Climate-Smart Conservation of Beaches and Dunes for Western Snowy Plover Recovery in Monterey Bay, California

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December 2019

Point Blue Conservation Science Publication
Point Blue Conservation Science
3820 Cypress Road #11
Petaluma CA 94954

Unpublished report of Point Blue Conservation Science to the US Fish and Wildlife Service
In partial fulfillment of cooperative agreement F15AC00642

Please cite this document as:
K.K. Neuman, R.W. Stein, C.R. Eyster, and T. Gardali. 2019. Climate-smart conservation of beaches and dunes for western snowy plover recovery, in Monterey Bay, California. Point Blue Conservation Science. Unpublished Report, 19pp.

1. Introduction

The Pacific Coast of North America is expected to be disproportionately affected by rising seas associated with climate change (Griggs et al. 2017). The federally listed Pacific Coast population of the western snowy plover (*Charadrius nivosus nivosus*) occupies beaches and dunes along the Pacific coastline of California, Oregon, and Washington, in the United States, and in Mexico, and therefore is also highly vulnerable to rising seas and other related climate change effects. The listed population has required intensive habitat and predator management to achieve modest population increases and it is likely that this will be necessary into the future. Because of the continued need for management, the snowy plover has been characterized as a conservation reliant species (Wiens and Gardali 2013) and restoration of the beach and dune ecosystem is a key conservation strategy identified in the Recovery Plan for the listed population (USFWS 2007).

The threat posed by climate change is causing practitioners and planners to rethink conservation and restoration objectives and approaches (Hansen et al. 2010). To ensure that ecosystems are resilient in future climate conditions, conservation and restoration approaches need to be climate-smart. The climate-smart approach is the process of enhancing present and future ecological function so that ecosystems will be resilient to a range of potential future climate conditions. Identification and implementation of climate-smart conservation strategies and actions will be a central to achieving recovery objectives for the snowy plover in the face of climate change. Monterey Bay is an important geography to plan for implementation of climate-smart recovery strategies for several reasons: the region accounts for a significant percentage of the listed Pacific coast population (~15%, Neuman et al. 2019, USFWS), successful management of non-climate stressors for the past 25 years has resulted in a "recovered" breeding population that has reached the regional recovery population target, and there is an established group of coastal landowners, managers and stakeholders that are working collaboratively to implement conservation actions. This guide lays the groundwork for maintaining the integrity of sandy beach and dune habitats that support snowy plovers in the face of climate change by increasing awareness of climate change impacts, identifying the vulnerabilities of the plover and the beach and dune environment in Monterey Bay, and providing climate-smart actions to increase climate resilience and build adaptive capacity.

The benefits of restoring sandy beaches and dunes extend beyond the snowy plover. As an ecotone between land and sea, the sandy shoreline is critical for nutrient cycling and supports a diversity of invertebrate fauna, surf zone fishes, shorebirds, marine mammals, and plant species (McLachlan and Brown 2006), including five federally protected plant and animal species or subspecies (Table 1; https://www.fws.gov/endangered/) and several California-designated species of special concern (CDFW 2018). Sandy beaches and dunes also provide important services to human communities threatened by the combined effects of sea level rise and accelerating coastal erosion. Beaches and dunes act as barriers to landward shoreline retreat and provide a natural protective buffer against coastal flooding and erosion, a benefit referred to as coastal protection (Arkema et al. 2013). In Monterey Bay, normal erosion of coastal dunes provides a significant sediment source for beaches (Patsch and Griggs 2007). Sandy beaches also are a significant source of aesthetic, recreational, and economic value to human communities (Kildow and Colgan 2005).

Maintaining the recovered snowy plover population in the Monterey Bay area into the future will only be possible by increasing the resiliency of the beach and dune ecosystem and this will require collaborative efforts among state and federal agencies, conservation NGOs, private landowners, and other coastal stakeholders. Key activities in this collaboration are identifying and prioritizing conservation investments at sites that are likely to be resilient to climate change, planning and implementing restoration projects that incorporate climate-smart strategies and actions, and monitoring the response of the snowy plover and other ecosystem attributes. This guide provides a framework to help guide these collaborative conservation investments.

Table 1. Federally protected plants and animals of the Monterey Bay beach and dune ecosystem

Scientific Name	Common Name	Federal Status
Chorizanthe pungens var. pungens	Monterey spineflower	Threatened
Chorizanthe robusta var. robusta	Robust spineflower	Endangered
Gilia tenuiflora ssp. arenaria	Monterey sand gilia	Endangered
Erysimum menziesii	Menzies wallflower	Endangered
Euphilotes enoptes smithi	Smith's blue butterfly	Endangered

2. Objectives

The objectives of this document are to 1) identify climate-smart strategies that will help maintain the recovered status of the Monterey Bay snowy plover population, and 2) assess the vulnerability of individual nesting sites along the Monterey Bay shoreline in order to identify opportunities for employing climate-smart strategies. The Recovery Plan for the listed population provides specific recovery objectives, delisting criteria, and population targets for recovery units and sub-regions (Table 2; USFWS 2007). Identification of climate-smart strategies, actions and opportunities for implementation is the first step toward incorporating an understanding of climate threats into future management of the snowy plover in Monterey Bay. It is our hope that when this climate-smart approach is implemented it will help to maintain the Monterey Bay snowy plover population at or above population targets in the near-term and also will provide a critical buffer for the population to adapt to changing environmental conditions over a longer time period.

Table 2. Recovery objectives, delisting criteria, and population targets for the Pacific Coast population of the western snowy plover.

Recovery Objectives	1. Maintain broadly distributed healthy population 2. Minimize threats with management actions 3. Monitor population size and productivity
Species Delisting Criteria	1. Maintain 3000 breeding adults distributed among 6 recovery units 2. Maintain annual productivity of > 1.0 chicks fledged per male in each recovery unit for at least 5 years prior to delisting
Recovery Unit and Regional Population Targets	1. Recovery Unit 4 (Sonoma, Marin, San Mateo, Santa Cruz, Monterey counties) has a target of 400 breeding adults 2. Monterey Bay has a target of 338 breeding adults

3. Ecology of Beaches, Dunes, and the Snowy Plover

Coastal dunes are limited in distribution and are considered a threatened ecosystem in California (Grossman et al. 1994, Sawyer and Keeler-Wolf 1995). Coastal dunes are composed of unconsolidated river sands, woody debris and sparse, low-growing vegetation (Pickart and Sawyer 1998). The beach and dune plant community is strongly influenced by repeated natural disturbance from wind, ocean waves, and salt spray. Areas that are subject to this regular natural disturbance are dominated by primary successional plant species, each of which have a unique role building and stabilizing incipient dunes, the first step toward the establishment of more advanced seral vegetation stages and larger and more stable dunes (Table 3, Sawyer and Keeler-Wolf 1995, Tobias 2015). Most of the rare and endemic plant and animal species within the coastal dune ecosystem, including the snowy plover, are dependent on primary successional habitat (Page et al. 2009, Pardini et al. 2015).

In Monterey Bay, coastal dunes are considered to be composed of three zones: beaches and foredunes, mid dunes, and rear dunes (Monterey Bay Dunes Coalition 1989). Snowy plovers primarily occur on beaches and in foredunes, which are characterized by seasonal deposition of wave-borne debris, including kelp wrack and driftwood, and sparse low-growing vegetation (Figure 1, Table 3). Most nesting also occurs on beaches and in foredunes, where the precocial chicks are attended by the male parent until they are capable of flying at approximately 1 month of age (Page et al. 2009). Younger chicks are more vulnerable to mortality due to lack of mobility and exposure to weather and predators (Colwell et al. 2007), and tend to spend more time sheltering and foraging in foredunes on invertebrates associated with dune plants (Page et al. 2009). As chicks increase in age and become more mobile and less dependent on their male parent for thermoregulation, they also spend an increasing amount of time foraging on more exposed beaches. Chicks of all ages retreat from threats into vegetated foredunes, often travelling through unvegetated interdune swales (Figure 2). Snowy plovers of all age classes forage on invertebrates associated with kelp wrack, such as flies and amphipods (Page et al. 2009), and thus are strongly associated with areas of kelp wrack deposition throughout the annual cycle (Dugan et al. 2003, Brindock and Colwell 2011).

Figure 1. Snowy plover chicks crouching in foredune with *Abronia, Lathyrus* and *Calystegia*

Table 3. Foredune plant species commonly associated with snowy plover nest sites in Monterey Bay (Point Blue unpubl. data) and roles in foredune building and stabilization in California, adapted from Tobias 2015.

Scientific Name	Common Name	Role
Abronia latifolia	yellow sand verbena	stabilizer
Abronia umbellata	pink sand verbena	stabilizer
Ambrosia chamissonis	beach bur	stabilizer
Atriplex leucophylla	saltbush	builder
Cakile maritima[1]	sea rocket	builder
Calystegia soldanella	beach morning glory	stabilizer
Camissoniopsis cheiranthifolia	beach primrose	stabilizer
Lathyrus littoralis	silky beach pea	stabilizer
Leymus mollis	American beach grass	builder

[1] non-native

Figure 2. Snowy plovers at interdune swale at Salinas River National Wildlife Refuge. Sparsely vegetated swales provide nest sites, channels for chick movement and roost areas in winter when beach areas are inundated by storm waves.

Nest Site Selection

Nest site selection is influenced by ecological, environmental, and social factors. Snowy plovers prefer nest sites that enhance camouflage of eggs and facilitate early detection of predators, are within or adjacent to areas occupied by other nesting plovers, and where they have nested successfully in previous years (Page et al. 2009, Colwell et al. 2011, Gómez-Serrano and López-López 2014). Nest site selection also is influenced by habitat characteristics at both small and larger spatial scales. At the microhabitat scale (within a few meters of the nest), snowy plovers select nest sites with minimal debris and low vegetative cover, where vegetative cover is composed of low-growing plant species (Tables 3-4), and often place nests near small objects or on low rises (Page et al. 2009). At larger spatial scales (>10m), plovers select sites that have lower vegetative cover (Muir and Colwell 2010) and are located on wider beaches (Patrick and Colwell 2014) both of which suggest a preference for more open habitats that facilitate early detection of predators.

Table 4. Vegetation characteristics at snowy plover nest sites in California.

Habitat	Cover (%)	Max height (cm)	County	Source
Beach	5-15	--	Santa Barbara	*Point Blue unpubl. data*
Beach, salt pan and fill	9	40	San Diego	*Powell and Collier 2000*
Beach	8	52	San Diego	*Powell 2001*

Microhabitat characteristics may have even greater influence on nest site selection when predation pressure is high (Page et al. 2009, Colwell et al. 2011, Herman and Colwell 2015). In Monterey Bay, where the risk of nest predation from common ravens (*Corvus corax*) is intense and episodic, nests are sometimes placed at sites with atypical features, such as directly under overhanging driftwood or concealed within low overhanging vegetation (Page et al. 2009, Point Blue unpubl. data, Figure 3). Plovers in Monterey Bay also respond to predation pressure from ravens by selecting nest sites that are further oceanward (i.e., much lower on the beach) in order to avoid the foredune area where ravens forage more intensively. Thus, even though plovers prefer a certain range of microhabitat characteristics, they also demonstrate a certain degree of adaptive capacity by selecting nest sites in response to specific predator threats.

Figure 3. Two egg snowy plover nest concealed under woody debris, Salinas River National Wildlife Refuge.

Winter Ecology

In winter, snowy plovers occur in flocks at many of the same sites along Monterey Bay that are used for nesting. Survival over the winter is negatively affected by predation and extreme cold weather events (Stenzel et al. 2007, Page et al. 2009, Point Blue unpubl. data). In addition, winter storm waves and high tides frequently combine to inundate roosting beaches, forcing plovers seek refuge on higher, wider beaches, within unvegetated interdune swales (Figure 2), or in bare rear dune areas. Thus, increased storm activity will reduce survival directly and indirectly by reducing available roosting habitat. Because annual survival is a key component of overall plover population stability (Nur et al. 1997), projected increases in frequency and duration of storms and colder winter temperatures may have population-level consequences.

4. Climate Change Projections

To identify possible vulnerabilities of the Monterey Bay snowy plover population to climate change, we compiled projected changes in sea level rise, temperature, precipitation, and heat waves for the period 2070-2100. Sea level rise projections and hazard exposure maps were obtained from NOAA's Sea Level Rise Viewer (https://coast.noaa.gov/sea level rise/beta/#/layer/sea level rise, local scenario: Monterey, California). For temperature, precipitation and heat waves, data from the medium and high Representative Concentration Pathways (RCP 4.5 and RCP 8.5) defined by the Intergovernmental Panel on Climate Change and adopted for California's 4th Climate Change Assessment (http://climateassessment.ca.gov/) were used. Data were obtained from https://cal-adapt.org/ for Monterey County, California.

Sea Level Rise

At the time of our analysis, the most recent and comprehensive set of relative sea level rise projections for Monterey, California, indicated that mean relative sea level could increase 44-308cm (1.4-9.8ft) between 2000 and 2100 (Table 5, Sweet et al. 2017).

Table 5. Relative sea level rise projections for five future emissions scenarios for Monterey Bay, California, 2000 - 2100. Source: Sweet et al. 2017.

Year	Intermediate low (cm)	Intermediate (cm)	Intermediate high (cm)	High (cm)	Extreme (cm)
2000	0	0	0	0	0
2010	2	4	6	7	7
2020	7	10	13	15	17
2030	10	15	20	26	31
2040	15	23	33	45	53
2050	19	33	49	68	81
2060	25	44	67	95	116
2070	29	56	88	124	155
2080	35	70	113	161	201
2090	39	84	138	201	249
2100	44	100	170	250	308

Flood exposure risk, or the potential loss of beach habitat as a result of inundation from rising seas, depends on a variety of factors, including beach width, topography, and backshore characteristics. We used flood exposure maps from the NOAA Sea Level Rise Viewer to understand regional patterns of flood exposure risk for seven contiguous sections of beaches and dunes in Monterey Bay, from Sunset Beach in the north to Monterey State Beach in the south. The NOAA Sea Level Rise Viewer provides exposure maps at sea level rise increments of 1 ft (30.5 cm) up to 6 ft (183 cm). For each foot of sea level rise (1ft through 6 ft) we classified the area of extant beach that is projected to be flooded into three categories (0-25% area flooded, 26-50%, and >50%) by viewing flood maps at the highest visual resolution. Low-lying and relatively flat beaches around river mouths had a higher exposure risk (Figure 4), with >50% of beach area projected to be flooded with 2-3 ft (61-91.5 cm) of sea level rise, which could happen as early as 2050 under higher emission scenarios (Table 5). Higher elevation and relatively steep profiles of the dune and bluff-backed beaches of southern Monterey Bay showed a lower exposure to sea level flood hazards.

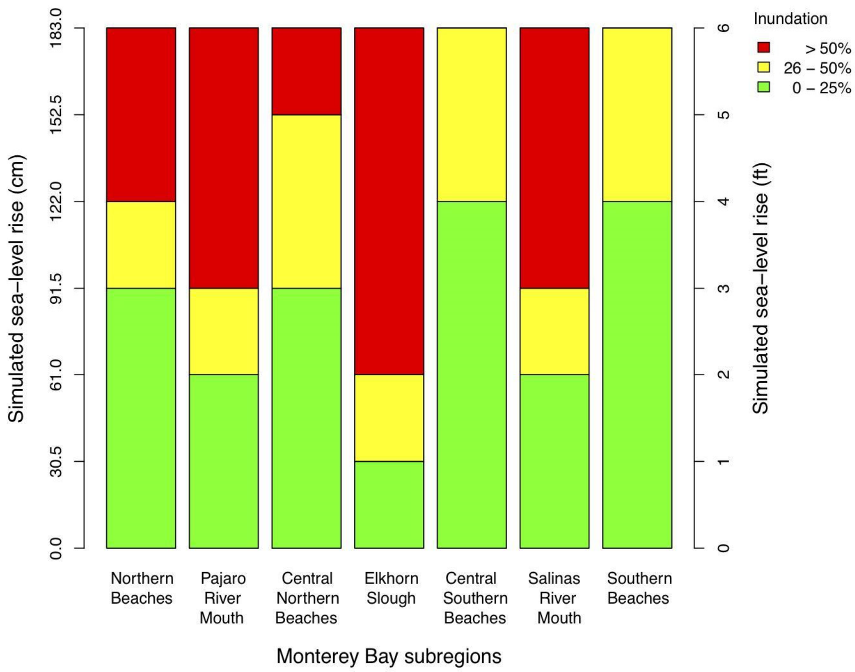

Figure 4. Sea level rise flood exposure thresholds at seven major sections of beaches and dunes, two river mouths, and at the mouth of Elkhorn Slough, Monterey Bay, California. Colors correspond to the percent of beach area projected to be flooded at each sea level rise increment. (*Northern Beaches*: Sunset and Palm Beach; *Central Northern Beaches*: Zmudowski and Moss Landing State Beaches; *Central Southern Beaches*: Salinas River State Beaches; *Southern Beaches*: North Marina dunes, Fort Ord Dunes State Park, Sand City, and Monterey State Beach).

Coastal Erosion

The southern Monterey Bay shoreline is on average the most erosive sandy shore in California (Hapke et al. 2006). Approximately 4.4 square miles of coastline in Monterey County is susceptible to erosion from expected sea level rise; projections indicate that by 2100 coastal dunes and cliffs will retreat by up to 1,300 feet and 720 feet, respectively (Heberger et al. 2009).

Temperature, Precipitation, Heat Waves, and Extreme Events

Under the RCP 4.5 and RCP 8.5 scenarios, minimum and maximum temperature, total annual precipitation, and heat wave duration are projected to increase (Table 6).

Table 6. Projected increases in temperature, precipitation and heat wave duration in Monterey County, California.

Monterey County	Historical (1960 – 2005)	Projected (2070 – 2099)	Change
Avg. Max Temp	66.3°F	71.1 - 73.8°F	+4.8 - 7.5°F
Avg. Min Temp	35.7°F	40.1 - 43.3°F	+4.4 - 7.6°F
Precipitation	28.7 in	29.8 - 34.5 in	+1.1 - 5.8 in
Heat waves (>89.8F)	5 days	19 - 31 days	+14 - +27 days

In addition to the effects described above, the Monterey Bay area is expected to experience more of the following climate patterns and related effects in the future:

- More frequent occurrence and greater intensity of extreme weather and weather-related events: heat waves, storms, flooding, droughts, wildfires
- Sea level rise will cause saltwater intrusion
- Increased groundwater demand will cause lowered water tables and decreased water quality
- Increased public safety and health risks: increased flood risk from levee stress or failure, decreased air and water quality, increased fire and flood risk
- Increased variability in coastal sediment supply related to extreme drought and flooding
- Ocean acidification causes decreases in productivity of coastal ecosystems, negatively impacting kelp forests and the sandy beach food web.

5. Vulnerability of the Snowy Plover and the Beach and Dune Ecosystem

Vulnerability to climate change is a function of the intrinsic sensitivity of a species, a population, a subpopulation, or a habitat, the level of exposure to changing environmental conditions, and the ability to adapt to those changes (Hutto et al. 2015). Beaches and dunes along the Monterey Bay shoreline are expected to be negatively impacted by climate change, especially by seal level rise and related effects. Because the Pacific Coast population of the western snowy plover depends exclusively on these coastal habitats, the population is also highly vulnerable to the impacts of climate change (Gardali et al. 2012, Hutto et al. 2015). We used the climate projections described above, literature on beach and dune ecology, and our knowledge of the ecology of the plover to qualitatively describe the climate vulnerability of a species and its habitat: the snowy plover and the beach and dune ecosystem (Table 7). Two predominant vulnerabilities were identified: a reduction in habitat area and quality, and higher nest and chick mortality. These vulnerabilities were related to projections for sea level rise, increased storms, and changes in sediment supply but also to increased heat and ocean acidification (Table 7).

Table 7. Predicted vulnerability of Monterey Bay beaches, dunes and snowy plovers to the secondary effects of projected climate impacts

Climate Impact	Secondary Effect	Snowy Plover and Habitat Vulnerabilities
Sea level rise	Narrower beaches Lower elevation beaches	Habitat area and quality reduced Higher nest mortality from flooding
Increased storm frequency and intensity *Extended storm season*	Narrower beaches Lower elevation beaches Increased coastal erosion Increased beach flooding Steeper foredune profile	Habitat area and quality reduced Higher mortality of nests and chicks, especially in first half of breeding season Plover high tide winter roost areas inundated more frequently Reduced winter survival
Decreased or variable riverine sediment supplies	Narrower beaches Lower elevation beaches Increased coastal erosion Steeper foredune profile	Habitat area and quality reduced Higher mortality of nests and chicks

Increased heat and drought	Increased human use of beaches Range expansion or shift of predator species	Higher nest, chick and adult mortality
Ocean acidification	Decrease in ocean productivity Decrease in kelp wrack Decrease in invertebrate prey	Higher adult and chick mortality due to lack of food

6. Climate-Smart Strategies and Actions for the Snowy Plover and the Beach and Dune Ecosystem

Climate-smart strategies are generalized approaches that provide a blueprint for developing a program to manage vulnerabilities to climate effects. Each climate-smart strategy is composed of specific actions (Table 8) that, when implemented, will minimize the vulnerabilities created by the secondary climate effects identified in Section 5. The strategies and actions that reduce multiple vulnerabilities should be the highest priority for implementation.

Strategy 1. ***Maintain Ecological Integrity of Beach and Dune Habitat***

Preserving and allowing natural ecological processes to occur provides time for species and habitats to adapt while biodiversity and the benefits of coastal protection and other ecosystem services are protected.

Strategy 2. ***Integrate Climate-Smart Principles into Habitat Restoration Design***

Climate-smart restoration is the process of enhancing present and future ecological function so that the restored portion of an ecosystem is resilient to a range of future climate conditions. The climate-smart restoration approach is explained in detail in Appendix A.

Strategy 3. ***Manage Non-Climate Stressors to Buffer Sensitive Species and Habitats***

Species and habitats can adapt to change but the pace is likely to be slow. Reducing the impacts of non-climate stressors provides the necessary time and space for adaptation to occur. Key non-climate stressors that negatively affect the sensitive species and fragile physical landforms of the beach and dune ecosystem are human-caused disturbance, invasive vegetation and human-subsidized predators.

Strategy 4. ***Plan and Prepare for Shoreline Retreat***

Based on climate projections for Monterey Bay, inland retreat of the shoreline is inevitable. Now is the time to identify strategic opportunities for conservation investments and to plan for future implementation to allow the existing shoreline to gradually shift inland. Longer-term actions include permanent protection and acquisition of resilient shoreline areas and negotiation of conservation easements. In areas where timelines are shorter, preparations for shoreline retreat include more immediate actions such as removing and relocating critical infrastructure.

Strategy 5. ***Research (Test and Experiment)***

Many emerging climate-smart strategies and actions are untested. Building in research, monitoring, and assessment for novel actions or techniques where data gaps exist will provide a platform to generate adaptive management and produce better solutions for the future. Pilot projects that can be scaled up have potential to provide very rapid, lower-cost feedback on the effectiveness of new techniques and can be used to guide future investments.

Strategy 6. ***Outreach***

Working with the human communities that use Monterey Bay beaches or live near them will be necessary to create stewards and advocates for addressing climate impacts on snowy plovers. Showing these communities the links between the impacts that sea level rise is projected to have on human infrastructure, plovers, and the beach and dune ecosystem will help build momentum and support for solutions that benefit both.

Table 8. Climate-smart strategies and actions to reduce secondary climate effects on beaches, dunes, and snowy plovers along the Monterey Bay, California shoreline.

Secondary Climate Effects and Vulnerabilities	**Climate-Smart Strategies and Actions**
Reduced habitat area and quality	***1. Maintain Ecological Integrity of Beach and Dune Habitat*** ◊ Promote positive sediment dynamics (e.g., manage rivers to maintain sediment flows) ◊ Promote beach and dune building by protecting processes of natural sand deposition and Aeolian transport ◊ Protect landform integrity by eliminating unnecessary beach access point and by planning new access points in areas that minimize erosion hazards ◊ Eliminate beach raking and kelp wrack removal to promote accumulation of biological inputs into sandy beach food web ***2. Integrate Climate-Smart Principles into Habitat Restoration Design*** ◊ Restore and improve quality of higher elevation beach and dune habitat ***3. Manage Non-Climate Stressors to Buffer Sensitive Species and Habitats*** ◊ Manage predators ◊ Manage human-caused disturbance ◊ Manage invasive non-native vegetation ***4. Plan and Prepare for Shoreline Retreat*** ◊ Identify strategic areas for planned shoreline retreat ◊ Acquire conservation easements in strategic areas ◊ Remove non-native vegetation in transition zone habitat to allow foredune ecology to transition into mid-dune habitats ◊ Protect alternate breeding and wintering habitats for snowy plovers (e.g. wetland-adjacent salt pan habitats such as Moss Landing Wildlife Area) ◊ Relocate infrastructure (e.g., roads, buildings) that is a barrier to shoreline retreat ***5. Research (Test and Experiment)*** ◊ Test and experiment with novel approaches (e.g., use indigenous materials for stabilization) to build new dunes and protect foredunes ◊ Test and experiment with beach nourishment techniques to minimize ecological impacts and protect shorelines ◊ Create early detection surveillance programs to monitor invasive, non-native vegetation and shifts in predator species and ranges ***6. Outreach*** ◊ Inform local policy makers and planners of the shared concern of sea level rise for both human infrastructure and plover viability; provide ideas for multiple-benefit solutions ◊ Reduce mechanical disturbance from humans to dunes through education and outreach, habitat restriction and closure and elimination of high impact activities

Increased nest loss from flooding	***2. Integrate Climate-Smart Principles into Habitat Restoration Design*** ◊ Promote natural dune profiles that will attenuate storm wave energy and provide plover nesting sites above the high tide line by controlling invasive vegetation ◊ Build and restore habitat refugia such as interdune and rear dune swales, sand levees that provide buffers from predators and human-caused disturbance ◊ Design topography and employ plant palettes that provide space for snowy plover chick movement across foredunes and into mid-dune areas ***3. Manage Non-Climate Stressors to Buffer Sensitive Species and Habitats*** ◊ Reduce nest predators that are causing snowy plovers to select lower elevation nest sites ***5. Research (Test and Experiment)*** ◊ Test and experiment with novel approaches (e.g., use indigenous materials for stabilization) to build new dunes and protect foredunes ◊ Test and experiment with beach nourishment techniques that minimize ecological impacts and protect shorelines
Increased chick and adult mortality	***1. Maintain Ecological Integrity of Beach and Dune Habitat*** ◊ Increase habitat connectivity by removing revetments and other barriers to plover movement along beachfronts ◊ Remove invasive vegetation (iceplant, European dune grass, non-native trees) ◊ Minimize the number of beach access points to prevent erosion hotspots that negatively affect the integrity of the dune landform ◊ Promote beach and dune building by protecting processes of littoral sand deposition and Aeolian transport ◊ Eliminate beach raking and kelp wrack removal to promote accumulation of biological inputs into sandy beach food web ***2. Integrate Climate-Smart Principles into Habitat Restoration Design*** ◊ Build and restore habitat refugia such as interdune and rear dune swales, sand levees that provide buffers from predators and human-caused disturbance ◊ Design topography and employ plant palettes that provide space for chick movement across foredunes and into mid-dune areas ***3. Manage Non-Climate Stressors to Buffer Sensitive Species and Habitats*** ◊ Reduce chick predators ◊ Trap and translocate predators of adult plovers ◊ Reduce human disturbance through habitat restriction, temporary closures and elimination of high impact activities ◊ Strategically plan beach access points to have minimal impact on sensitive nesting areas ***5. Research*** ◊ Test and experiment with novel approaches (e.g., use indigenous materials for stabilization) to build new dunes and protect foredunes ◊ Create surveillance programs to monitor shifts in predator species and ranges ***6. Outreach*** ◊ Inform the public through media or local presentations on the impact of climate projections on chick mortality ◊ Reduce human disturbance through education and outreach, habitat restriction and closure and elimination of high impact activities
Impacts on food resources	***1. Maintain Ecological Integrity of Beach and Dune Habitat*** ◊ Eliminate beach raking and kelp wrack removal to promote accumulation of biological inputs into sandy beach food web ◊ Protect and restore kelp beds

Impacts on food resources	◊ Reduce human disturbance through habitat restriction, temporary closures and elimination of high impact activities ***5. Research*** ◊ Test and experiment with seeding epifauna on beaches via placement of kelp wrack ◊ Test and experiment with beach nourishment techniques that minimize ecological impacts and protect shorelines ***6. Outreach*** ◊ Inform the public through media or local presentations about the importance of kelp wrack inputs into the sandy beach ecosystem in sustaining critical ecological functions of food web ◊ Reduce human disturbance through education and outreach, habitat restriction and closure and elimination of high impact activities

7. Site-Specific Habitat Vulnerability Assessment

In the following section, we assessed the sea level rise vulnerability of 12 beach and dune areas along the central and southern Monterey Bay shoreline. The purpose of this assessment was to identify the vulnerability of individual sites and opportunities to improve individual site resilience through implementation of specific climate-smart strategies and actions.

In order to do this, we assessed the following two components that influence site vulnerability:
1. CLIMATE EXPOSURE was assessed by examining sea level rise inundation exposure maps and the time to 25% exposure (inundation).
2. ADAPTIVE CAPACITY was assessed by examining physical landform attributes that affect vulnerability to sea level rise.

All snowy plover nesting and wintering sites along the contiguous shoreline from the Sunset Beach area in the north through Monterey State Beach in the south were included, an area that spans approximately 33 linear kilometers (Figure 5). Individual site boundaries were determined based on land ownership, land management, habitat type, and important geographic features (e.g. adjacent to river mouth; See Appendix B for detailed descriptions of site boundaries). The beaches of northern Santa Cruz County (Waddell Creek, Scott Creek, Laguna Creek, and Wilder Ranch beaches), Pt. Sur and Little Sur beaches in Monterey County were not included because they are not part of the contiguous sandy shoreline of Monterey Bay and they also lack the data sources necessary for assessment. The Moss Landing Wildlife Area also was not included because it is a different habitat type (salt pan), and this assessment was focused on the beach and dune ecosystem along the contiguous shoreline of Monterey Bay.

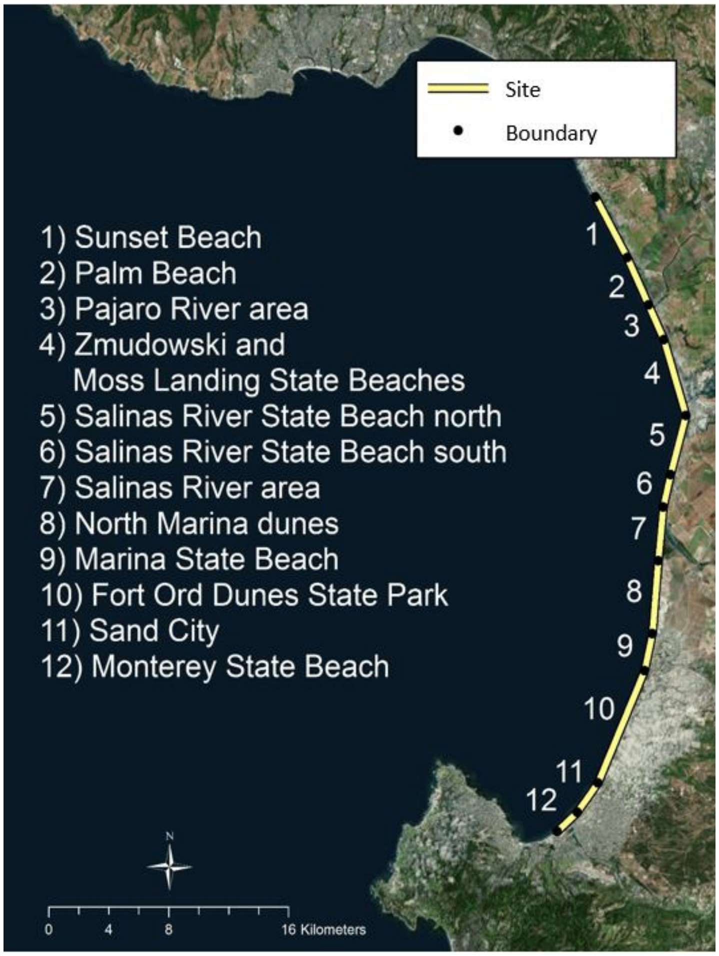

Figure 5. Site assessment study area, Monterey Bay, California

Climate Exposure

To manage sea level rise vulnerability from a climate-smart perspective it is important to know how quickly sea level rise will proceed and how severely beach and dune habitats will be impacted across Monterey Bay. To provide this information, we combined decadal sea level rise projection data for five future scenarios (Table 9) with habitat inundation thresholds for each of the 12 beach sections spanning Monterey Bay (Figure 5). Due to the extreme vulnerability of beaches, dunes, and the snowy plover to the impacts of sea level rise, we selected the most conservative threshold, when 25% of habitat will be inundated (i.e. the 25% inundation threshold). Projecting when the 25% inundation threshold could be reached was a two-step process. First, we fitted polynomial regression models to decadal sea level rise projection data for five scenarios, spanning 2000–2100. Third-order polynomial models had the best fit ($0.9985 \leq$ adj. r-square ≤ 0.9998 for the five relative sea level rise scenarios). Second, we used the fitted models to project the year when 25% habitat inundation is expected to occur for each beach segment (Table 9). Inundation thresholds were based on a static elevation model, which does not account for erosional effects. NOAA recommends using projections derived from the more severe relative sea level rise scenarios (i.e., the "High" and "Extreme" scenarios) when risk tolerance is low, such as when critical ecological functions are served, as is the case here. We visually assessed sea level rise inundation footprints in the NOAA Sea Level Rise Viewer to determine 25% inundation thresholds and we used the 25% inundation thresholds (Table 9) to assign a climate vulnerability score for each site where 2 ft = higher vulnerability, 3 ft = moderate vulnerability and 4 ft = lower vulnerability.

Table 9. Projected sea level rise and year when 25% area of habitat is projected to be inundated under five emissions scenarios for coastal sections of Monterey Bay, California.

		Intermediate				
Sites	**SLR (ft) when 25% Habitat Area Inundated**	**Low**	**Intermediate**	**High**	**High**	**Extreme**
Sunset Beach	3	>2100	2095	2073	2060	2054
Palm Beach	3	>2100	2095	2073	2060	2054
Pajaro River mouth	2	>2100	2074	2058	2048	2043
Zmudowski State Beach	3	>2100	2095	2073	2060	2054
Moss Landing State Beach	3	>2100	2095	2073	2060	2054
Salinas River State Beach, N.	4	>2100	>2100	2084	2069	2062
Salinas River State Beach, S.	4	>2100	>2100	2084	2069	2062
Salinas River mouth	2	>2100	2074	2058	2048	2043
North Marina Dunes	4	>2100	>2100	2084	2069	2062
Fort Ord Dunes State Park	4	>2100	>2100	2084	2069	2062
Sand City	4	>2100	>2100	2084	2069	2062
Monterey State Beach	4	>2100	>2100	2084	2069	2062

Adaptive Capacity and Vulnerability

Adaptive capacity is the ability of a resource to accommodate or buffer climate change impacts with minimal disruption (Glick et al. 2011). For the assessment of adaptive capacity, we used two landform attributes to characterize the quantity of habitat at the site level: total beach width and potential for landform retreat. Potential for landform retreat was defined as the width of the area from mean higher-high-water (MHHW) to the nearest inland human infrastructure or constraining landform (e.g. road or waterway). Beach widths (ESA unpubl. data) were measured from the 2009-2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth Digital Elevation Model, following methods of Jackson et al. (2015) and summarized in Newkirk et al. (2018). Potential for landform retreat was measured using the most current Google Earth imagery for each site. Finally, the vulnerability of each site within the climate exposure and adaptive capacity assessments was ranked and exposure versus adaptive capacity was plotted to produce groupings of similar sites.

Results

Climate exposure rankings were based on the time to the 25% of inundation threshold (Table 9, defined as time to SLR threshold 1). Landscape features and geography had a strong influence on the results. The two river mouth areas were the most vulnerable sites, and there is a general trend toward the northern half of Monterey Bay (north of Elkhorn Slough) showing higher inundation exposure risk (Table 10, Figure 6). Adaptive capacity was lowest along the southernmost Monterey Bay shoreline at Sand City and Monterey State Beach where human infrastructure is a significant barrier to shoreline retreat. Adaptive capacity was highest along the central and southern bay shoreline in a continuous stretch from the North Marina Dunes south through Fort Ord Dunes State Park where beaches are at least moderately wide and shorelines are less constrained from retreating inland (Table 10, Figure 6). Both river areas had high inundation exposure risk but also showed high adaptive capacity because the adjacent inland areas provide space for a retreating shoreline.

Table 10. Relative climate exposure and adaptive capacity rankings at 12 beach and dune sites, Monterey Bay, California. Climate exposure rankings are based on a sea level rise inundation threshold (time to 25% inundation) and adaptive capacity is based on physical characteristics of the landscape associated with resiliency.

Site	SLR Vulnerability	Climate Exposure Group[1]	Physical Characteristics		Adaptive Capacity Group[4]
			Landform Retreat[2]	Sandy Beach Width[3]	
Sunset Beach	2	moderate	2	3	high
Palm Beach	2	moderate	1	2	moderate
Pajaro River area	3	high	1	2	moderate
Zmudowski - Moss Landing State Beaches	2	moderate	2	2	high
Salinas River State Beach North	1	low	1	2	moderate
Salinas River State Beach South	1	low	1	2	moderate
Salinas River area	3	high	2	3	high
North Marina Dunes	1	low	2	2	high
Marina State Beach	1	low	2	2	high
Fort Ord Dunes State Park	1	low	2	2	high
Sand City	1	low	1	1	low
Monterey State Beach	1	low	1	1	low

[1]3 = highest vulnerability (25% of habitat inundated at 2ft of SLR), 2 = moderate vulnerability (25% of habitat inundated at 3ft of SLR), 1 = lower vulnerability (25% of habitat inundated at 4ft of SLR), from Table 9.

[2]Landform retreat: 1 = averaging <200m and 2 = averaging >200m from MHHW to nearest backshore constraining human infrastructure or natural landform

[3]Width of sandy beach in 2010 (see text); 1 = <35m, 2 = 35-50m, 3 = >50m

[4]Scores of sum of landform and beach width scores where 4-5 = high adaptive capacity, 3 = moderate adaptive capacity, 2 = low adaptive capacity

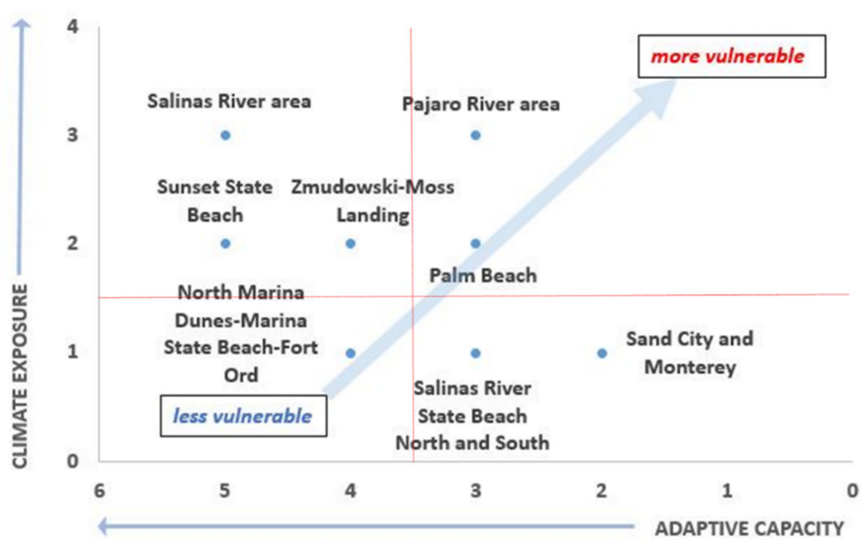

Figure 6. Climate exposure and adaptive capacity scores for 12 beach and dunes sites along the shoreline of Monterey Bay, California. Sites with *high* exposure and *low* adaptive capacity scores are most vulnerable. The four quadrants demarcate groupings of sites with similar levels of vulnerability.

Relative Vulnerability and Opportunities for Employing Climate-Smart Actions

In this section, sites were grouped based on their relative vulnerability along a scale where high exposure and low adaptive capacity was considered most vulnerable and low exposure and high adaptive capacity was considered least vulnerable (Fig. 6). Climate-smart strategies from Table 8 were recommended and, in some cases, specifically adapted to address the vulnerabilities of each group or a site within a group. The rationale for selecting and adapting strategies was based on the premise that as vulnerability of sites increases, management should move toward implementation of more aggressive and/or more experimental methodologies. The high level of threat and shorter timelines at the most vulnerable sites provides an opportunity for rapid feedback on the efficacy of experimental techniques and also provides the political, social and economic impetus to employ more intensive measures. In contrast, the relatively lower levels of threat at less vulnerable sites allows for the focus to be on long-term planning, and maintaining resiliency and ecosystem function through more traditional management while the data on efficacy of experimental techniques accumulates. In each grouping, a single site-based opportunity is provided and corresponds to one or more recommended actions (in bold).

1. Less Vulnerable (North Marina Dunes, Marina State Beach, Fort Ord Dunes State Park)

At these sites the beach and dune ecosystem is more intact and the extent of the physical landform is much greater than at other sites, resulting in a higher degree of natural adaptive capacity. Consequently, sea level rise exposure is a lower threat than at other sites along Monterey Bay. Recommended actions at these sites focus on enhancing existing adaptive capacity by protecting ecosystem processes, employing climate-smart restoration in habitat that will be future shoreline, and engaging in long-term planning to increase resilience and plan for shoreline retreat.

- Improve habitat quality by reducing human disturbance through education and outreach, habitat restriction and closure and elimination of high impact recreational activities
- Promote positive sediment dynamics (e.g. preserve normal river flows)
- **Employ climate-smart principles in habitat restoration plans**
- **Minimize the number of beach access points to prevent erosion hotspots that negatively affect the integrity of the dune landform**
- Promote beach and dune building by protecting processes of littoral sand deposition and Aeolian transport
- Protect and restore kelp beds
- Improve quality of higher elevation remaining habitat
- Improve and restore transition zone habitat
- Identify strategic areas for planned shoreline retreat
- Acquire conservation easements in identified strategic areas

Site-based opportunity (North Marina Dunes) *Most of the area comprising the North Marina Dunes is currently privately owned but is expected to transfer to public ownership in the next few years. This will provide a significant opportunity to employ climate-smart principles in the design of habitat restoration and planning of any new beach access areas.*

2. Moderately Vulnerable (Salinas River area, Zmudowski-Moss Landing State Beaches, Sunset Beach)

Sea level rise exposure is a moderate threat at these sites. Because there is no way to reduce exposure, recommended actions focus on increasing adaptive capacity where opportunities exist to protect and enhance ecosystem integrity, while also recognizing the need to begin addressing challenges related to shoreline retreat.

- **Improve habitat quality and preserve integrity of physical landforms by reducing human disturbance through habitat restriction and temporary closure and elimination of high impact activities**
- Promote positive sediment dynamics (e.g., preserve normal flows of Salinas and Pajaro Rivers)
- Protect and restore kelp beds
- Employ climate-smart principles in habitat restoration plans
- Improve quality of higher elevation remaining habitat
- Improve and restore transition zone habitat
- Identify strategic areas for planned shoreline retreat
- Acquire conservation easements in identified strategic areas

Site-based opportunity (Sunset Beach) *Activities that have high impacts on the physical integrity of beach and dune landforms include both recreational activities, such as hang-gliding and equestrian use, and operational activities, such as beach driving for law enforcement and lifeguard patrols. Reducing the impact of beach driving by reducing intensity (reduced number of trips, extent, and use of alternate transport modes) provides an opportunity to protect the integrity of physical landforms and improve ecological function by reducing known sources of mortality of beach invertebrates and snowy plovers.*

3. Very vulnerable (Sand City, Monterey, Salinas River State Beach North and South)
At these sites, sea level rise exposure is a lower threat than at some areas but there also is limited capacity for the landscape to adapt due to natural or anthropogenic barriers to landward retreat of the shoreline. Actions should focus on protecting the integrity of the existing landforms and remaining ecological processes and immediately preparing the landscape to transition to a new future state.

- Improve habitat quality and preserve integrity of physical landforms by eliminating high impact recreational activities
- **Reduce and relocate beach access points as necessary to reduce erosion and increase the integrity of the dune landform**
- Protect landforms and increase habitat connectivity by removing revetments and other barriers that interfere with natural functions of the sandy beach and dunes and inhibit snowy plover habitat use
- Promote positive sediment dynamics (e.g., preserve normal flows in the Salinas River which is an important sand source for Salinas River State Beach)
- Increase habitat refugia such as interdune or rear dune swales, sand levees
- Eliminate beach raking and kelp wrack removal
- Test and experiment with novel approaches (e.g., use indigenous materials for stabilization) to build new dunes and protect foredunes
- Test and experiment with beach nourishment that minimizes ecological impacts
- Test and experiment with seeding sandy beach epifauna via introduction of kelp wrack
- Prepare for retreat by moving or removing constraining human infrastructure (roads, buildings)

Site-based opportunity (Salinas River State Beach South) *The southern stretch of Salinas River State Beach has a high number of beach access points that were developed to provide access for groups of homes. The access points are subject to high levels of wind erosion and provide portals for increased wave run-up that further increases erosion. Reducing and re-routing beach access points and restoring damaged areas will protect the integrity of the dune landform, allow normal dune building to occur, provide nesting habitat for snowy plovers and protect adjacent private homes.*

4. Highly Vulnerable (Pajaro River, Palm Beach)
At these sites, sea level rise exposure is a significant near-term threat and there is very limited capacity for adaptation. Because there is no way to reduce exposure, actions at these sites should focus on protecting remaining ecological integrity and testing and experimentation. Inundation time horizons will produce immediate feedback for experiments to be assessed for effectiveness and adapted at these or other sites.

- Increase habitat connectivity by removing revetments and other barriers that interfere with natural functions of the sandy beach and dunes and inhibit snowy plover habitat use
- Remove beach access points to reduce erosion and increase the integrity of the dune landform
- **Test and experiment with novel approaches (e.g., use indigenous materials for stabilization) to build new dunes and protect foredunes**
- Test and experiment with beach nourishment that minimizes ecological impacts
- Test and experiment with seeding sandy beach epifauna via introduction of kelp wrack
- Prepare for retreat by moving or removing constraining human infrastructure (roads, buildings)

Site-based opportunity (Pajaro River) *The Pajaro River is a dynamic ecosystem component constrained within a managed landscape. To the north revetments and human infrastructure constrain the floodplain and to the south a narrow dune system buffers a large agricultural zone set within a system of interconnected wetlands. On both sides of the river, seasonal sand spits provide physical protections to adjacent human infrastructure and economic uses and also are important nesting areas for snowy plovers. These sand spits are low lying and so are extremely vulnerable to erosion and flooding. Using novel approaches to build new dunes and protect existing foredunes in this area provides an opportunity to adaptively improve novel techniques that will benefit human communities and improve habitat for snowy plover nesting.*

Best Actions for All Sites
At all sites reducing the impact of non-climate stressors will be a key strategy that will allow species and habitats the time needed to adapt.

- Reduce the impact of human disturbance on nesting snowy plovers and other sensitive beach and dune species through temporary (e.g. breeding season) habitat restrictions or closures and elimination of high impact recreational and operational activities
- Reduce populations of nest predators that cause snowy plovers to select lower elevation nest sites which increases vulnerability of nests to flooding from extreme high tide or storm events. Reduce the number of predators that specialize on plover chicks and therefore limit annual productivity. Reduce the number of predators that are a source of mortality for adult plovers.
- Create early-detection surveillance programs to monitor shifts in ranges and species composition of invasive vegetation and predator communities.

Acknowledgments

We thank Jacob Martin of the USFWS for the opportunity to collaborate on this project and for his ongoing support of efforts to recover the snowy plover in Recovery Unit 4. The following individuals contributed valuable time and expertise to this project: Amy Palkovic, Portia Halbert, and Tim Hyland of California State Parks, and Chris Caris of the USFWS, Salinas River National Wildlife Refuge. Maya Hayden of Point Blue Conservation Science provided valuable insights into the current thinking around coastal adaption and conducting vulnerability assessments and also provided constructive feedback on earlier versions of this report. This report was greatly improved by the comments of Catherine Hickey, Sam Veloz, and Lynne Stenzel of Point Blue Conservation Science. Blake Barbaree of Point Blue Conservation Science created the map for the site assessments. This work was made possible by the ongoing partnership and collaboration of the many dedicated individuals and organizations that comprise the Monterey Bay snowy plover working group.

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Appendices

Appendix A: Climate-Smart Restoration Principles

Point Blue developed a set of principles to assist practitioners and restoration teams develop climate-smart projects based on the principles developed by National Wildlife Federation (Stein et al. 2014) and Hansen et al. (2010). Though there is a long history of traditional ecological restoration of the beach and dune ecosystem in California and also in Monterey Bay, there is limited information on exactly how to make future projects climate-smart. These principles provide a framework for learning and for success across a broad range of possible future conditions.

1. *Show your work*. There is high uncertainty about how climate will change and how society will respond. The information we use to guide action today may be very different from the information we use to guide action in the future. By showing our work, we help future generations continue to adapt as new information becomes available. Showing your work aids in arriving at the best possible actions, as you asked and answer key questions about the project.

2. *Look forward but don't ignore the past*. Because climate change will create conditions that are different from past and current ones, setting forward-looking goals is essential. Using the best available climate models, at the scale appropriate, aids project design and likely increases the probability of long-term success. In cases where the available science is highly uncertain or divergent, restoration should be designed to succeed in multiple scenarios. The past can also help in designing projects to succeed in the future. Information on a species' or ecosystem's response to historic climatic extremes can serve as a useful analog to how they might fare under predicted future scenarios.

3. *Consider the broader context*. Climate change does not act alone in stressing ecosystems. It is essential to consider and plan for the full range of threats to the system. Success of individual projects is influenced by the surrounding land use, ecological setting (e.g., hydrology), and future conditions at regional scales. A landscape-scale perspective reinforces the need to keep connectivity as a key characteristic of restoration to improve the potential for species to move in response to climate change and for preserving the ecological processes for evolutionary adaptations to climate change.

4. *Build in ecological insurance*. Restoration approaches that incorporate redundancies and are robust to a range of future scenarios may act to provide insurance against uncertain future conditions. Increasing redundancy in restoration means replicating and diversifying critical components (e.g., plant the full complement of foredune species intermixed in high densities) and functions (e.g., allow for bare interdune swales to absorb and filter storm wave water). High ecological diversity is a form of ecological insurance that could reduce the probability of ecosystem collapse if it buffers change in functional composition of the community, and there is relatively little risk in increasing it in restoration projects.

5. *Build evolutionary resilience*. It is increasingly recognized that micro-evolutionary change can occur at the relatively short timescales relevant to natural resource management decisions, and may therefore be a critical pathway by which species escape extinction under climate change. Consequently, restoration actions that build evolutionary resilience by managing microevolution are climate-smart. Evolutionary resilience can be accomplished by restoration projects that increase the size and connectedness of populations to allow for the maintenance of genetic variation and ongoing evolution in order to keep pace with climate change and may increase the probability that an ecosystem can recover after climatic extremes.

6. *Include the human community*. The long-term success and growth of climate-smart ecological restoration projects will be facilitated by a community of advocates with an understanding of the what, why, and how to prepare systems for climate change. Additionally, project sustainability will be increased when people who understand and care about it can monitor and maintain it. Hence, projects where citizen stewards are involved will be better supported and their influence increased.

7. *Monitor and experiment*. Given the great uncertainties around how climate change will impact ecosystems and how society will respond, it is important to conduct ecological monitoring to manage adaptively to a rapidly changing future. Restoration experiments can help provide answer to key uncertainties, provide tools to access key information, and help evaluate effectiveness.

Appendix B. Detailed descriptions of site boundaries from Section 6

Site	Beach Length (km)	Land Ownership	Site Boundaries
Sunset Beach	3.6	CA State Parks, private	The southern end of the Monterey Bay Academy beach south to the northern boundary of the Shorebirds residential development
Palm Beach	2.7	CA State Parks	The southern end of the Shorebirds residential development south to the southern end of the Pajaro Dunes residential development
Pajaro River area	2.0	CA State Parks	The southern end of the Pajaro Dunes residential development south to the Zmudowski State Beach parking lot
Zmudowski - Moss Landing State Beaches	3.3	CA State Parks	The Zmudowski State Beach parking lot south to the southern boundary of Moss Landing State Beach
Salinas River State Beach North	2.9	CA State Parks	The northern boundary of Salinas River State Beach at the Sandholdt Rd. parking lot south to the northern end of the Monterey Dunes Colony residential development
Salinas River State Beach South	1.6	CA State Parks, private	The northern end of Monterey Dunes Colony south to the southern end of Monterey Dunes Colony
Salinas River area	2.8	CA State Parks, USFWS	The south end of the Monterey Dunes Colony south to the southern boundary of the Salinas River National Wildlife Refuge
North Marina Dunes	3.8	Big Sur Land Trust, private, MPRPD[1]	The southern boundary of Salinas River NWR south to the northern boundary of Marina State Beach, including the Martin and Cemex Dunes, the Marina Dunes Preserve, and the private beaches south of the Marina Dunes Preserve and north of Marina State Beach
Marina State Beach	1.7	CA State Parks	The boundaries of Marina State Beach
Fort Ord Dunes State Park	6.6	CA State Parks	The boundaries of Fort Ord Dunes State Park
Sand City	1.3	private, MPRPD	The southern boundary of Fort Ord Dunes State Park south to Bay Avenue in Sand City
Monterey State Beach	1.0	CA State Parks	The western terminus of Bay Avenue in Sand City south to the Harbor House Condominium residential development

[1] Monterey Peninsula Regional Parks District