtidal individuals providing a spawning refuge from harvest (Moore 2001). The gaper clam has low-moderate dispersal capability, possibly limited to less than 25 km due to the relatively short duration of the planktonic larval stage (21-30 days, depending on water temperature, Bourne and Smith 1972, Clark et al. 1975) and the retention effects of the coastal boundary layer (Largier 2003, Christy Juhasz, pers. comm., 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: Moderate

- Confidence of workshop participants: Moderate

Behavioral plasticity: Low

- Confidence of workshop participants: Moderate

Phenotypic plasticity: Low

- Confidence of workshop participants: Low

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

- Confidence of workshop participants: Moderate

Additional participant comments

Gaper clams are residents of nearshore, intertidal and subtidal estuarine habitat, so this species is adapted to a wide range of physical oceanographic changes that fluctuate during daily tidal cycles and seasonally, between winter and spring months (e.g. changes in salinity and hypoxia). However, sessile, benthic species have no way to avoid exposure brought on by future climate change scenarios and other anthropogenic effects, and intertidal populations are more likely to experience and be more susceptible to future change. The only behavioral modification the gaper clams can make in response to environmental exposure is to retract its siphon, however they are unable to fully close their shell valves.

Supporting literature

The gaper clam produces many offspring over a relatively short lifespan, with a maximum lifespan of 17 years (Moore 2001). The clams reach sexual maturity at about 2 to 3 years of age, and can release gametes more than once, though it is unknown how many times per year (Clark et al. 1975, Moore 2001, Christy Juhasz, pers. comm., 2014). Machell and De Martini (1971) showed that reproduction of *T. capax* clams in Humboldt Bay, CA (north of the study region) spawned between January and April, coinciding with decreases in seasonal water temperature and salinity. Clark et al. (1975) found that *T. nuttallii* populations in Elkhorn Slough spawned around the same time period between February and April, but were still actively spawning throughout the year and attributed this to large daily fluctuations in temperature

III. Management potential

Value of species to people: Moderate

- Confidence of workshop participants: High
- Description of value: Value exists for the popular sport fishery within the study region in Tomales Bay, Bodega Bay and Drakes Estero.

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

- Confidence of workshop participants: Moderate
- Description of possible management options: none identified

Supporting literature

In Tomales Bay in the 1990s, as many as 1,200 people were counted during one low tide digging for clams (Moore 2001); more current estimates are not available, and these numbers have likely dropped due to lack of transportation for clammers. In Bodega Bay a high count of several hundred clammers was observed during a low tide in 2012 (Christy Juhasz, pers. comm., 2014). Harvest is not considered a management concern for the gaper clam, however, and local population declines have been attributed instead to reduced tidal flow and increased sedimentation, which may reduce gaper clam habitat, and climatic factors, including long-term climate change and short-term ENSO cycles, which are difficult to manage (Moore 2001).

IV. Other Adaptive Capacity Factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): changes in air temperature (5, high), increased coastal erosion and runoff (5, moderate), decreased pH (4, moderate), decreased dissolved oxygen (DO) levels (4, high), changes in sea surface temperature (4, high), increased flooding (4, moderate), changes in precipitation (4, moderate), changes in salinity (4, moderate), increased storminess (3, moderate)

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

- Confidence of workshop participants: Moderate

Additional participant comments

Gaper clams reside in nearshore intertidal estuarine habitats and experience a wide range of physical oceanographic conditions on a daily (tidal cycles) and seasonal basis. However, this sessile benthic species has no way to avoid increased exposure resulting from anthropogenic climate change.

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

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

[8] Confidence level indicated by workshop participants.

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Krill[1]

Executive Summary

Krill	Score	Confidence
Sensitivity	1 Low	3 High
Exposure	5 High	3 High
Adaptive Capacity	4 Moderate-High	2 Moderate
Vulnerability	2 Low-Moderate	3 High

Krill are small euphausiid crustaceans that swarm in great concentrations in the study region due to high local productivity. Key climate sensitivities identified by workshop participants include sea surface temperature and dynamic ocean conditions (currents/mixing/stratification), and key non-climate sensitivities include pollution and poisons. The two most common species in this region, *Thysanoessa spinifera* and *Euphausia pacifica*, have a broad, transcontinental geographic distribution and a continuous, stable population at abundant levels. *T. spinifera* is found mostly in shallower water over the continental shelf and *E. pacifica* is usually found in deeper water toward the margin of the shelf and beyond. Krill biomass in the region varies interannually, potentially due to variations in water temperature. The literature indicates a variety of behavioral and physiological responses and adaptations to variable environmental conditions, such as water temperature, oxygen concentration and predation, both among and within species. Krill were identified as having low-moderate societal value, though they are critical components of the region's food web and a source of food for many species, and moderate management potential that may be possible through regulation of future harvest, though most stressors to this species are currently a result of oceanographic processes and climate impacts that would be difficult to manage.

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) (3, moderate), sea surface temperature (2, moderate)

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

- Description of benefit: Increased upwelling could lead to an increase in krill biomass.

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

- Confidence of workshop participants: Moderate

Additional participant comments

Little information is available on the direct impact of sea surface temperature on krill abundance, though this climate factor may affect their relative productivity in the study region. As the primary delivery method of deep, cold, nutrient-rich water, upwelling likely leads to increased krill abundance.

[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

Dynamic ocean conditions (currents/mixing/stratification)

Changes in the timing of upwelling impact krill, as late upwelling is generally associated with poor ocean productivity, low krill abundance, and subsequent late seabird breeding (Abraham and Sydeman 2004, Jahncke et al. 2008), whereas strong and early upwelling is associated with increased abundance of krill and above-average seabird breeding success. Weak upwelling years, including 2005 and 2006, result in a decline in phytoplankton and zooplankton abundance, including lipid-rich adult krill. This decline caused seabird breeding failure, decreased salmon survival and decreased blue whale sightings (Jahncke et al. 2008, Largier et al. 2010). Strong upwelling, on the other hand, may counteract rising sea surface temperatures and promote primary productivity (Largier et al. 2010), but 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 (Young et al. 2012), potentially decreasing the abundance of krill.

Sea Surface Temperature

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 krill abundance and trophic functioning (Young et al. 2012). Results from the 30-year California Cooperative Oceanic Fisheries Investigation (CalCOFI) dataset indicate overall an 80% decrease in zooplankton biomass since the early 1950s, with associated increases in ocean temperature in the southern California Bight region (Roemmich and McGowan 1995; McGowan et al. 1996, 1998, 2003). However, a closer look at the two dominant krill species in the region indicates no significant decrease, and instead, an increase in the abundance of a sub-tropical species (Brinton and Townsend 2003). Overall, the zooplankton community in the region has become more diverse and more sub-tropical as sea surface temperatures increase, with a greater composition of smaller and less lipid-rich species, which may have significant impacts on energy transfer and food web dynamics (Largier et al. 2010).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

Changes in prevailing wind patterns can cause changes in the timing and intensity of upwelling, which will potentially impact krill abundance and productivity (see Dynamic Ocean Conditions section above).

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: Moderate

Other critical dependencies: no answer provided

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

- Confidence of workshop participants: High

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

Additional participant comments

The only stressor that would be expected to significantly impact species abundance is fishing pressure, which does not currently exist in this region, though commercial fisheries do exist in the Southern ocean and around Japan.

Supporting literature

Though the only non-climate stressor identified for this species received a low sensitivity score, literature review was conducted on this factor in order to provide some information on its impact. However, it should be noted that krill is likely more sensitive to direct impacts from climate change rather than human activity.

Pollution and Poison

Dispersed oil is expected to negatively impact krill and other zooplankton in the study region (Mearns 2012, Vulnerability Assessment Workshop, pers. comm., 2014). 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 euphausiid populations in the region (Largier et al. 2010).

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): 5

- Confidence of workshop participants: High

Population status of the species (1=endangered; 5=robust): 4.5

- Confidence of workshop participants: Moderate

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

Supporting literature

Euphausiid biomass in the region, measured by acoustics, peaked in July 2013, and adult krill, which are larger and higher in lipid content than juveniles, dominate the zooplankton samples during cold water years, including 2013 (Elliott and Jahncke 2014). However, the percentage of adult stages in euphausiid samples appears to be declining since mid-2010 (Elliott and Jahncke 2014).

II. Intraspecific/Life history diversity

Vulnerability assessment workshop participants did not provide information for krill diversity/plasticity. However, evidence does exist that krill species display plasticity in behavior and phenotype to respond to environmental variation. For example, a dominant species in this study region, *Euphausia pacifica,* is able to shrink between moulting periods as an adaptation to periods of abnormally high water temperature (Marinovic and Mangel 1999), and variable hatching time of krill eggs has been documented as a function of temperature (Ross et al. 1988, Iguchi and Ikeda 1994). While faster development occurs at higher temperatures, this may not be the case in upwelling systems, where sustained warmer temperatures are often associated with periods of poorer productivity and less food available to euphausiids (Feinberg et al. 2006). Larval stages of an Antarctic species of krill can regulate metabolism over a wide range of oxygen concentrations and temperatures, apparently an adaptation to the highly variable conditions encountered during vertical migration (Quentin and Ross 1989). Swarming and migration behavior vary by species; *Thysanoessa spinifera* forms dense surface swarms during the day time for increased mating opportunities, which in turn provides enhanced feeding opportunities for large whales, and *Euphausia pacifica* exhibits mass diurnal vertical migration, swarming at the surface at night for mating and to minimize exposure to predators while feeding (Howard 2010).

Krill produce many offspring with a short generation time. Reproductive maturity is reached within 24 months (Vulnerability Assessment Workshop, pers. comm., 2014), the lifespan of krill species in this study region (Nicol and Endo 1999), and krill utilize broadcast spawning, with the female releasing her fertilized eggs into the water column that typically hatch within 2 days

(Gómez-Gutiérrez 2002). Krill can have multiple reproductive events in one season, with time between spawning lasting on the order of days (Cuzin-Roudy 2000).

III. Management potential

Value of species to people: Low-Moderate

- Confidence of workshop participants: Moderate
- Description of value: though low value to the general public, krill are recognized as being critical components of the region's food web and a source of food for many species

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

- Confidence of workshop participants: High
- Description of potential management options: though most stressors to this species are currently a result of oceanographic processes and climate impacts that would be difficult to manage, regulation of future harvest is a potential management option

Supporting literature

Krill are an important component of the pelagic food web, as they convert the primary productivity of their prey into a more suitable form for consumption for many species of marine top predators, including seabirds, fishes and whales (Saether et al. 1986, Elliott and Jahncke 2014).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

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

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

- Confidence of workshop participants: no score provided

Additional participant comments

Exposure to climate factors is directly related to the future direction of upwelling frequency and intensity.

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

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

[8] Confidence level indicated by workshop participants.

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Pacific Mole Crab (*Emerita analoga*)[1]

Executive Summary

Pacific mole crab	Score	Confidence
Sensitivity	2 Low-Moderate	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	3 Moderate	3 High

The Pacific mole crab (also called sand crab) is a decapod crustacean that burrows in the sand in the swash zone and uses its antennae to filter feed. This species occurs along sandy beaches from Alaska to Baja California in North America, and from Peru to Argentina in South America. Key climate sensitivities identified for this species by participants includes salinity, erosion, pH, and precipitation and key non-climate sensitivities include roads/armoring and land use change. The Pacific mole crab exhibits a transcontinental geographic extent, a healthy, continuous and connected population, and a high dispersal capability due to the long planktonic larval stage. This species overall displays moderate diversity/plasticity, including limited genetic diversity due to its high dispersal, but behavioral and phenotypic plasticity based on variable beach morphodynamics and diversity in reproductive strategy, including variable developmental forms that are able to reproduce and variable timing of reproductive cycles. The societal value for this species is considered low, with some value held by shore fishermen (though the scientific community values this species greatly for its important role as prey for birds and fish), and management potential is considered low-moderate, with some possibility to manage for beach erosion and nourishment.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): salinity (5, high), coastal erosion (3.5, moderate), precipitation (3, moderate), pH (3, moderate), sea level rise (2, low), dynamic ocean conditions (currents/mixing/stratification) (2, low), harmful algal blooms (2, low), sea surface temperature (1, moderate)

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

- Description of benefit: Increased wave action could make some sheltered beaches a more suitable wave-exposed habitat for mole crabs.

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

- Confidence of workshop participants: Moderate

Additional participant comments

Local populations are heavily dependent on successful larval recruitment, and changes in dynamic ocean conditions in response to climate change could have significant impacts on local

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

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

[3] Confidence level indicated by workshop participants.

populations. Additionally, decreasing ocean pH levels, exposure to fresh and brackish water, and HABs may have adverse impacts on local population abundance.

Supporting literature

Literature review was conducted for those factors scoring 3 or higher, although the other sensitivities identified should also be considered. Altered currents and mixing were also identified as a potential source of sensitivity for the species, though the degree of sensitivity is unknown, due to the possible impact on larval transport and subsequent recruitment (Sorte et al. 2001; Amy Dean, pers. comm., 2014).

Salinity

Artificial freshwater discharge from a canal was found to significantly impact the distribution, abundance, and life history traits of a related species of mole crab, *Emerita brasiliensis*, with decreased abundance of juveniles, males, females and ovigerous females, decreases in weight and fecundity, and disruption of female maturity patterns associated with the canal (Lercari and Defeo 1999).

Erosion

There is existing evidence of a high level of disturbance to mole crab populations if beaches are highly eroded, and there are beaches in California that lose much of their sand in the winter; if there is no sand, there is no habitat for mole crabs (Amy Dean, pers. comm., 2014). However, more recent experimental evidence on a related species, *Emerita talpoida*, indicates that the species can rapidly recover, and in some cases, maintain its abundance during even substantial loss of beach sand due to storm activity (Peterson et al., unpublished). Additionally, though it would be assumed that increased wave energy would impose a greater metabolic cost on mole crabs trying to maintain their position in the swash zone, no significant difference was found in oxygen uptake of the Pacific mole crab at varying levels of wave energy (Lastra et al. 2004), which suggests acclimation to this environmental variable. Consequently, it may be the response to erosion by managers that could impact this species most. Beach nourishment has been shown to inhibit adult *E. talpoida* burrowing behavior, negatively impacting its ability to feed and to maintain its position in the swash zone, due to an increased proportion of large shell pieces (>2mm) in nourished sand (Manning et al. 2013).

pH

The effects of decreasing pH on mole crabs will likely be felt most strongly during upwelling events that bring cold and deep water to the surface (Feely et al. 2008). This water is undersaturated in aragonite, and is expected to impede the ability of mole crabs to strengthen their exoskeletons with calcium carbonate, resulting in weaker exoskeletons (Raven 2005, Largier et al. 2010). Many studies have shown this effect on other invertebrate species, including the California Mussel, which precipitated weaker, thinner and smaller shells under projected 2100 CO_2 concentrations (Gaylord et al. 2011).

Precipitation

The potential impact of precipitation on the Pacific mole crab will likely be caused by subsequent increased exposure to freshwater due to more intense periods of river flow and freshwater discharge, altering the local salinity and impacting local mole crab abundance (see salinity section above). Altered precipitation patterns may also impact the timing of material transport to beach systems. Short, heavy precipitation events can increase freshwater sediment discharge and bolster beach and dune systems, though this dynamic is mediated by inland water and sediment retention structures such as dams (Slagel and Griggs 2008, Largier et al. 2010).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms and flooding

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

The mole crab was identified as moderately sensitive to storm and flooding events, primarily due to its sensitivity to change in salinity (see precipitation and salinity sections above). In general, however, this species is highly adapted to live in disturbed environments, so likely will not be greatly impacted by disturbance regimes.

III. Dependencies

Species dependence on one or more sensitive habitat types: Low

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

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: reproductive dependency

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

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

- Confidence of workshop participants: High

Additional participant comments

The mole crab has a low dependency on sensitive habitat due to the expected persistence of wave-disturbed beaches and is considered to be more of a generalist, and therefore may have greater flexibility to adapt to environmental changes.

Supporting literature

The ability of the species to burrow into a variety of grain sizes (Dugan et al. 2000), and a low dependency on specific prey, as the species filters various suspended food particles, such as detritus and phytoplankton, from the water column with its antennae (SIMoN 2014).

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): land use change (5, high), coastal roads/armoring (3, moderate), pollution and poisons (2, moderate)

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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.

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Low

- Confidence of workshop participants: Moderate

Supporting literature

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

Roads/Armoring

Coastal armoring and road construction, in response to enhanced erosion of bluffs and cliffs in the study region, prevent upland beach and dune migration in response to sea level rise (Largier et al. 2010, Vulnerability Assessment Workshop, pers. comm., 2014) and increased passive erosion, increasing the sensitivity of beach and dune systems (Dugan et al. 2008). These effects will only become more pronounced with sea level rise as these structures interact with waves and tides (Dugan et al. 2008). In addition, armoring can replace beach habitat, reducing beach extent and negatively impacting mole crabs (Dugan et al. 2008). Armoring is projected to increase, although beach nourishment is now being used more frequently as an alternative (Defeo et al. 2009).

Land Use Change

Land use change (i.e., development, watershed alterations, livestock grazing and agriculture) may disrupt sediment supply to beaches, and impact water quality in the region, resulting in high coliform, bacterial and toxic metal contamination (e.g., high mercury levels, ONMS 2010). In addition, development and landscape irrigation on top of coastal cliffs that often back beaches in the study region can increase internal pore pressures of cliff materials, decreasing resilience and accelerating coastal erosion (Griggs and Patsch 2004). The construction of jetties or breakwaters can deprive down coast fronting beaches of sand, while simultaneously increasing sediment delivery to up coast fronting beaches (Griggs and Patsch 2004).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 4

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Dispersal ability of the species: High

- Confidence of workshop participants: High

Maximum annual dispersal distance: unknown

Supporting literature

This species exhibits a broad geographic extent, from Alaska to Baja California, Mexico, in North America (SIMoN). The long planktonic period of the larval stage (lasting up to 130 days) enables wide dispersal of the species, potentially colonizing new areas and annually restocking already existing populations (Efford 1970, Tam et al. 1996) depending on coastal water transport dynamics. Dispersal plays an important role in the maintenance of northern populations (Oregon up to Vancouver Island), as these populations are thought to be supplied with larval stock from the more established California populations via larval drift in the Davidson Current (Sorte et al. 2001).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: Moderate

- Confidence of workshop participants: Low

Behavioral plasticity: Low-Moderate

- Confidence of workshop participants: Low

Phenotypic plasticity: Moderate-High

- Confidence of workshop participants: Low

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: Low

Supporting literature

Because of the wide dispersal capabilities of the planktonic larval stages, the species is thought to be approaching genetic homogeneity in the northeast Pacific (Dawson et al. 2011). There is evidence of complex sexual variation in a related mole crab species, *Emerita brasiliensis*, including seven developmental forms that are able to reproduce (e.g. precocious females, juveniles, intersex individuals), variable sex ratios and variable timing of reproductive cycles (Delgado and Defeo 2008). Phenotypic and behavioral diversity has been observed in the Pacific mole crab in association with variable beach morphodynamics, including growth pattern, reproductive biology and burrowing capacity, suggesting that the species is responsive to environmental variation (Brazeiro 2005).

III. Management potential

Value of species to people: Low

- Confidence of workshop participants: High
- Description of value: Shore based fisherman value this species as bait.

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

- Confidence of workshop participants: Low

- Description of potential management options: manage for beach erosion, as the species is expected to repopulate a disturbed beach fairly quickly (within a week or two, Hayden and Dolan 1974) if conditions improve and are suitable for their survival

Additional participant comments

Because mole crab populations are heavily dependent upon successful recruitment, which is influenced by dynamic ocean conditions, it will be difficult to actively manage climate change impacts to this species. The overall adaptive capacity assessment of this species assumes that recruitment is not affected by climate change impacts.

Supporting literature

Though this species is not generally valued by the public, the mole crab is recognized as a critical component of food web dynamics, providing the majority of biomass for birds and fishes in beach habitat in the study region (Largier et al. 2010). Though participants scored the management potential for the mole crab as low-moderate, there are many management actions dealing with coastal armament and upstream processes that can be taken to manage potential impacts (Dan Robinette, pers. comm., 2014).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

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

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

- Confidence of workshop participants: Moderate

Additional participant comments

Potential areas of refugia include poleward range shifts to avoid increased sea surface temperature, migration landward in response to sea level rise (if beach is available), and subtidal habitat to escape the impacts of erosion.

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

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

[8] Confidence level indicated by workshop participants.

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Northern Anchovy (*Engraulis mordax*) and Pacific Sardine (*Sardinops sagax caerulea*)[1]

Executive Summary

Northern Anchovy	Score	Confidence
Sensitivity	3 Moderate	2 Moderate
Exposure	3 Moderate	2 Moderate
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	3 Moderate	2 Moderate

Pacific Sardine	Score	Confidence
Sensitivity	3 Moderate	2 Moderate
Exposure	3 Moderate	2 Moderate
Adaptive Capacity	4 Moderate-High	2 Moderate
Vulnerability	3 Moderate	2 Moderate

Northern anchovy and Pacific sardine are small forage fish that serve as a critical food source for many important fish, bird and mammal species and support commercial and recreational fisheries in the study region. Northern anchovy occur from British Columbia to the Gulf of California in large schools near the ocean's surface, and Pacific sardine range from Southeast Alaska to the Gulf of California in nearshore and offshore waters along the coast. Key climate sensitivities identified for both species by workshop participants include sea surface temperature, dynamic ocean conditions (currents/mixing/stratification), dissolved oxygen, and pH. The only non-climate sensitivity identified is harvest. Both the Pacific sardine and Northern anchovy exhibit a transcontinental geographic extent and diminished, but stable, populations that are patchy with some degree of connectivity, due to moderate to high dispersal, depending on size and age of the fish as well as season. They exhibit overall moderate-high intraspecific diversity with moderate phenotypic and behavioral plasticity in morphology, diet, spawning behavior and age structure, which enables some degree of response to changes in environmental conditions. The Northern anchovy has considerably greater genetic diversity than the Pacific sardine, possibly due to life history differences and the collapse of the sardine fishery in the 1930s. Both species are valued for the commercial and recreational fisheries they support and their role in pelagic ecosystems. The likelihood to manage or alleviate climate impacts may be possible through further fisheries regulations, with is considered low-moderate for anchovy because there currently is no active management of this fishery (though that can easily change if necessary), and moderate for sardine, as this species is federally managed on an annual basis.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]):

- Both species: sea surface temperature (5, high), dynamic ocean conditions (currents/mixing/stratification) (5, high), pH (4, low), dissolved oxygen (DO) levels (4, high), salinity (3, moderate)

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

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

[3] Confidence level indicated by participants.

- Anchovy only: coastal erosion (3, low), air temperature (2, moderate), precipitation (2, moderate)

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

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

- Confidence of participants: Moderate

Additional participant comments

The Northern anchovy and Pacific sardine are pelagic species that occasionally travel in nearshore waters and can be affected by a variety of long-term climate changes. Climate change is expected to most affect these species through prey availability, by significantly impacting chlorophyll and primary ocean productivity, and consequently the food sources for anchovy and sardine, as well as preferred spawning habitat.

Supporting literature

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

Sea Surface Temperature

Anchovy and sardine populations alternate in abundance about every 25 years depending on ocean temperature; in the mid-1970s, the Pacific changed from a cool “anchovy regime” to a warm “sardine regime” and a shift back to an anchovy regime occurred in the middle to late 1990s (Chavez 2003). Sardine spawn in a wider range of temperatures (13-25˚C) than anchovy (11.5-16.5˚C). Average conditions during a sardine regime are similar to those during an El Niño event, when ocean temperature is warmer and productivity is lower (Chavez 2003); as ocean temperature continues to warm due to climate change, we may expect increasing frequency and length of sardine regimes. The spatial and seasonal distribution of sardine spawning is temperature-dependent; in warmer water, the center of spawning activity moves northward and occurs over a longer period of time (Butler 1987, Ahlstrom 1960), and sardine eggs and larvae are most abundant at temperatures of 13-15˚C (55-59˚F) (Hill et al. 2014).

Currents/Mixing/Stratification

In this broad category of climate impacts, upwelling and El Niño processes were identified as influencing the sensitivity of anchovy and sardines due to the impact on sea surface temperature. Upwelling has a significant impact on larval fish and the availability of food, which may drive population trends for the species (Vulnerability Assessment Workshop, pers. comm., 2014). Both processes may help drive the distribution and abundance of the species by impacting which fish “regime” is dominant; sardines are more abundant during warm water El Niño conditions, and anchovy dominate during cool water conditions that can be driven by coastal upwelling (Chavez 2003). Additional research suggests that this regime shift is controlled by the fluctuating abundance of the preferred prey of sardine and anchovy, with smaller plankton (preferred by sardine via filter feeding) being favored by weak upwelling, and larger plankton (preferred by anchovy via direct biting) being favored by strong upwelling (Rykaczewski and Checkley 2008). This upwelling difference may also separate sardine and anchovy populations to the offshore and nearshore habitats, respectively, as strong upwelling occurs along the coastal margin and weak upwelling occurs offshore from wind stress (Rykaczewski and Checkley 2008).

Oxygen

Dissolved oxygen is an environmental parameter that greatly impacts marine species and can lead to mass mortality events, behavioral modification, and a reduction in prey sources (Palsson et al. 2005, Palsson et al. 2008, NMFS 2013). Larvae of related sardine and anchovy species of the northern Benguela upwelling system have been documented to avoid low-dissolved oxygen waters, staying in waters with dissolved oxygen concentrations greater than 2 mL/L (Kreiner et al. 2011). Bertrand et al. (2012) suggest that along the upwelling coast of Peru, anchovy and sardines have different levels of tolerance to oxygen concentrations due to their different body sizes (smaller anchovies being more tolerant of lower dissolved oxygen) and other physiological differences. This relationship is the basis for the regime shift between anchovy and sardine populations, with sardine abundance declining during periods of upwelling that bring undersaturated concentrations of dissolved oxygen from oxygen minimum zones to the surface (Bertrand et al. 2012).

pH

The direct effects of decreased pH on fishes within the study region are not well understood (Largier et al. 2010), though one study outside of the region documented the impact of lower pH levels on larval clownfish olfactory cues, which caused disorientation (Munday et al. 2009). The impact of ocean acidification may also be felt indirectly by sardine and anchovy through impacts to their food supply, specifically zooplankton that form calcium carbonate shells, like copepods and pteropods. Decreased pH enhances shell degradation in pteropods and decreases calcification and oxygen consumption (Comeau et al. 2009, Lischka et al. 2010, Seibel et al. 2012), potentially impacting the abundance of this important food source.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind and storms

Overall species sensitivity to disturbance regimes: Low-Moderate

- Confidence of participants: Low

Additional participant comments

Both wind and storms have the potential to affect currents, mixing, upwelling and sea surface temperature and these factors can influence feeding patterns and habitat selection by sardine and anchovy populations (see climate-driven factors above).

III. Dependencies

Species dependence on one or more sensitive habitat types: Moderate-High (anchovy), High (sardine)

- Confidence of participants: High
- Sensitive habitats species is dependent upon: offshore/pelagic water column

Species dependence on specific prey or forage species: Moderate

- Confidence of participants: Moderate

Other critical dependencies: none identified

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

- Confidence of participants: Moderate

IV. Sensitivity and current exposure to non-climate stressors

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

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

- Confidence of participants: High

Overall species exposure to non-climate stressors: Low (in the study region)

- Confidence of participants: High

Additional participant comments

Because anchovy and sardine are open-water species, many of the common non-climate stressors that impact those in enclosed bays, estuaries and coastal waters are not expected to impact these species.

Supporting literature

Literature review was conducted only for harvest, as pollution and poisons scored only moderate-low for these species.

Harvest

Currently managed under the Coastal Pelagic Species Fishery Management Plan by the Pacific Fisheries Management Council, Pacific sardine and Northern anchovy are thought to be well-managed and not over-fished (Hill et al. 2014). Continuing current management of both species will be crucial to protecting their abundance and viability as the climate continues to change.

Historically, the sardine fishery developed during World War I in response to rising food demand, and collapsed in the 1950s. This collapse was initially blamed primarily on fishing pressure, though now is partially attributed to a climatic shift in ocean temperature, which controls the boom and bust cycles of both sardines and anchovies (see *Sea Surface Temperature* above). Abundance assessments are undertaken every year, and used to set an annual catch limit for the species (NOAA 2013).

The northern anchovy fishery was small until the collapse of the sardine stock in the 1950s, when anchovy then became the most abundant fish for the canning industry (NOAA 2013). Once the sardine fishery recovered, demand for anchovy decreased and today supports a small but valuable bait fishery (NOAA 2013). The northern anchovy is significantly less managed than the sardine, with the southern stock (San Francisco to Baja California) having last been assessed in 1995, and the northern stock (San Francisco to Washington) having never been assessed. This species is monitored but not assessed on an annual basis due to the low commercial landings (NOAA 2013). Should landings increase, managers will likely consider further assessing the species and implementing additional fishing regulations (NOAA 2013).

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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 participants.

V. Other sensitivities

Other critical factors likely to influence the sensitivity of the species: chlorophyll and ocean productivity

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

Additional participant comments

Climate change could have a huge effect on chlorophyll and ocean productivity, and consequentially, food sources for the anchovy. Overall, climate change will most impact anchovy through changes in its food source (prey availability) and preferred spawning habitat.

Adaptive Capacity

I. Extent, status, and dispersal ability

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

- Confidence of participants: High

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

- Confidence of participants: Low

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

- Confidence of participants: High

Dispersal ability of the species: Moderate

- Confidence of participants: Moderate

Maximum annual dispersal distance: 50-75km

- Confidence of participants: Low

Additional participant comments

Northern anchovy occur from British Columbia to the Gulf of California, Mexico, and the Pacific sardine occurs from Southeast Alaska to the Gulf of California, Mexico. With the substantially large range of the adult populations, both species are able to disperse, with maximum dispersal considered to be 50-75 km for anchovy and greater than 100 km for sardine. Extreme natural variability is characteristic of both species, so connectivity across species ranges at a given time is dependent on size and age as well as season.

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of participants: Low

Genetic diversity: High

- Confidence of participants: High

Behavioral plasticity: Moderate

- Confidence of participants: Low

Phenotypic plasticity: Moderate

- Confidence of participants: Low

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of participants: Low

Supporting literature

Though both species were identified by workshop participants as having high genetic variance, there is no evidence of genetic variation among the three Pacific sardine subpopulations (Hill et al. 2014), suggesting high gene flow across the entire species range. This is in contrast to the Northern anchovy, which shows substantial genetic variation within and between populations from the California stock (Hedgecock et al. 1989). This difference is thought to be the result of differing life history characteristics and the more recent arrival of the Pacific sardine to the California Current System (Gaggiotti and Vetter 1999). Morphometric differences among sardines have been attributed to phenotypic plasticity rather than genetic diversity (Hedgecock et al. 1989, De La Cruz-Agüero and García-Rodríguez 2004). Additionally, sardine exhibit plasticity in diet, spawning behavior and age structure, enabling the species to quickly adapt and exploit favorable environmental conditions (Agostini 2005). Anchovy display plasticity also in diet, based on food availability (Sirotenko and Danilevskin 1978), and in annual spawning events; for example, the decline of the sardine population was accompanied by a significant increase in the duration of anchovy spawning (Smith 1972).

Sardines may live up to 15 years, though commercial catches are typically composed of individuals less than 5 years (Hill et al. 2014). Sardines spawn in loosely aggregated schools in the upper 50 meters of the water column, with spawning peaking in April in the study region (Hill et al. 2014). Anchovies are shorter-lived, rarely exceeding 4 years old, with peak spawning activity between February and April, and females release batches of eggs every 7 to 10 days (NOAA 2013).

III. Management potential

Value of species to people: Moderate-High (anchovy), High (sardine)

- Confidence of participants: High
- Description of value: Value for both recreational and commercial fisheries. The commercial anchovy fishery was valued at $1,059,476 in 2013; the sardine fishery was valued at $1,555,912 in 2013.

Likelihood of managing or alleviating climate change impacts on species: Low-Moderate (anchovy), Moderate (sardine)

- Confidence of participants: Moderate
- Description of potential management options: The Northern anchovy is not currently actively managed; however, this can change relatively quickly if significant levels of catch occur or if biological or economic concerns arise. The Pacific sardine is federally managed on an annual basis and change in temperature (the species greatest sensitivity) is considered when setting harvest, which will help alleviate fishing pressure in response to climate change.

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

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

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

- Confidence of participants: Moderate

Additional participant comments

Potential areas of refugia from these climate factors are more northern or southern pelagic waters, or changes in depth.

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

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

[8] Confidence level indicated by participants.

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Ochre Sea Star (*Pisaster ochraceus*)[1]

Executive Summary

Ochre Sea Star	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

The ochre sea star is the largest 5-ray intertidal sea star in the study region. Its geographic range extends from Prince William Sound, Alaska to Isla Cedros, Baja California. Key climate sensitivities identified by workshop participants include air temperature, salinity, wave action and erosion, and key non-climate sensitivities include disease. The ochre sea star exhibits a transcontinental geographic extent, a healthy, continuous population (with the exception during a sea star wasting syndrome event that greatly diminishes the population), and a high dispersal capability. There is very little genetic diversity in the species due to extensive dispersal; the basis for the species' color polymorphism may be genetic, but is thought to be controlled by ecological factors. The ochre sea star displays behavioral and phenotypic responses to changes in food availability and exposure at low tide, and can regenerate body parts when lost due to dislodgement and predation. The societal value for this species was rated as moderate due to aesthetic value by the general public and scientific value in studying ecological relationships. 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), coastal erosion (4, low-moderate), sea surface temperature (3, low-moderate), sea level rise (3, moderate-high), dynamic ocean conditions (currents/mixing/stratification) (3, low), precipitation (2, low), dissolved oxygen (DO) levels (2, low-moderate), ocean pH (2, low-moderate)

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

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

- Confidence of workshop participants: Moderate

Additional participant comments

The ochre sea star is highly sensitive to wave action due to dislodgement, and is found only in the low to mid intertidal (reaching into the subtidal) for this reason.

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered. Additionally, elevated CO2 and water temperature may directly benefit the species, due to increased growth and feeding rates (Gooding et al. 2009).

Air Temperature

The effect of temperature on the physiology of the ochre sea star is complex; acute exposure to high temperatures positively impact feeding rates, whereas long-term exposure to high temperatures can depress feeding and growth rates and is actively resisted by individuals through an increase in body water content (Pincebourde et al. 2009). Individuals relocated to the high intertidal from the mid intertidal showed decreased feeding, weight loss and mortality (Petes et al. 2008), and rates of oxygen consumption increased with increasing air temperature (Fly et al. 2012), all of which indicate a metabolic cost to exposure. However, through increased water content and relocation to lower tidal zones, individuals are able to escape the impacts of exposure and high air temperatures.

Salinity

Activity and feeding response is directly impacted by salinity, with lower activity occurring at low salinity levels (15 psu) as compared to higher levels (30 psu, typical of open ocean). However, at 15 psu, individuals collected from sites with low natural salinity were more active than individuals collected at the higher salinity level locations, suggesting acclimatization or adaptation to low salinity is possible, though limits to this tolerance exist (Held and Harley 2009).

Wave Action

Though sea stars can secure themselves to the substrate using their tubefeet, they can be removed if wave forces are very high (SIMoN 2014), and consistently high wave forces may restrict the species to lower tidal heights.

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 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 disturbance regimes

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

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: Moderate

Supporting literature

Wind is highly desiccating to intertidal organisms and can dry out species that need to retain moisture for survival, enhancing the negative impact of increased air temperature (Bell 1995). Storms increase physical forces through enhanced wave exposure and increased erosion of coastal cliffs that can bury intertidal habitats (see wave action and erosion sections above). Flooding may have a similar effect by increasing sedimentation to the intertidal area, but may also result in compromised water quality (PISCO 2014), including an increase in harmful algal bloom events. Disease is the primary non-climate stressor that can be expected to impact the ochre sea star (see disease section below), and will likely be exacerbated by increased water temperature, as both pathogen survival and host susceptibility are enhanced (Friedman et al. 1997, Harvell et al. 1999, Raimondi et al. 2002, Largier et al. 2010). Extreme heat events can exacerbate the impacts of exposure to air (see air temperature section above).

III. Sensitivity and exposure to non-climate stressors

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

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: High

Overall current exposure to non-climate stressors: Moderate

- Confidence of workshop participants: High

Additional participant comments

The sea star wasting syndrome is a primary concern for the health of this species due to the massive die-offs that have occurred over the last year.

Supporting literature

Literature review was not conducted for recreation due to the low sensitivity score assigned, though this factor should still be considered when examining overall impact to the species from non-climate stressors.

Disease

Sea star wasting syndrome describes symptoms that occur in over 15 species of sea stars that lead to tissue decay, fragmentation, and eventual death. The latest occurrence of the syndrome began in June 2013 in Washington and has since spread from Alaska to Baja California, the entire extent of the ochre sea star’s range. Previous syndrome events were associated with the warm water temperatures of El Nino events (1983-84, 1997-98), but that association does not exist with this latest occurrence, which has exhibited an unprecedented geographic and temporal extent (Sea Star Wasting Syndrome 2014). Very recently, the cause of the syndrome was determined to be viral (Hewson et al. 2014). Because sea stars are dominant predators of intertidal and subtidal habitats and are considered keystone species, the ecological consequences of this syndrome may be severe. Recent studies, however, have shown substantial recruitment of new sea stars to a few areas in the region, which may enable rapid replenishment of affected populations if recruitment is widespread and the new recruits are unaffected by the syndrome (Sea Star Wasting Syndrome 2014).

IV. Dependencies

Species dependence on one or more sensitive habitat types: Low

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: no answer given

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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.

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: hard substrate in the low to mid intertidal for settling larvae and foraging adults

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

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

- Confidence of workshop participants: High

V. Other sensitivities: none identified

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: High

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

- Confidence of workshop participants: High

Dispersal ability of the species: High

- Confidence of workshop participants: High

Maximum annual dispersal distance: 75-100km by larvae from broadcast spawning

- Confidence of workshop participants: Low

Additional participant comments

The health of the population is highly compromised during sea star wasting syndrome events (see disease section above), and therefore the success of future ochre sea star populations is uncertain.

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: Moderate

- Confidence of workshop participants: High

Phenotypic plasticity: Low-Moderate

- Confidence of workshop participants: High

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: High

Supporting literature

This species is long-lived (though a subject of debate, considered to be around 20 years, SIMoN 2014) and exhibits high reproductive output through broadcast spawning, reproducing seasonally, many times throughout its life. Spawning occurs in April and May in the study region and in July further north (SIMoN 2014). In contrast to the genetic diversity score provided by workshop participants, the literature suggests that the ochre sea star has very low population genetic structure, suggesting high gene flow and low genetic diversity throughout its range (Harley et al. 2006). Color polymorphism is a striking characteristic of the species that varies with geography that may have an underlying genetic component, though is considered to be ecologically controlled, with some connection to diet (Harley et al. 2006). The species grows in proportion to its food supply and will increase or decrease in size in response to food availability, and can regenerate tube feet that may be ripped off due to dislodgement and any of its 5 rays that may be lost to predation (SIMoN 2014). Neurosensory cells scattered throughout their body enable behavioral responses to mechanical, chemical and optical stimuli (SIMoN 2014).

III. Management Potential

Value of species to people: Moderate

- Confidence of workshop participants: Low
- Description of value: aesthetic value and high affinity for the species held by the general public and the high research value in the study of rocky intertidal ecology and keystone species

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

- Confidence of workshop participants: Low
- Description of potential management options: Managing the impacts from recreation and coastal visitors may decrease negative impacts on the species, and the protection of upland/inland habitat may enable migration.

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

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

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

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

[8] Confidence level indicated by workshop participants.

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

- Confidence of workshop participants: Moderate

Additional participant comments

Potential areas of refugia from climate exposure include subtidal habitat to escape the impacts of air temperature and disturbance from increased storminess and wave action.

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Olympia Oyster (*Ostrea lurida*)[1]

Executive Summary

Olympia Oyster	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

The Olympia oyster is a bivalve filter-feeder that historically formed dense, clustered aggregates of individuals in low tidelands and estuaries from Northern British Columbia to Baja California. The species has suffered precipitous decline in the study region, and is the focus of many management and restoration efforts. Key climate sensitivities identified for this species by participants includes salinity and precipitation, and key non-climate sensitivities include dredging, invasive species, and pollution and poisons. The Olympia oyster exhibits a broad distribution and a fragmented population that is diminished from historical levels due primarily to over-harvest in the 1800s and early 1900s and pollution of the region's estuaries. The species has a high dispersal capability, but generally low diversity and plasticity. There is some indication of phenotypic plasticity in growth and physiology in response to environmental stressors, but this work is ongoing. Societal value for the Olympia oyster is high due to the commercial fishery that exists in some regions, as well as its critical role in improving estuarine water quality and providing benthic habitat, which is recognized by regional managers seeking to restore the native oyster. Management potential for climate stressors is low-moderate, though non-climate stressors, such as run-off from river outflows and invasive species, as well as broad-scale restoration efforts, can certainly be managed to increase the species' resiliency to climate change.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

Climate and climate-driven changes that may benefit the species: sea level rise

- Description of benefit: Sea level rise may result in increased habitat area for the species. However, the distribution of the species my simply shift upwards in response to sea level rise.

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

- Confidence of workshop participants: High

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

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

[3] Confidence level indicated by workshop participants.

Additional participant comments

Depending on the depth, sea level rise may benefit the species in some areas by opening up additional habitat with appropriate tidal range, though this is limited somewhat by additional predation pressure at lower tidal elevations which may lead to the species range simply shifting inland in response.

Supporting literature

Through the National Estuarine Research Reserve System (NERRS) Science Collaborative, researchers have studied the effects of many of these climate factors on oysters using lab experimentation and field surveys; confidence in the sensitivity of this species to climate change is high due to this work (Cheng et al. 2015, Ted Grosholz, pers. comm., 2014).

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

Salinity and Precipitation

Low salinity events commonly occur in late winter and spring during heavy, seasonal precipitation events that cause freshwater inundation of low-lying estuarine habitat, causing a sudden drop in salinity (Ferner 2013). This coincides with the development of older juvenile Olympia oysters (Ferner 2013), which were found to be highly sensitive to salinities below 15 psu, and salinities below 25 psu for extended periods of time (Cheng et al. 2015). More intense and longer duration low-salinity events leads to higher mortality and lower food intake by Olympia oysters in laboratory experiments, with population-level differences in this response (Cheng et al. 2015, Ferner 2013). Additional experimentation to test the additive effects of low salinity and high temperature during daytime low tides is ongoing (Ferner 2013).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms and flooding

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

The Olympia oyster was identified as being sensitive to storm and flooding disturbance regimes, due to its sensitivity to salinity (see salinity section above). The exposure to low-salinity water due to heavy precipitation and enhanced flooding from storm activity (especially near rivers) can have severe impacts on entire populations by causing mass mortality.

III. Dependencies

Species dependence on one or more sensitive habitat types: Moderate

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

Species dependence on specific prey or forage species: Low

- Confidence of workshop participants: High

Other critical dependencies: none provided

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

- Confidence of workshop participants: High

Supporting literature

The Olympia oyster overall has a low-moderate dependency on physical and biological characteristics that may impact its sensitivity, including a moderate dependency on hard, stable substrate for habitat within estuaries (Zabin et al. 2009) and a low dependency on specific prey, filtering suspended food particles, such as detritus and phytoplankton (Couch and Hassler 1989), from the water column.

IV. Sensitivity and current exposure to non-climate stressors

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

Overall species sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

Overall species exposure to non-climate stressors: Moderate

- Confidence of workshop participants: High

Additional participant comments

Currently, populations are limited in some locations, and loss of habitat to dredging may reduce habitat and population sizes, thus reducing resiliency of populations to climate change.

Dredging

Dredging may increase turbidity and sedimentation, alter tidal mixing and circulation, reduce nutrient outflow from marshes and swamps, and increase susceptibility to recurrent low dissolved oxygen levels (Johnston 1981). Oysters are particularly vulnerable to the effects of siltation, and may be harmed by contaminants released into the water column by dredging operations (Johnston 1981).

Invasive Species

Olympia oysters are impacted both directly and indirectly by invasive species. Two invasive predatory drills (gastropods) directly prey upon Olympia oysters and significantly limit their recovery and abundance (Buhle and Ruesink 2009). Further, predatory invasive oyster drills can limit the lower tidal distribution of Olympia oysters which may leave oysters more exposed to future increases in air temperatures (Kimbro et al. 2009). Indirectly, estuarine habitat dominated by invasive crabs and whelks exhibit much greater mortality of Olympia oysters as compared to habitat dominated by native crabs and whelks through alteration of the food web dynamics by inhibiting trait-mediated and density-mediated trophic cascades (Kimbro et al. 2009). Finally, the Olympia oyster is directly displaced by larger non-native oysters, including the Pacific oyster (Pacific Biodiversity Institute, Trimble et al. 2009).

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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.

Pollution and poisons

As filter feeders, Olympia oysters provide a critical water-filtering service for the region's estuaries, effectively improving water quality. However, in extracting various pollutants from the water, oysters quickly concentrate toxins in their tissues, which has been demonstrated to negatively impact individual health and population abundance (Pacific Biodiversity Institute). In Washington, spat production and adult growth of Olympia oysters were negatively impacted by the discharge of sulfite waste from pulp and paper mills, wiping out most of Puget Sound's population in the mid-1900s (Korringa 1976). Currently, populations are still threatened by exposure to mill and wastewater discharge and motor fuel, which causes physiological stress, degeneration of gill tissue, uptake of hydrocarbons, and mortality (Clark et al. 1974, Trimble et al. 2009). Also, anthropogenic nutrient loading can produce threatening levels of low dissolved oxygen (Wasson 2010, Cheng et al. 2015).

V. Other sensitivities: none identified

Additional participant comments

Olympia Oysters are very sensitive to the aforementioned climate and climate-driven changes. Local populations may be limited to areas with sufficient salinity levels and low levels of natural and human predation.

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): 3
- Confidence of workshop participants: High

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

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

Maximum annual dispersal distance: 5-25km
- Confidence of workshop participants: Moderate

Supporting literature

The Olympia oyster ranges from Northern British Columbia to Baja California, Mexico (Polson and Zacherl 2009). Once very abundant and widespread, the Olympia oyster has experienced a 64% decline in the spatial extent of oyster habitat and an 88% decline in oyster biomass over the last 100 years due to rampant harvest that occurred in the late 1800s and early 1900s (Ermgassen et al. 2013). The Olympia oyster has high dispersal capability and substantial gene flow among populations, with larvae traveling 5-25 km (Stick et al. 2009, Ted Grosholz, pers. comm., 2014). A study in Southern California found a high level of larval exchange among sites separated by as many as 75 km of coastline (Carson 2010). Larval movement and connectivity within San

Francisco Bay is currently being investigated by the NERR Science Collaborative by comparing shell chemistry at various sites; preliminary results suggest distinct trace element signatures across sites in the Bay (Cheng, NERRS Science Collaborative, unpublished data).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate
- Confidence of workshop participants: Moderate

Genetic diversity: Moderate
- Confidence of workshop participants: Moderate

Behavioral plasticity: Low
- Confidence of workshop participants: High

Phenotypic plasticity: Moderate
- Confidence of workshop participants: High

Overall degree of diversity/plasticity of the species: Low-Moderate
- Confidence of workshop participants: High

Supporting literature

Multi-stressor experiments have shown phenotypic plasticity in growth and physiology of Olympia oysters in response to experimental manipulation of temperature, salinity and dissolved oxygen (Cheng and Bible, NERRS Science Collaborative, unpublished data). The oyster is slow-growing, takes a year to reach sexual maturity, and may spawn a few times in a given year under optimal laboratory conditions (Baker 1995). Spawning typically occurs in this region in mid-summer (Hopkins 1937) when males release sperm that are taken in by females for internal fertilization. A brood of 250 to 300,000 larvae develop for 10 to 12 days before being released, where they remain in the water column for 11 to 16 days before settling to the substrate (Hopkins 1937).

III. Management potential

Value of species to people: High
- Confidence of workshop participants: High
- Description of value: Value as a commercially fished species, and as an important component for habitat restoration efforts in San Francisco Bay.

Likelihood of managing or alleviating climate change impacts on species: Low-Moderate
- Confidence of workshop participants: Moderate
- Description of potential management options: Water management with regard to watershed runoff and river outflows could ameliorate future low salinity events and low dissolved oxygen events, control of non-native predators would help to modify interactions with air temperatures (allowing occupancy of lower tidal zones), and restoration of populations would likely increase recruitment and population size, enhancing the oyster’s resiliency to climate change.

Supporting literature

An ongoing, large-scale restoration program is being conducted by the San Francisco Bay Living Shorelines program supported by the California State Coastal Conservancy (Grosholz and Zabin, unpubl. data, http://www.sfbaylivingshorelines.org/sf_shorelines_science.html). Efforts to understand obstacles to and develop best practices for Olympia oyster restoration efforts are ongoing through the NERRS Science Collaborative project, titled "Managing for resilience in the face of climate change: a scientific approach to targeted restoration efforts in San Francisco Bay and Elkhorn Slough, California[6]". The project is producing restoration planning tools to help regional managers select appropriate sites for successful restoration programs, taking into account projected climate conditions, and will be a valuable resource for managers and planners in the study region.

IV. Other adaptive capacities: none identified

Additional participant comments

The Olympia oyster may be able to adapt to some climate change scenarios. Improved management of this important species can facilitate greater resiliency to future climate change impacts.

Exposure

I. Future climate exposure[7]

Future climate and climate-driven changes identified (score[8], confidence[9]): increased flooding (5, high), changes in precipitation (5, high), changes in salinity (5, high), decreased pH (4, high), changes in sea surface temperature (4, high), changes in air temperature (4, high), increased coastal erosion and runoff (4, high), increased storminess (3, moderate)

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

- Confidence of workshop participants: High

Additional participant comments

Potential areas of refugia include mid-estuarine zones that may experience less exposure to low pH, upwelled waters, and estuarine zones that are less influenced and impacted by river inflows, which may decrease the species exposure to erosion/run-off, flooding, and changes in precipitation and salinity.

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[6] Project website: http://www.sfbaysubtidal.org/oysters_and_climate-about.html

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

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

[9] Confidence level indicated by workshop participants.

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Pacific Herring (*Clupea pallasii*)[1]

Executive Summary

Pacific Herring	Score	Confidence
Sensitivity	2 Low-Moderate	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	3 Moderate	2 Moderate

Pacific herring is a coastal schooling species of fish found from the surface waters to depths of 1,300 feet, migrating inshore every year to spawn in estuaries (including San Francisco and Tomales Bays). Pacific herring have numerous populations throughout the Pacific Ocean, ranging from Korea, around the rim of the North Pacific Basin to Baja California, Mexico. Key climate sensitivities identified for this species by workshop participants include sea surface temperature and salinity. No key non-climate sensitivities were identified by workshop participants; however, habitat degradation (due to pollution and dredging) may be an important consideration for the species. Pacific herring exhibits a broad, transcontinental distribution across the western and eastern Pacific coasts. Though workshop participants reported that the population regionally is diminished, recent biomass estimates based on commercial data indicate above-average spawning biomass in San Francisco Bay for the last 4 years. Pacific herring exhibit overall moderate diversity, with some degree of phenotypic plasticity in environmental tolerance, and broad geographic variation in size, genetic composition and recruitment. There is a low overall awareness of the species and the role it plays in ecosystems and food webs, resulting in low value to the general public. However, multiple actions can be taken to protect the future viability of the species, including precautionary management of harvest and protection of spawning grounds in the region's estuaries.

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), precipitation (3, high), pH (3, moderate), and dynamic ocean conditions (currents/mixing/stratification) (3, moderate), air temperature (2, high), dissolved oxygen (DO) levels (2, moderate)

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

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

- Confidence of workshop participants: High

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[1] Refer to the "Introduction to Assessment Summaries" section on page xx 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

Herring have demonstrated a very rapid response to short-term, climate-related variability with decreased recruitment and abundance occurring very suddenly with changes to oceanographic conditions (Beamish 2008).

Sea Surface Temperature

Enhanced ocean temperatures impact fish physiology by increasing the organism's oxygen demands (Portner and Knust 2007), reducing oxygen solubility in seawater, reducing the performance of energy metabolism proteins (Fields et al. 1993) and negatively impacting growth and respiration (Largier et al. 2010). Shifts in the latitudinal and depth distribution of fishes are also expected as water temperature increases, depending on species tolerance (Largier et al. 2010). Generally in California, herring are exposed to a temperature range between 8-10˚C (46-50˚F) (Miller and Schmidtke 1956). Pacific herring eggs are sensitive to changes in sea surface temperature, with survival of viable larvae exhibiting a lower tolerance limit of 4-5˚C (39-40˚F), a higher tolerance limit of 10˚C (50˚F) and maximum survival of larvae occurring at 6.85˚C (44˚F) (Alderdice and Velsen 1971). Catch statistics indicate that maximum population abundance occurs at spawning temperatures of 5-9˚C (40-48˚C) (Alderdice and Velsen 1971). However, larvae exhibit a wide range of temperature tolerance depending on their geographic location, suggesting plasticity in environmental tolerance (Barnhart 1988). Warm, nutrient-depleted waters of the 1982-83 El Niño event was associated with poor herring growth, possibly due to a reduction in food availability, and altered population distribution (Spratt 1984a,b). Ware (1991) also documented smaller adult sizes associated with warmer ocean temperatures during El Niño events due to reduced zooplankton abundance.

Salinity

Most spawning areas are characterized as having reduced salinity within calm and protected waters (CDFW 2014). Hatching success has been shown to decrease with increasing salinity (Taylor 1971), but extended periods below 20 ppt may inhibit herring spawning (Reilly and Moore 1983). However, there exists high variance in salinity tolerance in larvae, especially across the species geographic range (Barnhart 1988), and possibly determined by the conditions experienced by the eggs during incubation (Alderdice and Hourston 1985). In general, larvae appear to be euryplastic, able to withstand a range of environmental conditions, though optimal hatch and survival rates do vary across conditions which will likely impact population abundance of Pacific herring (Barnhart 1988). Salinity may be expected to vary more widely in the future due to enhanced precipitation events and flooding due to sea level rise and storm activity.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: storms and flooding

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Supporting literature

Because herring are dependent on sensitive nearshore and estuarine habitat for spawning, flooding due to sea level rise and more intense precipitation events and increased storminess is expected to impact the dynamics of herring populations (Beamish 2008). Sea level rise will increase shoreline erosion and saltwater intrusion in estuaries, possibly increasing salinity by as much as 9 practical salinity units (Knowles and Cayan, 2002). Unless there is a comparable increase in elevation of the land surface due to sediment delivery and availability, estuarine habitat will not be able to adjust to rising sea levels, and flooding will occur more frequently (Largier et al. 2010, Ackerly et al. 2012). Increased storm activity, including wave action, will have important implications for flooding of estuarine habitat, the state of the estuarine mouth, and the timing of estuarine mouth opening and closing (Largier et al. 2010). The mouths of estuaries will tend to close with stronger wave energy, and may close earlier or later than usual depending on the interaction with river flow.

III. Dependencies

Species dependence on one or more sensitive habitat types: High

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

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

- Confidence of workshop participants: Low

Other critical dependencies: none identified

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

- Confidence of workshop participants: Moderate

Supporting literature

Within estuarine habitat, Pacific herring are dependent on suitable spawning surfaces such as eelgrass and algae (Barnhart 1988). The loss of this biogenic habitat may have resulted in declined spawning in some areas of the study region, including Bolinas Lagoon (Sarah Allen, pers. comm., 2014). Biogenic habitat is one of most important factors that affect spawning, and sea surface temperature, salinity, and human stressors can affect eelgrass growth and expansion and thereby affect herring spawning (Sarah Allen, pers. comm., 2014).

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): harvest (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

Additional participant comments

Workshop participants did not identify any significant non-climate stressors for Pacific herring, and indicated that the species has only low sensitivity and low current exposure to harvest, though future harvest could play a stronger role in the sensitivity of the species. An additional

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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.

possible sensitivity identified by workshop participants is the lack of structures to aid in spawning, likely a result of habitat degradation and loss.

Supporting literature

In California, gill net fishing is permitted, though the market is relatively minor at this time, and herring roe are harvested only in San Francisco Bay for export to Japan (CDFW 2014). Loss of biogenic habitat (seagrass) that is critical for spawning through dredging and construction, and habitat degradation due to impaired water quality, are significant threats to herring populations (NMFS 2014). Impaired water quality has been linked to reduced metabolism in herring embryos and eggs (Eldridge et al. 1977) and enhanced mortality of eggs (Rice and Harrison 1978). Dredging, which results in an increase of sediment in spawning habitat, has been identified as an important impact to the species, as the presence of sediment on substrate is effective in inhibiting spawning behavior (Stacey and Hourston 1982).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

Geographic extent of the species (1=endemic; 5=transboundary): 4

- Confidence of workshop participants: Moderate

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: High

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: 25-50km

- Confidence of workshop participants: Low

Supporting literature

Though workshop participants reported that the population regionally is diminished, recent biomass estimates based on commercial data indicate above-average spawning biomass in San Francisco Bay for the last 4 years (Greiner et al. 2014). Data is not available for the Tomales Bay population, but because both Tomales and San Francisco herring feed in the California Current Large Marine Ecosystem, it may be assumed that the Tomales Bay population is seeing increased recruitment similar to San Francisco (Ryan Bartling, pers. comm., 2015).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Low

Genetic diversity: Moderate

- Confidence of workshop participants: Moderate

Behavioral plasticity: Moderate

- Confidence of workshop participants: Low

Phenotypic plasticity: Moderate

- Confidence of workshop participants: Low

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: Low

Supporting literature

There is some indication of plasticity in larval tolerance to environmental conditions, including temperature and salinity, based on geographic location and exposure of the eggs during incubation (Barnhart 1988). Broad geographic variation across the Pacific herring range, including size, genetic composition and recruitment, is likely adaptive and in response to local prey resources and climate regimes (Hay et al. 2008).

Beginning in October, and continuing as late as April (CDFW 2014), adult herring migrate inshore to estuaries to breed every year, spawning in shallow coastal areas between the subtidal and intertidal zones, depositing eggs on kelp, eelgrass, and other structures such as pier pilings and riprap (NMFS 2014). In the study region, Tomales Bay and San Francisco Bay have the largest spawning populations (Spratt 1981). Maximum lifespan is 19 years (NMFS 2014), but varies by geography. In San Francisco Bay, lifespan is up to 8 years with 80% of the population aged 6 years or less (Ryan Bartling, pers. comm., 2014).

III. Management potential

Value of species to people: Low

- Confidence of workshop participants: High
- Description of value: There is a low overall awareness of the species and the role it plays in ecosystems and food webs.

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

- Confidence of workshop participants: Moderate
- Description of potential management options: Management priorities for this species may include a precautionary approach to harvest, further research into requirements for successful recruitment, and protection of herring spawning grounds.

IV. Other adaptive capacity factors: none identified

Exposure[6]

I. Future climate exposure

Future climate and climate-driven changes identified (score[7], confidence[8]): changes in salinity (4, moderate), decreased pH (4, moderate), increased storminess (4, moderate), changes in sea surface temperature (4, moderate), changes in precipitation (3, moderate), increased coastal erosion and runoff (3, moderate)

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

- Confidence of workshop participants: Moderate

Supporting literature

Precipitation may cause an increase in freshwater exposure which affects eelgrass and algae substrate on which eggs are laid, but sea level rise and heat events that increase evapotranspiration may cause a decrease in local salinity (Largier et al. 2010). Refugia from climate exposure may be found in bays and estuaries where sea surface temperature may be lower and where eelgrass occurs (Sarah Allen, pers. comm., 2014).

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

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

[8] Confidence level indicated by workshop participants.

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Pteropod[1]

Executive Summary

Pteropod	Score	Confidence
Sensitivity	4 Moderate-High	2 Moderate
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	4 Moderate-High	2 Moderate

Pteropods are pelagic marine gastropods, consisting of two orders: the shelled Thecosomata and the non-shelled Gymnosomata. For the purposes of this assessment, focus will be on the shelled pteropods. Key climate sensitivities identified for this species assemblage by workshop participants include pH and dynamic ocean conditions (currents/mixing/stratification). No non-climate stressors were identified. Pteropod species have a broad, transcontinental geographic distribution and a continuous, stable population at abundant levels with moderate-high dispersal capabilities. Pteropods exhibit overall low diversity and plasticity, though morphological and behavioral diversity does exist between species, and plasticity has been documented in pteropod physiology. Additionally, pteropods exhibit multiple reproductive/life history strategies depending on the species. Genetic diversity in these species is largely unknown, though there is some evidence of high genetic differentiation in the Thecosome pteropods. Pteropods have low societal value due to their inconspicuous, offshore nature, though they do serve as a vital part of the ecosystem. The management potential for the species assemblage is considered low because pteropods are most critically impacted by the current and expected decrease in pH, which cannot be managed on a regional scale.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): pH (5, high), dynamic ocean conditions (currents/mixing/stratification) (4, high)

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

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

- Confidence of workshop participants: High

Additional participant comments

There is documented evidence that the ocean's chemistry is changing (pH is lowering due to increased CO_2 uptake), and there is also documented evidence of how this change in pH affects pteropods

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

pH

Limacina helicina has been used extensively to study the effects of ocean acidification on the shelled pteropods (Elliott and Jahncke 2014). This species is a critical mid-trophic component of pelagic food webs, both as a consumer and as prey for commercially important fish species, whales, and seabirds (Lischka et al. 2010). Shell diameter, shell increment and shell degradation in juveniles of *L. helicina* are significantly impacted by $p\text{CO}_2$ scenarios projected by the end of this century, severely affecting the abundance of juveniles that are critical for the following year's reproduction (Lischka et al. 2010). Adults exhibited a 28% decrease in calcification under conditions expected by 2100 (Comeau et al. 2009) and a 20% decrease in oxygen consumption (Seibel et al. 2012). Severe pteropod shell dissolution due to anthropogenic ocean acidification is estimated to have doubled in nearshore waters since pre-industrial conditions across the California Current Ecosystem (CCE), and will likely triple by 2050 (Bednaršek et al. 2014). 53% of onshore individuals and 24% of offshore individuals were found, on average, to exhibit severe dissolution damage in the CCE (Bednaršek et al. 2014), which indicates that habitat suitability for pteropods in the study region is declining.

Dynamic ocean conditions (currents/mixing/stratification)

As the primary delivery method of naturally low-pH and under-saturated waters (with respect to aragonite and calcite) that are enriched in CO_2 (Gruber et al. 2012), upwelling is the primary driver of pteropod abundance in the region (Vulnerability Assessment Workshop, pers. comm., 2014). Strong upwelling events transport these deep, under-saturated waters onto the continental shelf, sometimes reaching surface waters (Feely et al. 2008)). Though this is a natural process that may counteract rising sea surface temperatures and promote primary productivity (Largier et al. 2010), intense upwelling could shift plankton to deeper waters (Pringle 2007), potentially decreasing food availability for pteropods (Largier et al. 2010) and further exacerbate the under-saturation of aragonite necessary for shell building in pteropod juveniles. El Niño events and positive phases of the PDO suppress upwelling, reducing nutrient delivery to photic zones, decreasing primary productivity, but also decreasing pteropod exposure to under-saturated waters (Bi et al. 2011, Young et al. 2012).

II. Sensitivities to disturbance regimes: none identified

III. Dependencies

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

- Confidence of workshop participants: Moderate
- Sensitive habitats species is dependent upon: no answer provided

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

- Confidence of workshop participants: Moderate

Other critical dependencies: reproductive strategies of different pteropod species

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

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

- Confidence of workshop participants: Moderate

Supporting literature

Pteropods may more closely resemble specialists due to physiological adaptations to a holoplanktonic lifestyle, including aggressive planktonic predation, well-developed swimming behavior in gynmosomes (Harbison and Gilmer 1992, Lalli 1970, Lalli and Gilmer 1989), and the production of anti-predation compounds to reduce palatability in thecosomes (McClintock and Baker 1998).

IV. Sensitivity and current exposure to non-climate stressors: none identified

Supporting literature

Though workshop participants did not identify any non-climate stressors for pteropods, the impact of oil, identified for copepods, also applies to this species assemblage. Dispersed oil is expected to negatively impact pteropods and other zooplankton in the study region (Mearns 2012). 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 pteropod 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): 5

- Confidence of workshop participants: High

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: Moderate

Dispersal ability of the species: Moderate-High

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: >100km

- Confidence of workshop participants: Moderate

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: Moderate

- Confidence of workshop participants: Moderate

Behavioral plasticity: Low

- Confidence of workshop participants: Low

Phenotypic plasticity: Low

- Confidence of workshop participants: Low

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

- Confidence of workshop participants: Moderate

Supporting literature

Pteropods exhibit multiple reproductive/life history strategies depending on the species. Some species (e.g. *Limacina helicina*) are protandric hermaphrodites that use internal fertilization and produce floating egg masses, while others (e.g. *L. helicoides*, *L. inflata*) brood their young until they are juveniles or early veligers. The former strategy (egg masses) shows the highest fecundity; however, the planktonic egg masses may be exposed to corrosive waters and higher mortality rates than in the past (Lalli and Wells 1978). The genetics of pteropods is poorly studied, though significant genetic variation has been observed for some species, particularly Thecosome pteropods (Jennings et al. 2010). In this study region, *Limacina helicina*, is the most abundant Thecosome pteropod and is currently being documented and studied; six other Thecosome pteropods have been documented in our region but in far lower densities (Point Blue Conservation Science, unpublished data). Metabolic plasticity was demonstrated in response to regional phytoplankton concentration, with varying response to $p\text{CO}_2$ dependent on the baseline level of metabolism (Seibel et al. 2012). Though workshop participants indicated pteropods exhibit low behavioral plasticity, there is some indication that some species can change their daily vertical distribution pattern by migrating to upper supersaturated waters to avoid corrosive waters (Bednaršek 2015).

III. Management potential

Value of species to people: Low

- Confidence of workshop participants: High
- Description of value: low societal value due to their inconspicuous, offshore nature, though they do serve as a vital part of the ecosystem

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

- Confidence of workshop participants: High
- Description of possible management options: None identified. Because pteropods are so critically impacted by the current and expected decrease in pH, the only way to effectively manage the species would be to prevent ocean acidification from occurring.

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[4]

Future climate and climate-driven changes identified (score[5], confidence[6]): decreased pH (5, high), altered currents and mixing (5, high)

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

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

- Confidence of workshop participants: High

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[5] 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.

[6] Confidence level indicated by workshop participants.

Red Abalone (*Haliotis rufescens*)[1]

Executive Summary

Red Abalone	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	3 Moderate	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

Red abalone, a marine gastropod mollusk, is the largest abalone species in North America. This species inhabits rocks and crevices from the low intertidal to 180m in depth, ranging from Sunset Bay, Oregon to Baja California. Key climate sensitivities identified by workshop participants include dissolved oxygen, pH, air and sea surface temperature, and salinity and key non-climate sensitivities include harvest. Red abalone exhibit a transcontinental geographic extent and a very diminished, but stable population that is predominantly restricted to subtidal habitat due to historic over-harvest. Larvae have moderate-high dispersal capability, possibly dispersing up to 25 km, though distinct genetic variation among populations indicates that some geographic barriers to dispersal exist. Red abalone exhibit low-moderate behavioral diversity and low phenotypic plasticity, with some indication of plasticity in sensitivity to environmental change. The high societal value for red abalone is due to its value for harvest, aesthetics and recreation. The likelihood of managing or alleviating climate impacts is considered moderate, and will depend on managers' ability to maintain healthy populations to retain genetic diversity and recovery potential.

Sensitivity

I. Sensitivity to climate and climate driven changes

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

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

- Description of benefit: Increased upwelling could increase productivity, but it may also exacerbate ocean acidification

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

- Confidence of workshop participants: High

Additional participant comments

Though few red abalone are found in the intertidal due to over-harvest, sensitivity to warm air temperatures is still a concern for red abalone because it is a cold-adapted species.

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

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

[3] Confidence level indicated by workshop participants.

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered. No information was found regarding the impact of salinity or air temperature on red abalone.

Oxygen

Exposure to low-oxygen waters may be expected to occur more frequently with the projected increase in enhanced upwelling events (Largier et al. 2010). Mortality rates of juvenile red abalone exposed to low-oxygen water (40% saturation, mg/L) for short periods of time (3-6 hours every 3-5 days) did not differ from control animals; however, when exposure was extended to two 24 hour periods over 15 days, mortality rates were 5-20% higher than controls, and growth rates were significantly reduced (Kim et al. 2010). When combined with low-pH conditions, individual variation in growth rate increased, suggesting some degree of phenotypic plasticity (Kim et al. 2010). These results suggest that prolonged exposure to low-oxygen, upwelled water may significantly impact juvenile red abalone survival.

pH

pH is expected to continue to decrease, resulting in greater acidification of coastal waters, and this decrease will be more pronounced in upwelling centers, including the study region (Largier et al. 2010). Growth rates were significantly reduced for juvenile red abalone exposed to low-pH water (7.5) for two 24-hour periods over 15 days, though variation in the change in growth rate among individuals suggests some degree of phenotypic plasticity in pH sensitivity (Kim et al. 2010). Low pH (7.87) also resulted in significantly lower thermal tolerance in 2 of 4 larval stages tested, suggesting variability in sensitivity throughout the species life history (Zippay and Hofmann 2010).

Sea Surface Temperature

Sperm production in male red abalone is significantly lower when exposed to warm water (18°C) for 6 months, dropping from 300,000 presperm cells/mm^3 to 46,000 presperm cells/mm^3 (Rogers-Bennett 2010). Warmer water is also linked to slower growth rate (Haaker et al. 1998), decreased reproduction (Vilchis et al. 2005), and an increase in the onset of withering foot syndrome (Moore et al. 2002, Vilchis et al. 2005), a serious bacterial infection that causes mortality. The bacterium can reside within the tissues of abalone without manifestation of the syndrome, but warm water has been implicated as a trigger for development of the syndrome (Rogers-Bennett 2010).

II. Sensitivity to changes in disturbance regimes

Disturbance regimes identified: storms, disease, and harmful algal blooms (HABs)

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

Disease will likely have the largest impacts on red abalone. Extreme storm events that cause scouring and dislodgement of abalone may have significant adverse impacts to the species.

Supporting literature

Storms

Increasingly intense run-off during extreme storm events may cause increased sedimentation that may negatively impact red abalone due to sand scour, and increased freshwater input to the nearshore subtidal that may lead to higher resuspension of sediment resulting in increased turbidity and light attenuation (Largier et al. 2010).

Disease

Disease is projected to increase with warming water temperatures, due to enhanced pathogen development and survival, as well as host susceptibility (Harvell et al. 2002), and in red abalone, the onset of withering foot syndrome has been attributed to exposure to warm water temperatures (Vilchis et al. 2005) with mass syndrome expression occurring during strong El Niño events (Moore et al. 2011).

Harmful algal blooms (HABs)

HABs have increased in frequency and severity along the California coast during the past few decades, with blooms of dinoflagellates and *Pseudo-nitzschia* becoming more common (Southern California Marine Institute (SCMI) 2014). Substantial mortality of filter feeders, grazers and predators have been documented following a bloom (Southgate et al. 1984, Robertson 1991), and MPA baseline data indicated a 40% decline in red abalone density between 2010 and 2011 at sites along the Sonoma Coast, which coincided with a HAB in that region (Carr 2013). This event in Sonoma County (Bodega Bay to Anchor Bay) resulted in the largest die-off of marine invertebrates ever associated with a HAB in this region.

III. Dependencies

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

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: rocky reefs; where sea otters are present, cracks and crevices are relied upon as habitat (Steve Lonhart, pers. comm., 2014)

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

- Confidence of workshop participants: High

Other critical dependencies: sufficient adult density to ensure reproductive success of the species (Allee effect)

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

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

- Confidence of workshop participants: High

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): harvest (5, high), pollution and poisons (3, low), and invasive and problematic species (2, low)

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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.

Overall species sensitivity to non-climate stressors: Moderate

- Confidence of workshop participants: Low

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

- Confidence of workshop participants: High

Additional participant comments

Harvesting can negatively impact the species through the resulting Allee effect, which can restrict genetic diversity and the ability of the species to recover from climate change impacts.

Supporting literature

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

Harvest

Red abalone is the largest abalone species in North America, and is highly valued by both sea otters and humans, commanding high prices for its highly prized meat and iridescent shell used in jewelry, resulting in over-harvest (SIMoN 2014). The commercial fishery peaked in 1967 and steadily declined until it was closed in 1997. Over-harvest of the species can result in the Allee effect, due to insufficient adult density to support reproductive success, and restrict genetic diversity, which can have major implications for the species' ability to recover from climate events (Levitan et al. 1992).

V. Other sensitivities: None identified

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): 3

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: High

Dispersal ability of the species: (adult) – Low; (larval) – Moderate-High

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: 5-25km (larval)

- Confidence of workshop participants: Moderate

Supporting literature

The species is now most abundant subtidally, and is rare in the intertidal likely due to over harvesting (SIMoN 2014). While adults are capable of significant movement due to their strong muscular foot (and will move away from predatory sea stars), they often remain stationary, some staying hidden in the same crevice for their entire life (SIMoN 2014). Current estimates of larval dispersal in the literature range from several kilometers (Morgan and Shepherd 2006) up to 10 km (Hobday and Tegner 2002), though these estimates are based on only a 4-7 day larval duration. Recent work shows that larvae may remain competent in the water column for up to 32 days, which would allow for a greater dispersal distance, though settlement after 20 days resulted in significantly lower subsequent postlarval survival (Mccormick et al. 2012).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: no answer provided

- Confidence of workshop participants: n/a

Behavioral plasticity: Low-Moderate

- Confidence of workshop participants: Moderate

Phenotypic plasticity: Low

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Moderate

Additional participant comments

Though adults have somewhat limited mobility, individuals are able to “clamp down” and seal tightly to the substrate to limit exposure to oxygen stress in the subtidal and heat stress in the intertidal.

Supporting literature

Individual variation in growth rate response to upwelled water (low-pH and low-oxygen water) has been observed in juvenile red abalone, suggesting some degree of phenotypic plasticity in sensitivity to those factors (Kim et al. 2010). Genetic studies on multiple species of abalone find high genetic variation among populations, indicating that barriers to dispersal exist along the California coastline (Palumbi 2014); in particular, Cape Mendocino seems to be a breakpoint in the genetic structure of the red abalone (Gruenthal et al. 2007). This species is a broadcast spawner that can produce up to a million gametes in one breeding event, but is slow growing and can take 4 years to reach sexual maturity (SIMoN 2014). Spawning is greatest in the spring, typically from February to April, and can be triggered by environmental cues such as a sudden change in water temperature and exposure to air for 1-2 hours (SIMoN 2014).

III. Management potential

Value of species to people: High

- Confidence of workshop participants: High
- Description of value: valued for harvest, aesthetics, and recreation

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

- Confidence of workshop participants: Moderate

- Description of potential management options: Management efforts should focus on maintaining health populations of sufficient size to ensure genetic diversity and recovery potential from disturbances and climate change impacts.

IV. Other Adaptive Capacity Factors

Critical factors not addressed that may affect species' adaptive capacity: interactive effect of shell-boring worms and shells weakened by ocean acidification

- Degree to which these factors affect the habitat's adaptive capacity: Moderate
- Confidence of workshop participants: Low

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): decreased pH (5, high), sea level rise (5, high), changes in air temperature (5, high), decreased dissolved oxygen (DO) levels (3, moderate), changes in sea surface temperature (1, moderate), changes in salinity (1, high), and changes in precipitation (1, high)

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

- Confidence of workshop participants: High

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

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

[8] Confidence level indicated by workshop participants.

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Sea Urchin, Red (*Strongylocentrotus franciscanus*) and Purple (*S. purpuratus*)[1]

Executive Summary

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

Red and purple sea urchins, echinoderm invertebrates, inhabit low intertidal rocky reefs and subtidal kelp forests, reaching depths around 100 meters along the Pacific coast of North America, from Alaska to Baja California. The overall vulnerability of these species will likely vary greatly between intertidal and subtidal populations. Key climate sensitivities identified by workshop participants include dissolved oxygen, ocean pH, dynamic ocean conditions, air temperature and sea surface temperature and key non-climate sensitivities include pollution and poisons and harvest. Red and purple sea urchins exhibit transcontinental geographic extents and stable, continuous populations that are at abundant levels. Long-lived pelagic larvae enable high dispersal capability. The species are highly diverse genetically, and exhibit low-moderate behavioral plasticity, though they can alter the timing of spawning to coincide with phytoplankton density and alter their morphology in response to current flow. Societal value for urchins is moderate-high due to their culinary value, value to tourism, prey for sea otters, and as a viable fishery. The likelihood of managing or alleviating climate impacts was rated as low, though many management alternatives have been suggested in the literature to better manage harvest.

Sensitivity

I. Sensitivity to climate and climate driven changes

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

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

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

- Confidence of workshop participants: High

Supporting literature

Dissolved Oxygen

When dissolved oxygen (DO) concentrations fall to hypoxic levels, there are severe consequences for benthic communities, as the oxygen depleted water mass suffocates everything that cannot move out of the area, including sea urchins (Largier et al. 2010). Areas adjacent to

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

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

[3] Confidence level indicated by workshop participants.

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). High mortality of benthic invertebrates has been attributed to severe hypoxic events due to the shoaling of the oxygen minimum zone (Grantham et al. 2004, Chan et al. 2008). Further, reduced dissolved oxygen has been experimentally shown to reduce fertilization rates in an Australian species of urchin (Riveros et al. 1996).

pH

Ocean acidification is expected to negatively impact the production of calcium carbonate structures in many adult invertebrate species, including sea urchins (Guinotte and Fabry 2008), and has been demonstrated to negatively impact the larval stages of many calcium-building species (Largier et al. 2010), including reduced fertilization and delayed development in sea urchins (Kurihara et al. 2004, Yu et al. 2011). Decreased pH also decreases the production of heat shock proteins in the red sea urchin, impairing the animal's ability to respond to thermal stress (O'Donnell et al. 2008) and has been shown to impair cellular stress-response mechanisms that enable urchins to tolerate other environmental stressors (Evans and Hofmann 2012). A study of green sea urchin larvae indicated high plasticity in response to decreased pH (though increased mortality and decreased growth were still consequences of this decrease), with a physiological tipping point of 7.0 (Dorey et al. 2013).

Currents/mixing/stratification

Sea urchins spend the first part of their lives as free-floating plankton, which facilitates dispersal, feeding, and predator avoidance. Change in the timing or magnitude of seasonal currents and/or upwelling could reduce sea urchin larval survival (Largier et al. 2010) and impact larval dispersal (Vulnerability Assessment Workshop, pers. comm., 2014).

Temperature

A study on thermal tolerance in the purple sea urchin indicates that individuals from Pacific Grove, CA (just south of the study region) tolerate temperatures ranging from 5-23˚C (with an average annual range of 9-17˚C); however, exposure to cooler temperatures led to respiratory and behavioral acclimation, whereas exposure to warmer temperatures (20˚C) did not, and exposure to 25˚C was invariably lethal (Farmanfarmaian and Giese 1963). The southern range limit of the species is potentially controlled by this sensitive thermal tolerance of adults (Ebert 2010). Conversely, a range of temperatures (10-32˚C) had no impact on the survival of multiple larval stages or the expression of the stress-induced gene hsp70 in the purple urchin (Hammond and Hofmann 2010).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease and storms

Overall species sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Storms increase turbulence that exacerbates dislodgement of both sea urchins and the kelp that urchins often use as habitat and food.

Supporting literature

Storms

Increasingly intense run-off during extreme storm events may cause increased sedimentation that may negatively impact sea urchins due to sand scour, and increased freshwater input to the nearshore subtidal that may lead to higher re-suspension of sediment resulting in increased turbidity and light attenuation (Largier et al. 2010).

Disease

Disease is projected to increase with warming water temperatures due to enhanced pathogen development and survival as well as host susceptibility (Harvell et al. 2002), and increases in disease have been documented in *Strongylocentrotus* spp. in both the North Atlantic (pathogen unknown, >50% mortality) and Norway (pathogen unknown, 90% mortality) (Harvell et al. 1999). Fourteen bacterial strains have been detected in purple urchins collected in Monterey, CA, only 2 of which were able to initiate lesions (Gilles and Pearse 1986), and multiple localized mass mortalities of the red sea urchin have occurred in the study region, resulting in loss of spines and epidermis, lesions, and death (Pearse et al. 1977).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): pollution and poisons (5, moderate), harvest (3, moderate)

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

- Confidence of workshop participants: Moderate

Overall species exposure to non-climate stressors: Moderate

- Confidence of workshop participants: Moderate

Supporting literature

Pollution and poisons

Sea urchins can serve as indicators of poor water quality, as they are often one of the first organisms to show stress in polluted water, including lack of movement and drooping spines (MBA 2014). Exposure to oil has been documented to lead to defective embryogenesis and high larval mortality in a related species of urchin (Vashchenko 1980) and common chemicals found in anti-fouling paints have been shown to be toxic to urchin larvae in China (Kobayashi and Okamura 2002).

Harvest

The red sea urchin has a significant commercial fishery, and is fished throughout its range for the collection of gonads for the sushi trade. Commercial catch peaked in the late 1980s, and the catch per unit effort has been dropping since inception of the fishery in the 1970s (Andrew et al. 2002). Purple urchins have been harvested in California, but on a very limited basis (CDFG 2003). The market for the purple urchin is highly variable and much more specialized. Management measures are currently in place to protect the stock of red sea urchins, including restricted access and season, and a minimum size that allows for multiple years of spawning,

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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.

though the species is considered to be over-harvested and additional management options have been considered (Dewees et al. 2003).

IV. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: rocky reef, rocky intertidal areas, and kelp forests

Species dependence on specific prey or forage species: Low, the species feeds on a variety of macroalgae

- Confidence of workshop participants: High

Other critical dependencies: none identified

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

- Confidence of workshop participants: High

V. Other sensitivities

Other critical factors likely to influence the sensitivity of the species: trophic relationship with predators

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

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): 4

- Confidence of workshop participants: Low

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: High

Maximum annual dispersal distance: >100km

- Confidence of workshop participants: High

Additional participant comments

The adaptive capacity of these species will likely vary greatly between intertidal and subtidal populations. The two species have long-lived pelagic larvae that enable high dispersal, with maximum larval dispersal considered to be greater than 100 km.

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low

- Confidence of workshop participants: High

Genetic diversity: High

- Confidence of workshop participants: Moderate

Behavioral plasticity: Low-Moderate

- Confidence of workshop participants: High

Phenotypic plasticity: Low

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Additional participant comments

Sea urchins are broadcast spawners with external fertilization, producing many gametes in successive cycles and reproducing 3 times per year. Both species take around two years to reach sexual maturity.

Supporting literature

Despite having long-lived planktonic larvae, which should contribute to genetic homogenization, genetic studies indicate significant population subdivision in both sea urchin species, with high genetic differentiation over relatively short geographic distances (Edmands et al. 1996, Moberg and Burton 2000). A few examples of behavioral plasticity exist in the literature. The red urchin has been documented to alter its morphology based on current flow by flattening its spines to become more streamlined in response to high current velocity, presumably contributing to better attachment and preventing dislodgement (Stewart and Britton-Simmons 2011). There is some indication that the timing of spawning coincides with annual peak in phytoplankton bloom not by accident, but that spawning may be induced by a chemical released by phytoplankton (Himmelman 1975). Studies both north and south of the study region indicate that the majority of spawning occurs between December and March (Holland and Giese 1965, Gonor 1973).

III. Management potential

Value of species to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: culinary value, value to tourism, prey for sea otters and as a viable fishery

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

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

Supporting literature

A policy of protecting urchins in shallow-water refugia would offer an effective management strategy by enhancing recruitment (shallow-water individuals have larger gonads and larger spawning events) and by sheltering juveniles (Rogers-Bennett et al. 1995).

IV. Other Adaptive Capacity Factors

Critical factors not addressed that may affect species' adaptive capacity: population bottlenecks during larval settlement, and climate change impacts specific to the larval stage's ability to recruit and survive

- Degree to which these factors affect the habitat's adaptive capacity: Moderate-High
- Confidence of workshop participants: Low

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): decreased pH (4, moderate), decreased dissolved oxygen (DO) levels (4, moderate), increased storminess (2, low), changes in air temperature (2, high), changes in sea surface temperature (1, moderate), altered currents and mixing (1, low)

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

- Confidence of workshop participants: no score provided

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

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

[8] Confidence level indicated by workshop participants**.**

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Sea Palm (*Postelsia palmaeformis*)[1]

Executive Summary

Sea Palm	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	3 Moderate	3 High
Vulnerability	4 Moderate-High	3 High

Sea palm is a rocky intertidal kelp found along the coast from Vancouver Island, British Columbia to San Luis Obispo County, California, restricted to mid-high tidal ranges in areas with high wave action. Sea palm exhibits a broad geographic extent, a robust population that is somewhat fragmented, and a low dispersal capability. Key climate sensitivities identified by workshop participants include air temperature, salinity, wave action, pH and coastal erosion, and key non-climate sensitivities include harvest. This alga has moderate-high diversity in life history (with microscopic and macroscopic stages and variable reproduction timing), low behavioral plasticity, and moderate phenotypic plasticity due to its ability to respond morphologically and reproductively to environmental changes. The societal value for sea palm was rated as low-moderate, though commercial harvest of the species is increasing, and management potential was rated as low-moderate, though there is great opportunity in providing further protection for the species through management and regulation of commercial harvest.

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), sea level rise (3, moderate -high), dynamic ocean conditions (currents/mixing/stratification) (3, low), 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 potentially dislodge space competitors from rock habitat, leaving more available space for sea palms which are adapted to high wave stress.

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

- Confidence of workshop participants: Moderate

Additional participant comments

This species was identified as having moderate-high indirect sensitivity to pH, due to the negative impact that decreased pH is expected to have on the California mussel, a competitor for space, and on coralline algae, an important habitat for sea palm zoospores. Though sea palm was identified as being only moderately sensitive to water temperature, recent work by Dr. Michael

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

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

[3] Confidence level indicated by workshop participants.

Graham of Moss Landing Marine Laboratories has shown that zoospores are not able to grow into mature sporophytes in 18˚C temperature water (Arley Muth, pers. comm., 2014).

Supporting literature

Literature review was conducted for those factors scoring 4 or higher (with the exception of pH, for which no information is available aside from participant comments above), although the other sensitivities identified should also be considered.

Air temperature

Increased air temperature may indirectly negatively impact sea palm by exacerbating the physiological stress associated with emersion at low tide and at times of low wave action. Desiccation, or drying out, of algal tissue during emersion results in reduced photosynthetic efficiency, bleaching and sloughing off of algal tissue, and eventual mortality (Nielsen et al. 2006). Generally, sea palm adults are not exposed long enough to desiccating conditions to cause adverse effects, but this is reliant on constant wave splash and can be exacerbated by high temperatures (Vulnerability Assessment Workshop, pers. comm., 2014). The microscopic stages of sea palm are likely more sensitive to increased air temperature due to the enhanced risk of drying out when exposed on bare rock (Hutto 2011).

Salinity

The impact of salinity on kelp species has received little attention (Dayton 1985), though adverse effects of diluted salinity have been documented on two species of laminarian algae (Norton and South 1969) and on the germination of the Arctic kelp *Alaria esculenta* (Fredersdorf et al. 2009). Hurd (1919) demonstrated that bull kelp sporophytes develop blisters and wilt when subjected to rapid reductions in environmental salinity. Alternatively, healthy kelp forests have been observed growing in freshwater lenses in the Pacific Northwest (Dayton 1985).

Wave action

The relationship this species has with wave action is not straight-forward, and the species may actually benefit from an increase in wave force due to the removal of competitors for space (primarily the California mussel), though likely only up to a certain velocity (Vulnerability Assessment Workshop, pers.comm., 2014). Recent work that attempted to replicate the damaging effect of enhanced wave force by removing various numbers of fronds from mature adult sea palms demonstrated a temporary reduction in reproductive output followed by a fairly quick recovery, indicating no long-term effect of frond removal (Graham, unpublished data). However, studies investigating the impact of harvesting the fronds from adults demonstrated a significant reduction in recruitment and population size (Thompson et al. 2010). Overall, the species is highly adapted to extreme wave action due to its morphology and tissue characteristics (Holbrook 1991) and transplant studies have shown that the adults will not survive a low-energy environment due to enhanced desiccation (Nielsen et al. 2006), indicating that the sea palm will likely benefit from increased wave action.

Coastal erosion

Sea palm may be sensitive to the effects of coastal erosion through the direct burying of intertidal habitat (Vulnerability Assessment Workshop, pers. comm., 2014) and the inability to migrate inland in response to rising sea levels due to the loss and burying of potential habitat further landward (Largier et al. 2010).

II. Sensitivity to 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

Though there are no documented diseases that directly impact sea palm, the ecological dynamics of the rocky intertidal may be greatly altered by disease, including the sea star wasting syndrome that could effectively eliminate the major predator of the California mussel, sea palm's greatest competitor for space.

Supporting literature

Wind and extreme heat events

Wind and heat events often work together to exacerbate the negative effects of desiccation on sea palm microscopic stages (Hutto 2011) and on the bleaching and mortality of adult individuals (Nielsen et al. 2006).

Storms

Increased storm intensity and frequency will bring enhanced wave intensity to the rocky intertidal habitat, impacting the ecological dynamics of intertidal organisms, including the sea palm (see wave action section above).

Flooding

Flooding from sea level rise and increased storm activity will submerge sea palm which has been shown to cause declines in growth and reproductive output, likely due to lower average light levels (Nielsen et al. 2006).

III. Dependencies

Species dependence on one or more sensitive habitat types: Moderate
- Confidence of workshop participants: Moderate
- Sensitive habitats: available substrate in the highly exposed, mid-high rocky intertidal zone, including bare rock, turf algae, and mussel beds

Species dependence on specific prey or forage species: Low
- Confidence of workshop participants: High

Other critical dependencies: wave disturbance
- Degree of dependence: High
- Confidence of workshop participants: High

Specialization of species (1=generalist; 5=specialist): 5
- Confidence of workshop participants: High

Supporting literature

There is some indication that the most suitable substrate type for settlement and growth of the microscopic stages varies by environmental stressor, with bare rock being most suitable in areas of high wave action, and algal turfs being most suitable in areas exposed to high heat and desiccation events (Hutto 2011). Wave disturbance was identified as a critical dependency for the species due to its role in the removal of competitors (specifically, the California mussel) for space in the highly crowded intertidal environment (Dayton 1973, Paine 1988).

IV. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): harvest (5, high)

Overall species sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Low

Supporting literature

Harvest

It is unknown how much harvest of sea palm occurs throughout the region, though commercial harvest of this species is reportedly increasing in California due to a growing market for edible seaweeds and is unregulated and unmanaged at this time (Thompson et al. 2010). Sea palm contributes 45% of commercial seaweed harvest, and is vulnerable to overexploitation due to the species' limited dispersal, the location of its reproductive material on the harvested fronds, and small, localized populations that are at risk of extinction if spore production is limited (Thompson et al. 2010). Thompson et al. (2010) found highly variable responses to harvest of sea palm fronds based on the time of year of harvest, though harvest in general resulted in a 38% reduction in recruitment and a reduction of population size by 40-50%. The authors suggest that management action be taken to protect this species from overexploitation.

V. Other sensitivities: none identified

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: High

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

- Confidence of workshop participants: High

Dispersal ability of the species: Low-Moderate

- Confidence of workshop participants: High

Maximum annual dispersal distance: >100km

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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.

- Confidence of workshop participants: High

Supporting literature

This species exhibits a transcontinental geographic extent along much of the west coast of North America from British Columbia to Central California (Abbott and Hollenberg 1976). Population persistence of the sea palm is limited by the low dispersal capabilities of the microscopic spores (Dayton 1973, Paine 1988), with most dispersal occurring over distances of 1-5 meters (Coyer et al. 1997), though fertile adults that are removed from the substrate by wave action may be able to travel great distances and colonize new areas. Populations, therefore, do not easily colonize new areas, are vulnerable to local extinction, and must rely on the persistence of established patches from year to year (Dayton 1973).

II. Intraspecific/Life History Diversity

Diversity of life history strategies: Moderate-High

- Confidence of workshop participants: High

Genetic diversity: unknown

Behavioral plasticity: Low

- Confidence of workshop participants: Moderate

Phenotypic plasticity: Moderate

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Additional participant comments

Due to the nature of its biphasic life history, the sea palm has some flexibility in responding to environmental conditions and can reach reproductive age at various times based on environmental cues. Once grown, adults can form short and stout morphologies in response to heavy wave action, or grow tall and spindly when in a dense bed of other adults. Sea palms produce many offspring and have a shorter generation time, with spore release occurring just once during its annual life cycle, triggered by environmental cues.

Supporting literature

Sudden growth and recruitment of the settled microscopic spores has been observed immediately following manual and natural removal of mussels (Dayton 1973, Blanchette 1998), suggesting that these stages may be able to "hunker down" under mussels and other algae until appropriate environmental conditions trigger sudden growth (Hutto 2011). Genetic analyses indicate inbreeding in the species (Kusumo et al. 2006) and genetic bottlenecks due to boom-bust cycles in natural abundance (Whitmer 2002). However, due to the plasticity in both morphology and stages/timing of life history, the species may exhibit greater adaptive capacity in response to climate impacts.

III. Management Potential

Value of species to people: Low-Moderate

- Confidence of workshop participants: Moderate
- Description of value: Low value attributed to its limited harvest, and moderate value attributed to its value to the research and management community as a protected species and the state alga.

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

- Confidence of workshop participants: Low
- Description of potential management options: The most likely way to manage or alleviate climate change impacts would be manage harvest levels, which are already very low, or to restore/recolonize areas after extreme storm events.

Supporting literature

There is currently little to no regulation of commercial harvest of sea palm, and as harvest increases rapidly in California, management recommendations include: (1) mandating the frond trimming method, (2) limiting collection to once a year, and (3) closing the commercial season before the onset of reproduction (Thompson et al. 2010).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): 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)

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

- Confidence of workshop participants: Moderate

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

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

[8] Confidence level indicated by workshop participants.

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Southern Sea Otter (*Enhydra lutris nereis)*[1]

Executive Summary

Southern Sea Otter	Score	Confidence
Sensitivity	2 Low-Moderate	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	2 Low-Moderate	2 Moderate
Vulnerability	3 Moderate	2 Moderate

The southern sea otter inhabits nearshore marine habitats, including kelp forests, bays, estuaries, and the exposed outer coast of central California, from Half Moon Bay to Point Conception, with a small population at the Channel Islands in Southern California. Key climate sensitivities identified by workshop participants include changes in precipitation, decreased pH and wave action and key non-climate sensitivities include pollution and poisons. The southern sea otter is a threatened subspecies, whose population exhibits a limited geographic extent within the state of California and is isolated and fragmented. The species exhibits low dispersal, with females rarely traveling more than 20 miles from their home range. Recovery of the subspecies from its lowest level of just 50 individuals has been very slow and tenuous. The southern sea otter has low genetic diversity due to population bottleneck resulting from overharvesting by the fur trade and low-moderate phenotypic plasticity, but moderate-high behavioral plasticity. Some examples of diversity/plasticity in the species includes prey specialization dependent upon prey richness, and plasticity in the age of first reproduction dependent upon carrying capacity of the population. The societal value for the sea otter was rated as high due to its value as a charismatic megafauna species that often serves as an icon of coastal California, but the likelihood of managing or alleviating climate impacts was considered low-moderate.

Sensitivity

I. Sensitivity to climate and climate driven changes

<u>Climate and climate-driven changes identified (score[2], confidence[3])</u>: precipitation (4, moderate), pH (4, high), wave action (3, moderate), dynamic ocean conditions (currents/mixing/stratification) (2, moderate), coastal erosion (2, moderate), dissolved oxygen (DO) levels (2, moderate), salinity (1, low), sea surface temperature[4] (1, high)

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

- Description of benefit: Increased sea surface temperatures may expand the range of suitable habitat for the sea otter, though this is not supported by the literature.

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

- Confidence of workshop participants: Moderate

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

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

[3] Confidence level indicated by workshop participants.

[4] Reviewer noted that sea surface temperature is documented to have a strong negative effect on kelp forest habitat.

Supporting literature

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

Precipitation

As extreme precipitation events are expected to increase with climate change, an enhanced potential for coastal erosion and run-off can also be expected (PWA 2009). Land-based run-off has been implicated as a source of the parasite *Toxoplasma gondii*, one of the more significant infectious diseases that impact sea otter health. Otters sampled near areas of maximal freshwater runoff were 3 times more likely to test positive to the parasite than otters in areas of low flow (Miller et al. 2002), with proximity to urban areas a key factor in exposure (Steve Lonhart, pers. comm., 2014). Enhanced coastal run-off was also associated with the increased likelihood of infection from multiple other bacterial pathogens (Miller et al. 2010).

pH

The expected acidification of coastal waters, especially in upwelling centers, may have a long-term cascading effect on sea otters by altering the health, size and abundance of its prey, which are calcifying invertebrates (Center for Biological Diversity 2014). In this region, where prey limitation is already a challenge (Tinker et al. 2008), a further reduction in the availability and abundance of prey, as well as the size of each individual prey item, may directly impact the energetics of sea otters, as they may have to expend more energy in finding additional prey items to meet their energy demands. Alternatively, otters may need to expend less energy in processing their calcified prey due to weakened shells, which may result in a benefit from reduced pH (Steve Lonhart, pers. comm., 2014).

Wave Action

Enhanced wave action will likely impact the habitats that the sea otter relies on, including the kelp forest and nearshore habitats by impacting sediment redistribution and enhancing sand scour, forcing the movement of nearshore kelp forests into deeper water (Graham 1997) and creating greater intra-annual variability in kelp productivity and abundance (Graham et al. 1997). Wave action may potentially affect the availability and ease of extraction of sea otter prey, though there is no information available in the literature (Steve Lonhart, pers. comm., 2014), and may affect pup survival since females often leave pups in kelp beds while they forage (Sarah Allen, pers. comm. 2014).

II. Sensitivity to changes in disturbance regimes

Disturbance regimes identified: disease, storms, and wind

Overall species sensitivity to disturbance regimes: disease (5), storms (3), wind (2)

- Confidence of workshop participants: disease (high), storms (moderate), wind (low)

Supporting literature

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

Disease

Disease is projected to increase with warming water temperatures, due to enhanced pathogen development and survival, as well as host susceptibility (Harvell et al. 2002). From 1998 to 2003, disease was the leading cause of death in sea otters, accounting for 50% of the mortality when identified (SIMoN 2014). In a 2013 study of sea otter mortality, disease accounted for only 14% of full necropsies, though underlying disease is cited as being a potential cause for greater vulnerability to other causes of death, including shark bite, boat strike, and lesions (Miller et al. 2014). The most significant diseases affecting the sea otter include protozoal infections (*Toxoplasma gondii* and *Sarcocystis neurona*) that enter their habitat through freshwater output and whose eggs are found in cat feces (Miller et al. 2002). Other issues include infection by thorny headed worms, cardiomyopathy (a set of heart conditions with multiple causes), a variety of bacterial infections, and domoic acid poisoning from harmful algal blooms (SIMoN 2014).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[5], confidence[6]): pollution and poisons (5, high), predation (2, low), harvest of prey (2, low)

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

- Confidence of workshop participants: Low

Overall current exposure to non-climate stressors: Low-Moderate[7]

- Confidence of workshop participants: Moderate

Supporting literature

Literature review was conducted for those factors scoring 3 or higher, although the other sensitivities identified should also be considered. Additional non-climate stressors identified that may be important to consider include harmful algal blooms which result in shellfish poisoning (Miller et al. 2010) and human fisheries interactions (Sarah Allen, pers. comm., 2014).

Pollution and Poisons

As a result of run-off, sea otters are highly exposed to a number of pollutants. Residues of the pesticide DDT and the organic pollutant PCB are found in sea otter tissues at concentrations high enough to kill other species in the same family, and those that died of infectious diseases had higher concentrations of tributyltin (a chemical in anti-fouling paint used on boat hulls), though this association does not prove a causal link (SIMoN 2014). Oil spills are also a significant danger to sea otters and one large spill in central California could decimate the entire southern subspecies (SIMoN 2014). Exposure can result in hypothermia by reducing the insulting qualities of the otter's fur and can result in toxic levels of ingestion as otters constantly groom their fur in an attempt to remove oil (SIMoN 2014). One estimate reports the probability of death to be 50% for an otter that comes into contact with oil from a spill (USFWS 2003). Inhalation of aersols is also a significant toxin and causes mortality as occurred during the Exxon Valdez (Sarah Allen, pers. comm., 2014).

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

[6] Confidence level indicated by workshop participants.

[7] Reviewer notes that exposure to pollution and poisons is very localized, and likely moderate to high.

IV. Dependencies

Species dependence on one or more sensitive habitat types:

- Confidence of workshop participants: kelp (high), estuaries (moderate), nearshore (high)
- Sensitive habitats species is dependent upon: kelp forests (4), estuaries/coastal lagoons (2), and nearshore habitat (5)

Species dependence on specific prey or forage species: Low, feeds on a variety of benthic invertebrates

- Confidence of workshop participants: High

Other critical dependencies: none identified

Specialization of species (1=generalist; 5=specialist): 2[8]

- Confidence of workshop participants: High

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: High

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

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Moderate

Dispersal ability of the species: Low-Moderate

- Confidence of workshop participants: High

Maximum annual dispersal distance: 1-5km

- Confidence of workshop participants: High

Supporting literature

The southern sea otter exhibits a fairly limited geographic extent from Half Moon Bay to Point Conception, especially when compared to its historical range which reached almost continuously from Baja California around the Pacific to Japan (SIMoN 2014). After rebounding from its lowest population level of just 50 individuals in the early 1900s, the threatened subspecies, now numbering around 2900 individuals (Hattfield and Tinker 2013), is showing a very sluggish recovery, which may be due to multiple factors including disease, predation, pollution (SIMoN 2014), and human interaction (Sarah Allen, pers. comm., 2014). Movement of individuals varies greatly by sex, age, and location, with males traveling the furthest, around 200 miles from the

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[8] One reviewer did not agree with this ranking, stating that many sea otter biologists would not consider the species to be a generalist. An additional reviewer noted that in general, sea otter diet is diverse, but individuals may be highly specialized.

peripheries of the range to reach the more female-dense center, whereas females make more frequent, short-range trips (rarely more than 20 miles) (SIMoN 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low-Moderate

- Confidence of workshop participants: Low

Genetic diversity: Low

- Confidence of workshop participants: High

Behavioral plasticity: Moderate-High

- Confidence of workshop participants: Moderate

Phenotypic plasticity: Low-Moderate

- Confidence of workshop participants: Moderate

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

- Confidence of workshop participants: Moderate

Supporting literature

Due to the population bottleneck that occurred during the fur trade, which resulted in a southern subspecies of just 50 individuals, the genetic diversity of the southern sea otter is extremely low (Larson et al. 2012), which may make this species more vulnerable to change and lead to inbreeding depression. Sea otters show great diversity in behavior, however, that enables them to adapt to different environmental variables, including dietary polymorphism in response to a food-poor environment (Tinker et al. 2008). Plasticity has been observed as well, which gives the species an advantage, including plasticity in the age of first reproduction in the northern sea otter in response to the carrying capacity of the population (von Biela et al. 2009). The species is relatively long-lived (likely 20 years), which aids in adaptive capacity through behavioral changes, as evidenced by their use of tools, one of few mammal species to do so (Sarah Allen, pers. comm., 2014). Females take approximately 3 to 5 years to reach reproductive maturity and produce only one pup every 16 months with high maternal investment for one year following (Vulnerability Assessment Workshop, pers. comm., 2014; Sarah Allen, pers. comm., 2014). Pup mortality is estimated to be around 45%. Sea otters have a polygamous mating system, and the health and survival of females is of greater importance for population recovery than that of males (Miller et al. 2014).

III. Management potential

Value of species to people: High

- Confidence of workshop participants: High
- Description of value: value as a charismatic megafauna species that often serves as an icon of coastal California

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

- Confidence of workshop participants: Moderate
- Description of possible management actions: no answer provided

IV. Other Adaptive Capacity Factors

Critical factors not addressed that may affect species' adaptive capacity: impact of predation, impacts to key prey, and factors that limit the ability of the species to migrate north and south along the coast

- Degree to which these factors affect the habitat's adaptive capacity: High
- Confidence of workshop participants: Low

Exposure

I. Future climate exposure[9]

Future climate and climate-driven changes identified (score[10], confidence[11]): decreased pH (4, high), increased coastal erosion and runoff (4, moderate), changes in precipitation (3, moderate), increased storminess (3, moderate)[12]

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

- Confidence of workshop participants: Moderate

Additional participant comments

Increased coastal erosion and runoff, as well as changes in precipitation and increased storminess, may lead to increased exposure to land-based pollutants.

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

[10] 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.

[11] Confidence level indicated by workshop participants.

[12] Reviewer noted that sea surface temperature should be included as a future climate factor of importance due to its negative impact on important biogenic habitat, kelp beds.

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Surface Nesters: Brandt’s Cormorant (*Phalacrocorax penicillatus*) and Common Murre (*Uria aalge*)[1]

Executive Summary

Surface Nesters: Brandt’s Cormorant and Common Murre	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	3 Moderate	3 High
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	3 Moderate	3 High

Brandt’s cormorants and common murres are resident seabirds in the study area, and are characterized by nesting on open surfaces and diving for prey. Key climate sensitivities identified by workshop participants for these species includes extreme weather conditions, sea surface temperature, and dynamic ocean conditions (currents/mixing/stratification). Key non-climate sensitivities include aircraft and vessels, recreation, invasive species, harvest, and pollution and poisons. Brandt’s cormorants and common murres occur along the Pacific Coast of North America and have almost continuous population connectivity. The study area contains the southern-most colonies for these species in the Pacific, and populations are relatively stable and/or increasing. Brandt’s cormorants and common murres are highly dependent on undisturbed breeding habitat on coastal cliffs, offshore rocks, and islands. Common murres have fairly low reproductive potential, reproducing only once per year and having few chicks, whereas Brandt’s cormorants have greater reproductive potential than any other local seabird. These species exhibit some behavioral foraging diversity (i.e., foraging in different areas and on different species). Brandt’s cormorants and common murres likely have a low to low-moderate societal value (depending on the segment of society) and a low likelihood for managing or alleviating climate impacts. Continuing to mitigate disturbance via aerial, vessel, and public access restrictions may reduce cumulative stressors on these species.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

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

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

[3] Confidence level indicated by workshop participants.

Additional participant comments

Surface nesting species, including the Brandt's cormorant (*Phalacrocorax penicillatus*) and the common murre (*Uria aalge*), are mainly sensitive to any changes that affect their marine prey species or terrestrial breeding habitat, such as extreme weather conditions, sea surface temperatures, and currents/mixing/stratification.

Supporting literature

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

Extreme Weather Conditions

Extreme weather conditions can directly lead to mortality or breeding habitat disturbance of Brandt's cormorants and common murres. For example, storms can increase the potential for breeding habitat inundation, especially in low-lying areas (Young et al. 2012). Shifts in large-scale climatic forcings, such as the El Niño Southern Oscillation (ENSO), can also affect common murres and Brandt's cormorants by intensifying storm conditions and/or affecting marine processes and food webs, leading to partial or complete colony abandonment (Manuwal et al. 2002). For example, the 1982-83 El Niño led to high mortality of common murres along the central California coast (USFWS 1995) and to population declines in the breeding population of Brandt's cormorants on the Farallon Islands (Audobon Society 2014, Capitolo et al. 2014).

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 impacts that echo up the food chain and affect foraging seabirds such as the common murre and Brandt's cormorant (Young et al. 2012, Schmidt et al. 2014). For example, warmer sea surface temperatures have been correlated with decreased zooplankton abundance (Hill 1995, Roemmich and McGowan 1995), which can contribute to declines of key prey species, such as rockfish (*Sebastes* spp.) (Hill 1995), and affect the survival and reproductive success of diving piscivores (Young et al. 2012). Miller and Sydeman (2004) found that warmer sea surface temperatures correlated with decreased juvenile rockfish abundance in common murre diets.

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). La Niña conditions from 1999-2000 are thought to have contributed to large population increases in Brandt's cormorants in the Gulf of the Farallons (Capitolo et al. 2014).

Dynamic ocean conditions (currents/mixing/stratification)

Brandt's cormorants and common murres forage on a variety of prey species delivered by the California Coastal Current and different upwelling zones (Briggs et al. 1988, Largier et al. 2010, Cornell Lab of Ornithology 2014), and reproduction timing is correlated with high prey availability (Manuwal et al. 2002). Changes in currents, wind, upwelling rates and timing, stratification, and ocean mixing can alter the delivery timing and availability of prey species, affecting survival and reproductive success of Brandt's cormorants and common murres (Young et al. 2012). For example, 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 diving seabirds if zooplankton and other forage fish end up below the maximum dive depths for these species (Largier et al. 2010). 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).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: disease, storms, flooding, drought, intraspecific disturbance

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 other species within the breeding ranges of common murres and Brandt's cormorants could affect breeding success.

Supporting literature

As colonial nesters, infectious disease can spread quickly and extensively amongst Brandt's cormorants and common murres (Newman et al. 2004). Storms, especially those during breeding season and/or with large wave heights, can inundate breeding habitat and negatively impact breeding success (Young et al. 2012). Flooding of low-lying nesting habitat via sea level rise or storm surge can also reduce breeding success (Young et al. 2012). Drought may negatively impact the availability of native plant nesting material. In 2014, delayed rains meant extremely delayed onset of growth of Maritime goldfields (*Lasthenia maritime*), a key source of nesting material for Brandt's Cormorant (Point Blue, unpublished data). There was enough just in time, but an extreme drought with no significant rain may be different.

Common murres and Brandt's cormorants are sensitive to disturbance from other species, such as Western gulls (*Larus occidentalis*), Brown pelicans (*Pelecanus occidentalis*), common ravens (*Corvus corax*), and pinnipeds (Thayer et al. 1999, Warzybok et al. 2004, Apex Houston Trustee Council 2011). In addition, climate-driven expansion of competitors, such as the Humboldt Squid (*Dosidicus gigas*), could affect food availability and fitness of resident common murre and Brandt's cormorant populations (Young et al. 2012).

III. Dependencies

Species dependence on one or more sensitive habitat types: High (breeding habitat), Moderate (foraging habitat)

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: nearshore and offshore waters, cliffs, and rock islands

Species dependence on specific prey or forage species: Moderate

- Confidence of workshop participants: High

Other critical dependencies: timing of breeding and foraging availability

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

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

- Confidence of workshop participants: High

Additional participant comments

Common murres typically forage offshore. However, both species sometimes forage in areas outside their normal foraging grounds.

Supporting literature

Brandt's cormorants and common murres are colonial nesters, often nesting together on open surface areas (i.e., cliffs ledges, offshore rocks and islands) that are free of predators and human disturbance (Manuwal et al. 2002, Audobon Society 2014). Brandt's cormorants typically forage nearshore, especially in areas with kelp beds (Cornell Lab of Ornithology 2014). Both species exhibit some feeding diversity; for example, common murres feed on krill, schooling fish, and other aquatic prey (Apex Houston Trustee Council 2011), and Brandt's cormorants feed on fish, squid, shrimp, and crabs (Audubon Society 2014, Cornell Lab of Ornithology 2014).

IV. Sensitivity and current exposure to non-climate stressors

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

Additional participant comments

These stressors can make surface nesting species more vulnerable to climate stressors by affecting reproductive success and/or degrading habitat quality and food availability. Recreation-related disturbance includes dogs, jet skis, kayaks, and unmanned aerial vehicles.

Supporting literature

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

Invasive Species

Rodents, particularly house mice, were introduced to the Farallon Islands in the 19th century (USFWS 2013). Rodents change ecological relationships on islands (e.g., by eating native plants and invertebrates and/or by drawing in new predators), which can affect the availability and

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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.

quality of breeding habitat for surface nesting seabirds and/or increase rates of egg predation (USFWS 2013). Mice have apparently little impact on breeding murres and cormorants, but an introduction of rats on the Farallones could have disastrous consequences for these species (Russell Bradley, Point Blue, pers. comm., 2014).

Aircraft and Vessels
Disturbance from aircraft and vessels can contribute to nest failure and/or stress Brandt's cormorants and common murres, exacerbating their low reproductive potential. For example, disturbance during breeding season can lead to nest failure or colony desertion by Brandt's cormorants (Audbon Society 2014); to prevent these issues, the Farallon Islands has established a 300 foot special closure to protect seabirds from vessel disturbance during breeding season (Audobon Society 2014). Aircraft disturbance, particularly helicopters, has also been documented to increase the frequency of adult murre flushing, especially when aircraft are flown less than 305 m above sea level (Rojek et al. 2007). Boat disturbance also contributed to nest failure in several central California common murre colonies, particularly when boats approached within 50 m of nesting colonies and remained there for extended periods of time (Rojek et al. 2007).

Pollution and Poisons
Episodic pollution and poison events, such as oil spills, can kill Brandt's cormorants and common murres and/or affect prey availability or habitat quality. For example, the 1986 oil spill from the Apex Houston killed approximately 6000 common murres from San Francisco to Big Sur (Siskin et al. 1993 cited in USFWS 1995) and led to the abandonment of several onshore breeding habitat areas (Takekawa et al. 1990, Swartzman and Carter 1991, Carter et al. 1992 cited in USFWS 1995).

Recreation
Similar to disturbance from airplanes or vessels, disturbance related to recreation can cause nest failure or colony abandonment, especially during times of low food availability (Young et al. 2012).

Harvest
Harvest of prey species can reduce food availability for common murres and Brandt's cormorants. For example, increasing California sea lion (*Zalophus californianus*) populations and industrial fisheries may have reduced the number of young fish available for cormorant forage, slowing the recovery of Brandt's cormorant populations within the study area (Audobon Society 2014, Capitolo et al. 2014). Future expansion of the groundfish fisheries could exacerbate this trend, warranting further study (Audobon Society 2014).

V. Other sensitivities

Other critical factors likely to influence the sensitivity of the species: El Niño-Southern Oscillations (ENSO)

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

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)[6]: BRCO: 3, COMO: 5

- Confidence of workshop participants: High

Population connectivity of the species (1=isolated/fragmented; 5=continuous): 4

- Confidence of workshop participants: Moderate

Dispersal ability of the species: Moderate

- Confidence of workshop participants: Moderate

Maximum annual dispersal distance: >100km

- Confidence of workshop participants: High

Supporting literature

The study area contains the southern-most colonies for these species in the Pacific, and includes colonies that nest on cliffs and offshore rocks and islands (USFWS 1995, Apex Houston Trustee Council 2011, Cornell Lab of Ornithology 2014). Common murres are the most abundant breeding seabird in Central California (Apex Houston Trustee Council 2011), having rebounded from population lows in the late 1980s, with breeding colonies from Point Sur to Point Reyes and the largest breeding colony occurring in the Farallon Islands (Apex Houston Trustee Council 2011). California hosts over 75% of the world's population of breeding Brandt's cormorants (Audobon Society 2014), and the Farallon Islands breeding colony is one of the largest in the world (Capitolo et al. 2014, USFWS 2014). Brandt's cormorants have a diminished but generally stable population within the study region (Capitolo et al. 2014), with major declines in recent years at the Farallon Islands (Warzybok et al. 2012), though distributional shifts from islands to coastal communities may be occurring (Audobon Society 2014, Capitolo et al. 2014). These surface nesters are permanent residents in the study area, but do exhibit local movement. For example, Brandt's cormorants will migrate from the Farallon Islands to the mainland, or wander south in winter to forage along the Mexican coastline (Audobon Society 2014, Capitolo et al. 2014) or north up to British Columbia (Burles et al. 2008).

II. Intraspecific/Life history diversity

Diversity of life history strategies[6]: BRCO: Low-Moderate, COMO: Moderate-High

- Confidence of workshop participants: Moderate

Genetic diversity: Moderate

- Confidence of workshop participants: Low

Behavioral plasticity[6]: BRCO: Moderate, COMO: Low-Moderate

- Confidence of workshop participants: Moderate

Phenotypic plasticity[6]: BRCO: Moderate, COMO: Low-Moderate

- Confidence of workshop participants: Moderate

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[6] BRCO = Brandt's cormorant, COMO = common murre

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

- Confidence of workshop participants: Moderate

Additional participant comments

Brandt's cormorants have some plasticity in egg clutch size.

Supporting literature

Brandt's cormorants will forage in a diversity of habitats (i.e., nearshore, offshore, estuaries) (Audobon Society 2014). Brandt's cormorants nest in large colonies. They have only one reproductive event per year, laying 1 to 4 eggs in a constructed nest, and take 2 to 4 years to reach reproductive maturity. However, the species can relay after failed breeding attempts, resulting in a second chance for reproductive success (Russell Bradley, Point Blue, pers. comm., 2014).

Common murres can dive deeper (up to 180 m; Piatt and Nettleship 1985) than some other seabirds in order to access prey (Oedekoven et al. 2001), which may increase their resilience to changes in currents, upwelling, and prey availability. Common murres have also been documented to shift their foraging zones in response to changes in the marine environment and prey availability (Oedekoven et al. 2001). However, common murres can carry only one fish at time when foraging for nestlings, which could lead to higher energetic costs and consequences if foraging distance and time requirements increase due to prey declines (Young et al. 2012). Common murres have only one reproductive event per year, but can relay after breeding failure and their breeding season lasts from late April to early August during times of peak food availability (Manuwal et al. 2002). Common murres breed and nest in large dense colonies. They lay one egg per year, and eggs are laid directly on the ground with no nest. After a short on-land rearing period, chicks are raised at sea by males (Manuwal et al. 2002). Common murres take 3-5 years to reach reproductive maturity, and exhibit high fidelity to breeding sites, typically breeding at the site where they were born.

III. Management potential

Value of species to people: Low-Moderate

- Confidence of workshop participants: High
- Description of value: Low value to the general public, but moderate value to birders and nature enthusiasts.

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

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

Supporting literature

Common murre populations are still recovering from significant population declines in the 1980s, and recovery is currently being monitored and managed through the Common Murre Restoration Project[7], which includes re-establishment of common murre population at historical colony sites (i.e., Devil's Slide Rock, San Pedro Rock) (USFWS 1995). Establishment of both

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[7] http://www.fws.gov/sfbayrefuges/murre/index.htm

the Gulf of the Farallones and the Monterey Bay National Marine Sanctuaries helped reduce disturbance of murre and cormorant breeding colonies (Capitolo et al. 2014), and continuing to mitigate disturbance via aerial, vessel, and public access restrictions may reduce cumulative stressors on these species (Audobon Society 2014).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[8]

Future climate and climate-driven changes identified (score[9], confidence[10]): altered currents and mixing (4, moderate), changes in air temperature (3, moderate), changes in sea surface temperature (3, moderate), increased storminess (3, moderate), changes in salinity (3, moderate), decreased dissolved oxygen (DO) levels (3, moderate), decreased pH (3, moderate), increased flooding (2, moderate), increased coastal erosion and runoff (2, moderate), changes in precipitation (2, moderate), sea level rise (1, moderate)

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

- Confidence of workshop participants: Moderate

Supporting literature

Climate change will likely have indirect impacts on surface nesting Brandt's cormorants and common murres by affecting prey availability and habitat quality (Largier et al. 2010, Young et al. 2012). The nature of how some local seabird species, like Brandt's Cormorants on the Farallones, have responded to changes in climate has itself changed in recent years (Schmidt et al. 2014).

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

[9] 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.

[10] Confidence level indicated by workshop participants.

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Tidewater Goby (*Eucyclogobius newberryi*)[1]

Executive Summary

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

The tidewater goby, a small fish species endemic to California, inhabits coastal lagoons, estuaries and marshes from Smith River, just south of the Oregon border, to northern San Diego County. The key climate sensitivity identified for the species by workshop participants is precipitation, and the key-non climate sensitivity is land use change. The endangered tidewater goby, though highly adapted and resilient to variable environmental conditions, has experienced significant population reductions due to habitat loss and degradation. The species is endemic to California, and patchily distributed. The species does not actively disperse, limiting its ability to colonize new areas, though flooding and nearshore transport results in passive dispersal down-coast up to 15 km. Because of this limited dispersal, genetic diversity is high among populations separated by unfavorable habitat, though little or no known behavioral or phenotypic plasticity exists for the species, so overall diversity is low-moderate. Societal value for the tidewater goby is moderate, with scientists and managers recognizing the species' value, and potential for management is moderate, with managers having the ability to use land-use planning and regulations to improve goby habitat, thereby increasing its resilience to climate change impacts.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): precipitation (4, moderate), pH (2, low), sea level rise (2, low), and coastal erosion (2, low)

Climate and climate-driven changes that may benefit the species: sea level rise

- Description of benefit: Sea level rise could result in an increase of shallow water pool habitat, which would increase suitable habitat for the species. However, sea level rise may also transform pre-existing shallow water pools into deep water pools, thus decreasing available habitat. The overall impact of sea level rise on the tidewater goby will depend on specific local habitat conditions.

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

- Confidence of workshop participants: Moderate

Additional participant comments

The tidewater goby is highly sensitive to displacement from extreme storm events. However, extreme storm events may also assist in the nearshore dispersal of the species, enabling it to

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

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

[3] Confidence level indicated by workshop participants.

recolonize nearby coastal lagoons. Extreme storm events may also result in a loss of aquatic vegetation thus reducing suitable habitat for the tidewater goby.

Variability in precipitation impacts the tidewater goby in multiple ways by affecting streamflow and resulting lagoon dynamics. Gobies in general thrive in a system that is balanced with periodic heavy winter precipitation and consistent brackish conditions during dry months, but enhanced and prolonged periods of precipitation may negatively impact the species. If precipitation becomes more consistent and spread throughout the year, instead of the current Mediterranean pattern, lagoons would be open more often and would create less suitable habitat for gobies that rely on shallow sandy areas for spawning.

Supporting literature

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

Precipitation

Gobies are highly sensitive to drought in smaller wetlands due to the loss of suitable habitat and thus fair better during wetter years that produce greater streamflow (Lafferty et al. 1999a). However, increased streamflow can result in breaching and scouring of lagoons, substantial salinity reduction, flooding and subsequent local population loss due to passive dispersal (which also has its benefits) (USFWS 2005).

Additional comments provided after the vulnerability assessment workshop by Dr. Camm Swift, professor emeritus at the Natural History Museum of Los Angeles, indicate that the goby may also be somewhat sensitive to salinity, oxygen, wave action, currents/stratification and coastal erosion, though the species is generally recognized as being highly adapted to broad environmental conditions (Worcester and Lea 1996, USFWS 2005). Optimal conditions for tidewater gobies are in the lower one third of the salinity range and increased salinity is correlated with less robust habitat and diminished populations. Oxygen in the subsurface sandy substrate is critical for incubation of the eggs by the males in burrows. Wave action builds the sand berms that maintain the brackish lagoons optimal for tidewater gobies, and changes in the source direction of the waves could lead to deterioration of barrier berms and loss of lagoon habitat. Tidewater gobies do not tolerate much current and increases in current or tidal flows are detrimental. Stratification results in saline bottom water in lagoons that differentially absorb solar radiation which uses up oxygen leading to anoxic conditions low in the water column, driving brackish fauna like tidewater gobies into marginal shallows where they become vulnerable to predators. Coastal erosion can lead to fine sediments dominating lagoon substrates, in which tidewater gobies cannot dig breeding burrows.

II. Sensitivities to disturbance regimes

Disturbance regimes identified: flooding

Overall species sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Flooding events can impact both the habitat and reproductive success of the tidewater goby. Though the tidewater goby thrives in the natural Mediterranean disturbance regime of relatively brief flooding and scouring of lagoons during winter months with stabilization and consistent brackish conditions during dry months, increased variability and intensity of precipitation events, and subsequent flooding, may negatively impact the species. Gobies may be displaced through nearshore dispersal mechanisms when their habitat is flooded (Lafferty et al. 1999b; though this may benefit the species by enabling colonization of new habitat) and increased flooding may also interfere with reproduction success because the species is a substrate-nester.

III. Dependencies

Species dependence on one or more sensitive habitat types: High

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: brackish water habitat, including coastal lagoons and upstream creek and river systems

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

- Confidence of workshop participants: Moderate

Other critical dependencies: relatively clear water for visual breeding and courtship activities in spring/early summer and oxygenated sandy substrate at least 4-6 inches deep for breeding burrows.

- Degree of dependence: Moderate
- Confidence of workshop participants: no answer provided

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

- Confidence of workshop participants: Moderate

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): land use change (3, moderate) and invasive species (2, low)

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

- Confidence of workshop participants: Low

Overall species exposure to non-climate stressors: no answer provided

Supporting literature

Land-use change

Land-use practices such as conversion of coastal marsh to marinas, road and railway construction, freshwater diversion, grazing and agriculture, and flood control practices have all resulted in massive habitat loss and degradation throughout the goby's range (Lafferty et al. 1996). This has resulted in the extirpation of around half of the original populations, with most populations lost in Southern California and in the San Francisco Bay region (Swift et al. 1989).

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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.

Gobies use vegetated, shallow water habitats, and pre-existing development along the lagoon margins will preclude the ability of this habitat to expand as sea level rise causes lagoon water elevations to increase (Darren Fong, pers. comm., 2014).

Invasive species

Goby populations have historically been locally extirpated following the introduction of invasive species, particularly large piscivorous fish, including the killifish, yellowfin goby, and squawfish (Leidy 1984, Brittan et al. 1970, Lafferty et al. 1999a).

V. Other sensitivities: none identified

Adaptive Capacity

I. Extent, status, and dispersal ability

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

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

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: up to 15 km

- Confidence of workshop participants: Moderate

Supporting literature

This species is endemic to California, and thus exhibits a limited geographic extent, from Smith River in Del Norte County to northern San Diego County (USFWS 2005). The population is endangered (though USFWS has proposed a downlisting to “threatened”; Darren Fong, pers. comm., 2014) and somewhat fragmented and patchy due to the persistence of unsuitable habitat along the coastline that separates suitable habitat (Lafferty et al. 1999a). Dispersal is low and limited to 10-15 km at most for adults; larvae and small juveniles are thought to be too sensitive to higher salinities to be able to disperse (according to unpublished research by Hellmair at Humboldt State, Camm Swift, pers. comm., 2014). Dispersal is passive and a result of flooding and longshore currents that transport individuals to suitable habitat to the south (Lafferty et al. 1999b).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Low

- Confidence of workshop participants: no answer provided

Genetic diversity: High

- Confidence of workshop participants: no answer provided

Behavioral plasticity: Low

- Confidence of workshop participants: no answer provided

Phenotypic plasticity: Low-Moderate

- Confidence of workshop participants: no answer provided

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

- Confidence of workshop participants: no answer provided

The tidewater goby exhibits high genetic diversity due to its highly fragmented population, which is clearly the result of isolation and genetic drift (Earl et al. 2010). This work suggests that populations, especially in the southern range in northern San Diego County, are extremely divergent due to extensive isolation and may even represent a separate species (Earl et al. 2010). Genetic evidence indicates that populations throughout much of the range show extreme isolation and may be unlikely to recover from local extinction via dispersal from adjacent areas. This species also displays no known behavioral plasticity, and low-moderate phenotypic plasticity, mostly in subtle morphological features (Camm Swift, pers. comm., 2014).

Gobies reproduce in successive cycles, spawn nearly year-round, can undergo more than 4 reproductive events in a given year, and take 3-10 months to reach reproductive maturity, depending on the season (longer during colder temperatures) (Camm Swift, pers. comm., 2014). The tidewater goby exhibits a female-dominated breeding system, and males typically remain in one burrow and breed with successive females (Camm Swift, pers. comm., 2014).

III. Management potential

Value of species to people: Moderate

- Confidence of workshop participants: Moderate
- Description of value: endangered species and endemic to California

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

- Confidence of workshop participants: Moderate
- Description of potential management options: the species has proven amenable to management when wetland and lagoon habitat has been improved and exotic predators removed or controlled

Additional participant comments

There are generally good land-use planning and regulations in California to protect the natural fringe habitats around coastal lagoons and estuaries where this species is present, and support exists for protecting the species as it is considered endangered and endemic.

IV. Other adaptive capacity factors: none identified

Additional participant comments

Normally the species would be considered very adaptable to climate change under natural conditions, but the many constraints on the margins of wetlands and lagoons, the freshwater supply, and the presence of exotic species will complicate the species' normally good abilities to adapt.

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): changes in precipitation (3, moderate) and increased flooding (3, moderate)

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

- Confidence of workshop participants: Moderate

Additional participant comments

Potential areas of refugia from flooding include fringing wetlands (if present) of lagoons and creeks.

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

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

[8] Confidence level indicated by workshop participants.

Western Snowy Plover (*Charadrius alexandrinus nivosus*)[1]

Executive Summary

Snowy Plover	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	4 Moderate-High	2 Moderate
Adaptive Capacity	3 Moderate	2 Moderate
Vulnerability	4 Moderate-High	2 Moderate

The Western snowy plover is a federally threatened subspecies that breeds on coastal beaches from southern Washington to southern Baja California and relies on a variety of sensitive habitats, nesting in flat, open sandy areas just in front of coastal foredunes. Key climate sensitivities identified for the species by participants include sea level rise and coastal erosion/wave action, and key non-climate sensitivities include recreation, land use change, pollution and poisons, and invasive species. The Pacific coast population of the Western snowy plover exhibits a broad transcontinental geographic extent and a federally threatened population that is fragmented but likely connected due to high dispersal. The species exhibits some degree of reproductive plasticity, but limited genetic diversity and behavioral plasticity. The societal value for this species is complicated, with birders and some recreational users seeing great value in the species, though recreational use conflicts have caused some local opposition to conservation actions to protect the species from disturbance. Declines in abundance in recent decades are likely due to habitat loss, predation, and human disturbance, and the major future threat to the snowy plover from climate impacts is likely the loss of habitat and the inability for managers to address that loss on a large enough scale to maintain population abundance. Efforts to manage for human disturbance and predation have seen mixed results, but the population has yet to recover to previous levels.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven changes identified (score[2], confidence[3]): sea level rise (5, high), wave action (5, high), coastal erosion (5, high), precipitation (2, low), pH (1, low)

Climate and climate-driven changes that may benefit the species: coastal erosion

- Description of benefit: Coastal erosion could create additional habitat for the snowy plover

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

- Confidence of workshop participants: Moderate

Additional participant comments

The snowy plover was identified as being highly sensitive to climate-driven factors primarily due to the loss of nesting habitat and subsequent reductions in reproductive success. Potential short-

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

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

[3] Confidence level indicated by workshop participants.

term benefits to the species may be realized through the creation of new habitat as a result of enhanced coastal erosion, though in the long-term, cumulative habitat loss is expected.

Supporting literature

Sea Level Rise

Rising sea level can contribute to habitat fragmentation and loss, resulting in a reduction of foraging and nesting areas for snowy plovers (Chu-Agor et al. 2012). Using geomorphological models, combined with metapopulation information for the snowy plover in Florida, Aiello-Lammens et al. (2011) demonstrated that sea level rise will likely cause a decline in suitable habitat and carrying capacity for the snowy plover, increasing its risk of widespread decline and extinction. Habitat loss due to sea level rise for shorebirds in the San Francisco Bay region was estimated at upwards of 70%, exacerbated by seawalls and other structures that inhibit the migration of beach and dune habitat (Galbraith et al. 2002).

As managers consider impacts of sea level rise to snowy plovers in their specific regions, different beach types and settings should be considered, as beach response to sea level rise and sand supply failure will not be uniform in terms of the resulting consequence for snowy plover habitat (Peter Baye, pers. comm., 2014). Steep, narrow, cliff-backed beaches are more vulnerable to losing critical backshore habitat, whereas high dune/paleo-dune backed beaches are buffered from backshore habitat loss and can migrate inland, indicating habitat resilience even with accelerating sea level rise (Peter Baye, pers. comm., 2014). Barrier beaches may actually become more suitable for snowy plovers, as accelerated sea level rise and increased storm intensity may increase wash-over, negatively impacting the European beachgrass (see “invasive species” section for more information) and creating more open space breeding habitat (Peter Baye, pers. comm., 2014).

Coastal Erosion/Wave Action

These climate factors are considered together because they result in the same impacts to snowy plover population abundance. Intense winter storms, particularly during ENSO events, bring high wave energy that significantly alters beach profiles due to enhanced erosion (White and Allen 1999), negatively impacting snowy plover populations. During the 1997/1998 winter ENSO event, the snowy plover breeding population experienced a 10-30% range-wide decline (USFWS 2007) due to enhanced erosion from wave action that disrupted nesting habitat (Campbell 2013).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind, storms, and flooding

Overall species sensitivity to disturbance regimes: High

- Confidence of workshop participants: High

Additional participant comments

Storms and flooding can result in the loss of a brood during the nesting season, and strong winds can bury nests. Enhanced wave energy may impact the back beach nesting habitat and enhance erosion, reducing breeding success.

III. Dependencies

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

- Confidence of workshop participants: Moderate
- Sensitive habitats species is dependent upon: gravel bars, salt pans, and sandy beaches

Species dependence on specific prey or forage species: Low[4]

- Confidence of workshop participants: Moderate

Other critical dependencies: none identified

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

- Confidence of workshop participants: Moderate

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[5], confidence[6]): recreation (5, high), land use change (5, high), pollution and poisons (5, high), invasive species (4, high)

Overall species sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

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

- Confidence of workshop participants: High

Supporting literature

Though not identified by workshop participants, urban predators such as ravens and crows are an important limiting factor in breeding success at many sites (Dan Robinette, pers. comm., 2014), and may be a more significant threat to snowy plover populations than invasive species (Peter Baye, pers. comm., 2014).

Recreation

The snowy plover breeding season, from March to September, coincides with the busiest and most popular recreational use of beaches (California State Parks 2014). Impacts from human disturbance, especially from off-leash dogs, can cause nest abandonment and loss of eggs and unfledged chicks. Beach visitors also often leave trash behind, which attracts opportunistic predators such as the American crow and striped skunk (California State Parks 2014). In a study conducted by the Golden Gate National Recreation Area at Ocean Beach, San Francisco, 90% of observed dogs were off-leash, with 19 dogs (6% of those observed) chasing at least 62 snowy plovers, and roaming dogs (50% of those observed) inadvertently disturbing another 100 birds in just 40 hours of observation (Hatch 1996). Plovers were also observed to be disturbed by sand excavation, people, helicopters, bicycles, vehicles and kites (Hatch 1996).

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[4] Reviewer of this document noted that this may not be an accurate score for the snowy plover's dependence on specific prey, as talitrid amphipods are a very specific and critical food source for the species.

[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.

Land Use Change

The impact of land use change on snowy plovers is primarily through the introduction and exacerbation of predation by gulls, ravens, foxes, coyotes, dogs, feral cats, skunks and racoons that often follow human activity into snowy plover habitat (Campbell 2013; Vulnerability Assessment Workshop, pers. comm., 2014). Land use change (i.e., development, watershed alterations, livestock grazing and agriculture) may also disrupt sediment supply to plover habitat, and impact water quality in the region, resulting in high coliform, bacterial and toxic metal contamination (e.g., high mercury levels, ONMS 2010). Development and landscape irrigation on top of coastal cliffs that often back beaches and dunes in the study region can increase internal pore pressures of cliff materials, decreasing resilience and accelerating coastal erosion (Griggs and Patsch 2004), and beach grooming and nourishment can negatively impact brown algal wrack abundance, which will impact talitrid amphipods, an important prey for snowy plovers (Dan Robinette, pers. comm., 2014).

Land use and development on barrier beaches may change as a response to accelerated sea level rise and increased storminess. These areas may become economically unsustainable due to increased failure of beach armoring and catastrophic storm damage, and revert to open space compatible with plover habitat and spontaneous plover recolonization/recovery (Peter Baye, pers. comm., 2014).

Pollution and poisons

Threats to snowy plovers from pollution and poisons include oil from offshore spills that can coat foraging and nesting habitat (Vulnerability Assessment Workshop, pers. comm., 2014; SIMoN 2014), decreasing food availability and causing harmful physiological effects (SIMoN 2014), debris that can cause entanglement (which has been observed in abandoned monofilament fishing line, SIMoN 2014) and attraction of predators (Campbell 2013). Plovers may also be exposed to toxins such as heavy metals, and one study implicated the elevated concentration of mercury in the failure of eggs to hatch at Point Reyes National Seashore (Schwarzbach et al. 2005).

Invasive Species

Predation by introduced species has contributed to recent declines in snowy plover abundance, including the non-native Eastern red fox (California State Parks, 2014). Plovers prefer open, flat sand with sparse vegetation for nesting, and the invasive European beachgrass has decreased the availability of this habitat and changed the topography of the dunes, as well as created an impenetrable vegetative barrier for chicks between foraging and nesting areas (BLM 2014). Invertebrate densities are also lower in habitat dominated by European beachgrass as compared to native vegetation, limiting the foraging opportunities for plovers (BLM 2014). Management efforts by Point Reyes National Seashore show an increase in the number of plover chicks reared in areas immediately following removal of beachgrass (Campbell 2013).

V. Other sensitivities: none identified

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): 2

- Confidence of workshop participants: High

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

- Confidence of workshop participants: Moderate

Dispersal ability of the species: High

- Confidence of workshop participants: High

Maximum annual dispersal distance: >100km

- Confidence of workshop participants: High

Supporting literature

The Pacific coast population of the Western snowy plover exhibits a broad transcontinental geographic extent, from southern Washington to southern Baja California, Mexico and a federally threatened population. Declines in abundance in recent decades are due to habitat loss, predation, and human disturbance (California State Parks 2014). There are an estimated 2,400 breeding adults in the Pacific coast population, which breed exclusively on coastal beaches (in contrast to the reproductively distinct inland population, SIMoN 2014).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: Low-Moderate

- Confidence of workshop participants: Moderate

Behavioral plasticity: Low-Moderate

- Confidence of workshop participants: Low

Phenotypic plasticity: Low-Moderate

- Confidence of workshop participants: Low

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

- Confidence of workshop participants: Low

Additional participant comments

The species is able to produce a second clutch in any given year if the first reproductive attempt fails and can adapt the timing of reproduction somewhat based on environmental conditions. Limited behavioral adaptation has been exhibited in response to increased predation from ravens and cats, though there may be some degree of behavioral response to habitat loss through the use of other habitat types. There is likely very little genetic structure and diversity in the Pacific coast population due to high dispersal, and reduction of the population to just 2,000 individuals.

Supporting literature

The species reproduces in successive cycles throughout its lifespan, becoming reproductively mature at a little less than a year (310 days, Moller 2006). Breeding occurs from March to September and parents incubate the eggs for 4 weeks, followed by a 4-week fledgling period (California State Parks 2014).

III. Management potential

Value of species to people: Low-Moderate

- Confidence of workshop participants: Moderate
- Description of value: Birders value the species, but most recreational users (especially dog owners) do not due to recreational use conflicts.

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

- Confidence of workshop participants: High
- Description of potential management options: Most beaches have no place to migrate and the management actions of beach nourishment and sediment supply may help, but will likely conflict with recreational uses (and can also negatively impact snowy plover prey). Protecting refugia has high likelihood of success, but there are limited opportunities to do this.

Supporting literature

Despite intensive management measures at Point Reyes National Seashore, the snowy plover population there has not recovered to previous levels, declining from 50 individuals in 1987 to only 9 in 2012 (Campbell 2013).

IV. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[7]

Future climate and climate-driven changes identified (score[8], confidence[9]): increased coastal erosion and runoff (5, high), increased flooding (5, moderate), sea level rise (5, high), increased storminess (5, high), decreased sediment supply (3, moderate), decreased pH (2, low), changes in precipitation (2, low)

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

- Confidence of workshop participants: Moderate

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

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

[9] Confidence level indicated by workshop participants.

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Widow Rockfish (*Sebastes entomelas*)[1]

Executive Summary

Widow Rockfish	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	3 Moderate	3 High
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

Widow rockfish is a medium-sized, mid-water species important in both the recreational and commercial catches in California. The species occurs from Alaska to Baja California over high-relief substrata, most commonly at depths between 140 to 210 meters, though has been captured at depths from 24 to 549 meters. Key climate sensitivities identified by workshop participants for widow rockfish include dissolved oxygen, wave action, dynamic ocean conditions (currents/mixing/stratification) and pH. Key non-climate sensitivities include harvest and pollution/poisons. Widow rockfish exhibit a moderate to large geographic extent and a diminished, but generally stable, population that is nearly continuous. The center of distribution is British Columbia to Northern California. The range of larval dispersal is unknown, but some studies suggest that dispersal may be limited to less than 200 km. Widow rockfish exhibit overall moderate diversity due to moderate life history diversity and behavioral plasticity, including the ability to move out of areas experiencing unfavorable conditions, moderate-high genetic diversity, and moderate phenotypic plasticity, including the ability of females to spawn in response to favorable oceanographic conditions. The societal value for widow rockfish is moderate-high due to its harvest value, and because the population can be managed for harvest, the likelihood of managing or alleviating climate impacts was rated as moderate. If the fishery is managed to sustain healthy populations with increased genetic diversity, widow rockfish populations will be moderately able to withstand climate impacts.

Sensitivity

I. Sensitivities to climate and climate-driven factors

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

<u>Climate and climate-driven changes that may benefit the species</u>: no answer provided

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

- Confidence of workshop participants: Moderate

Additional participant comments

Upwelling has a significant impact on larval and juvenile rockfish and the availability of food, which may drive population trends for the species.

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[1] Refer to the introductory content of the results section on 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

Significant changes to dissolved oxygen (DO) can result from a number of physical and biological processes, including circulation, ventilation, air-sea exchange, production and respiration (Keeling and Garcia 2002, Deutsch et al. 2005, Bograd et al. 2008). A decline in midwater oceanic DO is predicted due to enhanced stratification and reduced ventilation (Sarmiento et al. 1998, Keeling and Garcia 2002). 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). DO levels under 2 mg/L have been observed to negatively impact rockfish prey sources (NMFS 2013), lead to mass mortality events (Palsson et al. 2008), and alter rockfish behavior and habitat use through movement to more tolerable conditions at shallower depths (Palsson et al. 2005). Though there is little information regarding habitat requirements of rockfish larvae, the larval stages of many other fish species are vulnerable to low DO (Boehlert and Morgan 1985, NMFS 2013).

Wave Action

Wave action is expected to most impact rockfish larvae (Vulnerability Assessment Workshop, pers. comm., 2014). Larval rockfish are subject to oceanographic conditions after birth, drifting in ocean currents in generally the upper 80 meters of the water column and may remain in the plankton for up to five months (Love et al. 2002).

Dynamic ocean conditions (currents/mixing/stratification)

In this broad category of climate impacts, upwelling and El Niño processes were identified by workshop participants as being the most influential on the sensitivity of widow rockfish. Cury and Roy (1989) found that a moderate degree of upwelling is ideal for the species; if upwelling is too weak, ocean productivity is too low to support an abundant year class, but if upwelling is too strong and persistent, larvae are transported offshore beyond favorable recruitment habitats for settling juveniles. Turbulence effectively separates fish larvae from food patches, decreasing larval survival. El Niño conditions, which suppress upwelling, have been shown to negatively impact female rockfish fecundity and growth rates, and repeated exposure to El Niño events may result in delay of maturation age, which can result in the reduction of lifetime egg production (Harvey 2005). The number of El Niño events likely will not change, though the likelihood of super El Niños doubled from one every 20 years in the previous century to one every 10 years in the 21st century (Cai et al. 2013). Additionally, enhanced stratification is expected to decrease dissolved oxygen levels in midwater habitats (Sarmiento et al. 1998, Keeling and Garcia 2002), with important repercussions for rockfish (see oxygen section above).

pH

The direct effects of decreased pH on fishes within the study region are not well understood (Largier et al. 2010), though one study outside of the region documented the impact of lower pH levels on larval clownfish olfactory cues, which caused disorientation (Munday et al. 2009). Altered behavioral responses, in the form of increased time spent seeking refuge, have recently been documented in juvenile rockfish when exposed to lower pH waters (7.75; projected for the next century in California) for one week, with recovery of normal behavior taking 12 days after a return to seawater at a normal pH level. The cause was traced to altered ion concentration in the blood, which impacts the fish's sensory system (Hamilton et al. 2013).

II. Sensitivities to disturbance regimes

Disturbance regimes identified: wind

Overall species sensitivity to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

Changes in seasonal wind patterns can result in changes to localized upwelling, which is a critical process for maintaining food supply for juvenile and adult fish.

Supporting literature

Climate change is expected to impact the intensity of upwelling by altering wind stress, and upwelling that is too weak or too intense can have negative impacts on larval rockfish (Cury and Roy 1989, see Dynamic Ocean Conditions section above).

III. Dependencies

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

- Confidence of workshop participants: High
- Sensitive habitats species is dependent upon: pelagic water column for larvae, nearshore kelp forest habitat for juveniles, and deep reef habitat for adults

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

- Confidence of workshop participants: High

Other critical dependencies: Cold water/upwelling to support an abundant boreal food supply for juveniles

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

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

- Confidence of workshop participants: Low-Moderate

Additional participant comments

El Niño events that push warmer waters northward can impact the food supply of juvenile fish. The species also does not recruit well during poor upwelling and El Niño events.

Supporting literature

Widow rockfish feed on krill and copepods during the larval and pelagic juvenile stage, and a variety of gelatinous zooplankton, small pelagic crustaceans (including krill), and small fishes as adults (Adams 1987, AFSC 2014).

IV. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): harvest (4, high) and pollution (oil and dispersants) (4, high)

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

- Confidence of workshop participants: High

Overall current exposure to non-climate stressors: Low

- Confidence of workshop participants: High

Additional participant comments

Local populations of widow rockfish that have been over-harvested will be more sensitive to climate impacts than healthy populations.

Supporting literature

Harvest

Widow rockfish are the third most frequently caught scorpaenid in California's commercial fishery, and are an important component of recreational landings (Starr et al. 2002), though recreational catch has been minimal in recent years (He et al. 2011). Total landings peaked in 1981 and have declined since, due to reduced population and increased regulations (Starr et al. 2002). The stock spawning biomass showed a steady decline between 1980 and 2001, at which point the stock began an increasing trend (He et al. 2011). Though the population was declared overfished in 2001, the latest stock assessment estimates the spawning biomass to be 51% of virgin spawning biomass and the population is now considered rebuilt (He et al. 2011)

Pollution

Oil and dispersants were identified by workshop participants as potential sources of pollution that may impact widow rockfish, particularly the larval and juvenile stages. 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 resources in the region (Largier et al. 2010). After the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, demersal rockfish species were the only fish species found dead in significant numbers, likely due to elevated hydrocarbon metabolites (Marty et al. 2003), indicating they may be particularly vulnerable to oil spills.

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): 4

- 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): 4

- Confidence of workshop participants: High

Dispersal ability of the species: High

- Confidence of workshop participants: High

Maximum annual dispersal distance: no answer provided

Supporting literature

Workshop participants rated widow rockfish as having high dispersal capability based on the fact that larvae can remain in the plankton for up to five months (Love et al. 2002). Mobile, long-lived species that have pelagic larvae typically are thought to have high dispersal, though few data exist for larval rockfish dispersal distance (Miller and Shanks 2004). However, recent studies on other rockfish species indicate dispersal distance may be less than previously thought for some species. Otolith microstructure and microchemistry were used to estimate larval dispersal for the black rockfish, which was found to be much more limited than models have projected, less than 120 km (Miller and Shanks 2004). Limited lifetime dispersal (between 100 and 200 km) was also indicated for the Northern Rockfish based on significant genetic structure and isolation-by-distance relationships among 11 microsatellite loci (Gharrett et al. 2011).

II. Intraspecific/Life history diversity

Diversity of life history strategies: Moderate

- Confidence of workshop participants: Moderate

Genetic diversity: Moderate-High

- Confidence of workshop participants: High

Behavioral plasticity: Low-Moderate

- Confidence of workshop participants: Low

Phenotypic plasticity: Moderate

- Confidence of workshop participants: High

Overall degree of diversity/plasticity of the species: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

An example of phenotypic plasticity is the ability of females to spawn in response to favorable oceanographic conditions, increasing the likelihood of larval survival.

Supporting literature

Behaviorally, the species may move to more favorable oceanographic conditions in response to a stressor (e.g. upwelled oxygen-poor water, Palsson et al. 2005). There is no evidence of separate genetic stocks of widow rockfish along its range, and the species is therefore treated from a management perspective as one stock (He et al. 2011).

Females generally spawn from December to April in this region and live to around 60 years, becoming more fecund with age (AFSC 2014). Released larvae drift in ocean currents and exhibit a very high mortality rate, up to 70% in laboratory conditions (Canino and Francis 1989).

III. Management potential

Value of species to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: Value for commercial and recreational fisheries.

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

- Confidence of workshop participants: High
- Description of potential management options: If harvest of the species is managed to sustain a genetically diverse population, it's likely the species would have increased capacity to succeed in a changing environment.

Additional participant comments

Though it will be difficult to manage the impacts of climate change on this species, human impacts, such as harvest levels, can be actively managed.

IV. Other adaptive capacity factors: none identified

Exposure[6]

I. Future climate exposure

Future climate and climate-driven changes identified (score[7], confidence[8]): altered currents and mixing (4, high), decreased pH (4, high), changes in sea surface temperature (3, high), increased storminess (3, moderate), decreased dissolved oxygen (DO) (2, moderate)

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

- Confidence of workshop participants: Moderate-High

Additional participant comments

Because the species range extends well north of the study region, the species may be able to seek refuge from warmer ocean temperatures in the northern stretches of its range. Sea surface temperature impacts stratification and ocean circulation patterns, influencing primary productivity and prey availability for rockfishes.

[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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Carbon Storage and Sequestration[1]

Executive Summary

Carbon Storage	Score	Confidence
Sensitivity	3 Moderate	2 Moderate
Exposure	5 High	3 High
Adaptive Capacity	2 Low-Moderate	3 High
Vulnerability	4 Moderate-High	3 High

California's coastal wetlands provide carbon storage and sequestration through the accumulation and long-term storage of organic and inorganic carbon material via various biological and physical processes. Coastal wetlands in the United States sequester an estimated 5 Tg C yr^{-1}, which accounts for approximately 1-2% of the carbon sink (Chmura et al. 2003). Coastal wetlands in the North-central California coastal region play an important role in mitigating the impacts of anthropogenic carbon emissions. Key climate sensitivities identified by workshop participants include sea level rise, extreme storm events, and sea surface temperature. Key non-climate sensitivities identified include pollution, land use change, recreation, and roads/armoring. Carbon storage can occur almost anywhere in the North-central California coastal region. Carbon storage and sequestration potential in the San Francisco Bay is likely high, and as such, any future policy decisions regarding this region may want to take this into consideration. Recently, attention has significantly increased on the establishment of national and global carbon markets. The establishment of such a market system could significantly increase the value of naturally occurring carbon storage and sequestration systems, and could incentivize the restoration, preservation, and maintenance of coastal wetland habitats.

Sensitivity

I. Sensitivity of ecosystem service components

Sensitivity of the provision of the ecosystem service to climate and climate-driven changes: Low-Moderate

- Confidence of workshop participants: Moderate

Climate and climate-driven changes identified: sea level rise, storminess, and sea surface temperature

Climate and climate-driven changes that may benefit the provision of the ecosystem service: decreased ocean pH

- Description of benefit: Lower ocean pH, or more acidic waters, may be beneficial to sea grass by increasing photosynthetic productivity, thus increasing carbon uptake and storage.

Additional participant comments

Upper marshlands will be more sensitive to drought conditions, while lower marshlands will be more sensitive to sea level rise.

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

Supporting literature

Sea level rise

The impacts of sea level rise on carbon storage and sequestration in marine ecosystems will depend upon several factors including: vertical accretion rates (influenced by the deposition of inorganic sediments or the accumulation and burial of organic material), compaction and subsidence rates, and the ability of wetlands to expand and/or migrate. Rising sea levels may initially increase estuarine surface area and result in increased plant biomass production and sediment deposition, enhancing carbon storage in regional tidal marshes (DeLaune and White 2012, South Bay Salt Pond Restoration Project 2015). However, rates of sea level rise that exceed the vertical accretion rate of sediment and organic material will eventually drown low-lying estuarine areas (Kirwan and Temmerman 2009, Mudd et al. 2009), reducing carbon storage by eliminating wetland habitat and by enhancing erosion of wetland soils that currently store significant carbon (DeLaune and White 2012). Coastal wetlands that are more dependent on organic accumulation rather than inorganic sediment deposition will likely be more impacted by rising sea levels (Stevenson et al. 1986, Stevenson and Kearney 2009). Salt marshes located in estuaries with low tidal ranges are expected to be more sensitive to rising sea levels due to decreased rates of sediment transport and vertical accretion (Simas et al. 2001). The impacts of rising sea levels may be negligible on coastal wetlands that are able to vertically accrete at rates that equal or exceed rates of sea level rise.

Storminess

Climate change is expected to result in more frequent, extreme storm events with larger storm surges, higher winds, and increased short duration/high precipitation events, all of which will affect rates of sediment deposition and erosion (Simas et al. 2001) and overall wetland extent, influencing carbon storage potential (DeLaune and White 2012). Storm intensity and direction, wind and wave conditions, and local geomorphological conditions all influence the extent of storm impacts on coastal wetlands (Simas et al. 2001). For example, winter wave heights, driven by extra-tropical cyclones in the North Pacific, can be in excess of 8 m (Wingfield and Storlazzi 2007), and large storm surges can kill wetland vegetation, increasing the likelihood of future erosion and associated carbon losses or transport of carbon-rich sediment to nearshore or shelf habitats (DeLaune and White 2012). Changes in wave height and direction can also expose previously sheltered areas to significant levels of erosion (Sallenger et al. 2002) and/or affect regional sediment transport and deposition processes (Scavia et al. 2002), which may have significant negative impacts to sensitive coastal wetland habitats and affect their ability to trap sediment and sequester carbon.

Sea surface temperature

Changes in sea surface temperatures are greater in estuaries relative to changes along the outer coast, and an overall increase in water temperature may lead to increased growth and distribution of coastal wetlands (Scavia et al. 2002), enhancing the capacity for estuarine habitat to sequester carbon. However, soil carbon density declines with increased temperature, likely due to enhanced decay rates (Chmura et al. 2003). Increasing sea surface temperatures may also result in the range expansion of both native and non-native species into new areas (Williams and Grosholz 2008), which can impact long-term carbon storage and sequestration (see invasive species section below), and may impact the incidence of disease, estuarine circulation, dissolved oxygen (DO) levels, and key physiological processes in temperature-sensitive primary-producing estuarine species, potentially impacting the capacity for marsh and estuarine habitat to sequester carbon.

II. Sensitivity to disturbance regimes

Disturbance regimes identified: flooding, wind, storms, and disease[2]

Overall sensitivity of the provision of the ecosystem service to disturbance regimes: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

Flooding and storm disturbance regimes will impact both salt marshes and seagrasses, but wind and disease disturbance regimes may only impact seagrasses.

Supporting literature

Wind

Winds influence estuarine circulation, salinity structure, and flushing rates (residence times) (Geyer 1997). Estuarine circulation is inhibited by onshore winds, which may also increase salinity gradients and reduce flushing rates, while offshore winds may enhance flushing and outflow, and reduces alongshore salinity gradients (Geyer 1997). A well-flushed estuary is more robust, healthy, and resilient than a poorly flushed estuary, due to the inhibition of sedimentation and depleted dissolved oxygen (Wolanksi 2007), enhancing carbon sequestration capacity.

Flooding

Coastal wetlands are sensitive to changes in flooding patterns and sediment loading (Ramsar 2002), which can impact vertical accretion rates. Although coastal wetlands are tolerant of periodic flooding, a flooding threshold likely exists, and longer flood durations and/or more frequent flooding can increase erosion and decrease organic plant contributions, accelerating wetland habitat deterioration (Kirwan and Megonigal 2013) and reducing current and future carbon storage (DeLaune and White 2012).

III. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified: land use changes, overwater/underwater structures, coastal roads and armoring, invasive species, pollution and poisons, recreation, aquaculture, and dredging[2]

Degree to which non-climate stressors affect the provision of the ecosystem service: Moderate-High

- Confidence of workshop participants: High

Degree to which non-climate stressors affect the sensitivity of the provision of the ecosystem service to climate change: Moderate

- Confidence of workshop participants: Moderate

Additional participant comments

Excessive nutrient pollution may negatively impact seagrass through increases in epiphytic algae. Aquaculture can displace seagrass beds. Overwater/underwater structures increase

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[2] Though peer-reviewed literature may exist, staff review was unable to locate supporting literature for this stressor.

shading, which can negatively impact seagrass beds, and land use changes can negatively impact salt marshes.

Supporting literature

Land use changes

Reclamation, engineering, and urbanization have resulted in the loss of extensive areas of seagrass and salt marsh (Mcleod et al. 2011). Increased sedimentation from land use changes may result in the burying of vegetative habitat or increase the duration of estuary mouth closure. Freshwater diversions for agriculture and other human uses can result in hypersaline conditions, reduced estuarine circulation, or more persistent closures of estuary mouths due to reduced tidal prism (ONMS 2010), all of which can negatively impact vegetative habitats and long-term carbon storage and sequestration.

Overwater/underwater structures

Overwater and underwater structures alter light regimes, wave energy, sediment and transport processes, substrate, and water quality, which can limit plant growth and recruitment (Nightingale and Simenstad 2001), decreasing carbon storage potential.

Coastal roads and armoring

Coastal armoring and road construction can prevent the inland migration or expansion of coastal wetland habitats in response to sea level rise. Where the inland border of coastal wetland habitats abuts roads, levees, or other armored structures, an accelerated loss of habitat may be expected (Dugan et al. 2008). Road construction and coastal armoring continues to be a problem in the study region, specifically in Bolinas Lagoon, Tomales Bay, and other areas of coastal development. Although the impacts of these structures are generally localized, they can be severe as they can result in the conversion and loss of habitats that sequester carbon (ONMS 2010).

Invasive species

Invasive and non-native species can cause changes in community species composition in coastal wetlands, which can result in changes to above-ground and below-ground carbon pools (Ehrenfeld 2003) and long-term carbon storage and sequestration. The net effect of invasive and non-native species on long-term carbon storage and sequestration will depend on numerous factors such as soil type, carbon mineralization rates, differences in root-to-shoot ratios, plant biomass, and productivity between native and invasive or non-native species (Ehrenfeld 2003).

Pollution and poisons

Coastal eutrophication, resulting from excess nutrient runoff from terrestrial sources, leads to increased epiphytic algae and macroalgae, which reduces available light for primary production. This can result in extensive loss of coastal vegetation, such as seagrass beds and saltmarshes (Duarte 2002, Mcleod et al. 2011) that store and sequester carbon.

IV. Other sensitivities: none identified

Adaptive Capacity

I. Intrinsic value

Value of the ecosystem service to people: Low-Moderate

- Confidence of workshop participants: Low

Degree to which people are willing to change their behavior to ensure provision of the ecosystem service: Low

- Confidence of workshop participants: High

Economic drivers that play a role in the management of the ecosystem service: Regulated carbon markets for carbon credits may drive efforts to more actively manage this ecosystem service.

Can the ecosystem service be accessed elsewhere, and how important is it to ensure provision of the ecosystem service in its current location(s): Carbon storage and sequestration can occur in a variety of terrestrial and marine locations.

Additional participant comments

The deep sea has a very large capacity to store and sequester carbon. Currently there is only a limited awareness of the issue on a local level. The carbon storage and sequestration capacity in the region of interest is high if marshes in the San Francisco Bay are included.

Supporting literature

Tidal marshes, seagrasses, and mangroves are identified by the Blue Carbon Initiative as the three coastal habitats that best accumulate, store, and sequester carbon (termed "blue carbon"; Howard et al. 2014). Restoration and conservation of these habitats could receive significant funding if blue carbon were included in market-based climate policy mechanisms, including regulated cap-and-trade; however, significant information needs exist, including scientific and economic analysis, and policy design and advocacy (Ullman et al. 2012).

Past and ongoing management activities that have reduced impacts to the region's estuaries and enhanced the health and resilience of carbon-sequestering coastal habitats include implementation of best management practices to reduce runoff, the closure and restoration of a mercury mine, the development of a vessel management plan to address illegal moorings in eelgrass, and the removal of abandoned vessels from Tomales Bay (ONMS 2010). Information on current management and restoration activities can be found for Bolinas Lagoon (http://farallones.noaa.gov/eco/bolinas/bolinas.html) and Tomales Bay (http://farallones.noaa.gov/eco/tomales/tomales.html).

II. Management potential

Rigidity / specificity of rules governing the provision of the ecosystem service or the areas that provide the ecosystem service: Moderate-High

- Confidence of workshop participants: Moderate

Conflicts with other services in the region: none

Services that mutually benefit from the provision of the ecosystem service: food production (aquaculture)

Likelihood of managing or alleviating climate change impacts on the provision of the ecosystem service: The likelihood will depend on public support and the political will to fund restoration and management efforts.

III. Other adaptive capacity factors: none identified

Additional participant comments

A good knowledge base currently exists for how to effectively restore mashes and seagrass beds.

Exposure

I. Future climate exposure[3]

Degree to which the provision of the ecosystem service is likely to be affected by climate change: High

- Confidence of workshop participants: High

Future climate and climate-driven changes identified: sea level rise, storminess, sea surface temperature, ocean pH, coastal erosion, and precipitation

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

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Flood and Erosion Protection[1]

Executive Summary

Carbon Storage	Score	Confidence
Sensitivity	5 High	3 High
Exposure	5 High	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	4 Moderate-High	3 High

Estuarine, beach, and dune coastal ecosystems provide natural protection against flooding and erosion from storms and storm surges to low-lying coastal areas. Key climate sensitivities identified by workshop participants include changes in precipitation, storm events, and sea level rise. Key non-climate sensitivities include land use change, overwater/underwater structures, roads/armoring, and sand mining. Coastal flood and erosion protection is primarily provided by two habitats, estuaries (salt marshes) and beaches and dunes. Given room to migrate and undisturbed supplies of naturally occurring sediment, these habitats are generally resilient and can respond to changing climatic conditions, although shifts may also occur in response to naturally occurring climatic variations. Attempts to manage and mitigate the erosion of cliffs and beach areas through the use of armoring and other measures disrupts the natural supply and transport of sediments critical for maintaining these habitats.

Sensitivity

I. Sensitivity of ecosystem service components

Sensitivity of the provision of the ecosystem service to climate and climate-driven changes: High

- Confidence of workshop participants: High

Climate and climate-driven changes identified: precipitation, storminess, coastal erosion and flooding, and sea level rise

Climate and climate-driven changes that may benefit the provision of the ecosystem service: none identified

Additional participant comments

Sea level rise is drowning wetlands that have no room to move, and increased storm intensity is increasing erosion.

Supporting literature

Precipitation

Changing patterns in precipitation will impact sediment deposition, river flows, erosion, and flooding. The seasonality of estuarine hydrology, including rainfall and water inflow from rivers into estuaries, influences the transport and deposition of sediments. Climate change may result in more frequent short duration/high precipitation events that may lead to increased frequency and severity of flooding events in estuaries.

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

Storminess / coastal erosion / flooding

Climate change is expected to result in more frequent extreme storm events with larger storm surges, higher winds, and increased short duration/high precipitation events, all of which will affect rates of sediment deposition and erosion (Simas et al. 2001). Waves are the main driver of beach and dune erosion, but storm-driven winds can also impact beach and dune habitats by moving unconsolidated sediments (Scavia et al. 2002). Winter wave heights, driven by extra-tropical cyclones in the North Pacific, can be in excess of 8 m (Wingfield and Storlazzi 2007). Waves can erode shorelines, alter sediment transport and deposition processes (Scavia et al. 2002), and may result in the inundation of beach and dune areas, forcing the landward retreat of these habitats and increasing the risk of coastal flooding (Storlazzi and Griggs 2000, Feagin et al. 2005, Wingfield and Storlazzi 2007). Changes in wave height and direction, in response to both climate change and natural variability, will expose previously sheltered beaches to significant levels of erosion (Sallenger et al. 2002), which may increase the potential for localized flooding and erosion.

Sea level rise

Sea level rise will allow waves and storm surges to penetrate further inland, making coastal areas more susceptible to flooding and erosion (Knowles and Cayan 2002, Faegin et al. 2005). Rising sea levels will result in increased tidal inundation and, when combined with higher storm surges, larger more energetic waves, and increased short duration/high precipitation events, will increase the vulnerability of low-lying coastal areas to flooding and erosion (Feenstra et al. 1998, Dolan and Walker 2004).

Sea level rise can inundate beach and dune habitats, increasing rates of shoreline erosion and forcing the upland retreat of these habitats (Faegin et al. 2005). Beach and dune habitats could incur a reduction in areal extent and/or an increase in fragmentation, shifting from continuous habitat to narrower, steeper, and isolated pocket beaches where man-made or natural barriers block upland retreat (Largier et al. 2010). Sea level rise can also disrupt successional dynamics and degrade habitat quality by preventing the formation of mature coastal dune vegetation communities (Faegin et al. 2005).

The impacts of sea level rise on coastal wetlands will depend upon several factors including vertical accretion rates, compaction rates, and the ability of wetlands to migrate. Coastal wetlands that vertically accrete at rates less than projected rates of sea level rise will eventually drown, resulting in the loss of vegetative habitat and a consequent reduction of flood and erosion protection (Largier et al. 2010, Ackerly et al. 2012). Coastal wetlands that are more dependent on organic accumulation rather than inorganic sediment deposition will likely be more impacted by rising sea levels (Stevenson et al. 1986, Stevenson and Kearney 2009).

II. Sensitivity to disturbance regimes

Disturbance regimes identified: wind, flooding, and storms

Overall sensitivity of the provision of the ecosystem service to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

In general, habitats that provide flood and erosion protection are resilient and adequately provide this ecosystem service under normal storm conditions. However, these habitats may be unable to provide adequate flood and erosion protection due to projected future changes in the frequency and intensity of extreme storm events.

Supporting literature

Wind

Winds influence the formation and erosion of dunes and impact estuarine circulation, salinity structure, and flushing rates (residence times) (Geyer 1997). Estuarine circulation is inhibited by onshore winds, which may also increase salinity gradients and reduce flushing rates, while offshore winds may enhance flushing and outflow as well as alongshore salinity gradients (Geyer 1997). Dunes, formed by the accumulation of sediments transported and deposited by winds, are sensitive to changes in prevailing wind patterns. Excessive winds can erode and destroy dunes, especially those composed of unconsolidated sediments (USGS 2014).

Flooding

Coastal wetlands are sensitive to changes in flooding patterns and sediment loading (Ramsar 2002), which can impact vertical accretion rates. Although coastal wetlands are tolerant of periodic flooding, a flooding threshold likely exists, and longer flood durations and/or more frequent flooding can increase erosion and decrease organic plant contributions, accelerating wetland habitat deterioration and reducing future flood protection (Kirwan and Megonigal 2013).

Storms

Storms constantly reshape coastal wetlands and beach and dune habitats through erosive and depositional processes. Energetic winter storms tend to be more erosive. If beach erosion is severe enough, or waves are large enough, waves can wash over and erode dune areas (CERC 1984). However, dunes may also be replenished by strong onshore winds, often associated with winter storms, through the transport and deposition of sand from beach areas onto dune areas. The overall impact of storms on beach and dune erosion will depend on specific geomorphological conditions, the intensity and direction of storms, as well as tides, currents, and other physical factors (Moran 2011).

III. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified: land use changes, overwater/underwater structures, coastal roads and armoring, and sand mining

Degree to which non-climate stressors affect the provision of the ecosystem service: High
Confidence of workshop participants: High

Degree to which non-climate stressors affect the sensitivity of the provision of the ecosystem service to climate change: High

- Confidence of workshop participants: High

Additional participant comments

Land use changes have already destroyed much of this ecosystem service. Sand mining removes the sediment in the littoral cell.

Supporting literature

Land use change

Land use change from dams, agriculture, coastal development and coastal infrastructure has significantly reduced the extent of coastal wetland and beach and dune habitats. For example, human development in the Central Bay from 1855-1979 destroyed significant tidal marsh and intertidal mudflat habitat, resulting in a 4% overall areal loss of these critical habitats in San Francisco Bay (Barnard et al. 2013). In addition, estuarine and coastal sediment regimes follow predictable patterns in relation to land use change, exhibiting a period of increased sedimentation associated with construction or activity, followed by reduced sediment supply as site and watershed management activities (e.g., dams, restoration projects) reduce streamflow variability and erosion potential (Barnard et al. 2013). Increased sedimentation from land use changes may result in the burying of oyster and eelgrass habitat (ONMS 2010), undermining their ability to trap and stabilize sediment and dampen incoming wave force (Borsje et al. 2011). Alternatively, reduced sediment supply as a result of intensified upstream watershed management and/or sediment reduction projects can enhance the vulnerability of sediment-dependent habitats (e.g., coastal wetlands) to sea level rise (Knowles et al. 2010). Freshwater diversions for agriculture and other human uses can result in hypersaline conditions, slow circulation, and the persistent closing of estuary mouths due to reduced tidal prism (ONMS 2010), affecting wetland plant composition, habitat productivity, and ecosystem service provision (Watson and Byrne 2009).

Overwater/underwater structures

Overwater and underwater structures can alter the supply and transport of sediment and impair the resiliency of estuary and beach/dune habitats. Dams, debris basins, and erosion reduction projects (e.g., installing riparian rip-rap) in upland watersheds can trap sediments and alter peak flows, which reduces sediment transport to estuary and beach/dune systems and can increase littoral cell sediment deficits and the potential for erosion (Willis and Griggs 2003, Slagel and Griggs 2008, Largier et al. 2010, Hestir et al. 2013), undermining the ability of these habitats to keep pace with sea level rise (Knowles 2010). For example, multiple dam projects on the Russian River reduced annual coarse-grained sediment supplies by more than 30% (Slagel and Griggs 2008).

Coastal roads and armoring

Coastal armoring and road construction prevent the inland migration of estuaries and beach/dune habitats in response to sea level rise, increase passive erosion, and increase the sensitivity of estuaries and beach/dune habitats to climate and climate-driven factors. Where the inland border of these habitats abuts roads, levees, or other armored structures, an accelerated loss of habitat may be expected (Fletcher et al. 1997, Dugan et al. 2008). Passive erosion related to armoring or road structures can shift habitat zones down the beach profile by “drowning” upper beach areas, disproportionally degrading upper and mid-beach habitat (Dugan et al. 2008). These effects will become more pronounced with sea level rise as these structures interact with waves and tides. In addition, armoring can displace beach habitat, thus reducing beach extent (Dugan et al. 2008). Road construction and coastal armoring continues to be a problem in the study region, specifically in Bolinas Lagoon, Tomales Bay, and other areas of coastal development. Although the impacts of these structures are generally localized, they can be severe as they can result in the conversion and loss of habitats and increase erosion rates (ONMS 2010). Coastal armoring is projected to increase in the future, but beach nourishment is now being used more frequently as an alternative (Defeo et al. 2009).

Sand mining

In general, open coastal and marine ecosystem sediment dynamics in north-central California are linked with anthropogenic activity within regional sediment-sheds, including sand mining, dredging, and aggregate mining (Barnard et al. 2013 and citations therein, Hein et al. 2013 and citations therein). Over the last century, the permanent removal of >200 million cubic meters of sediment from the San Francisco Bay is thought to have contributed to significant erosion of coastal beaches and the ebb tidal delta (Hein et al. 2013 and citations therein), undermining flood protection. Sand mining and aggregate mining are on-going activities, particularly in the Central Bay and Suisun Bay (Hanson et al. 2004, Barnard et al. 2013 and citations therein), and in combination with navigation-channel dredging, continue to affect sediment supply to estuarine and beach habitats within the study region (Barnard et al. 2013 and citations therein).

In addition, studies of historical dune erosion rates, both during and after coastal sand mining operations along the southern Monterey shoreline, indicate that sand mining operations may lead to increased erosion of dunes (Thornton et al. 2006). Griggs and Savoy (1985) suggest that sand mining depletes shore-connected shoals, which protect the shoreline by dissipating the energy of winter waves, thus allowing more energetic winter waves to reach further onshore and increase dune erosion. However, dune erosion rates before and after sand mining operations were not statistically significant along the entire coastline, indicating that sand mining may not be the causal factor behind increased dune erosion (Thornton et al. 2006).

IV. Other sensitivities

Other critical factors likely to influence the sensitivity of the provision of the ecosystem service: earthquakes and tsunamis[2]

- Confidence of workshop participants: High (if they occur)
- Confidence of workshop participants in the degree to which these factors influence the sensitivity of the ecosystem service provision: High (if they occur)

Adaptive Capacity

I. Intrinsic value

Value of the ecosystem service to people: High

- Confidence of workshop participants: High

Degree to which people are willing to change their behavior to ensure provision of the ecosystem service: Low-Moderate

- Confidence of workshop participants: High

Economic drivers that play a role in the management of the ecosystem service: property values, infrastructure values, recreational value of beaches and wetlands, nursery value of wetland habitat, cultural value, and aesthetic value

Can the ecosystem service be accessed elsewhere, and how important is it to ensure provision of the ecosystem service in its current location(s): Because this ecosystem service cannot be

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[2] Though peer-reviewed literature may exist, staff review was unable to locate supporting literature for this stressor.

accessed elsewhere for human benefit, it is very important that this ecosystem service continues to be provided in its current location.

Additional participant comments

The habitats that contribute to the provision of flood and erosion protection also contribute to the provision of many other services that are valued by humans, such as recreational opportunities, nursery habitat for animals valued by humans, and cultural and aesthetic values. As such, the value of flood and erosion protection depends on the values of the many other services that are also provided by the habitats that provide flood and erosion protection.

II. Management potential

Rigidity / specificity of rules governing the provision of the ecosystem service or the areas that provide the ecosystem service: Moderate

- Confidence of workshop participants: Moderate

Conflicts with other services in the region: There are no perceived conflicts with other ecosystem services.

Services that mutually benefit from the provision of the ecosystem service: recreation, water quality, habitat for beach and marsh flora and fauna

Likelihood of managing or alleviating climate change impacts on the provision of the ecosystem service: The likelihood of managing or alleviating climate change impacts will depend on the degree of public awareness about current and future climate change impacts on the provision of the flood and erosion protection ecosystem service. Restoration of beaches, dunes, and coastal wetlands may mitigate the impacts of climate change on the provision of this service.

Additional participant comments

There are guidelines but no rules about the management of this service. A common response to coastal erosion and flooding is to utilize built infrastructure rather than maintaining natural infrastructure. An unintended consequence of using built infrastructure may be the degradation of the natural provision of flood and erosion protection.

Supporting literature

Coastal habitat restoration and ecosystem engineering, commonly referred to as “living shorelines”, may bolster flood and erosion protection services in the face of climate change (Borsje et al. 2011, Coastal Conservancy 2012). Protecting, enhancing, and restoring habitats (e.g., wetlands, oyster beds) and species (e.g., dune and beach vegetation) that provide these services reduces the demand for and stress on hard engineering solutions (e.g., seawalls), minimizing long-term costs and mitigating the inadvertent interactions of these structures with climate change stressors (e.g., inhibited wetland migration) (Borsje et al. 2011). Living shoreline initiatives are supported by both the California Climate Change Adaptation Strategy and the State Coastal Conservancy Climate Change Policy (Coastal Conservancy 2012). In addition, San Francisco Bay has an on-going living shorelines project which aims to evaluate different sub-tidal restoration techniques and their ability to maintain flood and erosion protection services and other habitat functions (San Francisco Bay Living Shorelines Project 2015).

III. Other adaptive capacity factors

Other critical factors that may affect the provision of the ecosystem service: room to migrate

Degree to which these factors affect the provision of the ecosystem service: High

- Confidence of workshop participants: High

Additional participant comments

There is a currently a lot of built infrastructure along the coast. The locations where people are interested in the provision of the flood and erosion protection service are also the areas where there is limited room for habitats to migrate inland in response to climate change.

Exposure

I. Future climate exposure[3]

Degree of to which the provision of the ecosystem service is likely to be affected by climate change: High

- Confidence of workshop participants: High

Future climate and climate-driven changes identified: sea surface temperature, air temperature, ocean pH, salinity, sea level rise, storminess, coastal erosion, and flooding

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

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Food Production[1]

Executive Summary

Food Production	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	4 Moderate-High	3 High
Adaptive Capacity	4 Moderate-High	2 Moderate
Vulnerability	3 Moderate	3 High

The marine and coastal areas of north-central California provide a variety of food products, including fish, crustaceans, mollusks, echinoderms, and some harvestable algae[2]. The impacts of climate and climate-driven changes on food production will likely vary widely between different seafood species and stocks, with impacts being both direct (e.g., altered physiology in response to warming water temperatures) and indirect (e.g., altered fishery productivity as prey availability shifts in response to climate changes such as pH and upwelling). Key climate sensitivities identified by workshop participants include sea surface temperature, pH, dynamic ocean conditions (currents/mixing/stratification), and salinity. Key non-climate stressors identified by workshop participants include recreation (fishing), aquaculture, harvest, and pollutions and poisons. Workshop participants evaluated food production to be of high societal value, but did not evaluate the likelihood of managing or alleviating climate impacts for this service. Supporting literature suggests that fisheries contribute significantly to local and state economies, but sustainable seafood initiatives have met with mixed success, and that marine protected areas can be used to meet multiple goals (e.g., harvest and stock protection), and shifts in fishing regulations could be used to better maintain seafood stocks in the future.

Sensitivity

I. Sensitivity of ecosystem service components

Sensitivity of the provision of the ecosystem service to climate and climate-driven changes: Moderate

- Confidence of workshop participants: Moderate

Climate and climate-driven changes identified: sea surface temperature, ocean pH, dynamic ocean conditions (currents/mixing/stratification), salinity

Climate and climate-driven changes that may benefit the provision of the ecosystem service: none provided

- Description of benefits: The benefits of climate and climate-driven factors on food production will depend on individual species responses.

Additional participant comments

Some species will be more impacted than others, as individual species will have different responses to climate and climate-driven changes.

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

[2] This assessment provides only a general synthesis of vulnerability information across all food species. For more detailed information on specific resources (e.g., anchovy, red abalone, blue rockfish), please see the specific species vulnerability assessments elsewhere in this report.

Supporting literature

North-central California marine and coastal zones produce a variety of food products available for commercial and recreational harvest. Commercially fished stocks include anchovy, sardine, sea urchin, Dungeness crab, shrimp, squid, halibut, mackerel, tuna, white seabass, sole, salmon, sablefish, and more (CDFW 2015a). Recreational fisheries include halibut, sturgeon, salmon, surfperch, rockfish, lingcod, greenlings, mussels, red abalone, and Dungeness crab, among others (CDFW 2015b). Harvestable algae, including giant and bull kelp, edible seaweed (common genera: *Porphyra*, *Laminaria*, and *Monostrema*) and agar-bearing marine algae are utilized for both commercial and non-commercial purposes (CDFW 2015c). There will likely be high variability in the response of marine food species and populations to climate and climate-driven changes (Sydeman and Thompson 2013); generalized impacts across species are summarized below, while more detailed information on particular resources can be found in the individual species summaries elsewhere in this report.

Sea surface temperature

Warming sea surface temperatures can have direct effects on marine food species by affecting physiology, including metabolism and respiration (Botsford and Lawrence 2002, Sydeman and Thompson 2013). For example, warmer water can increase fish oxygen demand (Portner and Knust 2007), reduce energetic metabolic protein performance (Fields et al. 1999), and negatively affect respiration and growth for a variety of fish species (e.g., blue rockfish) (Largier et al. 2010). Warming temperatures also indirectly affect marine food production by altering food webs and trophic interactions (Sydeman and Thompson 2013). For example, warmer sea surface temperatures increase water column stability and reduce nutrient delivery and primary productivity, which can have cascading trophic effects and influence fish reproduction and survival (Sydeman and Thompson 2013 and citations therein). Warmer water temperatures have been linked with negative impacts in Dungeness crab larvae (Botsford and Lawrence 2002) as well as reduced survival and recruitment in Chinook and coho salmon populations (Botsford and Lawrence 2002; Lindley et al. 2009), leading to recreational and commercial closures of these salmon fisheries in California (Sydeman and Thompson 2013). Warmer water temperatures can also facilitate range shifts, altering predator/prey dynamics and leading to compositional changes in fish communities (Sydeman and Thompson 2013). Shifts in the Pacific Decadal Oscillation (PDO) and the El Niño Southern Oscillation (ENSO) can drastically alter water temperatures (McPhaden 1999), influencing primary productivity and subsequently, seafood production (King 2005, Overland et al. 2010, King et al. 2011, Sydeman and Thompson 2013).

pH

Increased oceanic uptake of carbon dioxide (CO_2) contributes to declines in ocean pH (Sydeman and Thompson 2013). Feely et al. (2008) show that pH is very low in upwelled waters along the coast of western North America, including in this study region. Low pH (i.e., “ocean acidification”) water, which has lower rates of calcium carbonate ($CaCO_3$), can contribute to declines in calcification rates (Gazeau et al. 2007, Doney et al. 2009, Doney 2010, Gruber et al. 2012) and can be corrosive to a wide variety of organisms, including mollusks (Guinotte and Fabry 2008) harvested for food, such as the California mussel (*Mytilus californianus*) (Gaylord et al. 2011). Lower pH has also been correlated with higher mortality of the Dungeness crab (*Cancer magister*) (Miller 2012). Declining pH can also affect fishery productivity by altering the availability of calcareous plankton, a key prey species (Sydeman and Thompson 2013).

Dynamic ocean conditions (currents/mixing/stratification)

The California Current is a dynamic ecosystem that varies geographically, seasonally, and temporally, supporting diverse ecosystems and many seafood species (Sydeman and Thompson 2013 and citations therein). Fisheries productivity is tied to upwelling and subsequent water mixing (Huyer 1983, King et al. 2011, Thompson et al. 2012), with moderate levels of upwelling resulting in maximum fish productivity (Cury and Roy 1989, Hannah 2011). Upwelling is influenced by winds and current shifts related to shifts in ENSO or PDO regimes (Sydeman and Thompson 2013). For example, warmer currents associated with La Niña events can increase stratification, reducing nutrient delivery to the euphotic zone and affecting larger food webs (Sydeman and Thompson 2013). Increasing sea surface temperatures are also driving increased stratification (Sydeman and Thompson 2013); thermoclines have become stronger and deeper in offshore waters of the region (Palacios et al. 2004), impacting primary productivity (Roemmich and McGowan 1995) and trophic interactions.

Salinity

Salinity can affect marine food production by directly impacting multiple fished species. Studies on the effect of salinity extremes (both high and low) indicate that, when combined with temperature stress, salinity can negatively impact rocky intertidal invertebrates (e.g., the California mussel) through increased embryonic mortality (Przeslawski et al. 2005, Deschaseaux et al. 2010) and decreased adult aerobic performance (Vajed Samiei et al. 2011). Salinity extremes can also negatively impact Pacific herring spawning and hatching (Taylor 1971, Reilly and Moore 1983).

II. Sensitivity to disturbance regimes

Disturbance regimes identified: wind, disease, storms, and harmful algal blooms (HABs)

Overall sensitivity of the provision of the ecosystem service to disturbance regimes: Moderate-High

- Confidence of workshop participants: no answer provided

Additional participant comments

Changing wind patterns and storm frequency and intensity will particularly impact the fishing industry. The impacts of disease and HABs on food production will depend upon individual and cumulative species responses.

Supporting literature

Wind

Wind patterns affect upwelling, which influences the health and productivity of a variety of valued seafood species and stocks (Sydeman and Thompson 2013 and citations therein). Wind can also desiccate rocky intertidal species (e.g., California mussel) (Bell 1995).

Disease

Diseases (e.g., viruses, bacterial infections, worm infestations) can affect many important seafood species, including red abalone, shrimp, clams, crabs, and a variety of marine fishes, affecting survival, growth, recruitment and/or marketability (Jester et al. 2009, Lafferty et al. 2015). For example, worms of the genus *Carcinonemertes* can infest Dungeness crabs and cause significant mortality in brooding eggs, reducing crab recruitment (Wickham et al. 1980). Marine diseases may increase with warming water temperatures due to enhanced pathogen development, survival, and dispersal, as well as new or increased host susceptibility (Friedman et al. 1997, Harvell et al. 2002, Raimondi et al. 2002, Largier et al. 2010).

Storms

Winter storms have increased in intensity since 1950 (Bromirski et al. 2003). Harvest of available seafood can be limited by poor weather conditions and/or condense harvest activities to specific areas along the coastline (e.g., developed harbors, protected beaches) (Gleason et al. 2010).

Harmful algal blooms

Harmful algal blooms (HABs) can have a variety of impacts on seafood species, including mortality, increased susceptibility to disease, depressed reproduction, habitat loss, and food web disruptions, among others (Burkholder 1998, Robinson and Graham 2014). Increases in HABs may be an indirect effect of warming ocean temperature (Burkholder 1998, Van Dolah 2005) or periods of warm water temperature (e.g., El Niño events; Burkholder 1998). Currently there have been no indications to suggest that water quality in the region is compromised due to HABs (CBNMS Condition Report 2009), although with the possible rise in ocean temperature the emergence and spread of HABs may increase (Largier et al. 2010). However, many other factors (e.g., nutrient inputs) influence the frequency, severity, and net effect of blooms on fisheries toxicity, making projections difficult (Anderson et al. 2002).

III. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified: recreation (fishing), aquaculture, harvest, pollutions and poisons

Degree to which non-climate stressors affect the provision of the ecosystem service: Moderate-High

- Confidence of workshop participants: High

Degree to which non-climate stressors affect the sensitivity of the provision of the ecosystem service to climate change: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

The effects of harvest activities will have the largest impact on food production. Regulatory changes in the current harvest levels will influence the sensitivity of food production to climate and climate-driven changes.

Supporting literature

Recreation

Recreational fishing, even catch-and-release, can affect fish stocks and future food production. For example, high recreational fish catches during the 1980s were identified as the main driver of depleted near-shore California fisheries and lower catch rates in subsequent years (Schroeder and Love 2002). In addition, recreational anglers may unintentionally introduce invasive species, which can threaten biological communities already being impacted by climate change (e.g., fish stocks) (Monterey Bay National Marine Sanctuary (MBNMS) 2008).

Aquaculture
Many important finfish and shellfish species rely on eelgrass beds for nursery habitat (NOAA 2011), and aquaculture operations can displace, convert, or alter these and other important marine ecosystems (Diana 2009). Aquaculture can also facilitate disease transmission to wild stocks (Diana 2009); this is of particular concern with farmed abalone (Culver and Kuris 2000, Lafferty and Ben-Horin 2013). However, aquaculture is an expanding industry that contributes significantly to marine food production (Brander 2007).

Harvest
Harvest affects age and population structures, which can affect future recruitment and fecundity (Schroeder and Love 2002, Sydeman and Thompson 2013). Depleted populations and populations with altered age/size distributions are generally more vulnerable to climate and climate-driven changes (Brander 2007, Sydeman and Thompson 2013). Fisheries harvest can also impact disease rates in both target and nontarget species and stocks by affecting species density and/or altering ecological relationships (Lafferty et al. 2015 and citations therein). Commercial kelp harvesting can also be detrimental for seafood species, as it destroys important habitat for juvenile fish species (CDFW 2008).

Pollution and poisons
Water pollution can impact the health of key seafood species (GFNMS 2008, MBNMS 2008, Largier et al. 2010). For example, degraded estuarine water quality can negatively affect harvested fish species that use estuaries as nurseries (Pendleton 2010). Pollution may include agricultural (inland and coastal) and urban runoff, vessel-based pollutants, legacy mining pollutants, sewage, and large particulates (e.g., plastic) (GFNMS 2008). In general, agricultural pollution sources are more influential within the boundaries of the sanctuary (GFNMS 2008), while urban runoff and sewage pollutants become increasingly significant from San Francisco southward (GFNMS 2008, Heal the Bay 2014). Coastal waters and estuaries are typically more vulnerable to water pollution impacts than open ocean areas within the study region (GFNMS 2008). Higher coastal water pollutant levels are typically associated with rainfall and elevated runoff, which occur most frequently during cooler weather periods (November-March) (Heal the Bay 2014).

IV. Other sensitivities: none identified

Adaptive Capacity

I. Intrinsic value

Value of the ecosystem service to people: High

- Confidence of workshop participants: High

Degree to which people are willing to change their behavior to ensure provision of the ecosystem service: Low-Moderate

- Confidence of workshop participants: Moderate

Economic drivers that play a role in the management of the ecosystem service: The consumer cost of food is often the driving factor in the choice of seafood, which drives demand and harvest levels.

Can the ecosystem service be accessed elsewhere, and how important is it to ensure provision of the ecosystem service in its current location(s): Yes, seafood can be accessed in numerous locations outside the North-central California coast and ocean regions, but fishing and aquaculture activities are culturally and economically important to numerous local communities in the region.

Additional participant comments

Some efforts, such as Seafood Watch, are changing consumer choices and behaviors, but the majority of the population is not willing to switch to, or pay for, more sustainable choices of seafood.

Supporting literature

In 2011, California fisheries were valued at roughly $200 million, with a majority of fished species being used for human food consumption (Sydeman and Thompson 2013). Demand for seafood is increasing globally, and is expected to continue to increase due to population growth (Owens 2008, Merino et al. 2012). However, there are an abundance of global fish markets (Brander 2007), and loss of recreational and commercial fisheries in the region would have significant impacts on both state and local economies (Pendleton 2010).

In response to declining fish stocks and ineffective policy solutions, market based strategies (e.g., eco-labeling) have been used to promote sustainable fisheries management and consumption (Owens 2008). Although these labeling efforts have met with localized success, they are undermined by unclear and/or unofficial seafood naming and labeling, (Jacquet and Polly 2007, 2008), consistent fish supply from non-participatory Asian markets (Jacquet and Polly 2007, 2008, Owens 2008), limited restaurant and aquaculture engagement (Owens 2008), and consumer perceptions and preferences (Hallstein and Villas-Boas 2009), among others.

II. Management potential

Rigidity / specificity of rules governing the provision of the ecosystem service or the areas that provide the ecosystem service: High

- Confidence of workshop participants: High

Conflicts with other services in the region: Yes

- Conflicting services: non-consumptive uses and the maintenance of healthy habitats and ecosystems. There are also allocation conflicts between commercial and recreational fishing.

Services that mutually benefit from the provision of the ecosystem service: tourism/recreational fishing

Likelihood of managing or alleviating climate change impacts on the provision of the ecosystem service: no answer provided

Additional participant comments

Reductions in current harvest levels could help buffer fish populations against climate change impacts. Increases in sustainable aquaculture and habitat protections, such as those enacted under the Marine Life Protection Act (MLPA) could help ensure the provision of food production in the region.

Supporting literature

Interconnected marine reserves may help maintain healthy population age structures and recruitment (Berkeley et al. 2004). Balanced fishing strategies, particularly for those species whose fecundity increases with age, could also help buffer vulnerable stocks from the effects of climate change by reducing selectivity/removal impacts (Garcia et al. 2012). Recreational and commercial take regulations can be used to maintain long-term stock survival (CDFW 2015d), but can restrict food procurement intensity in the short-term. Cooperative, multi-jurisdictional management for wide-ranging species and/or species that are increasing in recreational value (e.g., Pacific halibut) will likely play an important role in maintaining viable populations for the future (CDFW 2015d). The California Department of Fish and Wildlife (2008) contends that protected marine areas can be tailored to allow both seafood population recovery and harvest. Aquaculture expansion will likely play a key role in meeting future seafood demand (Merino et al. 2012), particularly if sustainable methods are used more widely (Naylor et al. 2009).

Marine food harvest can negatively affect other ecosystem services, including nutrient cycling and biodiversity (Brander 2007), particularly if practiced unsustainably. However, saltwater fishing is a major contributor to recreation and tourism in the study region (Pendleton 2010).

III. Other adaptive capacity factors: none identified

Exposure

I. Future climate exposure[3]

Degree of to which the provision of the ecosystem service is likely to be affected by climate change: Moderate-High

- Confidence of workshop participants: Moderate

Future climate and climate-driven factors identified: changes in sea surface temperature, sea level rise, decreased pH, decreased dissolved oxygen (DO) levels, altered currents and mixing, changes in salinity, increased storminess

Supporting Literature

Sea surface temperature

Subtropical species (e.g., sardine) may increase with warmer ocean temperatures, while cold-water affiliate species (e.g., salmon, rockfish) may decline (Sydeman and Thompson 2013).

Currents/mixing/stratification

Enhanced upwelling may bolster cold-water affiliate stocks (e.g., salmon, rockfish) but negatively impact subtropical species (e.g., sardine) (Sydeman and Thompson 2013). Delayed upwelling could affect seafood production by disrupting or altering species phenology and juvenile survival (Logerwell et al. 2003, Snyder et al. 2003, Sydeman and Thompson 2013).

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

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Recreation and Tourism[1]

Executive Summary

Recreation & Tourism	Score	Confidence
Sensitivity	3 Moderate	3 High
Exposure	4 Moderate-High	3 High
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	3 Moderate	3 High

Coastal and marine areas in north-central California provide a variety of land- and water-based recreational and tourism opportunities, and these activities are both highly valued by the public and significant contributors to California's economy, although they at times conflict with other ecosystem services (e.g., water quality, food production). Climate change impacts (e.g., warming inland temperatures, sea level rise) can alter the demand, supply, and quality of tourism and recreation opportunities in coastal and marine areas. Impacts can be direct (e.g., reduced beach extent as a result of sea level rise) or indirect (e.g., reduced wildlife viewing opportunities as warmer water temperatures increase disease incidence). Key climate sensitivities identified by workshop participants include air and sea surface temperature, sea level rise, wave height, storm intensity, and prevailing wind patterns. Key non-climate sensitivities identified by participants include land use changes, harvest, aquaculture, pollution, and recreation impacts. Workshop participants indicated that recreation and tourism are of high societal value, but did not evaluate the likelihood of managing or alleviating climate impacts for this service. Supporting literature suggests that there may be significant opportunities for increased education and outreach surrounding recreation and tourism and coastal and marine resources. Other management options (e.g., beach nourishment) require advanced study to minimize negative impacts.

Sensitivity

I. Sensitivity of ecosystem service components

<u>Sensitivity of the provision of the ecosystem service to climate and climate-driven changes</u>: Low-Moderate

- Confidence of workshop participants: High

<u>Climate and climate-driven changes identified</u>: air temperature, sea surface temperature, sea level rise, wave heights, prevailing wind patterns, storm intensity

<u>Climate and climate-driven changes that may benefit the provision of the ecosystem service</u>: wave heights, sea surface temperature, wind patterns

- Description of benefits: Increased wave heights could provide more opportunities for surfers, which could also increase tourism. Increases in sea surface temperature could make coastal and bay waters more conducive for swimming activities. Additionally, changes in sea surface temperature could result in changes to prevailing wind patterns, creating better conditions for sailing.

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

Additional participant comments

Climate and climate-driven changes could result in increased opportunities for some recreational activities, but may also cause more hazardous conditions for others, and could result in decreased use for some beach and water areas.

Supporting literature

The marine and coastal areas of north-central California provide a variety of recreational and tourism opportunities, including but not limited to: beach access, hiking, surfing, swimming, sailing, kayaking, scuba diving, windsurfing, wildlife viewing, and fishing. However, a majority of current literature related to climate change and marine/coastal tourism and recreation focuses on ecosystem effects, while literature linking these effects to tourism and recreation sectors is less abundant, particularly when looking at activities outside of beach-based recreation (Moreno and Amelung 2009).

Air temperature

Climate and weather play a significant role in determining vacation destinations (Amelung et al. 2007, WTO and UNEP 2008, Moser et al. 2009), and increases in regional air temperature may have primary effects on tourism and recreation by altering demand, travel plans, and visitation rates (Hall and Higham 2005, WTO and UNEP 2008). For example, warmer inland and urban temperatures may drive increased recreational demand in cooler coastal locations (Caldwell and Segall 2007). Temperature increases can also have secondary effects on tourism and recreation by altering environmental quality (Hall and Higham 2005, WTO and UNEP 2008). For example, vegetation shifts in response to changing temperature and precipitation regimes could affect scenic quality (Shaw and Loomis 2008).

Sea level rise

Sea level rise can impact recreational and tourism opportunities (Caldwell and Segall 2007) by affecting beach and wetland extent (Morris and Walls 2009). For example, sea level rise can increase rates of shoreline erosion, inundate current beaches (Feagin et al. 2005), and/or lead to net beach loss in areas experiencing passive erosion as a result of armoring (Largier et al. 2010). Alternatively, sea level rise may drive shifts in beach location (Morris and Walls 2009), particularly if beach and dune habitats have room to migrate inland (Yohe et al. 1999 cited in Morris and Walls 2009). Sea level rise also has implications for marine wetlands, as wetland loss may occur where inward migration is prevented by development, leading to loss of valuable fishing, waterbird hunting, and wildlife viewing opportunities (e.g., migratory birds) (Morris and Walls 2009). Loss of beach and wetland habitats also increases the vulnerability of other tourism and recreational areas and infrastructure to flooding and erosion from sea level rise and storm surges (WTO and UNEP 2008; for more information, see the Flooding and Erosion Ecosystem Service summary).

Sea surface temperature

Shifts in sea surface and water column temperature affect fish stocks, including recreational fish stocks and species valued for diving and snorkeling (WTO and UNEP 2008, Sydeman and Thompson 2013). Warmer water temperatures may be detrimental to salmon and rockfish; for example, warming ocean temperatures linked with interannual (El Niño/La Niña), interdecadal (Pacific Decadal Oscillation), and quasi interdecadal (North Pacific Gyre Oscillation) variability have been documented to affect recreationally important fish species (e.g., salmon) in north-central California (Cole 2000, Sydeman et al. 2013). Warming water temperatures may also facilitate marine pathogen expansion (Harvell et al. 2002; see discussion of disease below).

Wave heights
Waves are seasonal drivers of beach and dune erosion and accretion (Storlazzi and Griggs 2000, Wingfield and Storlazzi 2007, Hapke et al. 2009, Barnard et al. 2013), affecting the extent of sandy shoreline area available for recreation and tourism. For example, Ocean Beach experiences severe erosion during winter storms with large wave heights (Barnard et al. 2011), but typically recovers sediments during lower wave-energy periods in summer and fall (Hansen and Barnard 2010). Wave height varies according to many factors, including season, coastline orientation, local bathymetry, and storm climatology (Hapke et al. 2009). For example, El Niño periods typically feature larger waves that can cause significant erosion (Hapke et al. 2009). Waves can also increase coastal flooding and inundation, forcing the retreat of sandy shorelines further inland (Storlazzi and Griggs 2000, Wingfield and Storlazzi 2007). Changes in wave height and direction, in response to both climate change and natural variability, will expose previously sheltered beaches to significant levels of erosion (Sallenger et al. 2002). According to surveys of coastal visitors in Southern California, beach width is an important factor in determining beach visitation; respondents indicated that decreasing beach widths as a result of erosion would cause a 29% decrease in visitation relative to current levels (King 2001).

Storm intensity
Climate change is expected to result in more frequent extreme storm events with larger storm surges, higher winds, and increased short duration/high precipitation events, all of which will affect rates of sediment deposition and erosion (Simas et al. 2001) in common recreational areas (e.g., beaches, wetlands). For example, increasing storm intensity can interact with sea level rise to create larger wave heights that increase erosion and/or accretion along regional beaches (Moser and Tribbia 2006, Cayan et al. 2008), affecting the extent of areas available for recreation. Storm conditions also limit safe recreational access, and condense marine and coastal recreation to specific areas along the coastline (e.g., developed harbors, protected beaches) (Gleason et al. 2010).

Prevailing wind patterns
Wind, along with temperature and precipitation, likely plays a role in user preferences for recreation areas (e.g., acts a positive influence for wind-based activities, but as a negative influence for beach activities) (Moreno and Amelung 2009). Wind also affects upwelling, which influences the productivity of recreational and commercial fisheries (Sydeman and Thompson 2013 and citations therein).

II. Sensitivity to changes in disturbance regimes

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

Overall sensitivity of the provision of the ecosystem service to disturbance regimes: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

Flooding and storms may reduce access to some recreational areas and may also adversely impact infrastructure that supports recreation and tourism. Outbreaks of shellfish disease may result in reduced visitation and usage of coastal areas where recreational harvesting of shellfish takes place.

Supporting literature

Disease

Marine diseases can both directly and indirectly affect recreation and tourism opportunities. Direct impacts include beach closures as a result of harmful algal blooms or high bacteria levels (Turbow et al. 2004, California Environmental Protection Agency 2015) and recreational fishery closures due to dinoflagellate blooms and high levels of paralytic shellfish toxins (Jester et al. 2009, Lewitus et al. 2012). These toxins have been consistently present along the Marin County coast since 1999, and historic cases of human paralytic shellfish poisoning are most common along the central and northern California coast (Lewitus et al. 2012). Marine diseases can also indirectly affect recreation and tourism opportunities by affecting the health of iconic wildlife species (e.g., sea lions, seabirds, intertidal organisms) (Jester et al. 2009, Lafferty et al. 2015), degrading wildlife viewing quality and/or reducing wildlife viewing opportunities. For example, sea otters are a charismatic species that regularly draw land- and water-based viewers; however, they are sensitive to a variety of diseases and pathogens accumulated through shellfish intermediaries (Jessup et al. 2004). Marine disease may increase with warming water temperatures due to enhanced pathogen development, survival, and dispersal, as well as new or increased host susceptibility (Harvell et al. 2002). For example, heat-stressed hosts (e.g., seastars) may be more susceptible to infection (Harvell et al. 2002, White et al. 2014).

Flooding

Increased flooding as a result of sea level rise can inundate recreational areas (e.g., beaches, wetlands) and damage infrastructure and facilities used in tourism and recreation (IPCC 2007, Moreno and Amalung 2009). Increased freshwater flooding as a result of more frequent and/or severe extreme precipitation events can also damage cultural and historical assets valued for tourism, and/or recreational and tourism infrastructure (WTO and UNEP 2008).

Storms

Please refer to the storm intensity discussion in the climate sensitivity section above.

Wind

Please refer to the wind discussion in the climate sensitivity section above.

III. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified: land use changes, aquaculture, harvest, pollution and poisons, recreation

Degree to which non-climate stressors affect the provision of the ecosystem service: Low-Moderate

- Confidence of workshop participants: Moderate

Degree to which non-climate stressors affect the sensitivity of the provision of the ecosystem service to climate change: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Excessive nutrient pollution could negatively impact sea grass through increases in epiphytic algae. Aquaculture can displace sea grasses. Overwater/underwater structures increase shading, which can impact sea grass beds, and land use changes can negatively impact salt marshes.

Supporting literature

Land use changes

Land use changes can directly reduce natural habitat available for recreation and tourism, as well as exacerbate the impacts of climate change (e.g., flooding, erosion) (Nelson et al. 2013). For example, human development in the Central Bay from 1855-1979 destroyed significant tidal marsh and intertidal mudflat habitat, resulting in a 4% overall areal loss of these critical habitats in San Francisco Bay (Barnard et al. 2013) and increasing local flood vulnerability (Nelson et al. 2013). Further, water management activities (e.g., dams, erosion mitigation projects) in upland river basins alter sediment supply and delivery to regional beach and wetland habitats, affecting their ability to keep pace with sea level rise (Knowles 2010), and thus, their availability for recreational and tourism use.

Continued coastal development will likely drive increased demand for armoring (MBNMS 2008), which has implications for natural systems as well as recreation and tourism. For example, coastal armoring affects the scenic quality of the coastline (Stamski 2005), and can exacerbate beach erosion, affecting public access (Stamski 2005, Hanak and Moreno 2008).

Aquaculture

Many important recreational finfish and shellfish species rely on eelgrass beds for nursery habitat (NOAA 2011), and aquaculture operations can displace, convert, or alter these and other important marine ecosystems (Dianna 2009). Aquaculture can also facilitate disease transmission to wild stocks (Dianna 2009); this is of particular concern with farmed abalone (Colver and Kuris 2000, Lafferty and Ben-Horin 2013).

Harvest

Fisheries harvest can impact disease rates in both target and nontarget species and stocks by affecting fish density and/or by altering ecological relationships (Lafferty et al. 2015 and citations therein). In addition to reducing fish stocks (Schroeder and Love 2002), harvest also affects age and population structures, which can affect future recruitment (Sydeman and Thompson 2013), and subsequently, recreational opportunities.

Pollution and poisons

Water pollution can affect recreational access and the health of recreational users (MBNMS 2008, Heal the Bay 2014), as well as impact the health of species valued by recreational users (GFNMS 2008, MBNMS 2008). For example, degraded estuarine water quality can negatively affect recreational fish species that use estuaries as nurseries (Pendleton 2010), and runoff containing coliform bacteria can impair human health and has been linked with sea otter deaths (MBNMS 2008). Pollution may include agricultural (inland and coastal) and urban runoff, vessel-based pollutants, legacy mining pollutants, sewage, and large particulates (e.g., plastic) (GFNMS 2008). In general, agricultural pollution sources are more influential within the boundaries of the sanctuary (GFNMS 2008), while urban runoff and sewage pollutants become increasingly significant from San Francisco southward (GFNMS 2008, Heal the Bay 2014). Coastal waters and estuaries are typically more vulnerable to water pollution impacts than open ocean areas within the study region (GFNMS 2008). Higher coastal water pollutant levels are typically associated with rainfall and elevated runoff, which occur most frequently during cooler weather periods (November-March), and are thus typically decoupled with peak beach demand, but can coincide with favorable surfing conditions (i.e., storm swell) (Heal the Bay 2014). Many public health agencies within the state recommend the public stay out of coastal water bodies for three days following rain events due to elevated pollutant levels in resultant runoff, though recent studies indicate that a five-day safety period may garner larger public health benefits (Heal the Bay 2014). Declines in regional precipitation and runoff in recent years have contributed to reduced water pollutant loads in monitored beach locations, and shifting climate conditions will continue to play a role in coastal water quality (Heal the Bay 2014) and subsequently, recreational access and safety.

Recreation

Historic and current recreational use can affect future recreational quality and access, as well as exacerbate climate impacts. For example, high recreational fish catches during the 1980s were identified as the main driver of depleted near-shore California fisheries and lower catch rates in subsequent years (Schroeder and Love 2002). Similarly, trampling of tidepool areas can kill component species and degrade future recreational opportunities (MBNMS 2008, Smith et al. 2008). In addition, recreational users may facilitate invasive species invasion and establishment, which can threaten biological communities already being impacted by climate change and/or exacerbate climate-driven changes in recreational areas (MBNMS 2008). For example, Chinese mitten crabs (*Eriocheir sinensis*) were likely introduced to the San Francisco Estuary in an attempt to establish a new recreational fishery (MBNMS 2008). However, this species exacerbates erosion by burrowing, acts as a secondary intermediate host for a pathogen that affects marine mammals and humans, and preys on juvenile salmon (MBNMS 2008), whose populations are already stressed by changing climatic conditions (Sydeman and Thompson 2013).

IV. Other sensitivities

Other critical factors likely to influence the sensitivity of the provision of the ecosystem service: population density

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

Additional participant comments

Increased population density may result in an increase in recreational usage of coastal areas, which if not managed properly, may adversely impact the overall experience of people using and visiting coastal areas.

Supporting literature

Increased overall use and demand of marine and coastal resources as a result of population growth could affect recreational quality, safety, and availability (Sivas and Caldwell 2008). California’s population is projected to grow 38% to include over 51 million residents by 2060, with Marin, San Mateo, and San Francisco counties projected to experience population increases of roughly 12%, 17%, and 77%, respectively (numbers relative to 2010 population estimates; California Department of Finance 2015). Population increases will likely drive increased visitation and crowding at regional beaches and other recreational areas, and crowding can be exacerbated by regional erosion and reduction in beach widths (King 2001). Surveys of beach-goers in other regions (e.g., Southern California) indicate that increased crowding would significantly deter coastal visitation; beach users in northern California likely exhibit the same preferences for less crowded recreational opportunities (King 2001). In addition to crowding and erosion concerns, traffic (i.e., the time it takes to reach a recreational destination) and competition for parking also significantly influence coastal visitation rates, and will be affected by population growth (King 2001).

Adaptive Capacity

I. Intrinsic Value

Value of the ecosystem service to people: High

- Confidence of workshop participants: High

Degree to which people are willing to change their behavior to ensure provision of the ecosystem service: Moderate-High

- Confidence of workshop participants: Moderate

Economic drivers that play a role in the management of the ecosystem service: Recreation and tourism are driven, to a large extent, by economics.

Can the ecosystem service be accessed elsewhere, and how important is it to ensure provision of the ecosystem service in its current location(s): Yes. Because recreation and tourism have a large impact on the Northern California economy it is important that they do not shift to another location(s).

Supporting literature

Coastal and marine recreation and tourism are major contributors to California's economy (Dwight et al. 2007, Hanak and Moreno 2008), mirroring trends across the nation (Boesch et al. 2000). For example, they contributed $11 billion to California's gross domestic product in 2004 (Hanak and Moreno 2008), and have increased in value while other marine industries have decreased (Sivas and Caldwell 2008). Further, coastal recreation is highly valued by California citizens, with roughly 72% of the population visiting the coast at least once per year (Public Policy Institute of California 2003 cited in Pendleton et al. 2006).

However, place-based recreational and tourism operations typically have a limited ability to shift in response to changing climate conditions (Hall and Higham 2005), especially in north-central coastal California where access is highly restricted by topography (e.g., rocky cliffs) (Gleason et al. 2010). Conversely, consumers have much higher mobility (Hall and Higham 2005), and shifts in recreation/tourism supply and price can lead to positive feedback loops of declining demand (Shaw and Loomis 2008, Morris and Walls 2009), underscoring the importance of maintaining current opportunities within the study region.

II. Management Potential

Rigidity / specificity of rules governing the provision of the ecosystem service or the areas that provide the ecosystem service: Moderate

- Confidence of workshop participants: High

Conflicts with other services in the region: Yes

- Conflicting services: water quality, harvest (food production), research opportunities, biodiversity, and future energy production

Services that mutually benefit from the provision of the ecosystem service: none

Likelihood of managing or alleviating climate change impacts on the provision of the ecosystem service: none given

Additional participant comments

Recreation and tourism services are probably the easiest of the ecosystem services to mitigate the impacts of climate change. New supporting infrastructure can be built, additional regulations can be put in place, and efforts to educate and encourage behavioral changes in people that reduce the impacts of increased tourism and recreation can be pursued.

Supporting literature

Although north-central California tourism and recreational industries have limited ability to shift location in response to changing climate conditions (Hall and Higham 2005), there are opportunities to diversify and market new and/or adapted activities to better take advantage of current shoulder-season/low use periods and changing environmental conditions (Amelung et al. 2007, WTO and UNEP 2008). In addition, there are many adaptation options to maintain recreational/tourism access and mitigate infrastructure vulnerability (WTO and UNEP 2008). For example, monitoring programs, live webcams and up-to-date webpages, and detailed coastal management plans can help distribute use impacts and relocate activities in response to short-term perturbations (e.g., water quality related beach closures) (WTO and UNEP 2008). In addition, protecting and enhancing beach, wetland, and other nearshore ecosystems provides multiple benefits, as these locations are both used for recreational and tourism activities and protect critical tourism infrastructure from flooding, sea level rise, storm surge and other environmental changes (WTO and UNEP 2008).

However, managing for recreational opportunities requires balancing with other management objectives. For example, beach nourishment can offset erosion loss occurring on some coastal beaches, but has environmental implications and constraints and is less feasible in areas experiencing high wave energy (Hanak and Moreno 2008). Similarly, tide pool access needs to balance visitor demand while protecting sensitive fauna that respond negatively to disturbance (Smith et al. 2008). Visitation and activity regulations can be used to mitigate recreational impacts, particularly in the face of population growth and increasing demand for coastal recreation, but regulation effectiveness will largely depend on enforcement and designing regulations to mitigate the most severe impacts (Smith et al. 2008).

Some recreational and tourism activities conflict with other services; for example, high scuba diving use can undermine biodiversity and conservation (Davis and Tisdell 1995), pollution from recreational users (e.g., beach trash, fishing gear, motor oil) can impair water quality (Shealvy and Register 2007), and recreational fishing, even catch-and-release, can affect future harvest levels (Schroeder and Love 2002).

III. Other adaptive capacity factors

Other critical factors that may affect the provision of the ecosystem service: Education of the general public, decision-makers, and regulators

Degree to which these factors affect the provision of the ecosystem service: High

- Confidence of workshop participants: Moderate

Additional participant comments

Future climate and climate-driven changes may result in an overall increase in the use of a limited number of areas, which in turn, could adversely impact wildlife and habitats that provide other important ecosystem services. Accordingly, education of the general public and decision-makers will be very important to reduce the impacts of potential increases in recreation and tourism activities.

Supporting literature

Recreation and tourism can be used to increase education and awareness for marine and coastal issues. For example, federal and state agencies can coordinate with recreation providers and tourism operations to incorporate environmental education into their “on the water experiences” (MBNMS 2008). In addition, there are ample opportunities to increase education in coastal areas (e.g., beaches) (MBNMS 2008).

Exposure

I. Future climate exposure[2]

Degree of to which the provision of the ecosystem service is likely to be affected by climate change: Moderate-High

- Confidence of workshop participants: High

Future climate and climate-driven changes identified: air temperature, sea surface temperature, sea level rise, wave heights, prevailing wind patterns, storm intensity

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

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Water Purification[1]

Executive Summary

Water Purification	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	4 Moderate-High	3 High
Adaptive Capacity	3 Moderate	3 High
Vulnerability	3 Moderate	3 High

Water purification is a critically important ecosystem service provided by California coastal wetlands and filter-feeding organisms (e.g., oysters and mussels). Through various physical, biological, and chemical processes, wetlands and filter-feeding organisms purify surface and groundwater by trapping sediment, altering water chemistry, and removing pollutants such as metals, viruses, oils, pesticides and nutrients (e.g., nitrogen). The purified water supplied by California's coastal wetlands supports numerous industries, recreational activities, and wildlife habitats, and supplies clean drinking water to many local communities by recharging groundwater supplies (Osmond et al. 1995). Key climate sensitivities identified by workshop participants include sea level rise, storm activity, and precipitation. Key non-climate sensitivities include land use change, pollution, and recreation. Water purification is highly valued by the general public, especially for recreational opportunities and for the health of harvested seafood. Restoration activities are critical in ameliorating the impacts of human-caused sedimentation, and management activities should focus on those areas with the greatest potential for recovery and resilience (including potential for inland migration and sufficient sedimentation to keep pace with sea level rise). Additionally, improved communication and collaboration among the multiple agencies responsible for managing water quality may help ensure the provision of this ecosystem service.

Sensitivity

I. Sensitivity of ecosystem service components

Sensitivity of the provision of the ecosystem service to climate and climate-driven changes: Moderate-High

- Confidence of workshop participants: High

Climate and climate-driven changes identified: ocean pH, sea level rise, dissolved oxygen levels, turbidity, storminess, coastal erosion, wave action, and circulation

Climate and climate-driven changes that may benefit the provision of the ecosystem service: sea surface temperature

- Description of benefits: Increases in sea surface temperature may lead to increases in eelgrass.

Additional participant comments

Changes in large-scale circulation and assemblages of filter feeding organisms will impact the provision of the water purification ecosystem service.

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

Supporting literature

Ocean pH

Filter-feeding animals, such as oysters and mussels, contribute significantly to the cleaning of water in coastal wetlands. These organisms exhibit sensitivity to changes in ocean pH; for example, lower ocean pH levels have been shown to cause decreased rates of calcification and reduced rates of development in mussels and oysters (Talmage and Gobler 2009), as well as decreased metabolism in mussels (Michealidis et al. 2005). Lower ocean pH levels have also been shown to increase oyster and mussel larval mortality and result in smaller-sized adults with reduced filtration capacity (Michealidis et al. 2005).

Sea level rise

Coastal wetlands, which improve water quality by removing pollutants, trapping sediment, and altering water chemistry and nutrient levels through a variety of biological, physical, and chemical processes (Ecological Society of America 2015), are vulnerable to sea level rise. However, the overall vulnerability of wetlands and associated water purification services to sea level rise will depend upon several factors including vertical accretion rates (influenced by the deposition of inorganic sediments or the accumulation and burial of organic material), compaction and subsidence rates, and the ability of wetlands to expand and/or migrate. Rising sea levels may initially increase estuarine surface area and result in increased plant biomass production, potentially influencing water purification processes by slowing water velocity and facilitating mineral and organic particle deposition (Carter 1997). Conversely, rates of sea level rise that exceed the vertical accretion rate of sediment and organic material will eventually drown low-lying estuarine areas (Mudd et al. 2009, Kirwan and Temmerman 2009). Coastal wetland habitats that are unable to expand or migrate in response to rising sea levels because of natural barriers or man-made structures, or are unable to vertically accrete at a pace equal to, or greater than, the rate of sea level rise will eventually experience a decrease in biogenic habitat (Harley et al. 2006). Coastal wetlands that are more dependent on organic accumulation rather than inorganic sediment deposition will likely be more impacted by rising sea levels (Stevenson et al. 1986, Stevenson and Kearney 2009). Salt marshes located in estuaries with low tidal ranges are expected to be more sensitive to rising sea levels due to decreased rates of sediment transport and vertical accretion (Simas et al. 2001). The impacts of rising sea levels may be negligible on coastal wetlands that are able to vertically accrete at rates that equal or exceed rates of sea level rise.

Dissolved oxygen levels

Dissolved oxygen (DO) is essential for many benthic organisms in coastal wetland habitats, including filter-feeding oysters. Low levels of DO can increase stress on adult oysters and may increase mortality in juvenile oysters (Widdows et al. 1989). Extremely low levels of DO, or hypoxic conditions, can result in the loss of oysters and oyster reef habitat (Lenihan and Peterson 1998).

Circulation

Changes in coastal wetland circulation can impact dispersal and recruitment of marine organisms, and may result in reduced nutrient supplies with negative impacts on aquatic vegetation and filter-feeding organisms (Harley et al. 2006).

Turbidity
Increased turbidity will decrease the amount of light aquatic plants receive, reducing primary productivity. This may negatively impact filter-feeding animals, such as oysters, that depend on the oxygen generated by aquatic vegetation during primary production (NOAA 2012).

Storminess / wave action / coastal erosion
Climate change is expected to result in more extreme storm events with stronger winds, larger storm surges, and larger waves. Additionally, climate change may result in increased short duration/high precipitation events, which can increase the amount of pollution and sediment runoff. Changes in storm intensity may also result in changes to sediment transport and deposition processes (Simas, Nunes and Ferreira 2001), alter the timing of estuarine mouth opening and closing, increase soil and vegetation turnover, and increase water turbidity. The impact of these disturbances on vegetative habitats and filter-feeding organisms in coastal wetlands will depend upon specific storm and local geomorphological conditions (Simas, Nunes and Ferreira 2001). Winter waves, driven by extra-tropical cyclones in the North Pacific, can be in excess of 8 m (Wingfield and Storlazzi 2007) and erode shorelines and alter sediment transport and deposition processes (Scavia et al. 2002). Changes in wave height and direction will also expose previously sheltered areas to significant levels of erosion (Sallenger et al. 2002), which may have significant negative impacts on sensitive coastal wetland habitats.

II. Sensitivity to disturbance regimes

Disturbance regimes identified: disease[2], flooding, and storms

Overall sensitivity of the provision of the ecosystem service to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Additional participant comments

Although the overall impact on the provision of the water purification ecosystem service will be high, local responses to climate and climate-driven changes will vary.

Supporting literature

Flooding
Coastal wetlands are sensitive to changes in flooding patterns and sediment loading (Ramsar 2002), which can impact vertical accretion rates. Although coastal wetlands are tolerant of periodic flooding, a flooding threshold likely exists, and longer flood durations and/or more frequent flooding can increase erosion and decrease organic plant contributions, accelerating wetland habitat deterioration (Kirwan and Megonigal 2013) and undermining the provision of water purification services. Additionally, although wetlands depend on surface water flows to deliver sediment from upstream watersheds, extended freshwater flooding can cause oxygen deficiencies that affect biological and biogeochemical functioning (Carter 1997).

Storms
Storms constantly reshape coastal wetlands through erosive and depositional processes. Energetic winter storms tend to be more erosive. The overall impact of storms on coastal wetlands will depend on specific geomorphological conditions and the intensity and direction of

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[2] Though peer-reviewed literature may exist, staff review was unable to locate supporting literature for this stressor.

storms, as well as tides, currents, and other physical factors (Moran 2011). See discussion above under storminess/wave action/coastal erosion.

III. Sensitivity and exposure to non-climate stressors

Non-climate stressors identified: land use changes, overwater/underwater structures, coastal roads and armoring, invasive species[3], and pollution and poisons

Degree to which non-climate stressors affect the provision of the ecosystem service: Moderate

- Confidence of workshop participants: Moderate

Degree to which non-climate stressors affect the sensitivity of the provision of the ecosystem service to climate change: Moderate-High

- Confidence of workshop participants: Moderate

Additional participant comments

Land use changes, specifically the movement/expansion of wineries towards the coast in response to climate change and market forces, have had significant impacts on coastal wetlands and their ability to provide water purification services. Sea level rise and the resulting "coastal squeeze" will reduce the size of available coastal wetland habitat and reduce the overall capacity of coastal wetlands to provide this important ecosystem service.

Supporting literature

Land use changes

Reclamation, engineering, and urbanization have resulted in the loss of extensive areas of seagrass and salt marsh (Mcleod et al. 2011). Increased sedimentation from land use changes may result in the burying of vegetative and oyster habitat, or increase the duration of estuary mouth closure. Freshwater diversions for agriculture and other human uses can result in hypersaline conditions, reduced estuarine circulation, or more persistent closures of estuary mouths due to reduced tidal prism (ONMS 2010), all of which can negatively impact vegetative and oyster habitats.

Overwater/underwater structures

Overwater and underwater structures alter light regimes, wave energy, sediment and transport processes, substrate, and water quality, which can limit plant growth and recruitment or result in altered plant assemblages (Nightingale and Simenstad 2001).

Coastal roads and armoring

Coastal armoring and road construction can prevent the inland migration or expansion of coastal wetland habitats in response to sea level rise. Where the inland border of coastal wetland habitats abuts roads, levees, or other armored structures, an accelerated loss of habitat may be expected (Fletcher et al. 1997, Dugan et al. 2008). Road construction and coastal armoring continue to affect the study region, specifically in Bolinas Lagoon, Tomales Bay, and other areas of coastal development. Although the impacts of these structures are generally localized, they can be severe as they can result in the conversion and loss of habitat type and increase erosion rates (ONMS 2010).

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[3] Though peer-reviewed literature may exist, staff review was unable to locate supporting literature for this stressor.

Pollution and poisons

Coastal eutrophication, resulting from excess nutrient runoff from terrestrial sources, leads to lower DO levels, which may lead to increased stress and mortality in filter-feeding oysters and increased epiphytic algae and macroalgae. Increased epiphytic algae reduces available light for primary production, and can result in extensive loss of submerged aquatic vegetation (Duarte 2002, Mcleod et al. 2011).

IV. Other sensitivities: none identified

Adaptive Capacity

I. Intrinsic value

Value of the ecosystem service to people: High

- Confidence of workshop participants: High

Degree to which people are willing to change their behavior to ensure provision of the ecosystem service: Moderate

- Confidence of workshop participants: Moderate

Economic drivers that play a role in the management of the ecosystem service: recreational opportunities and health of locally produced seafood

Can the ecosystem service be accessed elsewhere, and how important is it to ensure provision of the ecosystem service in its current location(s): There is limited access to clean water. Continued provision of this ecosystem service is critically important to numerous local communities in the region.

Additional participant comments

Human intervention through increased bivalve aquaculture activities and restoration of coastal wetlands, will be needed to ensure the provision of water purification services in the future.

II. Management potential

Rigidity / specificity of rules governing the provision of the ecosystem service or the areas that provide the ecosystem service: Moderate-High

- Confidence of workshop participants: High

Conflicts with other services in the region: none identified

Services that mutually benefit from the provision of the ecosystem service: food production and recreation

Likelihood of managing or alleviating climate change impacts on the provision of the ecosystem service: The likelihood will depend on public support and the political will to manage coastal wetlands as a “living shoreline”, including reducing coastal development and only approving aquaculture activities in appropriate locations.

Additional participant comments

There are currently an abundance of rules and regulations governing coastal wetlands from multiple management agencies with overlapping jurisdictions. Improved communication and collaboration between these agencies can help ensure the provision of the water purification ecosystem service. Coastal wetland restoration projects, such as the efforts in Bolinas Bay to ameliorate the impacts of human-caused sedimentation, are already successfully underway. Coastal wetlands that are bound by natural or man-made barriers, or have insufficient rates of sedimentation, may be unable to move/migrate in response to rising sea levels and changing climactic conditions. This could result in the loss of significant portions of the region's coastal wetlands. Accordingly, it is critical that resource managers first identify coastal wetland areas with the highest adaptive capacities, and subsequently focus restoration and maintenance efforts on those areas.

III. Other adaptive capacity factors

Other critical factors that may affect the provision of the ecosystem service: sedimentation rates

Degree to which these factors affect the provision of the ecosystem service: High

- Confidence of workshop participants: no answer provided

Additional participant comments

Sedimentation rates that equal or exceed rates of sea level rise are required to maintain marsh plain areas and prevent the submersion of coastal wetland areas.

Exposure

I. Future climate exposure[4]

Degree of to which the provision of the ecosystem service is likely to be affected by climate change: Moderate-High

- Confidence of workshop participants: High

Future climate and climate-driven changes identified: sea surface temperature, ocean pH, sea level rise, dissolved oxygen (DO) levels, turbidity, storm intensity, coastal erosion, wave action, and circulation

Additional participant comments

Restoration of coastal wetlands can help ensure the provision of this and other important ecosystem services in the future.

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

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Conclusions and Next Steps

Marine resource managers realize the immediate threats of climate change to the resilience, health, and ecosystem services of the coastal and ocean places they protect, yet the resources to develop appropriate management options to prepare for and respond to a changing environment are limited (Gregg et al. 2011). This vulnerability assessment provides a foundation for understanding how and to what degree resources are threatened by climate change in the North-central California coast and ocean region, enabling resource managers and conservation planners to set management and planning priorities and more efficiently and effectively allocate resources to respond to, plan, and manage for the impacts of climate change.

Representatives from federal and state agencies, non-governmental organizations and academic institutions assessed the vulnerability of 44 species, habitats and ecosystem services to the impacts of climate change and non-climate stressors. Most resources were assessed as having moderate vulnerability, with a range from low-moderate to moderate-high vulnerability. Habitats and associated species and ecosystem services that exist at the land-sea interface (beaches and dunes, estuaries, and the rocky intertidal) were identified as being most vulnerable, and will likely be prioritized for the development of adaptive management recommendations.

This report is the first step in the development of climate-smart adaptation strategies that can be feasibly implemented by managers to help ensure long-term viability of the resources they are mandated to protect, and represents the first phase of "Climate-Smart Adaptation for the North-central California Coast and Ocean." The second phase of the project, initiated in early 2015, convenes a working group of the GFNMS Advisory Council of scientists and resource managers to 1) define distinct future climate scenarios for the study region and 2) develop prioritized adaptation action recommendations. Working group members will use this report and the Scenario Planning for Climate Change Adaptation guide (Moore et al. 2013) to define distinct scenarios for the study region based on the most uncertain and the most important (greatest impact) climatic and non-climatic drivers of change. Working Group members will meet and evaluate drivers of change that were identified in Phase 1 as contributors to focal resource vulnerability and rank those drivers by their relative uncertainty (in future direction and magnitude of change) and importance to management decisions. The working group will then select the top two or three most uncertain/impactful drivers and cross those drivers to create a set of plausible but also divergent scenarios to use in a scenario planning exercise. The working group will then name and describe each future scenario in preparation for the development of adaptation actions. Scenario planning is a successful and flexible approach to incorporate climate uncertainty into decision making to develop adaptation actions for multiple, plausible climate futures, and is especially useful when critical drivers of change are highly uncertain and cannot be controlled (Moore et al. 2013). Based on National Wildlife Federation and Point Blue Climate-Smart Conservation Principles, and using the developed scenarios as a framework, working group members will: 1) define criteria for prioritization of adaptation recommendations (e.g. feasibility, cost-effectiveness, climate-smart, collaborative, robustness across scenarios); 2) brainstorm potential management actions for each future scenario (in an iterative process, which may result in further revision of scenarios); 3) evaluate and prioritize brainstormed actions using defined criteria; and 4) determine a final set of recommended actions, linked to specific geographic locations within the study area.

Recommendations from the working group will be forwarded to the GFNMS Advisory Council for approval, and the approved recommendations will then be forwarded to the GFNMS superintendent, as well as other coastal resource management agencies in the region for consideration in their current or future adaptation planning efforts, including the Point Reyes National Seashore, Golden Gate National Recreation Area, California State Parks, California Department of Fish and Wildlife, US Fish and Wildlife Service, and the Counties of San Mateo, San Francisco, Marin and Sonoma. GFNMS will then adopt a final set of climate-smart adaptation strategies based on the Sanctuary Advisory Council recommendations, and work with the project team to develop an adaptation implementation plan, including a summary of adaptation actions, implementation prioritization and schedule, estimated cost and potential funding sources, and potential partners. The Implementation Plan will be divided into three project initiation sections: 1) Near-term (less than 5 years to implement; 2) Mid-term (5-10 years to implement); and 3) Long-term (over 10 years to implement). GFNMS staff will immediately begin incorporating adaptation strategies into sanctuary management as resources allow. Immediate actions may include revising permit review criteria, additional analysis on climate change impacts incorporated into NEPA documents, and prioritization of restoration activities based on climate change impacts.

Potential ecological outcomes of integrating adaptation actions into natural resource management in the region include restoring habitats and using nature-based solutions to protect infrastructure such as the restoration of hydrologic function and floodplains in Bolinas Lagoon to provide for future wetland upland migration as well as flood and erosion control; seagrass restoration and protection in Tomales Bay to provide increased habitat, carbon storage and sequestration, improved water quality, and protection of shoreside infrastructure by reducing coastal erosion; and beach nourishment projects to protect coastal infrastructure.

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Report Photo and Figure Credits

Figure	Description	Credit
Cover photo, left	Sea Palm	Sara Hutto, GFNMS
Cover photo, top	North-central California coastline	GFNMS/Beach Watch
Cover Photo, bottom right	California Hydrocoral	Steve Lonhart, MBNMS
Cover photo, bottom center	Black Oystercatcher	GFNMS/Beach Watch
Figure 1	Sea Palm	Sara Hutto, GFNMS
Figure 2	Rodeo Lagoon	Flickr member GGNRA_Laura
Figure 3	Map of study region	Tim Reed, GFNMS
Figure 4	Climate-Smart Conservation Cycle	Glick et al. 2011
Figure 5	Vulnerability Assessment Methodology	Sara Hutto, adapted from Jessi Kershner, EcoAdapt
Figures 6-11	Vulnerability Assessment Results	Jessi Kershner, EcoAdapt

Appendix A: Focal Resources Workshop agenda and participants

<u>North-central California Coast and Ocean Climate-Smart Adaptation</u>
Workshop 1: Focal Resources
California Academy of Sciences
February 11, 2014
9:30 am – 3:00 pm

Time	Subject
9:00 – 9:30	Sign-in and Coffee • Attendees will select Habitat Assemblage Break-out Group to participate in at sign-in
9:30 – 9:40	Welcome *Terry Gosliner, Dean of Science and Research Collections, California Academy of Sciences and Maria Brown, Superintendent, Gulf of the Farallones National Marine Sanctuary (GFNMS)*
9:40 – 10:00	Project and Workshop Overview *Sara Hutto, GFNMS*
10:00 – 10:20	Survey results: analysis, data, and orientation to materials *Sara Hutto, GFNMS*
10:20 – 10:30	Break (reconvene in break-out groups)
10:30 – 11:55	Habitat Assemblage Break-out Groups • Complete worksheet as a group and develop recommendations for final focal resources
12:00 – 12:45 *5 min for each group, 20 min for discussion*	Reports from Break-out Groups • Each group report their recommended habitats, species and ecosystem services • Discuss proposed removals/additions to list
12:45 – 1:45	Lunch
1:45 – 2:15	Finalize focal resources *Sara Hutto, GFNMS*
2:15 – 2:50	Planning for Workshop 2: • Review of the vulnerability assessment process • Discuss information needs and available resources for the vulnerability assessments *Lara Hansen, EcoAdapt*
2:50 – 3:00	Next Steps and Close-out *Sara Hutto, GFNMS*

Participant	**Affiliation**
Ben Becker	Point Reyes National Seashore
Maria Brown	Gulf of the Farallones National Marine Sanctuary
Amy Dean	Farallones Marine Sanctuary Association
Meredith Elliott	Point Blue Conservation Science
Rebecca Fris	California Landscape Conservation Cooperative
Holly Gellerman	California Department of Fish and Wildlife
Matt Gerhart	California State Coastal Conservancy
Joel Gerwein	California State Coastal Conservancy
Andrea Graffis	California Landscape Conservation Cooperative
Denise Greig	The Marine Mammal Center
Lara Hansen	EcoAdapt
Eric Hartge	Center for Ocean Solutions, Stanford University
Daphne Hatch	Golden Gate National Recreation Area
Kelley Higgason	Gulf of the Farallones National Marine Sanctuary
Dan Howard	Cordell Bank National Marine Sanctuary
Sara Hutto	Gulf of the Farallones National Marine Sanctuary
Jaime Jahncke	Point Blue Conservation Science
Rebecca Johnson	California Academy of Sciences
Suzanne Langridge	Natural Capital Project
Dina Liebowitz	California Ocean Science Trust
Dani Lipski	Cordell Bank National Marine Sanctuary
Steve Lonhart	Monterey Bay National Marine Sanctuary
Gerry McChesney	US Fish and Wildlife Service
Steven Morgan	UC Davis/Bodega Marine Lab
Hilary Papendick	California Coastal Commission
Lorraine Parsons	Point Reyes National Seashore
Karen Reyna	Gulf of the Farallones National Marine Sanctuary
Jan Roletto	Gulf of the Farallones National Marine Sanctuary
Claire Simeone	The Marine Mammal Center
Jonathon Stillman	UC Berkeley
Lisa Wooninck	Office of National Marine Sanctuaries, West Coast Region

Appendix B: Vulnerability Assessment Workshop agenda and participants

North-central California Coast and Ocean Climate-Smart Adaptation
Workshop 2: Vulnerability Assessment
Fort Mason
June 10-11, 2014

Tuesday, June 10th: 9:30 AM – 4:30 PM

Introduction to Vulnerability Assessments and Climate Trends for the Region

9:30	Welcome. Maria Brown, Gulf of the Farallones National Marine Sanctuary
9:35 – 9:40	Introduction to workshop goals and objectives. Sara Hutto, Gulf of the Farallones National Marine Sanctuary
9:40 – 9:45	Participant Introductions: name and affiliation
9:45 – 10:05	Presentation: *Climate trends in the north-central California coast – historic and projected changes.* Tom Suchanek, USGS.
10:05 – 10:25	Presentation: *Introduction to vulnerability assessments – foundational elements and key steps*. Lara Hansen, EcoAdapt
10:25 – 10:35	Presentation: *Introduction and orientation to vulnerability assessment worksheets*. Jessi Kershner, EcoAdapt
10:50 – 12:30	Vulnerability Assessment Breakout Groups: **Habitat type** Objectives for breakout groups: • Complete worksheets: sensitivity and exposure, adaptive capacity • Discuss overall vulnerability

LUNCH: 12:30 – 1:30 PM

1:30 – 1:50	Finish habitat vulnerability assessment
1:50 – 2:30	Breakout groups report back to share habitat vulnerability assessment findings with all participants and discuss rankings
2:45 – 4:20	Vulnerability Assessment Breakout Groups: **Species** Objectives for breakout groups: • Complete worksheets: sensitivity and exposure, adaptive capacity • Discuss overall vulnerability
4:20 – 4:30	Wrap up and next day preview

Wednesday, June 11th: 9:30 AM – 4:30 PM

9:30 – 9:40 Opening comments and overview of day's objectives.

9:40 – 10:30 Finish species vulnerability assessment

10:45 – 11:30 Breakout groups report back to share species vulnerability assessment findings with all participants and discuss rankings

11:30 – 12:30 Vulnerability Assessment Breakout Groups: **Ecosystem Services**

Objectives for breakout groups:

- Complete worksheets: sensitivity, and exposure, adaptive capacity
- Discuss overall vulnerability

LUNCH: 12:30 – 1:30 PM

1:30 – 2:15 Vulnerability Assessment Breakout Groups: **Ecosystem Services**

Objectives for breakout groups:

- Complete worksheets: sensitivity, and exposure, adaptive capacity
- Discuss overall vulnerability

2:15 – 3:00 Breakout groups report back to share human and economic vulnerability assessment findings with all participants and discuss rankings

3:15 – 4:15 Vulnerability Assessment Large Group Discussion: **Management Decisions.** Lara Hansen, EcoAdapt

4:15 – 4:30 Workshop wrap up and next steps

Participant	**Affiliation**	**Break-out groups**
Ben Becker	Point Reyes National Seashore	Offshore
Russ Bradley	Point Blue Conservation Science	Cliffs
Maria Brown	Gulf of the Farallones National Marine Sanctuary	Rocky Intertidal, Recreation and Tourism
Jennifer Brown	Monterey Bay National Marine Sanctuary	Rocky Intertidal, Biodiversity
Meredith Elliott	Point Blue Conservation Science	
Darren Fong	Golden Gate National Recreation Area	Carbon Storage and Sequestration
Holly Gellerman	California Department of Fish and Wildlife	Cliffs, Recreation and Tourism
Doug George	Applied Marine Sciences, Inc.	
Joel Gerwein	California State Coastal Conservancy	Beach and Dune, Carbon Storage and Sequestration
Andrea Graffis	California Landscape Conservation Cooperative	

Lara Hansen	EcoAdapt	Kelp Forest, Biodiversity
Eric Hartge	Center for Ocean Solutions, Stanford University	Nearshore and Estuaries, Flood and Erosion Protection
Daphne Hatch	Golden Gate National Recreation Area	Cliffs, Flood and Erosion Protection
Kelley Higgason	Gulf of the Farallones National Marine Sanctuary	Cliffs
Dan Howard	Cordell Bank National Marine Sanctuary	Offshore, Biodiversity
Sara Hutto	Gulf of the Farallones National Marine Sanctuary	Rocky Intertidal
Jaime Jahncke	Point Blue Conservation Science	Offshore
Joanne Kerbavaz	California State Parks	Beach and Dune, Recreation and Tourism
Jessi Kershner	EcoAdapt	Carbon Storage and Sequestration
Kristy Kroeker	UC Davis/Bodega Marine Lab	Kelp Forest, Carbon Storage and Sequestration
Suzanne Langridge	UC Santa Cruz	Nearshore and Estuaries
Dina Liebowitz	California Ocean Science Trust	Kelp Forest
Dani Lipski	Cordell Bank National Marine Sanctuary	Offshore
Mary Matella	California Coastal Commission	Beach and Dune, Flood and Erosion Protection
Steven Morgan	UC Davis/Bodega Marine Lab	Rocky Intertidal
Tenaya Norris	The Marine Mammal Center	Nearshore and Estuaries
Paul Reilly	California Department of Fish and Wildlife	Nearshore and Estuaries
Karen Reyna	Gulf of the Farallones National Marine Sanctuary	Offshore
Jake Reynolds	Gulf of the Farallones National Marine Sanctuary	
Deb Schlafmann	California Landscape Conservation Cooperative	Nearshore and Estuaries, Recreation and Tourism
Jonathon Stillman	UC Berkeley	Kelp Forest, Carbon Storage and Sequestration
Tom Suchanek	US Geological Survey	
Sam Veloz	Point Blue Conservation Science	Beach and Dune
Deb Wilson-Vandenburg	California Department of Fish and Wildlife	Kelp Forest, Biodiversity

Appendix C: Contributors and Reviewers to assessment reports[6]

Focal Resource	Contributor(s)	Reviewer(s)
American Dune Grass	Beaches and Dunes break-out group	Peter Baye (Ph.D., Botanist, unaffiliated)
Black Oystercatcher	Kirsten Lindquist (Farallones Marine Sanctuary Association)	Kirsten Lindquist (Farallones Marine Sanctuary Association)
Black Rail	Julian Wood (Point Blue Conservation Science)	Laurie Hall (UC Davis)
Blue Rockfish	Kelp forest break-out group	Steve Lonhart (Monterey Bay National Marine Sanctuary)
Blue Whale	Jaime Jahncke	Meredith Elliot, Sarah Allen (National Park Service)
California Mussel	Rocky Intertidal break-out group	Amy Dean (Farallones Marine Sanctuary Association)
Cassin's Auklet	Jaime Jahncke, Meredith Elliot, Russ Bradley, Bill Sydeman (Farallon Institute)	Meredith Elliot
Cavity Nesters	Cliffs break-out group	Russ Bradley
Copepod	Offshore break-out group	Meredith Elliot
Coralline Algae	Kelp forest break-out group	Steve Lonhart (Monterey Bay National Marine Sanctuary)
Dune Grass	Darren Fong and Camm Swift (Professor Emeritus)	Peter Baye (Ph.D., Botanist, unaffiliated)
Gaper Clam	Christy Juhasz (CDFW)	Christy Juhasz (CDFW), Kirsten Ramey (CDFW), Peter Kalvass (CDFW)
CA Hydrocoral and Red sponge	Offshore break-out group	Dani Lipski
Krill	Offshore break-out group	Meredith Elliot
Mole Crab	Beaches and Dunes break-out group; Amy Dean (FMSA)	Dan Robinette (Point Blue Conservation Science)
Northern Anchovy/Pacific Sardine	Chelsea Protasio (CDFW)and Kirk Lynn (CDFW)	Briana Brady (CDFW), Sarah Allen (NPS)
Ochre Sea Star	Rocky Intertidal break-out group	Amy Dean (Farallones Marine Sanctuary Association)
Olympia Oyster	Ted Grosholz (UC Davis)	Ted Grosholz (UC Davis)
Pacific Herring	Nearshore break-out group	Sarah Allen (NPS), Kirsten Ramey (CDFW), Ryan Bartling (CDFW)
Pteropod	Jaime Jahncke, Meredith Elliot, Russ Bradley	Meredith Elliot

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[6] See participant list in Appendix B if affiliation is not listed

Red Abalone	Kelp forest break-out group	Steve Lonhart (Monterey Bay National Marine Sanctuary)
Sea Otter	Nearshore break-out group	Sarah Allen (NPS), Steve Lonhart (Monterey Bay National Marine Sanctuary)
Sea Palm	Rocky Intertidal break-out group	Amy Dean (Farallones Marine Sanctuary Association)
Sea Urchins	Kelp forest break-out group	Steve Lonhart (Monterey Bay National Marine Sanctuary)
Snowy Plover	Beaches and Dunes break-out group	Dan Robinette (Point Blue Conservation Science), Peter Baye (Ph.D., Botanist, unaffiliated)
Surface Nesters	Cliffs break-out group	Russ Bradley
Tidewater Goby	Darren Fong	Ted Grosholz (UC Davis)
Widow Rockfish	Offshore break-out group	Dani Lipski
Kelp Forest	Kelp forest break-out group	Steve Lonhart (Monterey Bay National Marine Sanctuary)
Beaches and Dunes	Beaches and dunes break-out group	Dan Robinette (Point Blue Conservation Science)
Benthic Shallow Banks	Offshore break-out group	Dani Lipski
Cliffs	Cliffs break-out group	Russ Bradley
Estuaries	Nearshore break-out group	Ted Grosholz (UC Davis)
Nearshore	Nearshore break-out group	Sarah Allen (NPS)
Pelagic	Offshore break-out group	Meredith Elliot
Rocky Intertidal	Rocky Intertidal break-out group	Amy Dean (Farallones Marine Sanctuary Association)
Flood and Erosion Protection	Flood and erosion protection break-out group	Daphne Hatch
Carbon Storage and Sequestration	Carbon storage and sequestration break-out group	Jessi Kershner
Food Production	Food production break-out group	Jessi Kershner
Water Purification	Water purification break-out group	Jessi Kershner
Recreation and Tourism	Recreation and tourism break-out group	Daphne Hatch

Appendix D: Vulnerability Assessment Scores

The following score tables provide vulnerability component scores and individual element scores assigned by workshop participants and assessment contributors for all 44 habitats, species, and ecosystem services considered as part of the Climate-Smart Adaptation Project for the North-central California Coast and Ocean. Score tables are listed in alphabetical order within resource categories, with habitat scores presented first, followed by species scores, and ecosystem services scores.

Beaches and Dunes – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Sensitivities to Climate & Climate-Driven Factors
• Precipitation
• pH
• Sea level rise
• Wave action
• Coastal erosion
• Sediment supply and movement
• Wind</td><td colspan="2">Overall: 4 Moderate-High
• 2 Low-Moderate
• 1 Low
• 5 High
• 5 High
• 5 High
• 5 High
• 3 Moderate</td><td>Overall: 3 High
• 2 Moderate
• 1 Low
• 3 High
• 3 High
• 3 High
• 3 High
• 3 High</td></tr>
<tr><td>Disturbance Regimes
• Wind
• Storms</td><td colspan="2">Overall: 5 High</td><td>Overall: 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Roads/armoring
• Recreation
• Invasive species
• Overwater/underwater structures
• Dredging</td><td colspan="2">Overall: 4 Moderate-High
• 5 High
• 3 Moderate
• 3 Moderate
• 4 Moderate-High
• 3 Moderate</td><td>Overall: 3 High
• 3 High
• 3 High
• 2 Moderate
• 3 High
• 2 Moderate</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor
• Roads/armoring
• Recreation
• Invasive species
• Overwater/underwater structures
• Dredging</td><td colspan="2">Overall: 3 Moderate</td><td rowspan="2">Overall: 3 High
• 3 High
• 3 High
• 3 High
• 2 Moderate
• 2 Moderate</td></tr>
<tr><td>LOCAL
• 5 High
• 5 High
• 5 High
• 5 High
• 4 Moderate-</td><td>REGIONAL
• 2 Low-Moderate
• 2 Low-Moderate
• 2 Low-Moderate
• 2 Low-Moderate
• 2 Low-Moderate</td></tr>
</table>

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
	High		
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**3 Moderate (Altered but not degraded)**	**2 Moderate**
Habitat Continuity	**3 Moderate (Patchy across an area with some connectivity among patches)**	**2 Moderate**
Habitat Resistance	**2 Low-Moderate**	**2 Moderate**
Habitat Recovery	**3 Moderate**	**2 Moderate**
Habitat Diversity – Physical/Topographical	**2 Low-Moderate**	**2 Moderate**
Habitat Diversity – Component Species	**3 Moderate**	**2 Moderate**
Habitat Diversity – Functional Groups	**2 Low-Moderate**	**2 Moderate**
Habitat Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**3 High**
Other Adaptive Capacities • Sediment Supply	**Overall: 5 High**	**Overall: 3 High**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 5 High**	**Overall: 3 High**
• Sea level rise	• **5 High**	• **3 High**
• Increased storminess	• **5 High**	• **3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Exposure Factor	Exposure Evaluation	Confidence
- Increased coastal erosion runoff - Increased flooding	- **5 High** - **3 Moderate**	- **3 High** - **1 Low**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Cliffs – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Air temperature • Precipitation • Salinity • Sea level rise • Wave action • Coastal erosion • Extreme weather events	**Overall: 3 Moderate** • **2 Low-Moderate** • **3 Moderate** • **2 Low-Moderate** • **3 Moderate** • **4 Moderate-High** • **4 Moderate-High** • **5 High**	**Overall: 3 High** • **2 Moderate** • **2 Moderate** • **1 Low** • **3 High** • **3 High** • **3 High** • **3 High**
Disturbance Regimes • Wind • Storms (wave height) • Flooding • Drought	**Overall: 4 Moderate-High**	**Overall: 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Recreation • Roads/Armoring • Invasive Species • Urban Runoff • Overwater/underwater Structures	**Overall: 3 Moderate** • **4 Moderate-High** • **2 Low-Moderate** • **4 Moderate-High** • **2 Low-Moderate** • **3 Moderate** • **2 Low-Moderate**	**Overall: 3 High** • **3 High** • **3 High** • **3 High** • **2 Moderate** • **2 Moderate** • **2 Moderate**
Non-Climate Stressors – Current Exposure • Land use change	**Overall: 1 Low** **LOCAL** • **5 High (Urban); 2 Low-Moderate** **REGIONAL** • **2 Low-Moderate**	**Overall: 1 Low** • **2 Moderate**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
	(Rural)		
• Recreation	• **3 Moderate (Urban); 1 Low (Rural)**	• **1 Low**	• **3 High**
• Roads/armoring	• **2 Moderate-Low (Urban); 1 Low (Rural)**	• **1 Low**	• **3 High**
• Invasive species	• **1 Low**	• **1 Low**	• **3 High**
• Urban runoff	• **3 Moderate (Urban); 1 Low (Rural)**	• **1 Low**	• **2 Moderate**
• Overwater/underwater structures	• **2 Low-Moderate (Urban); 1 Low (Rural)**	• **1 Low**	• **2 Moderate**
Other Sensitivities • Tsunami • Earthquakes	**Overall: 4 Moderate-High**		**Overall: 2 Moderate**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**4 Moderate-High (Minor to moderate alterations)**	**3 High**
Habitat Continuity	**3 Moderate (Patchy across an area with some connectivity among patches)**	**3 High**
Habitat Resistance	**4 Moderate-High**	**2 Moderate**
Habitat Recovery	**2 Low-Moderate**	**2 Moderate**
Habitat Diversity – Physical/Topographical	**2 Low-Moderate**	**3 High**
Habitat Diversity – Component Species	**1 Low**	**3 High**
Habitat Diversity – Functional Groups	**1 Low**	**3 High**
Habitat Value	**4 Moderate-High**	**2 Moderate**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
Air temperature	**1 Low**	**2 Moderate**
Change in precipitation	**2 Low-Moderate**	**2 Moderate**
Change in salinity	**1 Low**	**3 High**
Increased erosion runoff	**4 Moderate-High**	**3 High**
Increased flooding	**2 Low-Moderate**	**1 Low**
Increased sea level rise	**2 Low-Moderate**	**2 Moderate**
Increased storminess	**4 Moderate-High**	**3 High**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Estuaries – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors	**Overall: 3 Moderate**	**Overall: 3 High**
- Air temperature	- **3 Moderate**	- **3 High**
- Sea surface temperature	- **4 Moderate-High**	- **3 High**
- Precipitation	- **4 Moderate-High**	- **3 High**
- Salinity	- **2 Low Moderate**	- **3 High**
- Oxygen	- **3 Moderate**	- **3 High**
- pH	- **3 Moderate**	- **3 High**
- Sea level rise	- **5 High**	- **3 High**
- Wave action	- **4 Moderate-High**	- **3 High**
- Currents/mixing/stratification	- **2 Low Moderate**	- **3 High**
- Coastal erosion	- **3 Moderate**	- **2 Moderate**
- Turbidity	- **2 Low-Moderate**	- **2 Moderate**
Disturbance Regimes	**Overall: 4 Moderate-High**	**Overall: 3 High**
- Storms	- **4 Moderate-High**	- **3 High**
- Disease	- **3 Moderate**	- **2 Moderate**
- Flooding	- **5 High**	- **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 5 High**	**Overall: 3 High**
- Land use change	- **5 High**	- **3 High**
- Overwater/underwater structures	- **4 Moderate-High**	- **3 High**
- Roads/armoring	- **4 Moderate-High**	- **3 High**
- Invasive & other problematic species	- **4 Moderate-High**	- **3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
	LOCAL	**REGIONAL**	
• Land use change	• **4 Moderate-High**	• **4 Moderate-High**	• **3 High**
• Overwater/underwater structures	• **4 Moderate-High**	• **4 Moderate-High**	• **3 High**
• Roads/armoring	• **4 Moderate-High**	• **Not Answered**	• **3 High**
• Invasive & other problematic species	• **4 Moderate-High**	• **4 Moderate-High**	• **3 High**
Other Sensitivities • Potential for restoration and resilience • Public attention and awareness of issue	**Overall: 5 High**		**Overall: 3 High**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	**Adaptive Capacity Evaluation**	**Confidence**
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**2 Low-Moderate (Somewhat degraded)**	**3 High**
Habitat Continuity	**2 Low-Moderate (Somewhat isolated and/or fragmented, i.e. patchy)**	**3 High**
Habitat Resistance	**1 Low**	**3 High**
Habitat Recovery	**4 Moderate-High**	**3 High**
Habitat Diversity – Physical/Topographical	**5 High**	**3 High**
Habitat Diversity – Component Species	**5 High**	**3 High**
Habitat Diversity – Functional Groups	**4 Moderate-High**	**2 Moderate**
Habitat Value	**4 Moderate-High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**1 Low**
Other Adaptive Capacities • Room to migrate	**Overall: 5 High**	**Overall: 3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 5 High**	**Overall: 3 High**
Increased air temperature	**4 Moderate-High**	**3 High**
Changes in precipitation	**5 High**	**3 High**
Increased sea surface temperature	**5 High**	**3 High**
Increased coastal erosion/runoff	**5 High**	**3 High**
Decreased pH	**3 Moderate**	**2 Moderate**
Increased flooding	**5 High**	**3 High**
Decreased oxygen	**3 Moderate**	**2 Moderate**
Sea level rise	**4 Moderate-High**	**2 Moderate**
Increased storminess	**5 High**	**3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Kelp Forests – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 2 Low-Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Air temperature • Sea surface temperature • Precipitation • Salinity • Oxygen • pH • Sea level rise • Wave action • Currents/mixing/stratification • Coastal erosion • Turbidity	**Overall: 3 Moderate** • **1 Low** • **4 Moderate-High** • **2 Low-Moderate** • **5 High** • **5 High** • **3 Moderate** • **2 Low-Moderate** • **5 High** • **2 Low-Moderate (local)** **4 Moderate-High (large scale)** • **1 Low (chronic)** **2 Low-Moderate (acute)** • **Not Answered**	**Overall: 3 High** • **3 High** • **3 High** • **2 Moderate** • **3 High** • **3 High** • **2 Moderate** • **1 Low** • **3 High** • **2 Moderate** • **2 Moderate** • **Not Answered**
Disturbance Regimes • Disease • Storms	**Overall: 4 Moderate-High** • **2 Low-Moderate** • **5 High**	**Overall: 2 Moderate** • **1 Low** • **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Harvest algae/kelp • Harvest grazers • Harvest mid-trophic level organisms • Pollution • Oil spills	**Overall: 3 Moderate** • **1 Low** • **2 Low-Moderate** • **1 Low** • **5 High** • **3 Moderate**	**Overall: 2 Moderate** • **3 High** • **2 Moderate** • **3 High** • **3 High** • **1 Low**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
	LOCAL	**REGIONAL**	
Harvest algae/lelp	**1 Low**	**1 Low**	**3 Moderate**
Harvest grazers	**3 Moderate**	**2 Low-Moderate**	**2 Moderate**
Harvest mid-trophic level organisms	**3 Moderate**	**3 Moderate**	**3 Moderate**
Pollution	**4 Moderate-High**	**1 Low**	**2 Moderate**
Oil spills	**1 Low**	**1 Low**	**1 Low**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**4 Moderate-High (Minor to moderate alterations)**	**3 High**
Habitat Continuity	**2 Low-Moderate (Somewhat isolated and/or fragmented, i.e. patchy)**	**3 High**
Habitat Resistance	**3 Moderate**	**2 Moderate**
Habitat Recovery	**4 Moderate-High**	**2 Moderate**
Habitat Diversity – Physical/Topographical	**5 High**	**3 High**
Habitat Diversity – Component Species	**5 High**	**3 High**
Habitat Diversity – Functional Groups	**5 High**	**3 High**
Habitat Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities • Nutrients	**Overall: 3 Moderate**	**Overall: 1 Low**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 3 High**
Sea surface temperature (chronic)	**1 Low**	**2 Moderate**
El Niño (increased sea surface temperature)	**2 Low-Moderate**	**1 Low**
Decreased dissolved oxygen	**2 Low-Moderate**	**1 Low**
Increased storminess	**5 High**	**3 High**
Decreased pH	**5 High**	**3 High**
Salinity	**1 Low**	**3 High**
Precipitation	**1 Low**	**3 High**
Flooding	**1 Low**	**3 High**
Sea level rise	**5 High**	**3 High**
Coastal erosion	**1 Low**	**3 High**
Currents/mixing	**4 Moderate-High**	**2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 3 High

Nearshore soft-bottom – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate

Overall Confidence[2]: 3 High

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation		Confidence
Sensitivities to Climate & Climate-Driven Factors	**Overall: 3 Moderate**		**Overall: 2 Moderate**
- Sea surface temperature	**3 Moderate**		**2 Moderate**
- Precipitation	**2 Low-Moderate**		**1 Low**
- Salinity	**2 Low-Moderate**		**2 Moderate**
- Oxygen	**2 Low-Moderate**		**2 Moderate**
- pH	**4 Moderate-High**		**2 Moderate**
- Wave action	**4 Moderate-High**		**3 High**
- Currents/mixing/stratification	**3 Moderate**		**1 Low**
- Coastal erosion	**5 High**		**3 High**
- Turbidity	**4 Moderate-High**		**2 Moderate**
Disturbance Regimes	**Overall: 3 Moderate**		**Overall: 3 High**
- Wind	**3 Moderate**		**2 Moderate**
- Disease	**3 Moderate**		**2 Moderate**
- Storms	**4 Moderate-High**		**3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 3 Moderate**		**Overall: 3 High**
- Pollution and poisons	**4 Moderate-High**		**3 High**
- Energy production	**1 Low**		**3 High**
- Transportation	**2 Low-Moderate**		**3 High**
- Land use change	**4 Moderate-High**		**3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
- Pollution and poisons	**4 Moderate-High**	**2 Low-Moderate**	**2 Moderate**
- Energy production	**2 Low-Moderate**	**1 Low**	**3 High**
- Transportation	**2 Low-Moderate**	**1 Low**	**3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
- Land use change	- **2 Low-Moderate**	- **1 Low**	- **2 Moderate**
Other Sensitivities - Sea temperature at depth and mid-column	**Overall: 3 Moderate**		**Overall: 2 Moderate**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High(Transcontinental)**	**3 High**
Structural & Functional Integrity	**4 Moderate-High (Minor to moderate alterations)**	**3 High**
Habitat Continuity	**5 High (Continuous)**	**3 High**
Habitat Resistance	**4 Moderate-High**	**3 High**
Habitat Recovery	**Not Answered**	**3 High**
Habitat Diversity – Physical/Topographical	**2 Low-Moderate**	**3 High**
Habitat Diversity – Component Species	**3 Moderate**	**3 High**
Habitat Diversity – Functional Groups	**3 Moderate**	**2 Moderate**
Habitat Value	**2 Low-Moderate**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Altered currents/mixing	• **2 Low-Moderate**	• **2 Moderate**
• Increased sea surface temperature gradient	• **4 Moderate-High**	• **2 Moderate**
• Increased coastal erosion and runoff	• **5 High**	• **3 High**
• Decreased pH	• **5 High**	• **3 High**
• Increased storminess	• **4 Moderate-High**	• **3 High**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 3 High

Offshore Rocky Reefs – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 2 Low-Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation		Confidence
Sensitivities to Climate & Climate-Driven Factors	**Overall: 3 Moderate**		**Overall: 2 Moderate**
• Sea surface temperature	• **1 Low**		• **1 Low**
• Oxygen	• **5 High**		• **3 High**
• pH	• **3 Moderate**		• **1 Low**
• Currents/mixing/stratification	• **3 Moderate**		• **2 Moderate**
Disturbance Regimes: none identified	**N/A**		**N/A**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 1 Low**		**Overall: 2 Moderate**
• Pollution	• **1 Low**		• **2 Moderate**
• Harvest (gear)	• **1 Low**		• **2 Moderate**
• Invasive species	• **3 Moderate**		• **2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**		**Overall: 2 Moderate**
	LOCAL	**REGIONAL**	
• Pollution	• **1 Low**	• **1 Low**	• **3 High**
• Harvest (gear)	• **1 Low**	• **2 Low-Moderate**	• **1 Low**
• Invasive species	• **1 Low**	• **2 Low-Moderate**	• **2 Moderate**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**3 Moderate (Distribution within single state to two states)**	**3 High**
Structural & Functional Integrity	**3 Moderate (Altered but not degraded)**	**3 High**
Habitat Continuity	**1 Low (Isolated and/or fragmented)**	**3 High**
Habitat Resistance	**Not Answered**	**Not Answered**
Habitat Recovery	**2 Low-Moderate**	**3 High**
Habitat Diversity – Physical/Topographical	**2 Low-Moderate**	**3 High**
Habitat Diversity – Component Species	**4 Moderate-High**	**3 High**
Habitat Diversity – Functional Groups	**4 Moderate-High**	**3 High**
Habitat Value	**4 Moderate-High**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Sea surface temperature • Oxygen • Decreased pH • Currents/mixing/stratification	**Overall: 2 Low-Moderate** • **1 Low** • **2 Low-Moderate** • **4 Moderate-High** • **2 Low-Moderate**	**Overall: 2 Moderate** • **1 Low** • **1 Low** • **3 High** • **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Pelagic Water Column – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Air temperature • Sea surface temperature • Precipitation • Salinity • Oxygen • pH • Currents/mixing/stratification • Turbidity • Upwelling	**Overall: 3 Moderate** • **2 Low-Moderate** • **3 Moderate** • **3 Moderate** • **1 Low** • **4 Moderate-High** • **4 Moderate-High** • **5 High** • **Not Answered** • **5 High**	**Overall: 3 High** • **2 Moderate** • **3 High** • **3 High** • **2 Moderate** • **3 High** • **2 Moderate** • **3 High** • **Not Answered** • **3 High**
Disturbance Regimes • Wind • Storms	**Overall: 5 High**	**Overall: 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Harvest • Pollution	**Overall: 1 Low** • **1 Low** • **1 Low**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor • Harvest • Pollution	**Overall: 1 Low** **LOCAL** • **1 Low** • **1 Low** **REGIONAL** • **2 Low-Moderate** • **1 Low**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate**
Other Sensitivities • Noise	**Overall: 3 Moderate**	**Overall: 1 Low**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**4 Moderate-High (Minor to moderate alterations)**	**3 High**
Habitat Continuity	**5 High (Continuous)**	**3 High**
Habitat Resistance	**Not Answered**	**Not Answered**
Habitat Recovery	**4 Moderate-High**	**3 High**
Habitat Diversity – Physical/Topographical	**1 Low**	**3 High**
Habitat Diversity – Component Species	**4 Moderate-High**	**3 High**
Habitat Diversity – Functional Groups	**4 Moderate-High**	**3 High**
Habitat Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Air temperature	• **5 High**	• **3 High**
• Sea temperature	• **5 High**	• **3 High**
• Precipitation	• **2 Low-Moderate**	• **3 High**
• Salinity	• **1 Low**	• **3 High**
• Oxygen	• **5 High**	• **3 High**
• pH	• **5 High**	• **3 High**
• Currents/mixing/stratification	• **5 High**	• **3 High**

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Exposure Factor	**Exposure Evaluation**	**Confidence**
- Upwelling	- **5 High**	- **3 High**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 3 High

Rocky Intertidal – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Air temperature	**• 5 High**	**• 3 High**
• Sea surface temperature	**• 3 Moderate**	**• 1 Low**
• Precipitation	**• 2 Low-Moderate**	**• 1 Low**
• Salinity	**• 5 High**	**• 2 Moderate**
• Oxygen	**• 2 Low-Moderate**	**• 1 Low**
• pH	**• 4 Moderate-High**	**• 1 Low**
• Sea level rise	**• 3 Moderate**	**• 2 Moderate**
• Wave action	**• 5 High**	**• 3 High**
• Currents/mixing/stratification	**• 3 Moderate**	**• 1 Low**
• Coastal erosion	**• 4 Moderate-High**	**• 1 Low**
Disturbance Regimes • Wind • Disease • Storms • Flooding • Extreme heat events	**Overall: 5 High**	**Overall: 2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 1 Low**
• Land use change	**• 3 Moderate**	**• 1 Low**
• Armoring	**• 4 Moderate-High**	**• 2 Moderate**
• Pollution/oil spills	**• 4 Moderate-High**	**• 1 Low**
• Harvest	**• 3 Moderate**	**• 1 Low**
• Recreation/trampling	**• 4 Moderate-High**	**• 1 Low**
• Invasives/species range expansions	**• 4 Moderate-High**	**• 2 Low**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
• Boat groundings	**• 3 Moderate**		**• 1 Low**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 4 Moderate-High**		**Overall: 2 Moderate**
	LOCAL	**REGIONAL**	
• Land use change	**• 2 Low-Moderate**	**• 1 Low**	**• 1 Low**
• Armoring	**• 5 High**	**• 1 Low**	**• 3 High**
• Pollution/oil spills	**• 4 Moderate-High**	**• 1 Low**	**• 1 Low**
• Harvest	**• 2 Low-Moderate**	**• 1 Low**	**• 1 Low**
• Recreation/trampling	**• 4 Moderate-High**	**• 1 Low**	**• 2 Moderate**
• Invasives/species range expansions	**• 4 Moderate-High**	**• 1 Low**	**• 1 Low**
• Boat groundings	**• 5 High**	**• 1 Low**	**• 3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 High (Transcontinental)**	**3 High**
Structural & Functional Integrity	**5 High (Pristine)**	**3 High**
Habitat Continuity	**3 Moderate (Patchy across an area with some connectivity among patches)**	**3 High**
Habitat Resistance	**2 Low-Moderate**	**2 Moderate**
Habitat Recovery	**5 High**	**3 High**
Habitat Diversity – Physical/Topographical	**4 Moderate-High**	**3 High**
Habitat Diversity – Component Species	**5 High**	**3 High**
Habitat Diversity – Functional Groups	**5 High**	**3 High**
Habitat Value	**4 Moderate-High**	**1 Low**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
Increased air temperature	**5 High**	**3 High**
Change in precipitation	**5 High**	**3 High**
Change in salinity	**5 High**	**2 Moderate**
Altered currents	**4 Moderate-High**	**1 Low**
Increased water temperature	**5 High**	**2 Moderate**
Increased erosion	**3 Moderate**	**2 Moderate**
Decreased pH	**5 High**	**3 High**
Increased flooding/runoff	**3 Moderate**	**2 Moderate**
Sea level rise	**5 High**	**3 High**
Increased storms	**3 Moderate**	**2 Moderate**
Decreased oxygen	**2 Low-Moderate**	**1 Low**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

American Dune Grass – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 3 Moderate**	**Overall: 3 High**
• Air temperature	**• 1 Low**	**• 1 Low**
• Precipitation	**• 2 Low-Moderate**	**• 2 Moderate**
• Sea Level Rise	**• 4 Moderate-High**	**• 3 High**
• Wave action	**• 4 Moderate-High**	**• 3 High**
• Coastal erosion	**• 4 Moderate-High**	**• 3 High**
• Other: Sediment Supply	**• 4 Moderate-High**	**• 3 High**
Disturbance Regimes • Storms	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Dependencies	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Dependence on sensitive habitat types o Dunes	**• 5 High**	**• 3 High**
• Dependence on specific prey or forage species	**• 1 Low**	**• 3 High**
• Other dependencies o Sediment supply to keep up with SLR	**• 5 High**	**• 2 Moderate**
• Generalist or specialist?	**• 5 (Specialist)**	**• 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Roads/armoring	**• 4 Moderate-High**	**• 3 High**
• Recreation	**• 3 Moderate**	**• 2 Moderate**
• Invasives	**• 5 High**	**• 3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
	LOCAL	**REGIONAL**	
- Roads/armoring	- **5 High**	- **3 Moderate**	- **3 High**
- Recreation	- **5 High**	- **2 Low-Moderate**	- **3 High**
- Invasives	- **5 High**	- **4 Moderate-High**	- **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**1 (Isolated and/or fragmented)**	**3 High**
Dispersal Ability	**2 Low-Moderate**	**2 Moderate**
Maximum Annual Dispersal Distance	**<1 km**	**1 Low**
Intraspecific/Life History Diversity	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
- Diversity of life history strategies	- **2 Low-Moderate**	- **2 Moderate**
- Genetic diversity	- **Not Answered**	- **Not Answered**
- Behavioral plasticity	- **N/A**	- **N/A**
- Phenotypic plasticity	- **3 Moderate**	- **1 Low**
Species Value	**1 Low**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 5 High**	**Overall: 3 High**
• Increased coastal erosion and runoff	**• 5 High**	**• 3 High**
• Increased storminess	**• 5 High**	**• 3 High**
• Sea level rise	**• 5 High**	**• 3 High**
• Sediment supply and movement	**• 5 High**	**• 3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Black Oyster Catcher – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Air temperature • Precipitation • Sea level rise • Wave action • Coastal erosion	**Overall: 4 Moderate-High** • **1 Low** • **4 Moderate-High** • **5 High** • **5 High** • **4 Moderate-High**	**Overall: 3 High** • **2 Moderate** • **3 High** • **3 High** • **3 High** • **2 Moderate**
Disturbance Regimes • Wind • Storms • Flooding	**Overall: 5 High**	**Overall: 3 High**
Dependencies • Dependence on sensitive habitat types o Rocky intertidal • Dependence on specific prey or forage species • Other dependencies: none identified • Generalist or specialist?	**Overall: 5 High** • **5 High** • **4 Moderate-High** • **N/A** • **5 (Specialist)**	**Overall: High** • **3 High** • **2 Moderate** • **N/A** • **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Pollution and poisons • Recreation	**Overall: 5 High** • **5 High** • **4 Moderate-High** • **5 High**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate** • **2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor • Not Answered	**Not Answered**	**Not Answered**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 5 High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**2 Moderate**
Dispersal Ability	**Unknown**	**1 Low**
Maximum Annual Dispersal Distance	**Not Answered**	**Not Answered**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 1 Low** • **1 Low** • **Not Answered** • **1 Low** • **Not Answered**	**Overall: 3 High** • **3 High** • **Not Answered** • **2 Moderate** • **Not Answered**
Species Value	**5 High**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Changes in precipitation • Increased coastal erosion and runoff • Increased flooding • Sea level rise • Increased storminess	**Overall: 5 High** • **4 Moderate-High** • **4 Moderate-High** • **5 High** • **5 High** • **5 High**	**Overall: 3 High** • **2 Moderate** • **2 Moderate** • **3 High** • **3 High** • **3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Black Rail – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Precipitation	• **3 Moderate**	• **2 Moderate**
• Salinity	• **4 Moderate-High**	• **3 High**
• Sea level rise	• **5 High**	• **3 High**
• Wave action	• **2 Low-Moderate**	• **3 High**
• Storm severity and frequency	• **4 Moderate-High**	• **3 High**
Disturbance Regimes	**Overall: 5 High**	**Overall: 2 Moderate**
• Storms		
• Flooding		
Dependencies	**Overall: 3 Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types	• **5 High**	• **3 High**
o Tidal marsh		
• Dependence on specific prey or forage species	• **2 Low-Moderate**	• **2 Moderate**
• Other dependencies: none identified	• **N/A**	• **N/A**
• Generalist or specialist?	• **3 (Both generalist and specialist characteristics)**	• **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Pollution and poisons	• **4 Moderate-High**	• **2 Moderate**
• Invasives	• **4 Moderate-High**	• **3 High**
• Predation	• **5 High**	• **3 High**
• Land use change	• **5 High**	• **3 High**
• Roads/armoring	• **3 Moderate**	• **3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 4 Moderate-High**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
• Pollution and poisons	• **3 Moderate**	• **3 Moderate**	• **2 Moderate**
• Invasives	• **2 Low-Moderate**	• **2 Low-Moderate**	• **3 High**
• Predation	• **5 High**	• **5 High**	• **3 High**
• Land use change	• **5 High**	• **5 High**	• **3 High**
• Roads/armoring	• **4 Moderate-High**	• **4 Moderate-High**	• **2 Moderate**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**2 (Moderate to large geographic region within a single state)**	**3 High**
Population Status	**1 (Endangered)**	**3 High**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**3 High**
Dispersal Ability	**2 Low-Moderate**	**2 Moderate**
Maximum Annual Dispersal Distance	**Not Answered**	**Not Answered**
Intraspecific/Life History Diversity	**Overall: 1 Low**	**Overall: 2 Moderate**
• Diversity of life history strategies	• **1 Low**	• **2 Moderate**
• Genetic diversity	• **Not Answered**	• **Not Answered**
• Behavioral plasticity	• **Not Answered**	• **Not Answered**
• Phenotypic plasticity	• **Not Answered**	• **Not Answered**
Species Value	**2 Low-Moderate**	**2 Moderate**

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Likelihood of Managing or Alleviating Climate Impacts	**4 Moderate-High**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 3 High**
• Changes in precipitation	• **1 Low**	• **2 Moderate**
• Changes in salinity	• **2 Low-Moderate**	• **3 High**
• Increased flooding	• **3 Moderate**	• **3 High**
• Sea level rise	• **3 Moderate**	• **3 High**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 3 High

Blue Rockfish – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Sea surface temperature	**• 3 Moderate**	**• 2 Moderate**
• Salinity	**• 4 Moderate-High**	**• 2 Moderate**
• Oxygen	**• 5 High**	**• 3 High**
• pH	**• 4 Moderate-High**	**• 1 Low**
• Dynamic ocean conditions (currents/mixing/stratification)	**• 2 Low-Moderate**	**• 2 Moderate**
• Other: Pacific Decadal Oscillation	**• 4 Moderate-High**	**• 3 High**
Disturbance Regimes • Storms • Disease	**Overall: 4 Moderate-High**	**Overall: 3 High**
Dependencies	**Overall: 3 Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types o Kelp forest o Nearshore	**• 4 Moderate-High**	**• 3 High**
• Dependence on specific prey or forage species	**• 2 Low-Moderate**	**• 3 High**
• Other dependencies o Lack of successful reproduction in El Niño years o Lack of recruitment with poor upwelling	**• 2 Low-Moderate**	**• 3 High**
• Generalist or specialist?	**• 3 (Both generalist and specialist characteristics)**	**• 3 High**

---

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 3 Moderate**		**Overall: 3 High**
• Harvest	**• 4 Moderate-High**		**• 3 High**
• Energy production	**• 3 Moderate**		**• 2 Moderate**
• Pollution and poisons	**• 3 Moderate**		**• 2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**		**Overall: 1 Low**
	LOCAL	**REGIONAL**	
• Harvest	**• 5 High**	**• 3 Moderate**	**• 3 High**
• Energy production	**• 1 Low**	**• 1 Low**	**• 1 Low**
• Pollution and poisons	**• 1 Low**	**• 2 Low-Moderate**	**• 1 Low**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**4 (Stable population at abundant levels)**	**3 High**
Population Connectivity	**5 (Continuous)**	**3 High**
Dispersal Ability	**4 Moderate-High**	**3 High**
Maximum Annual Dispersal Distance	**75-100 km**	**2 Moderate**

---

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Intraspecific/Life History Diversity - Diversity of life history strategies - Genetic diversity - Behavioral plasticity - Phenotypic plasticity	**Overall: 3 Moderate** - **3 Moderate** - **4 Moderate-High** - **3 Moderate** - **3 Moderate**	**Overall: 2 Moderate** - **3 High** - **2 Moderate** - **1 Low** - **2 Moderate**
Species Value	**4 Moderate-High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**1 Low**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors - Changes in sea surface temperature - Decreased dissolved oxygen - Changes in salinity - Decreased pH - Increased storminess - El Niño events	**Overall: 3 Moderate** - **2 Low-Moderate** - **1 Low** - **1 Low** - **3 Moderate** - **4 Moderate-High** - **5 High**	**Overall: 2 Moderate** - **2 Moderate** - **2 Moderate** - **2 Moderate** - **3 High** - **3 High** - **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Blue Whale – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Sensitivities to Climate & Climate-Driven Changes
• Sea surface temperature
• Dynamic ocean conditions (currents/mixing/stratification)</td><td colspan="2">Overall: 2 Low-Moderate
• 2 Low-Moderate
• 2 Low-Moderate</td><td>Overall: 1 Low
• 2 Moderate
• 1 Low</td></tr>
<tr><td>Disturbance Regimes: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td>Dependencies
• Dependence on sensitive habitat types
  o Continental shelf
• Dependence on specific prey or forage species
• Other dependencies
  o Less offspring in unfavorable conditions
• Generalist or specialist?</td><td colspan="2">Overall: 4 Moderate-High
• 2 Low-Moderate

• 5 High
• 3 Moderate

• 5 (Specialist)</td><td>Overall: 3 High
• 3 High

• 3 High
• 3 High

• 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Pollution and poisons
• Human interactions
• Anthropogenic noise</td><td colspan="2">Overall: 5 High

• 5 High
• 5 High
• 5 High</td><td>Overall: 3 High

• 3 High
• 3 High
• 3 High</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor

• Pollution and poisons
• Human interactions
• Anthropogenic noise</td><td colspan="2">Overall: 5 High</td><td rowspan="2">Overall: 3 High

• 3 High
• 3 High
• 3 High</td></tr>
<tr><td>LOCAL
• 5 High
• 5 High
• 5 High</td><td>REGIONAL
• 5 High
• 5 High
• 5 High</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**1 (Endangered)**	**3 High**
Population Connectivity	**Not Answered**	**Not Answered**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**>100 km**	**Not Answered**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Not Answered**	**Not Answered**
Species Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Changes in sea surface temperature • Altered currents and mixing	**Overall: 5 High** • **5 High** • **5 High**	**Overall: 2 Moderate** • **3 High** • **1 Low**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

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[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

California Hydrocoral and Red Sponge – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
Sensitivities to Climate & Climate-Driven Changes	**Overall: 3 Moderate**		**Overall: 1 Low**
• Oxygen	**3 Moderate**		**1 Low**
• pH	**3 Moderate**		**1 Low**
• Dynamic ocean conditions (currents/mixing/stratification)	**4 Moderate-High**		**3 High**
Disturbance regimes: none identified	**N/A**		**N/A**
Dependencies	**Overall: 3 Moderate**		**Overall: 2 Moderate**
• Dependence on sensitive habitat types o Rocky substrate	**5 High**		**3 High**
• Dependence on specific prey or forage species	**2 Low-Moderate**		**2 Moderate**
• Other dependencies: none identified	**N/A**		**N/A**
• Generalist or specialist?	**3 (Both generalist and specialist characteristics)**		**1 Low**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 5 High**		**Overall: 3 High**
• Pollution and poisons	**4 Moderate-High**		**3 High**
• Harvest	**4 Moderate-High**		**3 High**
• Invasive species	**5 High**		**3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
• Pollution and poisons	**1 Low**	**1 Low**	**3 High**
• Harvest	**2 Low-Moderate**	**2 Low-Moderate**	**2 Moderate**
• Invasive species	**1 Low**	**1 Low**	**2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**3 (Distribution within single state to two states)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**3 (Patchy across an area with some connectivity among patches)**	**2 Moderate**
Dispersal Ability	**4 Moderate-High**	**3 High**
Maximum Annual Dispersal Distance	**Not Answered**	**Not Answered**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Not Answered**	**Not Answered**
Species Value	**4 Moderate-High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 3 Moderate**	**Overall: 3 High**
• Changes in sea surface temperature	**• 3 Moderate**	**• 3 High**
• Decreased pH	**• 4 Moderate-High**	**• 3 High**
• Altered currents and mixing	**• 3 Moderate**	**• 3 High**
• Decreased dissolved oxygen	**• 2 Low-Moderate**	**• 1 Low**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 3 High

California Mussel – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Air temperature	**• 5 High**	**• 3 High**
• Sea surface temperature	**• 3 Moderate**	**• 1 Low**
• Precipitation	**• 2 Low-Moderate**	**• 1 Low**
• Salinity	**• 5 High**	**• 2 Moderate**
• Oxygen	**• 2 Low-Moderate**	**• 1 Low**
• pH	**• 4 Moderate-High**	**• 1 Low**
• Sea level rise	**• 3 Moderate**	**• 2 Moderate**
• Wave action	**• 5 High**	**• 3 High**
• Dynamic ocean conditions (currents/mixing/stratification)	**• 3 Moderate**	**• 1 Low**
• Coastal erosion	**• 4 Moderate-High**	**• 1 Low**
Disturbance Regimes	**Overall: 5 High**	**Overall: 2 Moderate**
• Wind		
• Disease		
• Storms		
• Flooding		
• Extreme heat events		

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Dependencies	**Overall: 2 Low-Moderate**		**Overall: 3 High**
• Dependence on sensitive habitat types	**• 1 Low**		**• 3 High**
• Dependence on specific prey or forage species	**• 1 Low**		**• 3 High**
• Other dependencies o Mid-intertidal height of exposed rocky shores	**• 5 High**		**• 3 High**
• Generalist or specialist?	**• 3 (Both generalist and specialist characteristics)**		**• 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**		**Overall: 1 Low**
• Land use change	**• 3 Moderate**		**• 1 Low**
• Armoring	**• 4 Moderate-High**		**• 2 Moderate**
• Pollution and poisons	**• 4 Moderate-High**		**• 1 Low**
• Harvest	**• 3 Moderate**		**• 1 Low**
• Recreation	**• 4 Moderate-High**		**• 1 Low**
• Invasive species	**• 4 Moderate-High**		**• 2 Moderate**
• Boat groundings	**• 3 Moderate**		**• 1 Low**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**		**Overall: 2 Moderate**
	LOCAL	**REGIONAL**	
• Land use change	**• 2 Low-Moderate**	**• 1 Low**	**• 1 Low**
• Armoring	**• 5 High**	**• 1 Low**	**• 3 High**
• Pollution/oil spills	**• 4 Moderate-High**	**• 1 Low**	**• 1 Low**
• Harvest	**• 2 Low-Moderate**	**• 1 Low**	**• 1 Low**
• Recreation/trampling	**• 4 Moderate-High**	**• 1 Low**	**• 2 Moderate**
• Invasives/species range expansions	**• 4 Moderate-High**	**• 1 Low**	**• 1 Low**
• Boat groundings	**• 5 High**	**• 1 Low**	**• 3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**5 (Continuous)**	**3 High**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**50-100 km**	**3 High**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **1 Low** • **4 Moderate-High** • **1 Low** • **3 Moderate**	**Overall: 3 High** • **3 High** • **3 High** • **3 High** • **3 High**
Species Value	**3 Moderate**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Changes in air temperature	• **5 High**	• **3 High**
• Changes in precipitation	• **5 High**	• **3 High**
• Changes in salinity	• **5 High**	• **2 Moderate**
• Altered currents and mixing	• **4 Moderate-High**	• **1 Low**
• Changes in sea surface temperature	• **5 High**	• **2 Moderate**
• Increased coastal erosion and runoff	• **2 Low-Moderate**	• **2 Moderate**
• Decreased pH	• **5 High**	• **3 High**
• Increased flooding	• **3 Moderate**	• **2 Moderate**
• Sea level rise	• **5 High**	• **3 High**
• Increased storminess	• **3 Moderate**	• **2 Moderate**
• Decreased dissolved oxygen	• **2 Low-Moderate**	• **1 Low**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Cassin's Auklet – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Air temperature	**• 1 Low**	**• 2 Moderate**
• Sea surface temperature	**• 3 Moderate**	**• 3 High**
• Precipitation	**• 1 Low**	**• 3 High**
• Salinity (for prey species)	**• 2 Low-Moderate**	**• 1 Low**
• Oxygen (for prey species)	**• 2 Low-Moderate**	**• 1 Low**
• pH (for prey species)	**• 2 Low-Moderate**	**• 1 Low**
• Sea level rise	**• 2 Low-Moderate**	**• 3 High**
• Wave action	**• 1 Low**	**• 2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	**• 3 Moderate**	**• 2 Moderate**
• Coastal erosion	**• 2 Low-Moderate**	**• 2 Moderate**
• Other: Extreme Weather Events	**• 4 Moderate-High**	**• 3 High**
Disturbance Regimes • Disease • Storms • Flooding • Drought	**Overall: 4 Moderate-High**	**Overall: 3 High**
Dependencies	**Overall: 5 High**	**Overall: 3 High**
• Dependence on sensitive habitat types		
o Breeding habitat (offshore, predator-free islands)	**• 5 High**	**• 3 High**
o Feeding habitat (mid-water pelagic)	**• 2 Low-Moderate[3]**	**• 3 High**
• Dependence on specific prey or forage species	**• 4.5 High[4]**	**• 3 High**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Average of two submitted scores (1,3).
[4] Average of two submitted scores (4,5).

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>o Availability of krill</td><td colspan="2"></td><td></td></tr>
<tr><td>- Other dependencies</td><td colspan="2">- 5 High</td><td>- 3 High</td></tr>
<tr><td>o Timing of breeding</td><td colspan="2"></td><td></td></tr>
<tr><td>- Generalist or specialist?</td><td colspan="2">- 4 (Mostly specialist)</td><td>- 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity</td><td colspan="2">Overall: 2 Low-Moderate</td><td>Overall: 2 Moderate</td></tr>
<tr><td>- Fisheries</td><td colspan="2">- 2 Low-Moderate</td><td>- 1 Low</td></tr>
<tr><td>- Pollution</td><td colspan="2">- 1 Low</td><td>- 2 Moderate</td></tr>
<tr><td>- Oil spills</td><td colspan="2">- 5 High</td><td>- 3 High</td></tr>
<tr><td>- Invasives (rodents)</td><td colspan="2">- 5 High</td><td>- 3 High</td></tr>
<tr><td>- Invasives (plants)</td><td colspan="2">- 1 Low</td><td>- 1 Low</td></tr>
<tr><td>- Energy production</td><td colspan="2">- 2 Low-Moderate</td><td>- 3 High</td></tr>
<tr><td>- Researcher disturbance</td><td colspan="2">- 1 Low</td><td>- 2 Moderate</td></tr>
<tr><td>- Land use change</td><td colspan="2">- 2 Low-Moderate</td><td>- 3 High</td></tr>
<tr><td>Non-Climate Stressors – Current Exposure to Stressor</td><td colspan="2">Overall: 1 Low</td><td>Overall: 3 High</td></tr>
<tr><td></td><td>LOCAL</td><td>REGIONAL</td><td></td></tr>
<tr><td>- Fisheries</td><td>- 2 Low-Moderate</td><td>- 2 Low-Moderate</td><td>- 1 Low</td></tr>
<tr><td>- Pollution</td><td>- 1 Low</td><td>- 1 Low</td><td>- 2 Moderate</td></tr>
<tr><td>- Oil spills</td><td>- 2 Low-Moderate</td><td>- 2 Low-Moderate</td><td>- 3 High</td></tr>
<tr><td>- Invasives (rodents)</td><td>- 1 Low</td><td>- 1 Low</td><td>- 3 High</td></tr>
<tr><td>- Invasives (plants)</td><td>- 2 Low-Moderate</td><td>- Not Answered</td><td>- 3 High</td></tr>
<tr><td>- Energy production</td><td>- 1 Low</td><td>- 1 Low</td><td>- 3 High</td></tr>
<tr><td>- Researcher disturbance</td><td>- 1 Low</td><td>- Not Answered</td><td>- 2 Moderate</td></tr>
<tr><td>- Land use change</td><td>- 1 Low</td><td>- 1 Low</td><td>- 3 High</td></tr>
<tr><td>Other Sensitivities</td><td colspan="2">Overall: 5 High</td><td>Overall: 3 High</td></tr>
<tr><td>- Climate impacts on krill and copepods</td><td colspan="2">- 5 High</td><td>- 3 High</td></tr>
<tr><td>- El Niño, major basin-scale oceanographic change</td><td colspan="2">- 4 Moderate-High</td><td>- 3 High</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[5]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[6]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**4.5 (Transcontinental)[7]**	**3 High**
Population Status	**3 (Diminished but generally stable)[8]**	**3 High**
Population Connectivity	**3.5 (Almost continuous)[9]**	**3 High**
Dispersal Ability	**3.5 Moderate-High[9]**	**2 Moderate**
Maximum Annual Dispersal Distance	**>100 km**	**3 High**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 3 Moderate** • **3.5 Moderate-High[9]** • **2.5 Moderate[10]** • **3 Moderate[8]** • **3 Moderate[8]**	**Overall: 3 High** • **3 High** • **2 Moderate[11]** • **2.5 High[10]** • **2.5 High[10]**
Species Value	**1.5 Low-Moderate[12]**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[5]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[6]: 3 High

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[5] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[6] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.
[7] Average of two submitted scores (4,5).
[8] Average of two submitted scores (2,4).
[9] Average of two submitted scores (3,4).
[10] Average of two submitted scores (2,3).
[11] Average of two submitted scores (1,3).
[12] Average of two submitted scores (1,2).

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Changes in air temperature	• **3 Moderate**	• **2 Moderate**
• Changes in precipitation	• **2 Low-Moderate**	• **2 Moderate**
• Changes in salinity	• **3 Moderate**	• **2 Moderate**
• Altered currents and mixing	• **4 Moderate-High**	• **2 Moderate**
• Changes in sea surface temperature	• **3 Moderate**	• **2 Moderate**
• Increased coastal erosion and run-off	• **2 Low-Moderate**	• **2 Moderate**
• Decreased pH	• **3 Moderate**	• **2 Moderate**
• Increased flooding	• **2 Low-Moderate**	• **2 Moderate**
• Decreased dissolved oxygen	• **3 Moderate**	• **2 Moderate**
• Sea level rise	• **1 Low**	• **2 Moderate**
• Increased storminess	• **2 Low-Moderate**	• **2 Moderate**

Overall Averaged Ranking (Exposure)[5]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[6]: 2 Moderate

Cavity Nesters: Ashy Storm Petrel (ASSP), Tufted Puffin (TUPU), Pigeon Guillemot (PIGU) – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate (TUPU, PIGU), 4 Moderate-High (ASSP) **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Air temperature	• **2 Low-Moderate**	• **2 Moderate**
• Sea surface temperature	• **3 Moderate**	• **2 Moderate**
• Precipitation	• **1 Low**	• **2 Moderate**
• Salinity	• **2 Low-Moderate**	• **1 Low**
• Oxygen	• **2 Low-Moderate**	• **1 Low**
• pH	• **2 Low-Moderate**	• **1 Low**
• Sea level rise	• **1 Low**	• **3 High**
• Wave action	• **1 Low**	• **2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	• **3 Moderate**	• **2 Moderate**
• Coastal erosion	• **2 Low-Moderate**	• **2 Moderate**
• Extreme weather conditions	• **5 High**	• **3 High**
Disturbance Regimes • Disease • Storms • Flooding • Drought • Interspecific disturbance	**Overall: 5 High**	**Overall: 3 High**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**	**Confidence**
Dependencies	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Dependence on sensitive habitat types o ASSP: Pelagic, surface o TUPU: Pelagic, offshore foraging o PIGU: Benthic, nearshore	• **Breeding habitat: 5 High; Feeding habitat: 3 Moderate**	• **3 High**
• Dependence on specific prey or forage species	• **3 Moderate**	• **3 High**
• Other dependencies o Timing of breeding o Foraging availability	• **5 High**	• **3 High**
• Generalist or specialist?	• **3 (Both generalist and specialist characteristics)**	• **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Aircraft/vessels	• **3 Moderate**	• **3 High**
• Land use change	• **2 Low-Moderate**	• **3 High**
• Pollution and poisons	• **5 High**	• **3 High**
• Harvest	• **3 Moderate**	• **3 High**
• Energy production	• **2 Low-Moderate**	• **3 High**
• Recreation	• **4 Moderate-High**	• **3 High**
• Invasive Species	• **5 High**	• **3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**	**Overall: 3 High**

Sensitivity Factor	Sensitivity Evaluation		Confidence
	LOCAL	**REGIONAL**	
- Aircraft/vessels	- **3 Moderate**	- **2 Low-Moderate**	- **3 High**
- Land use change	- **2 Low-Moderate**	- **1 Low**	- **3 High**
- Pollution and poisons	- **2 Low-Moderate**	- **2 Moderate**	- **3 High**
- Harvest	- **1 Low**	- **1 Low**	- **3 High**
- Energy production	- **1 Low**	- **1 Low**	- **3 High**
- Recreation	- **2 Low-Moderate**	- **1 Low**	- **3 High**
- Invasive Species	- **1 Low**	- **1 Low**	- **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent		
o ASSP	- **2 (Moderate to large geographic region within a single state)**	- **3 High**
o TUPU	- **5 (Transcontinental)**	- **3 High**
o PIGU	- **5 (Transcontinental)**	- **3 High**
Population Status		
o ASSP	- **2 (Threatened)**	- **3 High**
o TUPU	- **5 (Healthy and/or expanding)**	- **3 High**
o PIGU	- **5 (Healthy and/or expanding)**	- **3 High**

---

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Population Connectivity		**Not Answered**
ASSP	**2 (Somewhat isolated and/or fragmented)**	
TUPU	**5 (Continuous)**	
PIGU	**5 (Continuous)**	
Dispersal Ability	**Not Answered**	**Not Answered**
Maximum Annual Dispersal Distance	**Not Answered**	**Not Answered**
Intraspecific/Life History Diversity	**Overall: 2 Low-Moderate**	**Overall: 3 High**
Diversity of life history strategies		
ASSP	**1 Low**	**3 High**
TUPU	**2 Low-Moderate**	
PIGU	**3 Moderate**	
Genetic diversity		
ASSP	**3 Moderate**	**1 Low**
TUPU	**3 Moderate**	
PIGU	**3 Moderate**	
Behavioral plasticity		
ASSP	**2 Low-Moderate**	**2 Moderate**
TUPU	**2 Low-Moderate**	
PIGU	**2 Low-Moderate**	
Phenotypic plasticity		
ASSP	**1 Low**	**2 Moderate**
TUPU	**2 Low-Moderate**	
PIGU	**2 Low-Moderate**	
Species Value		
ASSP	**1 Low**	**3 High**
TUPU	**4 Moderate-High**	**3 High**
PIGU	**2 Low-Moderate**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 1 Low (ASSP); 3 Moderate (TUPU and PIGU)

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Changes in air temperature	• **2 Low-Moderate**	• **2 Moderate**
• Changes in precipitation	• **2 Low-Moderate**	• **2 Moderate**
• Changes in salinity	• **3 Moderate**	• **2 Moderate**
• Altered currents/mixing	• **4 Moderate-High**	• **2 Moderate**
• Changes in sea surface temperature	• **3 Moderate**	• **2 Moderate**
• Increased coastal erosion & runoff	• **2 Low-Moderate**	• **2 Moderate**
• Decreased pH	• **3 Moderate**	• **2 Moderate**
• Increased flooding	• **2 Low-Moderate**	• **2 Moderate**
• Decreased dissolved oxygen	• **3 Moderate**	• **2 Moderate**
• Sea level rise	• **1 Low**	• **2 Moderate**
• Increased storminess	• **3 Moderate**	• **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Boreal Copepods – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Sensitivities to Climate & Climate-Driven Changes
• Sea surface temperature
• Salinity
• Dynamic ocean conditions (currents/mixing/stratification)</td><td colspan="2">Overall: 4 Moderate-High
• 4 Moderate-High
• 4 Moderate-High
• 4 Moderate-High</td><td>Overall: 3 High
• 3 High
• 3 High
• 3 High</td></tr>
<tr><td>Disturbance Regimes
• Wind</td><td colspan="2">Overall: 4 Moderate-High</td><td>Overall: 3 High</td></tr>
<tr><td>Dependencies
• Dependence on sensitive habitat types
• Dependence on specific prey or forage species
• Other dependencies
o Ability to go into diapause
• Generalist or specialist?</td><td colspan="2">Overall: 1 Low
• 1 Low
• 1 Low
• 2 Low-Moderate
• 2 (Mostly generalist)</td><td>Overall: 2 Moderate
• 3 High
• 1 Low
• 2 Moderate
• 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Pollution and poisons</td><td colspan="2">Overall: 1 Low
• 1 Low</td><td>Overall: 3 High
• 3 High</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor
• Pollution and poisons</td><td colspan="2">Overall: 1 Low</td><td rowspan="2">Overall: 3 High
• 3 High</td></tr>
<tr><td>LOCAL
• 1 Low</td><td>REGIONAL
• 1 Low</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**3 (Distribution within single state to two states)**	**1 Low**
Population Status	**4 (Stable population at abundant levels)**	**1 Low**
Population Connectivity	**5 (Continuous)**	**1 Low**
Dispersal Ability	**5 High**	**1 Low**
Maximum Annual Dispersal Distance	**>100 km**	**1 Low**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate** • **3 Moderate**	**Overall: 1 Low** • **1 Low** • **1 Low** • **2 Moderate** • **2 Moderate**
Species Value	**1 Low**	**1 Low**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 1 Low

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Altered currents and mixing • Changes in salinity • Changes in sea surface temperature	**Overall: 5 High** • **5 High** • **5 High** • **5 High**	**Overall: 3 High** • **3 High** • **3 High** • **3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Coralline Algae – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]**: 3 Moderate** **Overall Confidence**[2]**: 3 High**

SENSITIVITY

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Sensitivities to Climate & Climate-Driven Changes
• Air temperature
• Sea surface temperature
• Precipitation
• Salinity
• pH
• Coastal erosion</td><td colspan="2">Overall: 3 Moderate
• 4 Moderate-High
• 4 Moderate-High
• 1 Low
• 2 Low-Moderate
• 4 Moderate-High
• 2 Low-Moderate</td><td>Overall: 3 High
• 3 High
• 3 High
• 3 High
• 1 Low
• 2 Moderate
• 3 High</td></tr>
<tr><td>Disturbance Regimes
• Storms</td><td colspan="2">Overall: 1 Low</td><td>Overall: 2 Moderate</td></tr>
<tr><td>Dependencies
• Dependence on sensitive habitat types
  o Rocky substrate
• Dependence on specific prey or forage species
• Other dependencies
  o Presence of grazers of competing algae
• Generalist or specialist?</td><td colspan="2">Overall: 3 Moderate
• 5 High

• 1 Low
• 4 Moderate-High

• 1 (Generalist)</td><td>Overall: 3 High
• 3 High

• 3 High
• 3 High

• 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Nutrient pollution</td><td colspan="2">Overall: 2 Low-Moderate
• 2 Low-Moderate</td><td>Overall: 2 Moderate
• 2 Moderate</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor
• Nutrient pollution</td><td colspan="2">Overall: 2 Low-Moderate</td><td rowspan="2">Overall: 3 High
• 3 High</td></tr>
<tr><td>LOCAL
• 3 Moderate</td><td>REGIONAL
• 1 Low</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Overall Averaged Ranking (Sensitivity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**2 (Somewhat isolated/fragmented)**	**2 Moderate**
Dispersal Ability	**1 Low**	**2 Moderate**
Maximum Annual Dispersal Distance	**1-5 km**	**2 Moderate**
Intraspecific/Life History Diversity • Diversity of life history strategies • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **3 Moderate** • **1 Low** • **2 Low-Moderate**	**Overall: 3 High** • **2 Low-Moderate** • **3 Moderate** • **2 Moderate**
Species Value	**1 Low**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Changes in air temperature • Changes in sea surface temperature • Decreased pH	**Overall: 3 Moderate** • **1 Low** • **3 Moderate** • **5 High**	**Overall: 3 High** • **3 High** • **2 Moderate** • **3 High**

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 3 High

Gaper Clam – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Air temperature	**• 3 Moderate**	**• 2 Moderate**
• Sea surface temperature	**• 4 Moderate-High**	**• 2 Moderate**
• Precipitation	**• 4 Moderate-High**	**• 2 Moderate**
• Salinity	**• 2 Low-Moderate**	**• 2 Moderate**
• Oxygen	**• 3 Moderate**	**• 2 Moderate**
• pH	**• 4 Moderate-High**	**• 2 Moderate**
• Wave action	**• 3 Moderate**	**• 2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	**• 2 Low-Moderate**	**• 2 Moderate**
• Coastal erosion	**• 4 Moderate-High**	**• 2 Moderate**
Disturbance Regimes • Disease • Storms • Flooding	**Overall: 3 Moderate**	**Overall: 1 Low**
Dependencies	**Overall: 3 Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types o Soft-bottom subtidal o Estuaries	**• 5 High**	**• 3 High**
• Dependence on specific prey or forage species	**• 1 Low**	**• 3 High**
• Other dependencies: none identified	**• N/A**	**• N/A**
• Generalist or specialist?	**• 2 (Mostly generalist)**	**• 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 3 Moderate**		**Overall: 1 Low**
• Harvest	**3 Moderate**		**1 Low**
• Recreation	**2 Low-Moderate**		**1 Low**
• Dredging	**3 Moderate**		**1 Low**
• Overwater/underwater structures	**3 Moderate**		**1 Low**
• Pollutions and poisons	**5 High**		**2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 3 Moderate**		**Overall: 1 Low**
	LOCAL	**REGIONAL**	
• Harvest	**4 Moderate-High**	**4 Moderate-High**	**1 Low**
• Recreation	**2 Low-Moderate**	**2 Low-Moderate**	**1 Low**
• Dredging	**3 Moderate**	**3 Moderate**	**1 Low**
• Overwater/underwater structures	**3 Moderate**	**2 Low-Moderate**	**1 Low**
• Pollutions and poisons	**2 Low-Moderate**	**2 Low-Moderate**	**2 Moderate**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**4 (Stable population at abundant levels)**	**2 Moderate**
Population Connectivity	**4 (Almost continuous)**	**2 Moderate**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**2 Low-Moderate**	**2 Moderate**
Maximum Annual Dispersal Distance	**Not Answered**	**Not Answered**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 1 Low** • **2 Low-Moderate** • **3 Moderate** • **1 Low** • **1 Low**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate** • **2 Moderate** • **1 Low**
Species Value	**3 Moderate**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Decreased pH • Decreased dissolved oxygen • Changes in sea surface temperature • Changes in air temperature • Increased coastal erosion and runoff • Increased flooding • Changes in precipitation • Changes in salinity • Increased storminess	**Overall: 4 Moderate** • **4 Moderate-High** • **4 Moderate-High** • **4 Moderate-High** • **5 High** • **5 High** • **4 Moderate-High** • **4 Moderate-High** • **4 Moderate-High** • **3 Moderate**	**Overall: 2 Moderate** • **2 Moderate** • **3 High** • **3 High** • **3 High** • **2 Moderate** • **2 Moderate** • **2 Moderate** • **2 Moderate** • **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Krill – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 2 Low-Moderate

Overall Confidence[2]: 3 High

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Sea surface temperature • Dynamic ocean conditions (currents/mixing/stratification)	**Overall: 2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate**
Disturbance Regimes • Wind	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Dependencies • Dependence on sensitive habitat types • Dependence on specific prey or forage species • Other dependencies: none identified • Generalist or specialist?	**Overall: 1 Low** • **1 Low** • **1 Low** • **N/A** • **2 (Mostly generalist)**	**Overall: 3 High** • **3 High** • **2 Moderate** • **N/A** • **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Pollution and poisons	**Overall: 1 Low** • **1 Low**	**Overall: 3 High** • **3 High**
Non-Climate Stressors – Current Exposure to Stressor • Pollution and poisons	**Overall: 1 Low** **LOCAL** • **1 Low** **REGIONAL** • **1 Low**	**Overall: 3 High** • **3 High**
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 1 Low

Overall Averaged Confidence (Sensitivity)[4]: 3 High

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**4 (Stable population at abundant levels)**	**2 Moderate**
Population Connectivity	**5 (Continuous)**	**1 Low**
Dispersal Ability	**5 High**	**1 Low**
Maximum Annual Dispersal Distance	**25+ km**	**1 Low**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Not Answered**	**Not Answered**
Species Value	**2 Low-Moderate**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Altered currents and mixing • Changes in salinity • Changes in sea surface temperature	**Overall: 5 High** • **5 High** • **5 High** • **5 High**	**Overall: 3 High** • **3 High** • **3 High** • **3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Mole Crab – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	**Sensitivity Evaluation**	**Confidence**
Sensitivities to Climate & Climate-Driven Changes	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Sea surface temperature	• **1 Low**	• **2 Moderate**
• Precipitation	• **3 Moderate**	• **2 Moderate**
• Salinity	• **5 High**	• **3 High**
• pH	• **3 Moderate**	• **2 Moderate**
• Sea level rise	• **2 Low-Moderate**	• **1 Low**
• Dynamic ocean conditions (currents/mixing/stratification)	• **2 Low-Moderate**	• **1 Low**
• Coastal erosion	• **3.5 Moderate-High[3]**	• **2 Moderate**
• Harmful algal blooms	• **2 Low-Moderate**	• **1 Low**
Disturbance Regimes	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Storms		
• Flooding		
Dependencies	**Overall: 1 Low**	**Overall: 3 High**
• Dependence on sensitive habitat types	• **1 Low**	• **3 High**
• Dependence on specific prey or forage species	• **1 Low**	• **3 High**
• Other dependencies	• **3 Moderate**	• **2 Moderate**
o Reproductive dependency		
• Generalist or specialist?	• **1 (Generalist)**	• **3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

[3] Average of two submitted scores (5, 2)

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Pollution and poisons
• Roads/armoring
• Land use change</td><td colspan="2">Overall: 3 Moderate
• 2 Low-Moderate
• 3 Moderate
• 5 High</td><td>Overall: 3 High
• 2 Moderate
• 2 Moderate
• 3 High</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor
• Pollution and poisons
• Roads/armoring
• Land use change</td><td colspan="2">Overall: 1 Low</td><td rowspan="2">Overall: 2 Moderate
• 2 Moderate
• 2 Moderate
• Not Answered</td></tr>
<tr><td>LOCAL
• 2 Low-Moderate
• 1 Low
• Not Answered</td><td>REGIONAL
• 1 Low
• 1 Low
• Not Answered</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[4]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[5]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**5 (Continuous)**	**3 High**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**Unknown**	**N/A**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 3 Moderate** • **3 Moderate** • **3 Moderate** • **2 Low-Moderate** • **4 Moderate-High**	**Overall: 1 Low** • **2 Moderate** • **1 Low** • **1 Low** • **1 Low**

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[4] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[5] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Species Value	**1 Low**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**1 Low**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[4]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[5]: 2 Moderate

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EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 5 High**	**Overall: 3 High**
• Increased coastal erosion and runoff	• **5 High**	• **3 High**
• Decreased pH	• **5 High**	• **3 High**
• Sea level rise	• **5 High**	• **3 High**
• Changes in sea surface temperature	• **5 High**	• **3 High**
• Changes in precipitation	• **5 High**	• **3 High**
• Changes in salinity	• **5 High**	• **3 High**
• Increased storminess	• **5 High**	• **3 High**
• Altered currents and mixing	• **5 High**	• **3 High**
• Increased flooding	• **3 Moderate**	• **2 Moderate**

Overall Averaged Ranking (Exposure)[4]: 5 High

Overall Averaged Confidence (Exposure)[5]: 3 High

Northern Anchovy – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Air temperature	• **2 Low-Moderate**	• **2 Moderate**
• Sea surface temperature	• **5 High**	• **3 High**
• Precipitation	• **2 Low-Moderate**	• **2 Moderate**
• Salinity	• **3 Moderate**	• **2 Moderate**
• Oxygen	• **4 Moderate-High**	• **3 High**
• pH	• **4 Moderate-High**	• **1 Low**
• Dynamic ocean conditions (currents/mixing/stratification)	• **5 High**	• **3 High**
• Coastal erosion	• **3 Moderate**	• **1 Low**
Disturbance Regimes • Wind • Storms	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
Dependencies	**Overall: 3 Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types o Offshore/Pelagic water column	• **4 Moderate-High**	• **3 High**
• Dependence on specific prey or forage species	• **3 Moderate**	• **2 Moderate**
• Other dependencies: none identified	• **N/A**	• **N/A**
• Generalist or specialist?	• **3 (Both generalist and specialist characteristics)**	• **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Harvest	• **5 High**	• **3 High**
• Pollution and poisons	• **2 Low-Moderate**	• **2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**		**Overall: 3 High**
 - Harvest - Pollution and poisons	**LOCAL** - **1 Low** - **1 Low**	**REGIONAL** - **1 Low** - **1 Low**	 - **2 Moderate** - **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**1 Low**
Population Connectivity	**3 (Patchy across an area with some connectivity among patches)**	**3 High**
Dispersal Ability	**3 Moderate**	**2 Moderate**
Maximum Annual Dispersal Distance	**50-75 km**	**1 Low**
Intraspecific/Life History Diversity - Diversity of life history strategies - Genetic diversity - Behavioral plasticity - Phenotypic plasticity	**Overall: 4 Moderate-High** - **3 Moderate** - **5 High** - **3 Moderate** - **3 Moderate**	**Overall: 1 Low** - **1 Low** - **3 High** - **1 Low** - **1 Low**
Species Value	**4 Moderate-High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors • Changes in sea surface temperature • Decreased dissolved oxygen • Changes in salinity • Decreased pH • Increased storminess • Altered currents and mixing • Increased coastal erosion and runoff	**Overall: 3 Moderate** • **5 High** • **4 Moderate-High** • **3 Moderate** • **4 Moderate-High** • **2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate**	**Overall: 2 Moderate** • **3 High** • **3 High** • **2 Moderate** • **1 Low** • **1 Low** • **1 Low** • **1 Low**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Ochre Sea Star – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Air temperature • Sea surface temperature • Precipitation • Salinity • Oxygen • pH • Sea level rise • Wave action • Dynamic ocean conditions (currents/mixing/stratification) • Coastal erosion	**Overall: 3 Moderate** • **5 High** • **3 Moderate** • **2 Low-Moderate** • **5 High** • **2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate** • **5 High** • **3 Moderate** • **4 Moderate-High**	**Overall: 2 Moderate** • **3 High** • **1 Low** • **1 Low** • **2 Moderate** • **1 Low** • **1 Low** • **2 Moderate** • **3 High** • **1 Low** • **1 Low**
Disturbance Regimes • Wind • Disease • Storms • Flooding • Extreme heat events	**Overall: 5 High**	**Overall: 2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Dependencies</td><td colspan="2">Overall: 2 Low-Moderate</td><td>Overall: 3 High</td></tr>
<tr><td>• Dependence on sensitive habitat types</td><td colspan="2">• 1 Low</td><td>• 3 High</td></tr>
<tr><td>• Dependence on specific prey or forage species
o CA Mussel</td><td colspan="2">• 1 Low</td><td>• 3 High</td></tr>
<tr><td>• Other dependencies
o Hard substrate</td><td colspan="2">• 5 High</td><td>• 3 High</td></tr>
<tr><td>• Generalist or specialist?</td><td colspan="2">• 2 (Mostly generalist)</td><td>• 3 High</td></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity</td><td colspan="2">Overall: 3 Moderate</td><td>Overall: 3 High</td></tr>
<tr><td>• Disease</td><td colspan="2">• 5 High</td><td>• 3 High</td></tr>
<tr><td>• Recreation</td><td colspan="2">• 1 Low</td><td>• 3 High</td></tr>
<tr><td>Non-Climate Stressors – Current Exposure to Stressor</td><td colspan="2">Overall: 3 Moderate</td><td>Overall: 3 High</td></tr>
<tr><td></td><td>LOCAL</td><td>REGIONAL</td><td></td></tr>
<tr><td>• Disease</td><td>• 3 Moderate</td><td>• 5 High</td><td>• 3 High</td></tr>
<tr><td>• Recreation</td><td>• 4 Moderate-High</td><td>• 1 Low</td><td>• 3 High</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**5 (Continuous)**	**3 High**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**50-100 km**	**1 Low**

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Intraspecific/Life History Diversity - Diversity of life history strategies - Genetic diversity - Behavioral plasticity - Phenotypic plasticity	**Overall: 2 Low-Moderate** - **1 Low** - **4 Moderate-High** - **3 Moderate** - **2 Low-Moderate**	**Overall: 3 High** - **3 High** - **3 High** - **3 High** - **3 High**
Species Value	**3 Moderate**	**1 Low**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**1 Low**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors - Changes in air temperature - Changes in precipitation - Changes in salinity - Altered currents and mixing - Changes in sea surface temperature - Increased coastal erosion and runoff - Decreased pH - Increased flooding - Sea level rise - Increased storminess - Decreased dissolved oxygen	**Overall: 4 Moderate-High** - **5 High** - **5 High** - **5 High** - **4 Moderate-High** - **5 High** - **3 Moderate** - **5 High** - **3 Moderate** - **5 High** - **3 Moderate** - **2 Low-Moderate**	**Overall: 2 Moderate** - **3 High** - **3 High** - **2 Moderate** - **1 Low** - **2 Moderate** - **2 Moderate** - **3 High** - **2 Moderate** - **3 High** - **2 Moderate** - **1 Low**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Olympia Oyster – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Air temperature • Sea surface temperature • Precipitation • Salinity • Oxygen • pH • Wave action • Currents/mixing/stratification • Coastal erosion • Other: Sedimentation from runoff and currents	**Overall: 3 Moderate** • **2 Low-Moderate** • **2 Low-Moderate** • **5 High** • **5 High** • **3 Moderate** • **3 Moderate** • **2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate** • **3 Moderate**	**Overall: 3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **2 Moderate** • **2 Moderate** • **2 Moderate** • **3 High**
Disturbance Regimes • Storms • Flooding	**Overall: 5 High**	**Overall: 3 High**
Dependencies • Dependence on sensitive habitat types o Hard substrate to gravel in estuaries • Dependence on specific prey or forage species • Other dependencies: none identified • Generalist or specialist?	**Overall: 2 Low-Moderate** • **3 Moderate** • **1 Low** • **N/A** • **3 (Both generalist and specialist characteristics)**	**Overall: 3 High** • **3 High** • **3 High** • **N/A** • **3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 5 High**		**Overall: 3 High**
• Pollution and poisons	**• 3 Moderate**		**• 2 Moderate**
• Dredging	**• 5 High**		**• 2 Moderate**
• Invasive and other problematic species	**• 5 High**		**• 3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 3 Moderate**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
• Pollution and poisons	**• 3 Moderate**	**• 2 Low-Moderate**	**• 2 Moderate**
• Dredging	**• 2 Low-Moderate**	**• 2 Low-Moderate**	**• 2 Moderate**
• Invasive and other problematic species	**• 5 High**	**• 3 Moderate**	**• 3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**3 High**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**3 High**
Dispersal Ability	**3 Moderate**	**3 High**
Maximum Annual Dispersal Distance	**5-25 km**	**2 Moderate**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **2 Low-Moderate** • **3 Moderate** • **1 Low** • **3 Moderate**	**Overall: 3 High** • **2 Moderate** • **2 Moderate** • **3 High** • **3 High**
Species Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Decreased pH • Changes in sea surface temperature • Changes in air temperature • Increased coastal erosion & runoff • Increased flooding • Changes in precipitation • Changes in salinity • Increased storminess	**Overall: 5 High** • **4 Moderate-High** • **4 Moderate-High** • **4 Moderate-High** • **4 Moderate-High** • **5 High** • **5 High** • **5 High** • **3 Moderate**	**Overall: 3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Pacific Herring – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 3 Moderate**	**Overall: 3 High**
• Air temperature	• **2 Low-Moderate**	• **3 High**
• Sea surface temperature	• **4 Moderate-High**	• **3 High**
• Precipitation	• **3 Moderate**	• **3 High**
• Salinity	• **4 Moderate-High**	• **3 High**
• Oxygen	• **2 Low-Moderate**	• **2 Moderate**
• pH	• **3 Moderate**	• **2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	• **3 Moderate**	• **2 Moderate**
Disturbance Regimes • Storms • Flooding	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Dependencies	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Dependence on sensitive habitat types o Estuaries	• **5 High**	• **3 High**
• Dependence on specific prey or forage species	• **2 Low-Moderate**	• **1 Low**
• Other dependencies: none identified	• **N/A**	• **N/A**
• Generalist or specialist?	• **3 (Both generalist and specialist characteristics)**	• **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 1 Low**	**Overall: 3 High**
• Harvest	• **1 Low**	• **3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
	LOCAL	**REGIONAL**	
- Harvest	- **1 Low**	- **1 Low**	- **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	**Adaptive Capacity Evaluation**	**Confidence**
Geographic Extent	**4 (Moderate to large geographic area)**	**2 Moderate**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**3 (Patchy across an area with some connectivity among patches)**	**2 Moderate**
Dispersal Ability	**5 High**	**2 Moderate**
Maximum Annual Dispersal Distance	**25-50 km**	**1 Low**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 3 Moderate** • **2 Low-Moderate** • **3 Moderate** • **3 Moderate** • **3 Moderate**	**Overall: 1 Low** • **1 Low** • **2 Moderate** • **1 Low** • **1 Low**
Species Value	**1 Low**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
- Changes in precipitation	- **3 Moderate**	- **2 Moderate**
- Coastal erosion and runoff	- **3 Moderate**	- **2 Moderate**
- Changes in salinity	- **4 Moderate-High**	- **2 Moderate**
- Decreased pH	- **4 Moderate-High**	- **2 Moderate**
- Increased storminess	- **4 Moderate-High**	- **2 Moderate**
- Changes in sea surface temperature	- **4 Moderate-High**	- **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Pacific Sardine – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Sea surface temperature • Salinity • Oxygen • pH • Dynamic ocean conditions (currents/mixing/stratification)	**Overall: 4 Moderate-High** • **5 High** • **3 Moderate** • **4 Moderate-High** • **4 Moderate-High** • **5 High**	**Overall: 3 High** • **3 High** • **2 Moderate** • **3 High** • **1 Low** • **3 High**
Disturbance Regimes • Wind • Storms	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
Dependencies • Dependence on sensitive habitat types o Offshore/Pelagic water column • Dependence on specific prey or forage species • Other dependencies: none identified • Generalist or specialist?	**Overall: 4 Moderate-High** • **5 High** • **3 Moderate** • **N/A** • **3 (Both generalist and specialist characteristics)**	**Overall: 3 High** • **3 High** • **2 Moderate** • **N/A** • **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Harvest • Pollution and poisons	**Overall: 4 Moderate-High** • **5 High** • **2 Low-Moderate**	**Overall: 3 High** • **3 High** • **2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
	LOCAL	**REGIONAL**	
• Harvest • Pollution and poisons	• **1 Low** • **1 Low**	• **1 Low** • **1 Low**	• **2 Moderate** • **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	**Adaptive Capacity Evaluation**	**Confidence**
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**3 (Patchy across an area with some connectivity among patches)**	**3 High**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**>100 km**	**3 High**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 4 Moderate-High** • **3 Moderate** • **5 High** • **3 Moderate** • **3 Moderate**	**Overall: 1 Low** • **1 Low** • **3 High** • **1 Low** • **1 Low**
Species Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Changes in sea surface temperature	**• 5 High**	**• 3 High**
• Decreased dissolved oxygen	**• 4 Moderate-High**	**• 3 High**
• Changes in salinity	**• 3 Moderate**	**• 2 Moderate**
• Decreased pH	**• 4 Moderate-High**	**• 1 Low**
• Increased storminess	**• 2 Low-Moderate**	**• 1 Low**
• Altered currents and mixing	**• 2 Low-Moderate**	**• 1 Low**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Pteropod – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • pH • Dynamic ocean conditions (currents/mixing/stratification)	**Overall: 5 High** • **5 High** • **4 Moderate-High**	**Overall: 3 High** • **3 High** • **3 High**
Disturbance Regimes: none identified	**N/A**	**N/A**
Dependencies • Dependence on sensitive habitat types • Dependence on specific prey or forage species • Other dependencies: none identified • Generalist or specialist?	**Overall: 3 Moderate** • **2 Low-Moderate** • **4 Moderate-High** • **N/A** • **4 (Mostly specialist)**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate** • **N/A** • **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Not Answered	**Not Answered**	**Not Answered**
Non-Climate Stressors – Current Exposure to Stressor • Not Answered	**Not Answered**	**Not Answered**
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**4 (Stable population at abundant levels)**	**1 Low**
Population Connectivity	**5 (Continuous)**	**2 Moderate**
Dispersal Ability	**4 Moderate-High**	**2 Moderate**
Maximum Annual Dispersal Distance	**>100 km**	**2 Moderate**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 1 Low** • **2 Low-Moderate** • **3 Moderate** • **1 Low** • **1 Low**	**Overall: 1 Low** • **2 Moderate** • **2 Moderate** • **1 Low** • **1 Low**
Species Value	**1 Low**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Altered currents and mixing • Decreased pH	**Overall: 5 High** • **5 High** • **5 High**	**Overall: 3 High** • **3 High** • **3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Red Abalone – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Air temperature	**5 High**	**3 High**
• Sea surface temperature	**4 Moderate-High**	**3 High**
• Salinity	**4 Moderate-High**	**2 Moderate**
• Oxygen	**5 High**	**3 High**
• pH	**5 High**	**2 Moderate**
• Sea level rise	**2 Low-Moderate**	**1 Low**
• Wave action	**3 Moderate**	**3 High**
• Dynamic ocean conditions (currents/mixing/stratification)	**3 Moderate**	**3 High**
• Coastal erosion	**2 Low-Moderate**	**3 High**
Disturbance Regimes • Disease • Storms • Harmful Algal Blooms	**Overall: 5 High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
Dependencies	**Overall: 4 Moderate-High**		**Overall: 3 High**
• Dependence on sensitive habitat types o Rocky intertidal o Rocky reef o Kelp forest	**• 4 Moderate-High**		**• 3 High**
• Dependence on specific prey or forage species	**• 2 Low-Moderate**		**• 3 High**
• Other dependencies o The allee effect	**• 5 High**		**• 3 High**
• Generalist or specialist?	**• 3 (Both generalist and specialist characteristics)**		**• 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 3 Moderate**		**Overall: 1 Low**
• Harvest	**• 5 High**		**• 3 High**
• Pollution and poisons	**• 3 Moderate**		**• 1 Low**
• Invasive and other problematic species	**• 2 Low-Moderate**		**• 1 Low**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
• Harvest	**• 5 High**	**• 3 Moderate**	**• 3 High**
• Pollution and poisons	**• 3 Moderate**	**• 1 Low**	**• 2 Moderate**
• Invasive and other problematic species	**• 1 Low**	**• 1 Low**	**• 3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**3 (Diminished but generally stable)**	**2 Moderate**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**3 High**
Dispersal Ability	**1 Low**	**3 High**
Maximum Annual Dispersal Distance	**5-25 km**	**2 Moderate**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **3 Moderate** • **Not Answered** • **2 Low-Moderate** • **1 Low**	**Overall: 3 High** • **2 Moderate** • **Not Answered** • **2 Moderate** • **3 High**
Species Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Changes in sea surface temperature • Decreased pH • Decreased dissolved oxygen • Changes in air temperature • Changes in salinity • Sea level rise • Changes in precipitation	**Overall: 3 Moderate** • **1 Low** • **5 High** • **3 Moderate** • **5 High** • **1 Low** • **5 High** • **1 Low**	**Overall: 3 High** • **2 Moderate** • **3 High** • **2 Moderate** • **3 High** • **3 High** • **3 High** • **3 High**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 3 High

Sea Palm – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Air temperature • Sea surface temperature • Precipitation • Salinity • Oxygen • pH • Sea level rise • Wave action • Dynamic ocean conditions (currents/mixing/stratification) • Coastal erosion	**Overall: Moderate-High** • **5 High** • **3 Moderate** • **2 Low-Moderate** • **5 High** • **2 Low-Moderate** • **4 Moderate-High** • **3 Moderate** • **5 High** • **3 Moderate** • **4 Moderate-High**	**Overall: 2 Moderate** • **3 High** • **1 Low** • **1 Low** • **2 Moderate** • **1 Low** • **1 Low** • **2 Moderate** • **3 High** • **1 Low** • **1 Low**
Disturbance Regimes • Wind • Disease • Storms • Flooding • Extreme heat events	**Overall: 5 High**	**Overall: 2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Dependencies	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Dependence on sensitive habitat types o Coralline algae turfs	**• 3 Moderate**	**• 2 Moderate**
• Dependence on specific prey or forage species	**• 1 Low**	**• 3 High**
• Other dependencies o Wave disturbance to remove competitors	**• 5 High**	**• 3 High**
• Generalist or specialist?	**• 5 (Specialist)**	**• 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 5 High**	**Overall: 3 High**
• Harvest	**• 5 High**	**• 3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
• Harvest	**LOCAL** **• 3 Moderate** **REGIONAL** **• 1 Low**	**• 1 Low**
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**3 High**
Dispersal Ability	**2 Low-Moderate**	**3 High**
Maximum Annual Dispersal Distance	**<1km, >100km**	**3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 3 Moderate** • **4 Moderate-High** • **Not Answered** • **1 Low** • **3 Moderate**	**Overall: 2 Moderate** • **3 High** • **1 Low** • **2 Moderate** • **3 High**
Species Value	**2 Low-Moderate**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**1 Low**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors • Changes in air temperature • Changes in precipitation • Changes in salinity • Altered currents and mixing • Changes in sea surface temperature • Coastal erosion and runoff • Decreased pH • Increased flooding • Sea level rise • Increased storminess • Decreased dissolved oxygen	**Overall: 4 Moderate-High** • **5 High** • **5 High** • **5 High** • **4 Moderate-High** • **5 High** • **2 Low-Moderate** • **5 High** • **3 Moderate** • **5 High** • **3 Moderate** • **2 Low-Moderate**	**Overall: 2 Moderate** • **3 High** • **3 High** • **2 Moderate** • **1 Low** • **2 Moderate** • **2 Moderate** • **3 High** • **2 Moderate** • **3 High** • **2 Moderate** • **1 Low**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Sea Urchin, Red and Purple – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes • Air temperature • Sea surface temperature • Oxygen • pH • Dynamic ocean conditions (currents/mixing/stratification)	**Overall: 4 Moderate-High** • **4 Moderate-High** • **3 Moderate** • **4 Moderate-High** • **4 Moderate-High** • **4 Moderate-High**	**Overall: 3 High** • **3 High** • **3 High** • **3 High** • **3 High** • **3 High**
Disturbance Regimes • Disease • Storms	**Overall: 4 Moderate-High**	**Overall: 3 High**
Dependencies • Dependence on sensitive habitat types o Rocky reef o Rocky intertidal o Kelp forest • Dependence on specific prey or forage species o Algae • Other dependencies: none identified • Generalist or specialist?	**Overall: 3 Moderate** • **5 High** • **1 Low** • **N/A** • **2 (Mostly generalist)**	**Overall: 3 High** • **3 High** • **3 High** • **N/A** • **3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Harvest • Pollution and poisons	**Overall: 4 Moderate-High** • **3 Moderate** • **5 High**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 3 Moderate**	**Overall: 2 Moderate**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation		Confidence
	LOCAL	**REGIONAL**	
- Harvest - Pollution and poisons	- **4 Moderate-High** - **4 Moderate-High**	- **1 Low** - **1 Low**	- **2 Moderate** - **2 Moderate**
Other Sensitivities - Trophic relationships with predators	**Overall: 4 Moderate-High**		**Overall: 2 Moderate**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**4 (Stable population at abundant levels)**	**1 Low**
Population Connectivity	**5 (Continuous)**	**2 Moderate**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**>100 km**	**3 High**
Intraspecific/Life History Diversity - Diversity of life history strategies - Genetic diversity - Behavioral plasticity - Phenotypic plasticity	**Overall: 2 Low-Moderate** - **1 Low** - **5 High** - **2 Low-Moderate** - **1 Low**	**Overall: 3 High** - **3 High** - **2 Moderate** - **3 High** - **3 High**
Species Value	**4 Moderate-High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**2 Moderate**
Other Adaptive Capacities - Bottleneck during larval settlement - Climate effects on recruitment success and larval survival	**Overall: 4 Moderate-High**	**Overall: 1 Low**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Changes in air temperature	• **2 Low-Moderate**	• **3 High**
• Changes in sea surface temperature	• **1 Low**	• **2 Moderate**
• Decreased pH	• **4 Moderate-High**	• **2 Moderate**
• Decreased dissolved oxygen	• **4 Moderate-High**	• **2 Moderate**
• Increased storminess	• **2 Low-Moderate**	• **1 Low**
• Altered currents and mixing	• **1 Low**	• **1 Low**

Overall Averaged Ranking (Exposure)[3]: 2 Low-Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Southern Sea Otter – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Sea surface temperature	• **1 Low**	• **3 High**
• Precipitation	• **4 Moderate-High**	• **2 Moderate**
• Salinity	• **1 Low**	• **1 Low**
• Oxygen	• **2 Low-Moderate**	• **2 Moderate**
• pH	• **4 Moderate-High**	• **3 High**
• Wave action	• **3 Moderate**	• **2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	• **2 Low-Moderate**	• **2 Moderate**
• Coastal erosion	• **2 Low-Moderate**	• **2 Moderate**
Disturbance Regimes	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Wind	• **2 Low-Moderate**	• **1 Low**
• Disease	• **5 High**	• **3 High**
• Storms	• **3 Moderate**	• **2 Moderate**
Dependencies	**Overall: 2 Low-Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types		
o Kelp	• **4 Moderate-High**	• **3 High**
o Estuaries	• **2 Low-Moderate**	• **2 Moderate**
o Nearshore	• **5 High**	• **3 High**
• Dependence on specific prey or forage species	• **1 Low**	• **3 High**
• Other dependencies: none identified	• **N/A**	• **N/A**
• Generalist or specialist?	• **2 (Mostly generalist)**	• **3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

<table>
<tr><th>Sensitivity Factor</th><th colspan="2">Sensitivity Evaluation</th><th>Confidence</th></tr>
<tr><td>Non-Climate Stressors – Degree Stressor Affects Sensitivity
• Predation
• Pollution and poisons
• Harvest</td><td colspan="2">Overall: 4 Moderate-High
• 2 Low-Moderate
• 5 High
• 2 Low-Moderate</td><td>Overall: 1 Low
• 1 Low
• 3 High
• 1 Low</td></tr>
<tr><td rowspan="2">Non-Climate Stressors – Current Exposure to Stressor
• Predation
• Pollution and poisons
• Harvest</td><td colspan="2">Overall: 2 Low-Moderate</td><td rowspan="2">Overall: 2 Moderate
• 3 High
• 2 Moderate
• 1 Low</td></tr>
<tr><td>LOCAL
• 4 Moderate-High
• 2 Low-Moderate
• 1 Low</td><td>REGIONAL
• 2 Low-Moderate
• 2 Low-Moderate
• 1 Low</td></tr>
<tr><td>Other Sensitivities: none identified</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Overall Averaged Ranking (Sensitivity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**3 (Distribution within single state to two states)**	**3 High**
Population Status	**1 (Endangered)**	**3 High**
Population Connectivity	**2 (Somewhat isolated and/or fragmented)**	**2 Moderate**
Dispersal Ability	**2 Low-Moderate**	**3 High**
Maximum Annual Dispersal Distance	**1-5 km**	**3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **2 Low-Moderate** • **1 Low** • **4 Moderate-High** • **2 Low-Moderate**	**Overall: 2 Moderate** • **1 Low** • **3 High** • **2 Moderate** • **2 Moderate**
Species Value	**5 High**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities • Hunting and predation • Impacts to key prey • Ability to migrate north and south along the coast	**Overall: 3 Moderate**	**Overall: 1 Low**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors • Changes in precipitation • Decreased pH • Increased storminess • Increased coastal erosion and runoff	**Overall: 4 Moderate-High** • **3 Moderate** • **4 Moderate-High** • **3 Moderate** • **4 Moderate-High**	**Overall: 2 Moderate** • **2 Moderate** • **3 High** • **2 Moderate** • **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Surface Nesters: Brandt's Cormorant and Common Murre – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• Air temperature	• **2 Low-Moderate**	• **2 Moderate**
• Sea surface temperature	• **3 Moderate**	• **2 Moderate**
• Precipitation	• **1 Low**	• **2 Moderate**
• Salinity	• **2 Low-Moderate**	• **1 Low**
• Dissolved oxygen	• **2 Low-Moderate**	• **1 Low**
• pH	• **2 Low-Moderate**	• **1 Low**
• Sea level rise	• **1 Low**	• **3 High**
• Wave action	• **1 Low**	• **2 Moderate**
• Dynamic ocean conditions (currents/mixing/stratification)	• **3 Moderate**	• **2 Moderate**
• Coastal erosion	• **2 Low-Moderate**	• **2 Moderate**
• Extreme weather events	• **5 High**	• **3 High**
Disturbance Regimes • Disease • Storms • Flooding • Drought • Disturbance	**Overall: 5 High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
Dependencies	**Overall: 4 Moderate-High**		**Overall: 3 High**
- Dependence on sensitive habitat types			
o Breeding habitat	**5 High**		**3 High**
o Foraging habitat	**3 Moderate**		**3 High**
- Dependence on specific prey or forage species	**3 Moderate**		**3 High**
- Other dependencies	**5 High**		**3 High**
o Timing of breeding			
o Foraging availability			
- Generalist or specialist?	**3 (Both generalist and specialist characteristics)**		**3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**		**Overall: 3 High**
- Land use change	**2 Low-Moderate**		**3 High**
- Pollution and poisons	**5 High**		**3 High**
- Harvest	**3 Moderate**		**3 High**
- Energy production	**2 Low-Moderate**		**3 High**
- Recreation	**4 Moderate-High**		**3 High**
- Invasive species	**5 High**		**3 High**
- Aircraft and vessels	**5 High**		**3 High**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 1 Low**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
- Land use change	**2 Low-Moderate**	**1 Low**	**3 High**
- Pollution and poisons	**2 Low-Moderate**	**2 Moderate**	**3 High**
- Harvest	**1 Low**	**1 Low**	**3 High**
- Energy production	**1 Low**	**1 Low**	**3 High**
- Recreation	**2 Low-Moderate**	**1 Low**	**3 High**
- Invasives	**1 Low**	**1 Low**	**3 High**
- Aircraft/vessels	**3 Moderate**	**2 Moderate**	**3 High**

Sensitivity Factor	Sensitivity Evaluation	Confidence
Other Sensitivities • El Niño	**Overall: 4 Moderate-High**	**Overall: 3 High**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status		
o Brandt's Cormorant	**3 (Diminished but generally stable)**	**3 High**
o Common Murre	**5 (Healthy and/or expanding)**	**3 High**
Population Connectivity	**4 (Almost continuous)**	**2 Moderate**
Dispersal Ability	**3 Moderate**	**2 Moderate**
Maximum Annual Dispersal Distance	**>100 km**	**3 High**
Intraspecific/Life History Diversity	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Diversity of life history strategies		
o Brandt's Cormorant	• **4 Moderate-High**	• **3 High**
o Common Murre	• **2 Low-Moderate**	• **3 High**
• Genetic diversity		
o Brandt's Cormorant	• **3 Moderate**	• **1 Low**
o Common Murre	• **3 Moderate**	• **1 Low**
• Behavioral plasticity		
o Brandt's Cormorant	• **3 Moderate**	• **2 Moderate**
o Common Murre	• **2 Low-Moderate**	• **2 Moderate**
• Phenotypic plasticity		
o Brandt's Cormorant	• **3 Moderate**	• **2 Moderate**
o Common Murre	• **2 Low-Moderate**	• **2 Moderate**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Species Value	**2 Low-Moderate**	**3 High**
Likelihood of Managing or Alleviating Climate Impacts	**1 Low**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Changes in air temperature	• **3 Moderate**	• **2 Moderate**
• Changes in precipitation	• **2 Low-Moderate**	• **2 Moderate**
• Changes in salinity	• **3 Moderate**	• **2 Moderate**
• Altered currents and mixing	• **4 Moderate-High**	• **2 Moderate**
• Changes in sea surface temperature	• **3 Moderate**	• **2 Moderate**
• Increased coastal erosion & runoff	• **2 Low-Moderate**	• **2 Moderate**
• Decreased pH	• **3 Moderate**	• **2 Moderate**
• Increased flooding	• **2 Low-Moderate**	• **2 Moderate**
• Decreased dissolved oxygen	• **3 Moderate**	• **2 Moderate**
• Sea level rise	• **1 Low**	• **2 Moderate**
• Increased storminess	• **3 Moderate**	• **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Tidewater Goby – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
• Precipitation	• **4 Moderate-High**	• **2 Moderate**
• pH	• **2 Low-Moderate**	• **1 Low**
• Sea level rise	• **2 Low-Moderate**	• **1 Low**
• Coastal erosion	• **2 Low-Moderate**	• **1 Low**
Disturbance Regimes	**Overall: 4 Moderate-High**	**Overall: 3 High**
• Flooding		
Dependencies	**Overall: 3 Moderate**	**Overall: 3 High**
• Dependence on sensitive habitat types	• **5 High**	• **3 High**
o Brackish water (Coastal Lagoons and Upstream in creek/river systems)		
• Dependence on specific prey or forage species	• **2 Low-Moderate**	• **2 Moderate**
• Other dependencies	• **3 Moderate**	• **Not Answered**
o Clear water for breeding		
o Oxygenated sandy substrate for burrow		
o Nearby populations		
• Generalist or specialist?	• **2 (Mostly generalist)**	• **2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
• Land use change	• **3 Moderate**	• **2 Moderate**
• Invasive and other problematic species	• **2 Low-Moderate**	• **1 Low**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Non-Climate Stressors – Current Exposure to Stressor • Land use change • Invasive and other problematic species	**Not Answered**	**Not Answered**
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Geographic Extent	**1 (Endemic)**	**3 High**
Population Status	**1 (Endangered)**	**3 High**
Population Connectivity	**2 (Somewhat isolated and/or fragmented, i.e. patchy)**	**2 Moderate**
Dispersal Ability	**1 Low**	**2 Moderate**
Maximum Annual Dispersal Distance	**5-25 km, documented up to 15 km**	**2 Moderate**
Intraspecific/Life History Diversity • Diversity of life history strategies • Genetic diversity • Behavioral plasticity • Phenotypic plasticity	**Overall: 2 Low-Moderate** • **1 Low** • **5 High** • **1 Low** • **2 Low-Moderate**	**Not Answered**
Species Value	**3 Moderate**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**3 Moderate**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Changes in precipitation • Increased flooding	**Overall: 3 Moderate** • **3 Moderate** • **3 Moderate**	**Overall: 2 Moderate** • **2 Moderate** • **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 3 Moderate

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Western Snowy Plover – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 2 Moderate**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Changes	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Precipitation	**• 2 Low-Moderate**	**• 1 Low**
• pH	**• 1 Low**	**• 1 Low**
• Sea level rise	**• 5 High**	**• 3 High**
• Wave action	**• 5 High**	**• 3 High**
• Coastal erosion	**• 5 High**	**• 3 High**
Disturbance Regimes	**Overall: 5 High**	**Overall: 3 High**
• Wind		
• Storms		
• Flooding		
Dependencies	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• Dependence on sensitive habitat types	**• 4 Moderate-High**	**• 2 Moderate**
o Gravel bars		
o Salt pans		
• Dependence on specific prey or forage species	**• 1 Low**	**• 2 Moderate**
• Other dependencies: none identified	**• N/A**	**• N/A**
• Generalist or specialist?	**• 4 (Mostly specialist)**	**• 2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 5 High**	**Overall: 3 High**
• Recreation	**• 5 High**	**• 3 High**
• Invasive and other problematic species	**• 4 Moderate-High**	**• 3 High**
• Land use change	**• 5 High**	**• 3 High**
• Pollution and poisons	**• 5 High**	**• 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	**Sensitivity Evaluation**		**Confidence**
Non-Climate Stressors – Current Exposure to Stressor	**Overall: 4 Moderate-High**		**Overall: 3 High**
	LOCAL	**REGIONAL**	
- Recreation	- **5 High**	- **4 Moderate-High**	- **3 High**
- Invasive and other problematic species	- **5 High**	- **4 Moderate-High**	- **3 High**
- Land use change	- **5 High**	- **4 Moderate-High**	- **2 Moderate**
- Pollution and poisons	- **5 High**	- **1 Low**	- **3 High**
Other Sensitivities: none identified	**N/A**		**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	**Adaptive Capacity Evaluation**	**Confidence**
Geographic Extent	**5 (Transcontinental)**	**3 High**
Population Status	**2 (Threatened)**	**3 High**
Population Connectivity	**3 (Patchy across an area with some connectivity among patches)**	**2 Moderate**
Dispersal Ability	**5 High**	**3 High**
Maximum Annual Dispersal Distance	**>100 km**	**3 High**
Intraspecific/Life History Diversity	**Overall: 2 Low-Moderate**	**Overall: 1 Low**
- Diversity of life history strategies	- **3 Moderate**	- **2 Moderate**
- Genetic diversity	- **2 Low-Moderate**	- **2 Moderate**
- Behavioral plasticity	- **2 Low-Moderate**	- **1 Low**
- Phenotypic plasticity	- **2 Low-Moderate**	- **1 Low**
Species Value	**2 Low-Moderate**	**2 Moderate**
Likelihood of Managing or Alleviating Climate Impacts	**2 Low-Moderate**	**3 High**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Adaptive Capacity)[3]: 3 Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 2 Moderate

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EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
• Changes in precipitation	• **2 Low-Moderate**	• **1 Low**
• Increased coastal erosion and runoff	• **5 High**	• **3 High**
• Increased flooding	• **5 High**	• **2 Moderate**
• Sea level rise	• **5 High**	• **3 High**
• Increased storminess	• **5 High**	• **3 High**
• Decreased pH	• **2 Low-Moderate**	• **1 Low**
• Decreased sediment supply	• **3 Moderate**	• **2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

Carbon Storage and Sequestration – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Sea level rise • Storm events • Sea surface temperature	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
Disturbance Regimes • Wind • Disease • Flooding • Storms	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor • Land use change • Overwater/underwater structures • Recreation • Aquaculture • Roads/armoring • Invasive and other problematic species • Pollution and poisons • Dredging	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Overwater/underwater structures • Recreation • Aquaculture • Roads/armoring • Invasive and other problematic species • Pollution and poisons • Dredging	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Other Sensitivities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 2 Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Service Value	**2 Low-Moderate**	**1 Low**
Societal Willingness to Change Behavior	**1 Low**	**3 High**
Rigidity/Specificity of Service Management	**4 (Rules are specific with some space for interpretation)**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 2 Low-Moderate

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, and exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors - Sea level rise - Storms - Sea surface temperature - pH - Increased erosion - Precipitation changes (extreme events)	**Overall: 5 High**	**Overall: 3 High**

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Flood and Erosion Protection – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 4 Moderate-High **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Increased precipitation • Increased storminess • Increased coastal erosion • Increased flooding • Sea level rise • Increased storm events	**Overall: 5 High**	**Overall: 3 High**
Disturbance Regimes • Wind • Flooding • Storms	**Overall: 4 Moderate-High**	**Overall: 3 High**
Non-Climate Stressors – Current Exposure to Stressor • Land use change • Overwater/underwater structures • Roads/armoring • Other: sand mining	**Overall: 5 High**	**Overall: 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Overwater/underwater structures • Roads/armoring • Other: sand mining	**Overall: 5 High**	**Overall: 3 High**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Other Sensitivities • Earthquakes • Tsunamis	**Overall: 5 High**	**Overall: 3 High**

Overall Averaged Ranking (Sensitivity)[3]: 5 High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Service Value	**5 High**	**3 High**
Societal Willingness to Change Behavior	**2 Low-Moderate**	**3 High**
Rigidity/Specificity of Service Management	**3 (Rules are moderately specific)**	**2 Moderate**
Other Adaptive Capacities • Habitat migration	**Overall: 5 High**	**Overall: 3 High**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Sea surface temperature • Air temperature • Sea level rise • Increased erosion • Storminess • Increased flooding • Changes in salinity	**Overall: 5 High**	**Overall: 3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, and exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Exposure)[3]: 5 High

Overall Averaged Confidence (Exposure)[4]: 3 High

Food Production – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Sea surface temperature • pH • Oxygen • Currents/mixing/stratification • Salinity	**Overall: 3 Moderate**	**Overall: 2 Moderate**
Disturbance Regimes • Wind • Disease • Storms	**Overall: 4 Moderate-High**	**Not Answered**
Non-Climate Stressors – Current Exposure to Stressor • Recreation • Aquaculture • Harvest • Pollution and poisons	**Overall: 4 Moderate-High**	**Overall: 3 High**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Recreation • Aquaculture • Harvest • Pollution and poisons	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
Other Sensitivities • Regulatory changes in harvest levels	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Service Value	**5 High**	**3 High**
Societal Willingness to Change Behavior	**2 Low-Moderate**	**2 Moderate**
Rigidity/Specificity of Service Management	**5 (Rules are very specific)**	**3 High**
Other Adaptive Capacities • World fishery demand reduction • Increase sustainable aquaculture • Habitat protections	**Overall: 3 Moderate**	**Overall: 2 Moderate**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Sea surface temperature • pH • Oxygen • Currents/mixing/stratification • Salinity • Wind/storms	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 2 Moderate

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, and exposure evaluation columns above.

[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Recreation and Tourism – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Sensitivities to Climate & Climate-Driven Factors • Warmer inland temperatures • Increased wave height • Increased storminess • Sea surface temperature • Increased wind • Sea level rise	**Overall: 2 Low-Moderate**	**Overall: 3 High**
Disturbance Regimes • Wind • Disease • Flooding • Storms	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
Non-Climate Stressors – Current Exposure to Stressor • Land use change • Aquaculture • Harvest • Pollution and poisons	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Aquaculture • Harvest • Pollution and poisons	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Other Sensitivities • Population density	**Overall: 4 Moderate-High**	**Overall: 3 High**

Overall Averaged Ranking (Sensitivity)[3]: 3 Moderate

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Service Value	**5 High**	**3 High**
Societal Willingness to Change Behavior	**4 Moderate-High**	**2 Moderate**
Rigidity/Specificity of Service Management	**3 (Rules are moderately specific)**	**3 High**
Other Adaptive Capacities • Education of the public	**Overall: 5 High**	**Overall: 2 Moderate**

Overall Averaged Ranking (Adaptive Capacity)[3]: 5 High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

EXPOSURE

Exposure Factor	Exposure Evaluation	Confidence
Future Climate Exposure Factors • Warmer inland temperatures • Increased wave height • Increased storminess • Sea surface temperature • Increased wind • Sea level rise	**Overall: 4 Moderate-High**	**Overall: 3 High**

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, and exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 3 High

Water Purification – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking[1]: 3 Moderate **Overall Confidence[2]: 3 High**

SENSITIVITY

Sensitivity Factor	**Sensitivity Evaluation**	**Confidence**
Sensitivities to Climate & Climate-Driven Factors • pH • Sea level rise • Precipitation • Dissolved oxygen • Turbidity • Storm activity • Coastal erosion (wave action) • Circulation	**Overall: 5 High**	**Overall: 3 High**
Disturbance Regimes • Wind • Flooding • Storms	**Overall: 5 High**	**Overall: 3 High**
Non-Climate Stressors – Current Exposure to Stressor • Land use change • Recreation • Aquaculture • Harvest • Pollution and poisons • Dredging • Other: shipping	**Overall: 3 Moderate**	**Overall: 2 Moderate**

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) * (1/Adaptive Capacity).

[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.

Sensitivity Factor	Sensitivity Evaluation	Confidence
Non-Climate Stressors – Degree Stressor Affects Sensitivity • Land use change • Recreation • Aquaculture • Harvest • Pollution and poisons • Dredging • Other: shipping	**Overall: 4 Moderate-High**	**Overall: 2 Moderate**
Other Sensitivities • Desalination brine • Agricultural land use • Dredging practices	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**

Overall Averaged Ranking (Sensitivity)[3]: 4 Moderate-High

Overall Averaged Confidence (Sensitivity)[4]: 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Service Value	**5 High**	**3 High**
Societal Willingness to Change Behavior	**3 Moderate**	**2 Moderate**
Rigidity/Specificity of Service Management	**4 (Rules are specific with some space for interpretation)**	**2 Moderate**
Other Adaptive Capacities: none identified	**N/A**	**N/A**

Overall Averaged Ranking (Adaptive Capacity)[3]: 4 Moderate-High

Overall Averaged Confidence (Adaptive Capacity)[4]: 3 High

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[3] Overall averaged ranking is an average of the sensitivity, adaptive capacity, and exposure evaluation columns above.
[4] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

EXPOSURE

Exposure Factor	**Exposure Evaluation**	**Confidence**
Future Climate Exposure Factors • Sea temperature • pH • Sea level rise • Precipitation • Dissolved oxygen • Turbidity • Storm activity • Coastal erosion (wave action) • Circulation	**Overall: 4 Moderate-High**	**Overall: 3 High**

Overall Averaged Ranking (Exposure)[3]: 4 Moderate-High

Overall Averaged Confidence (Exposure)[4]: 3 High