2025

VULNERABILITY ASSESSMENT

FOR SAN MATEO'S MARINE PROTECTED AREAS

Sea & Shore SOLUTIONS

Prepared by Sea & Shore Solutions
for the California Marine Protected Area
Collaborative Network

About this Report

This report, developed by Sea & Shore Solutions in partnership with the Marine Protected Area Collaborative Network, synthesizes results from the pilot Rapid Vulnerability Assessment for two marine protected areas in San Mateo County. It shares the background that led to this project, methodological approach, regional climate summary, vulnerability scores, and suggested strategies to address vulnerabilities. Findings are relevant for state resource managers, local government staff, community partners, and academic institutions conducting research in the region, or those interested in applying lessons learned and these methodologies more broadly.

Acknowledgments

Funding for this project was provided by the Marine Protected Area Collaborative Network. The project team thanks the San Mateo Collaborative for participation in two vulnerability assessment workshops. Special thank you to San Mateo Collaborative co-chairs, Natalie Downe and Marina Luccioni, for helping to convene the Collaborative and schedule workshops. We would also like to thank all scientific experts that shared their knowledge through individual interviews, scientific summary review, and participation in the vulnerability assessment workshops.

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Executive Summary

California's Marine Protected Areas (MPAs) are socially and ecologically important areas set aside for long-term conservation. These areas can support long-term resilience, particularly in the face of climate change. To better understand how these areas might be impacted by human and environmental changes, the California Marine Protected Area Collaborative Network (MPACN) partnered with Sea & Shore Solutions to conduct a pilot Rapid Vulnerability Assessment (RVA) for two MPAs in San Mateo County: Montara State Marine Reserve (SMR) and Pillar Point State Marine Conservation Area (SMCA).

Approach

The RVA method involved five key steps:

1. Define the scope by identifying critical assets and stressors through stakeholder input
2. Construct asset-specific scientific summaries through literature review and expert interviews
3. Undertake the assessment through workshops to evaluate risk and adaptive capacity
4. Develop adaptation strategies through an additional workshop, aiming to reduce vulnerability by increasing adaptive capacity or minimizing risk
5. Synthesize results in a narrative report

This structured approach, developed for MPAs in North America, allowed for a comprehensive evaluation of climate and non-climate impacts on selected assets.

Results

The assessment focused on three key assets:

1. Harbor Seals in Montara SMR
2. Tidepools in Pillar Point SMCA
3. Sea Stars in Montara SMR and Pillar Point SMCA

Results indicate low to high vulnerability across a range of climate stressors.

	CLIMATE STRESSOR	VULNERABILITY
HARBOR SEALS IN MONTARA STATE MARINE RESERVE	Increased Water Temperature	LOW
	Sea Level Rise	MODERATE
	Ocean Acidification	LOW
TIDEPOOLS IN PILLAR POINT STATE MARINE CONSERVATION AREA	Sea Level Rise	MODERATE
	Increased Daytime Air Temperature	MODERATE
	Increased Water Temperature	MODERATE
SEA STARS IN MONTARA STATE MARINE RESERVE & PILLAR POINT STATE MARINE CONSERVATION AREA	Increased Water Temperature	HIGH
	Ocean Acidification	MODERATE
	Sea Level Rise	MODERATE

Recommended Strategies

Through this method, the following strategies were identified as promising avenues to explore for reducing vulnerability:

Harbor Seals in Montara SMR

- Build Stewardship through Increased City Education and Engagement Initiatives
- Increase Monitoring of Haulouts and Enable Dynamic Management Protection

Tidepools in Pillar Point SMCA

- Increase the Number of Tidepool Docents–Especially During Low Tides
- Identify Natural Refugia Areas and Strengthen Protections

Sea Stars in Montara SMR and Pillar Point SMCA

- Build a Science to Management Working Group
- Investigate Resilient Genotypes for Potential Outplanting
- Identify Climate Refugia and Apply Area-Based Protections

Contents

Introduction

California is home to a remarkable 840 miles of treasured coastline. California's marine resources are renowned for their iconic beauty, productivity, wildscapes, heritage, and provision of economic resources. In 1999, the California Legislature passed the Marine Life Protection Act to protect the long-term health and culture of California's marine life (Marine Life Protection Act, 1999). This act established a statewide network of marine protected areas (MPAs), defined as "named, discrete geographic marine or estuarine areas designed to protect or conserve marine life and habitat" (Marine Life Protection Act, 1999). Today California supports a world-class system of 124 MPAs.

California's MPAs are managed through the statewide MPA Management Program, which operates under four primary pillars: Research & Monitoring, Enforcement & Compliance, Outreach & Education, and Policy & Permitting (Marine Life Protection Act, 1999). Adaptive management is central to this program, allowing MPAs to respond to emerging environmental threats (e.g., ocean acidification, rising waters, changing temperatures) through data-driven decision-making and ongoing policy updates.

The Marine Protected Area Collaborative Network

The MPA Collaborative Network (MPACN) is a trusted organization in California that engages local communities and stakeholders in climate adaptation planning for MPAs. The MPACN has 14 chapters, called Collaboratives, with over 1,700 members representing over 450 organizations throughout California, including management agencies, recreational and commercial fishers, NGOs, science and academia, Indigenous people and Tribal Nations, ocean businesses, community volunteers, and more. Through its climate initiative, MPACN conducted 14 regional forums gathering insights from 167 participants on environmental change concerns and potential solutions (MPACN, 2024). Additionally, a statewide survey with 382 respondents assessed broader trends in environmental change and ocean acidification concerns. Findings culminated in 15 reports—14 Collaborative reports and a statewide summary—that provide actionable recommendations to decision-makers. A consistent recommendation across these reports is the necessity to conduct vulnerability assessments for California's MPAs.

To begin implementing these recommendations, the MPACN issued a Climate + MPA microgrant opportunity. A range of 13 projects were proposed and three were selected for funding, including this pilot Rapid Vulnerability Assessment (RVA) for two MPAs in the San Mateo Collaborative.

Figure 1. California's Marine Protected Area Collaboratives.

Pilot Vulnerability Assessment Project

This project was built upon the repeated recommendation to conduct vulnerability assessments to evaluate the climate impacts that will affect the MPAs and nearby communities, which emerged through the MPACN's Climate Reports. The San Mateo Collaborative in particular identified this need, noting that San Mateo County has a specific goal of "educating the general public about climate change and its impacts on vulnerable communities" (MPACN, 2024). For this reason, San Mateo was selected as the Collaborative to host the RVA pilot.

RVAs are an emerging tool that can be used as an initial step in the adaptation planning process. An RVA focuses on species, habitats, or systems of interest, and helps identify the greatest risks posed to them by the impacts of climate change. An RVA identifies factors that contribute to vulnerability, which can include both the direct and indirect effects of climate change, as well as non-climate stressors (e.g., land use change, habitat fragmentation, pollution, and invasive species). This approach explores vulnerability as a function of risk and adaptive capacity. The assessment methodology enables investigation of habitats, species, communities, and other resources related to MPAs. This project enabled initial scoping of the approach to test efficacy and relevance within the CA MPA framework. Results can be utilized directly by decision makers and stakeholders, and will also serve as a valuable case study to develop and implement RVA methods that can later be replicated at a larger scale across the MPACN.

Approach

Area of Interest

San Mateo county has two MPAs: Montara State Marine Reserve (SMR) and Pillar Point State Marine Conservation Area (SMCA) (Figure 2). The MPAs are directly adjacent to each other, extending from the coastline to the edge of California's state waters. Montara SMR is a Fully Protected MPA, prohibiting all injury, damage, take, or possession of all living, geological, or cultural marine resources (California Code of Regulations Title 14, Section 632 (b)(65-66). Pillar Point SMCA allows the recreational and commercial take of pelagic fish, Dungeness crab, and market squid, but other activities are prohibited.

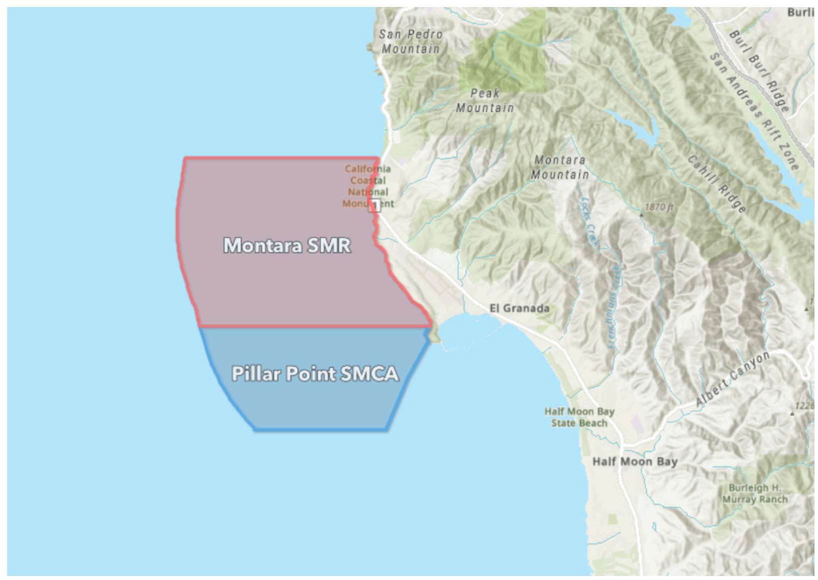

Figure 2. The MPAs of interest for this Rapid Vulnerability Assessment: Montara State Marine Reserve and Pillar Point State Marine Conservation Area.

Rapid Vulnerability Assessment Methods

The vulnerability of San Mateo MPAs to climate risks was assessed by utilizing a structured RVA methodology to identify key assets of interest (e.g., habitats, species, geographic formations, infrastructure, etc.), assess climate and non-climate risks, evaluate adaptive capacity (e.g., social and ecological factors of resilience and adaptation), calculate vulnerability for each asset, and develop science-based strategies to reduce vulnerabilities (CEC, 2017). This methodology was developed specifically for MPAs in North America, and has been utilized at length across different management regimes, including the National Marine Sanctuary System.

The RVA method includes several specific terms and definitions that are necessary to understand the methodology and application of results:

Adaptation: The process of adjusting natural or human systems in response to actual or expected climate impacts, with the goal of moderating harm or exploiting beneficial opportunities.

Adaptive Capacity: The ability of a habitat, species, or community to adjust to climate stress, moderate potential damages, take advantage of opportunities, or cope with the consequences.

Asset: Any species or habitat within the MPA that is under evaluation in the vulnerability assessment.

Climate Stress: Any environmental pressure or challenge directly linked to climate change (e.g., increased sea surface temperatures, ocean acidification, sea level rise) that affects the resilience and functioning of an asset.

Consequence: The strength of potential impact (from negligent to catastrophic) on an asset if exposed to a specific climate stress, taking into account factors such as sensitivity, importance, and potential damage.

Likelihood: The probability or chance (from rare to almost certain) that a specific climate stressor will impact an asset within a defined timeframe.

Non-Climate Stress: Human-induced or natural pressures unrelated to climate change (e.g., overfishing, habitat destruction, pollution) that may exacerbate the vulnerability of assets.

Risk: The combination of the likelihood of an adverse event occurring and the magnitude of its potential consequences, highlighting the degree of threat to an asset.

RVA Subgroup: A group of MPA Collaborative members dedicated to participating in workshops, providing reviews, and making recommendations to conduct the RVA.

Vulnerability: The degree to which an asset is susceptible to harm from exposure to climate stresses, taking into account both its sensitivity to those stresses and its adaptive capacity (Figure 3).

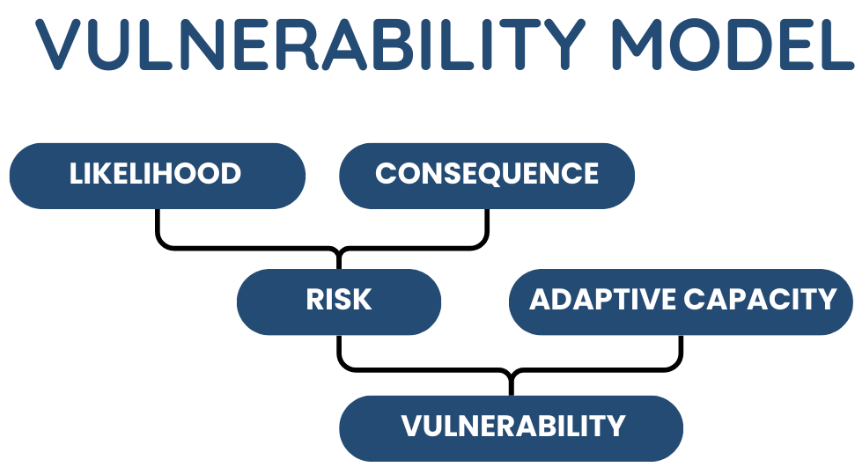

Figure 3. The vulnerability assessment model used in the Rapid Vulnerability Assessment (RVA) method.

An RVA is completed across five main methodological steps (Figure 4). Each step is explained in more detail below.

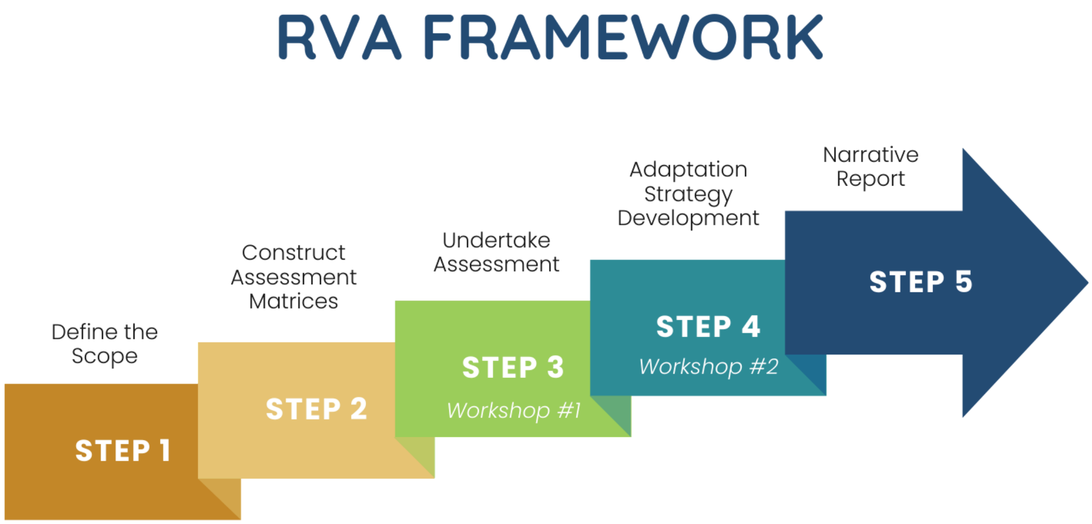

Figure 4. Five step Rapid Vulnerability Assessment (RVA) framework.

Preparing for the Assessment

To set the stage prior to initiating the RVA, we first developed a regional climate summary that assessed climate related stressors in the region (Appendix A). The summary was informed by a thorough literature review and peer-reviewed by subject matter experts, providing a solid foundation for the upcoming RVA workshops. Climate stressors for investigation included ocean acidification, water and air temperature, dissolved oxygen, currents, upwelling, precipitation, sea level rise, turbidity, coastal erosion, salinity, storms, harmful algal blooms, El Nino Southern Oscillation, and Pacific Decadal Oscillation. In the final summary, each stressor is detailed in terms of historical condition, current condition, and future projections.

Step 1: Define the Scope

The first step of the process identifies critical assets within San Mateo's MPAs, ensuring that perspectives from community members, scientific experts, and resource managers are integrated into the process. This identification exercise was conducted through a webinar with aforementioned stakeholders to set the stage for the upcoming RVA process. The agenda included an overview of the RVA process, allowed time for discussion and questions, and guided the attendees through an interactive exercise to identify key timescales (e.g., near term, long term, very long term), assets (e.g., habitats, species, infrastructure), and stressors (both climate and non-climate) relevant to their assessment. A follow up survey was later circulated to participants to confirm the Collaborative's selections.

A total of nine individuals participated in the interactive poll. The outcome of this identification exercise indicated that participants were most interested in exploring vulnerabilities in the near term (10 years), as compared to longer time horizons (Figure 5).

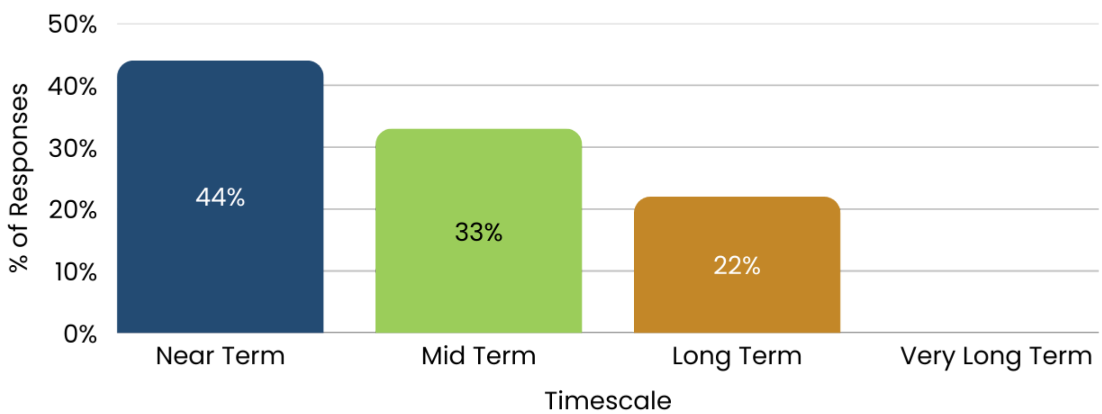

Figure 5. Responses from the San Mateo Collaborative group indicating the timescale of interest for the Rapid Vulnerability Assessment pilot at Pillar Point SMCA and Montara SMR. Near term is present to 10 years, mid term is the next 50 years, long term is the next 100 years, and very long term is more than 100 years in the future.

Across both MPAs, participants were most concerned about rising water temperatures (20%; n=9), ocean acidification (14%; n=6), and storms (14%; n=6) as climate-related stressors in the region (Figure 6). Non-climate stressors discussed included land-source pollution (19%; n=8), invasive species (19%; n=8), marine-source pollution (12%; n=5), and disease (12%; n=5).

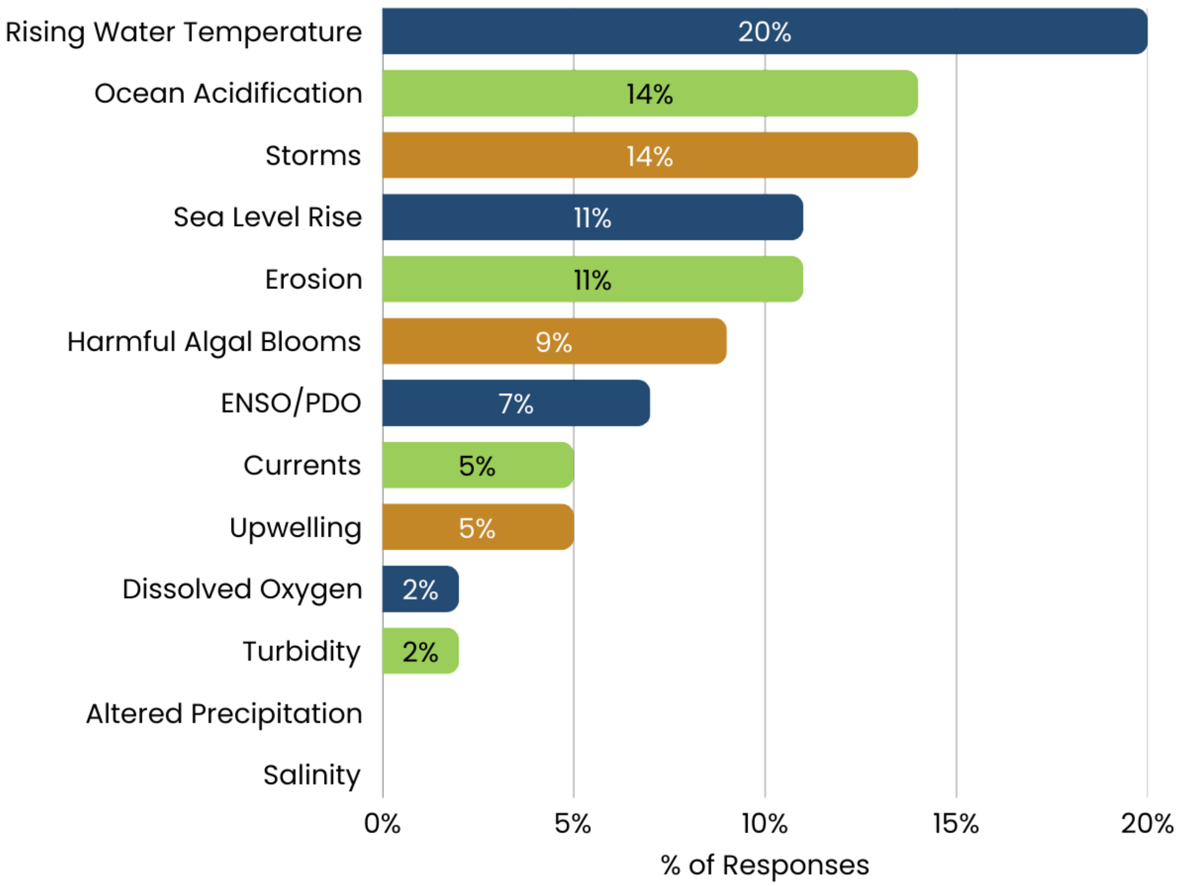

Figure 6. Responses from the San Mateo Collaborative group indicating their perceived climate stressors in the region. Respondents could select up to five climate change impacts of concern.

During the webinar, attendees brainstormed assets of interest for the RVA pilot (Table 1). Top responses were distributed to participants through an online survey for final selection. Options that were not introduced during the brainstorm were not included in the survey (marked with "–" in the table below). Through this survey, sea stars and tidepools were selected as the final assets for investigation in Pillar Point SMCA and harbor seals and sea stars were selected for Montara SMR.

Table 1. Assets that were brainstormed during the initial Scoping Webinar and selected in the follow-up survey. The final selected assets are bolded and marked with blue cells.

Asset	Montara SMR		Pillar Point SCMA	
	Webinar Mentions	Survey Votes	Webinar Mentions	Survey Votes
Abalone	0	–	3	0
Anemones	3	0	2	0
Beach Wrack	1	0	0	–
Bull Kelp	1	0	2	0
Clams	0	–	1	0
Crab	2	0	1	1
Flame Lined Chiton	1	1	1	0
Groupers	1	0	0	–
Halibut	0	–	1	0
Harbor Seals	**3**	**6**	1	0
Hermit Crabs	0	–	1	0
Humans	0	–	1	1
Mussel Beds	0	2	1	0
Nudibranch	0	–	2	1
Octopuses	1	1	1	1
Owl Limpets	1	0	1	1
Oystercatchers	0	–	1	0
Pelicans	2	1	3	1

Table 1. Assets that were brainstormed during the initial Scoping Webinar and selected in the follow-up survey. The final selected assets are bolded and marked with blue cells.				
Plankton	2	2	0	–
Purple Sea Snails	0	–	1	0
Rockfish	2	1	2	1
Rockweed	0	–	1	
Rocky Intertidal	0	–	1	1
Salmon	0	–	2	0
Sandy Beach	1	0	0	–
Sea Otters	0	–	1	1
Sea Palm	2	0	1	0
Sea Star	**1**	**3**	**5**	**3**
Sea Urchins	2	0	3	1
Seagrasses	0	–	1	0
Seaweed	1	1	1	1
Sharks	1	0	3	0
Stream Ocean Water Quality	1	0	0	–
Surf Grass	0	–	1	0
Surf Smelt	0	–	1	0
Tidepools	0	–	**2**	**2**
Velella Velella	0	–	1	0
Wandering Meatloaf	0	–	1	2

Step 2: Construct Assessment Matrices

Following the identification of assets and stressors, S&S created asset-specific assessment summaries that consider climate and non-climate stressors. These summaries were informed by a thorough literature review and expert interviews, and reviewed by subject matter experts. Summaries were provided to workshop participants prior to the RVA workshop to ensure a solid foundation. Outcomes from the assessments were organized in a worksheet to walk RVA participants through the assessment in the following steps.

Step 3: Undertake the Assessment

The third step is to assess the vulnerability for each asset by evaluating two key factors: risk and adaptive capacity. This was completed in a 4-hour virtual workshop, held on January 28, 2025, with Collaborative members, resource managers, and scientific experts with expertise in the region. The workshop included two exercises, detailed below. To promote expansive discussion, each exercise was facilitated by S&S using the assessment worksheets developed in Step 2.

Exercise 1: Assess Risk

In the first exercise, workshop participants assessed the cumulative effects of climate and non-climate stressors on identified assets. The first step was to estimate the likelihood of each climate stressor occurring in the region on a five point scale from rare to almost certain. Participants then identified the combined consequence of each climate stressor and non-climate stressor on a five point scale from negligible to catastrophic. The combination of these assessments provides a ranking of risk from low to extreme (Figure 7).

LIKELIHOOD \ CONSEQUENCE	NEGLIGIBLE	MINOR	MODERATE	MAJOR	CATASTROPHIC
RARE	LOW	LOW	LOW	LOW	LOW
UNLIKELY	LOW	LOW	MODERATE	MODERATE	MODERATE
POSSIBLE	LOW	MODERATE	MODERATE	HIGH	HIGH
LIKELY	LOW	MODERATE	HIGH	EXTREME	EXTREME
ALMOST CERTAIN	LOW	MODERATE	HIGH	EXTREME	EXTREME

Figure 7. The Rapid Vulnerability Assessment method identifies risk as a function of likelihood that the climate stress will occur and consequences to the asset from that occurrence. This table provides the rubric for making this assessment.

Exercise 2: Evaluate Adaptive Capacity

In the second exercise, participants evaluated their perceived social and ecological resilience of the assets to stressors. Participants were provided a list of 16 possible adaptive factors to spark discussion, including extent, distribution, & connectivity, past evidence of recovery, biodiversity, staff capacity, stakeholder relationships, and science/technical support. In some cases, certain adaptive factors were not applicable to a chosen asset and were removed from the assessment and replaced with more applicable factors. The participants then scored each factor on a five point scale from (1) critically low to (5) superior. The average of all factor scores determined the measure for adaptive capacity.

The results from exercise 1 and 2 provide the information necessary to calculate vulnerability scores, which are derived using a function table, categorizing vulnerability on a scale from low to high (Figure 8). The resulting scores offer a clear, quantitative assessment of vulnerability, helping to identify the most pressing issues and areas in need of management attention.

RISK	ADAPTIVE CAPACITY: LOW	ADAPTIVE CAPACITY: MODERATE	ADAPTIVE CAPACITY: HIGH
LOW	LOW	LOW	LOW
MODERATE	MODERATE	MODERATE	LOW
HIGH	HIGH	MODERATE	MODERATE
EXTREME	HIGH	HIGH	MODERATE

Figure 8. The Rapid Vulnerability Assessment method calculates vulnerability as a function of risk and adaptive capacity. This table provides the rubric for making this assessment.

Step 4: Adaptation Strategy Development

A second 4-hour workshop was held on February 6, 2025 to develop related strategies to reduce the identified vulnerabilities. During this workshop, participants collaboratively worked through two additional exercises–detailed below–to develop and refine strategies for reducing vulnerability by mitigating the identified risk factors and enhancing the adaptive capacity of MPAs. The resulting strategies are valuable for local, regional, and state management agency implementation, and should be used to inform climate-ready management planning and guide future actions.

Exercise 3: Strategy Development

Participants used the final vulnerability score as a reference to brainstorm strategies to reduce vulnerability by either reducing likelihood or increasing adaptive capacity:

1. *Reducing Risk*: Reduce the likelihood or consequence of climate stressors. While addressing ocean acidification may be difficult due to its broad and pervasive nature, this exercise will focus on mitigating non-climate stressors to reduce overall impact.
2. *Increasing Adaptive Capacity*: Increase the social and ecological resilience of the assets, with an emphasis on solutions that are feasible at the community or local resource management level. Ideally, these strategies will empower

and inspire communities to take action, bypassing the need for potentially slow or politically challenging state-level policy changes.

This exercise allowed participants to brainstorm as many approaches as possible, even if they are ambitious or unlikely to occur in the current socio-economic environment. Once the list was complete, participants ranked each strategy in terms of cost and efficacy (low, medium, or high).

Exercise 4: Create Implementation Plans

In the final exercise, participants identified two top strategies from Exercise 3 and developed an implementation plan that identified key factors for achieving the target strategies. Implementation components included:

- *Leader and potential partners*: Who is responsible for making this happen? Identify individuals, positions, or organizations.
- *Monitoring & evaluation criteria*: How would you know if this strategy was working?
- *Funding/costs*: Is new funding needed? Is there a likely source?
- *Existing or needed management mechanisms*: Does the mandate to enact the strategy exist? Would policy need to change?
- *Timeline*: When will the strategy start and how long will it take?

Step 5: Narrative Report

The final results of this effort, including identified strategies and implementation plans will be distributed and discussed with the MPACN members and state resource managers through this report and related outreach materials such as a webinar and a StoryMap.

Results Overview

Results of the RVA method provide vulnerability scores for each climate stressor on a scale from Low to High (Figure 9). Six of the nine climate stressors were scored as Moderate, two were Low, and only one is High (increased water temperature for sea stars). Details about the considerations for each of these scores is provided below, along with the top two recommended strategies to reduce vulnerability for each asset.

	CLIMATE STRESSOR	VULNERABILITY
HARBOR SEALS IN MONTARA STATE MARINE RESERVE	Increased Water Temperature	LOW
	Sea Level Rise	MODERATE
	Ocean Acidification	LOW
TIDEPOOLS IN PILLAR POINT STATE MARINE CONSERVATION AREA	Sea Level Rise	MODERATE
	Increased Daytime Air Temperature	MODERATE
	Increased Water Temperature	MODERATE
SEA STARS IN MONTARA STATE MARINE RESERVE & PILLAR POINT STATE MARINE CONSERVATION AREA	Increased Water Temperature	HIGH
	Ocean Acidification	MODERATE
	Sea Level Rise	MODERATE

Figure 9. Overview of final vulnerability scores for three climate stressors for each asset.

Climate Impacts

The regional climate summary investigates the current and projected status of 13 climate parameters. The summary is meant to establish a common understanding of climate impacts in the region, as a baseline for the upcoming workshops. Figure 10 provides a high-level summary of the climate impacts, and the full climate summary is available in Appendix A.

SCIENCE-BASED PROJECTION

PARAMETER	SCIENCE-BASED PROJECTION	PARAMETER	SCIENCE-BASED PROJECTION
WATER TEMP	Increase in both surface and sub-surface temperature	TURBIDITY	Increase
SEA LEVEL RISE	Increase to 1.0 - 2.1 meters by 2100	COASTAL EROSION	Accelerated erosion, 60-80 meters by 2100
DISSOLVED OXYGEN	Decrease, particularly in deeper waters	SALINITY	Variable
CURRENTS	Altered circulation and seasonal variability	STORMS	Increase in severity and frequency
UPWELLING	Intensification of upwelling	HARMFUL ALGAL BLOOMS	More frequent and intense
PRECIPITATION	Increase in variability and severity	ENSO/PDO	Intensification of El Nino events
OCEAN ACIDIFICATION	Increase. pH decrease by 0.3 - 0.4 units by 2100		

CONFIDENCE

High — Moderate to High — Moderate

Figure 10. High level summary of science-based projections for 13 climate parameters. The color of the square indicates scientific confidence from moderate to high; any scientific findings with low confidence were not considered in this assessment.

Montara State Marine Reserve

HARBOR SEALS

RESULTS-AT-A-GLANCE

Climate Stressors

- Increased Water Temperature
- Sea Level Rise
- Ocean Acidification

Non-Climate Stressors

- Human Disturbance & Harassment
- Pollution and Contaminants
- Fisheries Impacts

Adaptive Capacity

- Ecological Capacity = Good
- Social Capacity = Fair
- Combined Capacity = High

Ecological Strengths

- Extent & Distribution
- Value/Importance
- Evidence of Recovery

Social Strengths

- Stakeholder Relationships
- Organizational Capacity
- Existing Mandate

Final Vulnerability Scores

	RISK	ADAPTIVE CAPACITY	VULNERABILITY
INCREASED WATER TEMPERATURE	MODERATE	HIGH	LOW
SEA LEVEL RISE	EXTREME	HIGH	MODERATE
OCEAN ACIDIFICATION	MODERATE	HIGH	LOW

Recommended Strategies

Build Stewardship through Increased City Education and Engagement Initiatives

Cost: Low to Medium

Efficacy: High

Increase Monitoring of Haulouts and Enable Dynamic Management Protection

Cost: High

Efficacy: High

Harbor Seals in Montara State Marine Reserve

Harbor seals (*Phoca vitulina*) are small, non-migratory pinnipeds commonly found along the Northern Hemisphere's coasts. They have streamlined bodies and can dive to depths of 1,500 feet, though they usually forage in shallower waters (Zier & Gaydos, 2014). As opportunistic feeders, their diet favors fish like herring and cod, as well as squid and crustaceans, but adapts to local prey availability (Zier & Gaydos, 2014). Harbor seals are vital to the overall ocean and coastal ecosystem, acting as both predators and prey within the marine food web. Reproduction occurs during late spring and early summer, with females birthing a single pup after an 11-month gestation (NOAA Fisheries, 2025). Pups, born on beaches or rocky outcrops, are capable swimmers within their first few hours and nurse for 4–6 weeks, gaining significant weight during this period (NOAA Fisheries, 2025). Harbor seals haul out on land regularly to rest, molt, and avoid predators, such as orcas and sharks (NOAA Fisheries, 2025).

Harbor seals are a common marine mammal in the Montara SMR (Figure 11). These seals are known for using the region as both a haul-out site and a breeding area; San Mateo County through Sonoma County hosts California's largest breeding population of harbor seals (Lowry et al., 2008). The Montara SMR coastline is characterized by rocky intertidal zones and nearby kelp forests, which offer shelter and feeding opportunities for harbor seals. These areas are especially important during pupping season, as they provide relatively undisturbed environments for raising their young. The seals primarily feed on fish and other marine organisms found in the nutrient-rich waters of the California Current, typically foraging in close proximity to their haul-out sites (Grigg et al., 2012).

Despite protections such as the federal Marine Mammal Protection Act and the California Marine Life Protection Act, seals face threats such as human disturbance, pollution, and potential impacts from climate change. Montara's MPA status aims to mitigate these threats by restricting activities that could harm the marine ecosystem or disrupt wildlife.

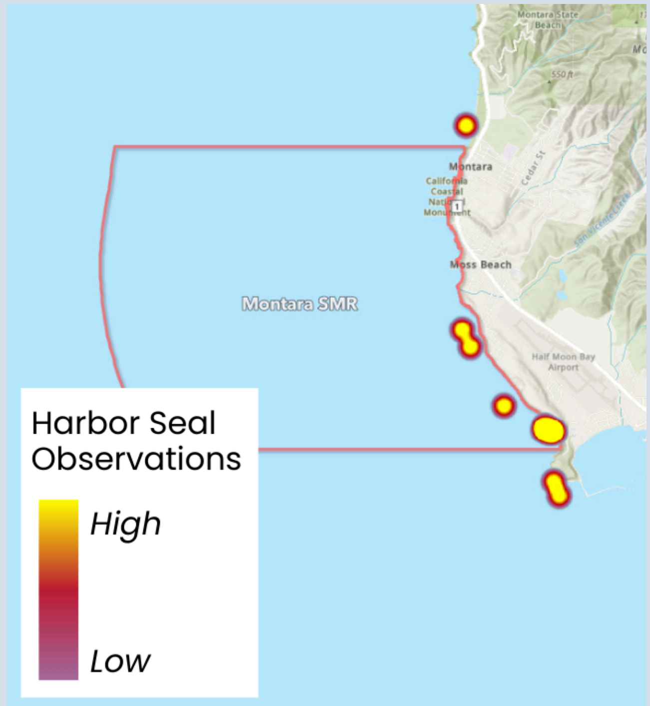

Figure 11. Harbor seal observations (2003) on the Montara SMR coastline, along with beach access opportunities.

Stressors

The three climate stressors identified in this RVA related to harbor seals were rising ocean temperatures, sea level rise, and ocean acidification. All climate stressors were determined to have an 'almost certain' likelihood.

Climate Stressors

Increased Water Temperature

Warmer waters can alter the distribution and abundance of prey species, such as fish and squid, on which harbor seals depend (Gibson et al., 2007; Largier et al., 2011). This may lead to increased foraging efforts and reduced energy intake, potentially impacting reproductive success and pup survival rates (Largier et al., 2011; Sydeman and Allen, 2006). Changes in prey availability are particularly concerning for populations in nutrient-rich areas like Montara SMR, where ecosystem dynamics are finely balanced.

Sea Level Rise

Coastal habitats, including beaches and rocky haul-out sites, are critical for resting, pupping, and molting. Sea level rise threatens to reduce the availability and quality of these essential areas (Figure 12). Since harbor seals rely on undisturbed haul-out sites for pupping, habitat loss could lead to crowding and increased vulnerability to predation and human disturbance (Groothedde, 2011; Ruiz-Mar et al., 2022).

Ocean Acidification

Ocean acidification, due to increased atmospheric CO_2, affects the marine food web. Species like shellfish and other invertebrates that harbor seals prey on are particularly affected (Largier et al., 2011). Acidification may also alter kelp forest ecosystems, indirectly impacting species that depend on these habitats (Marshall et al., 2017). As a top predator in the ecosystem, harbor seals are vulnerable to cascading ecological effects caused by shifts in prey populations and ecosystem structure.

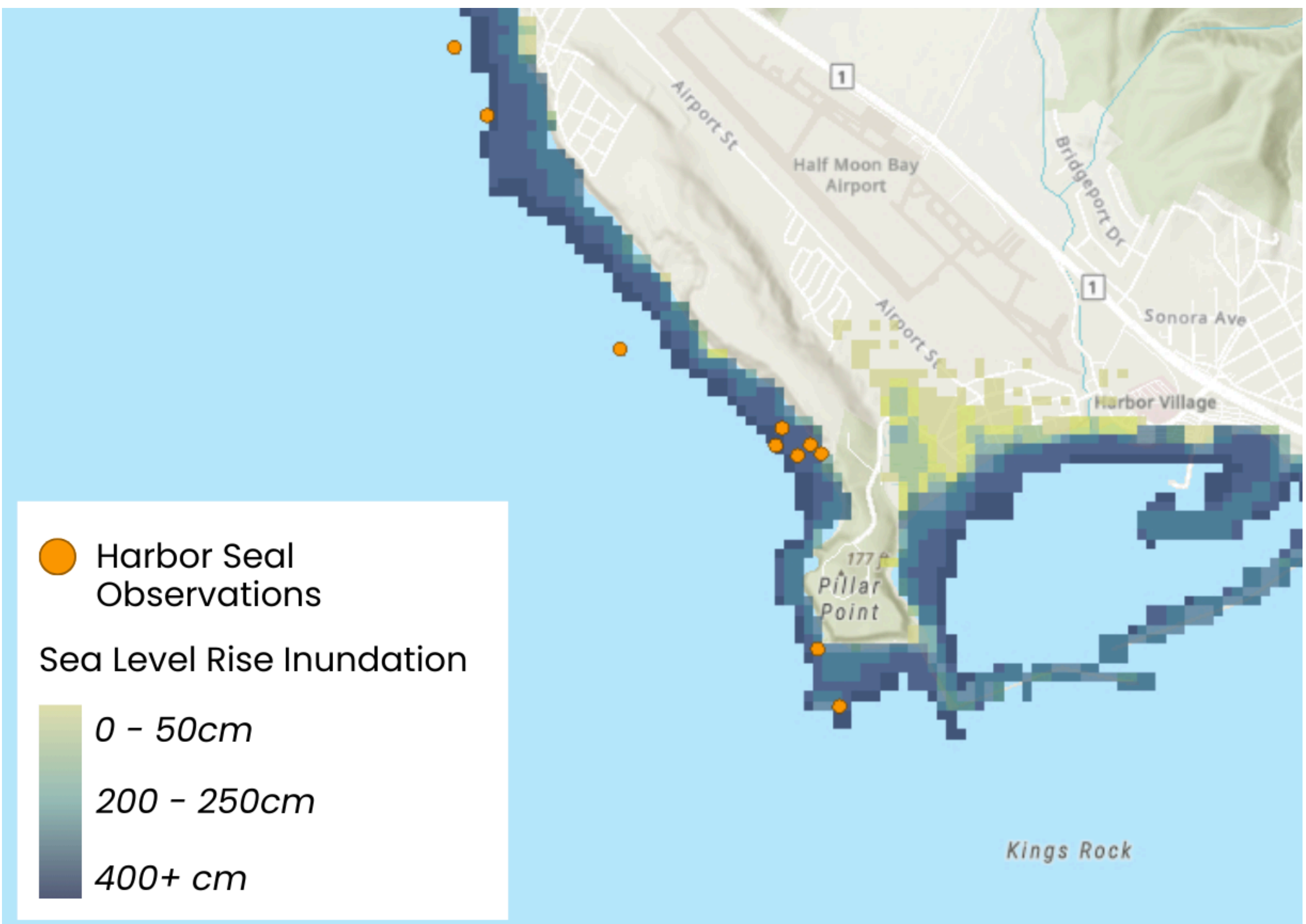

Figure 12. Harbor seal observations (2003) and predicted sea level rise, indicating inundation of a key haul out area in the southern corner of the SMR.

Non-Climate Stressors

Human Disturbance and Harassment

Harbor seals are highly sensitive to human disturbance and harassment. Beachgoers and recreationalists can disrupt their resting and pupping behaviors, causing seals to flee haul-out sites and expend critical energy. Direct human disturbance, such as actively interacting with wildlife, moving pups, or approaching in close proximity, can be extremely damaging. The Marine Mammal Center reports that about 30% of all animals that are brought in for rehabilitation or care have been impacted by human disturbance (Marine Mammal Center, 2024). Harbor seal mothers routinely leave their pups on the beach while they search for food; well-meaning people often think these pups are in danger or abandoned and intervene, which can result in actual separation of mothers and pups. Chronic disturbance can lead to increased stress levels, reduced pup survival, and potential abandonment of critical habitat (Becker et al., 2009).

Pollution and Contaminants

Coastal waters near Montara SMR face pollution from urban runoff, agricultural inputs, and marine debris. Heavy metals, persistent organic pollutants, and plastics can accumulate in harbor seal tissues, affecting their immune and reproductive systems (Greig et. al, 2011). Harbor seals in Central California are most impacted by at least 6 major contaminants, including polychlorinated biphenyls (PCB), summed dichlorodiphenyltrichloroethan and its metabolites (DDT), and polybrominated diphenylethers (PBDE) (Greig et al., 2019). Despite bans on their production and use, the contaminants still persist in the marine environment, and it's critical to monitor their impact over time. Seals are particularly vulnerable to bioaccumulation because they are apex predators, concentrating the toxins present in the food chain (Gobas and Arnot, 2010).

Fisheries Impacts

Harbor seals are at risk of entanglement in active and derelict fishing gear, including gillnets and crab pots, which can cause injury or death. Additionally, competition with commercial fisheries for prey resources can lead to habitat displacement and reduced food availability in regions where fish stocks are heavily exploited (Dau et al., 2009).

Cumulative Risk & Consequence

The cumulative consequence of climate stressors in tandem with the non-climate stressors was determined to be *major* for sea level rise and *minor* for rising ocean temperature and ocean acidification. As sea level rise increases, the participants noted that this could lead to a greater concentration of beachgoers and human activity that could disturb seals in smaller areas, pollution and contaminant concentration may increase, and territory conflicts with fisheries could lead to displacement from their traditional habitat. Rising ocean temperatures may also attract more beachgoers and recreational activities on the beach, which could lead to more litter and marine debris that may entangle or harm seals. Additionally, as ocean temperatures rise, availability of preferred prey species is likely to change which can increase competition with fisheries. No clear relationship between human disturbance and ocean acidification was determined. However, ocean acidification was determined to have combined effects with relation to pollution and fisheries due to marine chemistry changes and shellfish availability.

Adaptive Capacity

The ecological adaptive capacity for harbor seals is Good (4). Extent and Value were both ranked as Very Good (5) because harbor seals are a dominant species on the coast and people are concerned about and compassionate towards them. Additionally, as predators within their ecosystem, they help maintain a healthy balance within the food web. Past Evidence of Recovery was scored as Good (4) because the species has recovered significantly from commercial hunting prior to the establishment of the Marine Mammal Protect Act. Connectivity (2 = Poor) was the only ecological factor to score below a Good (4) rating, as seals typically stay within a 15-31 mile range.

The social adaptive capacity for harbor seals is Fair (3.5). Science and technical support, ability to learn and change, and responsiveness were each ranked as Poor (2). Although there is some monitoring from the California Department of Fish and

Wildlife, there is no long-term population monitoring or census. The most recent census is several years old and the most recent federal stock assessment was published in 2015 (NOAA SAR, 2015). Therefore, a majority of recent information about the local harbor seal population is anecdotal. The science that does exist is not consistently integrated into decision-making processes. Even though there are strong existing protections through the federal Marine Mammal Protection Act and the State-level MPA, enforcement is very difficult and often under-implemented. However, partner relationships and organizational capacity for harbor seals are Good (4), which may provide avenues for strengthening protections through community-based efforts.

The combined adaptive capacity for harbor seals is High (3.75).

Vulnerability

When combining risk and adaptive capacity, the overall vulnerability of harbor seals is low in regards to rising ocean temperatures and ocean acidification, and moderate in regards to sea level rise (Figure 13).

HARBOR SEALS	RISK	ADAPTIVE CAPACITY	VULNERABILITY
INCREASED WATER TEMPERATURE	MODERATE	HIGH	LOW
SEA LEVEL RISE	EXTREME	HIGH	MODERATE
OCEAN ACIDIFICATION	MODERATE	HIGH	LOW

Figure 13. Risk, adaptive capacity, and vulnerability scores for Harbor Seals, on a scale from Low to Extreme.

Recommended Strategies

Drawing on the full list of brainstormed strategies from the third exercise, workshop participants identified multiple approaches and strategies for increasing the adaptive capacity of harbor seals in Montara SMR. These were determined to have varying levels of efficacy and costs. All brainstormed strategies are available in Appendix B.

Build Stewardship through Increased City Education and Engagement Initiatives

Low to Medium Cost | High Efficacy

Leveraging and building relationships through increased city-sponsored education and engagement initiative is a low cost and highly efficient strategy to cultivate a community that values and protects harbor seals. This initiative would have a direct impact on local behavior and foster a sense of ownership and responsibility for the safety and conservation of seals. There are already great resources from the marine mammal commission that can be utilized and adapted for the local area. This initiative is likely to reach a broad audience and create tangible behavior changes in how people interact with harbor seals.

- **Leader and potential partners**
    - City of San Mateo
    - California Department of Fish and Wildlife
    - California State Parks
    - MPACN

- **Monitoring & evaluation criteria**
    - New relationships with city staff
    - Creation and placement of billboards
    - Creation and placement of other advertising materials
    - Reduction in enforcement actions and calls
    - Increased positive docent intercepts
    - Pre- and post- surveys with community members to assess efficacy

- **Funding/costs:** Funding would be needed for the following items:
    - In person meeting with city staff (lunch)
    - Facilitation of brainstorming and communications strategizing
    - Graphic design
    - Physical materials (Billboards, signs, etc.)
    - Pre- and post- surveys to evaluate efficacy

- **Existing or needed management mechanisms**
    - Not applicable. Management mechanisms are not needed, just new and strengthened relationships.

- **Timeline**: 1-2 years

Increase Monitoring of Haul-outs and Enable Dynamic Management Protection

High Cost | High Efficacy

Increased monitoring and dynamic protections are likely to be highly effective, but include high costs for technology, personnel, and rapid response. Dynamic management informed by increased monitoring would enable the provision of real-time protection based on the seals' immediate areas. This would require support from relevant authorities such as the CA Department of Fish & Wildlife, NOAA, and others, thus requiring strong partnerships and collaborative efforts.

- **Leader and potential partners**
    - MARINe Lab at University of California, Santa Cruz
    - California Department of Fish and Wildlife
    - California State Parks
    - California Ocean Protection Council
    - California Ocean Science Trust
    - University research
    - National Park Service: lessons from similar effort for elephant seals

- **Monitoring & evaluation criteria**
    - Spatial model to predict new haul-out areas
    - Increased monitoring
    - Dynamic protections for new haul-out areas
    - Reduction in seal harassment

- **Funding/costs -** Funding would need to be procured for the following items:
    - Spatial model creation
    - Running spatial model at regular intervals

    - Likely a public process if protections are changing
    - Staff training
    - Monitoring costs
    - Increased enforcement

- **Existing or needed management mechanisms**
    - U.S. Marine Mammal Protection Act
    - MLPA
    - Dynamic management capability

- **Timeline**: Long term, likely 3-5 years

Pillar Point State Marine Conservation Area

TIDEPOOLS

RESULTS-AT-A-GLANCE

Climate Stressors

- Sea Level Rise
- Increased Daytime Air Temperature
- Increased Water Temperature

Non-Climate Stressors

- Altered Sediment Transport
- Disease
- Human Disturbance

Adaptive Capacity

- Ecological Capacity = High
- Social Capacity = Fair
- Combined Capacity = High

Ecological Strengths

Spatial Extent
Value & Importance
Physical Diversity

Social Strengths

Existing Mandate
Organizational Capacity
Partner Relationships

Final Vulnerability Scores

	RISK	ADAPTIVE CAPACITY	VULNERABILITY
SEA LEVEL RISE	MODERATE	MODERATE	MODERATE
INCREASED DAYTIME AIR TEMP	HIGH	MODERATE	MODERATE
INCREASED WATER TEMPERATURE	HIGH	MODERATE	MODERATE

Recommended Strategies

Increase the Number of Tidepool Docents, Especially During Low Tides

Cost: Medium

Efficacy: High

Identify Natural Refugia Areas and Strengthen Protections

Cost: High

Efficacy: High

Tidepools in Pillar Point State Marine Conservation Area

The tidepools at Pillar Point SMCA play crucial ecological roles within the coastal ecosystem. Ochre sea stars (*Pisaster ochraceus*), is a keystone predator, regulating mussel populations, preventing them from monopolizing space, and allowing other species to thrive, which maintains biodiversity (Schultz et al., 2016). Grazing species, such as snails, limpets, and chitons, help control algal growth, ensuring light penetration and promoting a balanced habitat (Denny & Gaines, 2007; Dethier, 1982). Tidepools also serve as vital shelter and nursery grounds, offering refuge for juvenile fish, invertebrates, and other species, protecting them from predators and the harsh conditions of wave action (Moring, 1986). Together, these interactions contribute to the overall health and resilience of the intertidal ecosystem.

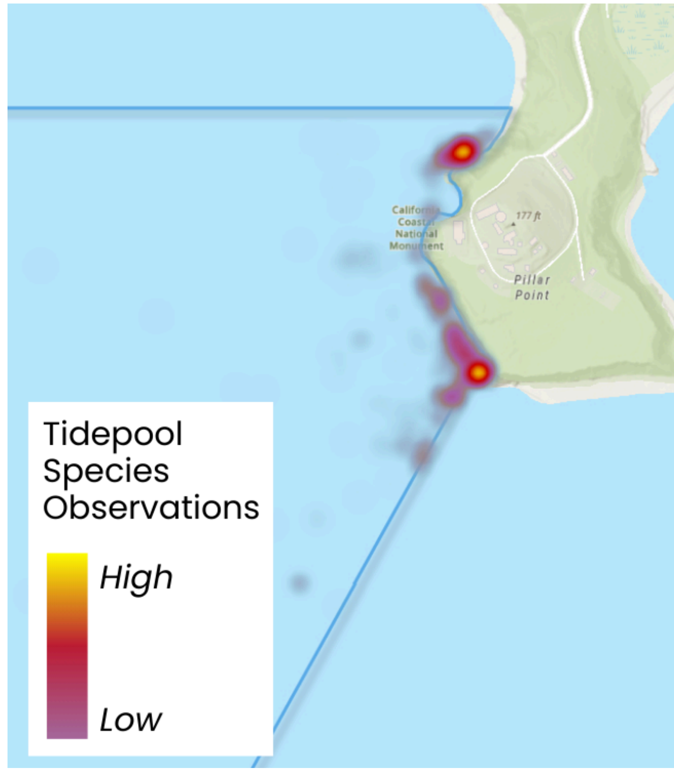

Figure 14. All iNaturalist observations (accessed on November 24, 2024) on the Pillar Point SMCA coastline.

Tidepools at the SMCA are directly adjacent to unprotected tidepools at the larger Pillar Point. This proximity is important to recognize, as visitors may not recognize the difference between the protected tidepools in the SMCA and the nearby unprotected tidepools. These two tidepool areas are also different in terms of tidepool formation. Tidepools in the SMCA are a narrow band within a cove, and typically only available during low tide. These are generally difficult to access due to the rugged terrain.

Injury, damage, take, or possession of all living, geological, or cultural marine resources is prohibited in the SMCA, with a few exceptions. Recreational and commercial take of pelagic fish, Dungeness crab, and market squid are allowed, with restrictions on allowed gear types. These exceptions do not include species that would be commonly found in a tidepool (e.g., mussels).

Animal and plant species are abundant in the Pillar Point SMCA. A selection of primary species is listed and mapped below (Figure 14).

- **Flora:**
  - **Seaweeds:** The tidepools host a variety of algae, including green sea lettuce (*Ulva spp.*), red algae (*Corallina officinalis*), and brown rockweed (*Fucus distichus*). In deeper pools, large brown kelps like giant kelp (*Macrocystis pyrifera*) are sometimes observed.
  - **Seagrasses:** In calmer sections of Pillar Point, eelgrass (*Zostera marina*) may form beds that stabilize the substrate and provide habitat for small marine organisms.
- **Invertebrates:**
  - **Mollusks:** Black turban snails (*Tegula funebralis*), limpets, chitons, and California mussels (*Mytilus californianus*) dominate the rocky surfaces.
  - **Echinoderms:** Ochre sea stars (*Pisaster ochraceus*), bat stars (*Patiria miniata*), and brittle stars are abundant. The occasional giant pink sea star (*Pisaster brevispinus*) and, historically, sunflower sea stars (*Pycnopodia helianthoides*) have been observed.
  - **Crustaceans:** Shore crabs (*Pachygrapsus crassipes*), hermit crabs, and barnacles cling to rocky surfaces and crevices.
  - **Anemones:** Aggregating anemones (*Anthopleura elegantissima*) and giant green anemones (*Anthopleura xanthogrammica*) adorn tidepools, adding vibrant colors to the habitat.
- **Fish:** Tidepool sculpins (*Oligocottus maculosus*) and blennies are common, darting among the rocks and algae.
- **Birds and Mammals:** Black oystercatchers forage for mussels and snails, while harbor seals frequently rest on rocky outcrops near Pillar Point.

Stressors

The three climate stressors investigated in this RVA related to tidepools are sea level rise, increased daytime air temperature, and increased water temperature. All climate stressors were found to have an "almost certain" likelihood in the RVA workshop.

Climate Stressors

Sea Level Rise

Sea level rise poses a threat to tidepool ecosystems through multiple mechanisms such as sand inundation and exacerbated coastal erosion (Jordaan et al., 2011; Macieira et al., 2015; Rilov et al., 2021). Tidepool systems have limited ability to retreat landward; as sea levels rise, it is expected to eventually narrow the coastline significantly. Sea level rise is projected to impact the Pillar Point SMCA by about 300-350cm, resulting from 1.41 m sea level rise coupled with extreme storm events (UC Berkeley, 2016).

Increased Daytime Air Temperature

Extreme heat events are expected to increase along California's coast (Ekstrom and Moser, 2012). Rising daytime air temperatures, particularly during low tides, pose a significant threat to tidepool ecosystems as the intertidal organisms face prolonged periods of heat stress. For example, in 2019 in Bodega Bay, widespread mussel die-offs and bleaching events in intertidal zones lead to mass mortality events (Cagel, 2019). The combination of direct thermal stress and its cascading effects through the food web makes increased air temperature one of the most significant climate-related threats to tidepool communities.

Increased Water Temperature

Rising ocean temperatures, driven by climate change, pose a serious risk to tidepool ecosystems with research documenting substantial changes in intertidal species community composition (Sorte et al., 2016). As waters warm steadily and extreme temperature events become more frequent, species distributions are shifting (Sorte et al., 2016). While it is difficult to document evidence to make broad generalizations of species shifts poleward–to colder regions–it is well supported that temperature is a major factor of determining ranges of intertidal species. There have been documented cases of poleward range expansions in northern California that are potentially disrupting existing ecological relationships in tidepools (Rivadeneira & Fernández, 2005; Sanford et al., 2019). However, geographical features like headlands can act as barriers, preventing northern-shifting larvae from completing their migration. Disruption of larval transport and species redistribution can lead to changes in community composition, likely affecting the balance of tidepool ecosystems and their biodiversity. Documented negative impacts from 2014-2016 marine heatwave included loss of species diversity and abundance, as well as changes to community composition and structure (Sanford et al., 2019).

Non-Climate Stressors

Altered Sediment Transport

Sediment transport can affect tidepools by altering their physical structure and the delicate balance of their ecosystems. Excessive sediment deposition, often driven by erosion, storms, or human activities like construction and coastal development, can bury tidepools, smothering organisms such as crabs, anemones, sea stars, and algae and clogging the gills of filter-feeding organisms like barnacles and mussels (Shives & Dunbar, 2010). Fine sediments can obstruct the feeding structures of these filter feeders and reduce habitat complexity, making it difficult for certain species to thrive (Petraitis et al., 2008). Sediment can also reduce water clarity, limiting light penetration and inhibiting photosynthesis for primary producers like seaweeds and algae, which are critical to the food web (Dethier, 1982). Conversely, sediment removal caused by strong wave action or human activity can strip tidepools of essential substrates, destabilizing the habitat (Bretz, 1995; Petraitis et al., 2008). These changes in sediment dynamics can disrupt the ecological balance, impacting biodiversity and the resilience of tidepool communities.

Disease

Marine diseases and wasting events pose a significant threat to tidepool ecosystems, particularly as environmental stressors weaken organisms' immune responses. Various species, including sea urchins, are affected by diseases that spread through populations, potentially disrupting the ecological balance of tidepools (Feehan & Scheilbling, 2014). Rising temperatures and other environmental stressors can compromise organisms' immune systems, making them more susceptible to pathogens and increasing disease transmission rates (Larson et al., 2023). This vulnerability can lead to mass mortality events, such as those caused by sea star wasting disease, affecting not only the directly impacted species, but also cascading through the food web to disrupt entire tidepool communities (Miner et al., 2018).

Human Disturbance

Tourism and recreation stress tidepools. Trampling on delicate organisms, such as anemones, barnacles, and algae, physically damages these species and disrupts their habitats. Collection of shells or living organisms depletes local populations and affects the ecological balance. Human activity also increases the risk of pollution from litter, sunscreen, and other contaminants entering the water. In 2022, the Pillar Point Tidepool Stewards program was started to address these issues. By engaging with visitors and educating them about sustainable harvesting practices volunteers are demonstrating the ecological importance of the area. Most interactions have been positive, and people are keen to tidepool sustainably once they are educated (Downe, 2022). However, it is important to note that while this is a stressor, the experts we talked to did not feel that human disturbance was as harmful as the other non-climate stressors.

Cumulative Risk & Consequence

All non-climate stressors are expected to be exacerbated by climate change. Furthermore, the combined influence of both climate and non-climate stressors is anticipated to create compounding effects across the system. The cumulative consequence level of sea level rise was determined to be *minor* and increased daytime air temperature and increased water temperature is *moderate*.

Specifically, altered sediment transport was found to have compounded effects with the climate stressors by contributing to coastal erosion rates, increasing heat-related stress, and increased upwelling and altered mixing. Disease is likely to interact with climate stressors by facilitating easier disease transmission within populations, increasing physiological stress related to heat, and making organisms more susceptible to illness. Human disturbance is anticipated to compound with climate stressors to create space conflicts due to a greater concentration of human activity in reduced intertidal areas and an increase in recreational activities and the number of beachgoers.

Adaptive Capacity

The average for ecological potential was High (4). Only connectivity and past evidence of recovery scored below the average and were scored as Fair (3). Connectivity was scored as Fair because, while there is notable larval transport that connects tidepools across the region, large areas of sandy shore make for inconsistent connectivity. Past evidence of recovery was previously thought to be stronger, but more recent research is showing declines in recovery over the last decade, especially related to sea star wasting syndrome. Extent distribution and value/importance received 'Superior' (5) scores because tidepools are a dominant feature of this coast line and very valuable to visitors and recreational harvesters.

The average for social potential was scored Fair (3). Ability to learn and change as well as proactive management both scored Poor (2) because there are only three wardens for all of San Mateo. While docents can help fill that gap, there are responsibilities of a warden that can not and should not be replicated by volunteer docents, such as enforcement and management of difficult visitors. The only social factor that scored Superior was existing mandate because the workshop attendees reported that they do not foresee any impact to the current MPA mandate and management structure.

The combined social and ecological adaptive capacity for tidepools was determined to be Moderate, leaning towards High (3.6).

Vulnerability

The vulnerability level for all three stressors (sea level rise, increased daytime air temperature, and increased water temperatures) was determined to be moderate (Figure 15).

TIDEPOOLS	RISK	ADAPTIVE CAPACITY	VULNERABILITY
SEA LEVEL RISE	MODERATE	MODERATE	MODERATE
INCREASED DAYTIME AIR TEMP	HIGH	MODERATE	MODERATE
INCREASED WATER TEMPERATURE	HIGH	MODERATE	MODERATE

Figure 15. Risk, adaptive capacity, and vulnerability scores for Tidepools, on a scale from Low to Extreme.

Recommended Strategies

Drawing on the full list of brainstormed strategies from the third exercise, workshop participants identified multiple approaches and strategies for increasing the adaptive capacity of tidepools in Pillar Point SMCA. These were determined to have varying levels of efficacy and costs. All brainstormed strategies are available in Appendix B.

Increase the Number of Tidepool Docents–Especially During Low Tides

Medium Cost | High Efficacy

Increasing the number of tidepool docents, particularly during low tides, presents a cost-effective strategy with significant potential for positive impact on MPA stewardship and public engagement. Due to their already existing established network, expertise, and convening power, The MPACN is well-positioned to lead an initiative to increase tidepool docents. Increasing docents is likely to be highly effective because of the many potential benefits such as reduced visitor impact, increased public awareness, enhanced visitor experience, improved data collection, and stronger community engagement.

- **Leader and potential partners**
  - MPACN

- **Monitoring & evaluation criteria**
    - Reduction in formal and informal enforcement actions
    - Increased docent interceptions with positive interactions
    - Decreased handling and maneuvering in tidepools during low tides
    - Increased docent hours
    - Consider hosting tidepool tours during vulnerable times by permit

- **Funding/costs -** Funding would need to be procured for the following items:
    - Advertising to increase the docent volunteer pool
    - Creation of new training materials

- **Existing or needed management mechanisms**
    - Ranger enforcement can be used as backup in extreme cases

- **Timeline:** Very fast, around 3 months

Identify Natural Refugia Areas and Strengthen Protections

High Cost | High Efficacy

Identification of natural refugia areas is a very actionable, but resource intensive initiative. Results would allow for the more fine-scale protection of important refugia, which would increase efficacy of conservation efforts and help ensure on-the-ground results.

- **Leader and potential partners**
    - MARINe Lab at University of California, Santa Cruz
    - California Department of Fish and Wildlife
    - Shorezone
    - California Ocean Protection Council
    - California Ocean Science Trust
    - University researchers

- **Monitoring & evaluation criteria**
    - Identification of refugia from warming ocean waters
    - Increased or added protections for refugia
    - Monitoring of species in refugia
    - Increased survival of tidepool species

- **Funding/costs -** Funding would need to be procured for the following items:
  - Research to identify refugia (in situ monitoring and modeling)
  - Likely some sort of public process if adding protections
  - Monitoring costs

- **Existing or needed management mechanisms**
  - Would require a larger exploration of laws/management requirements
  - Possibly add protections and strengthen enforcement

- **Timeline**: Likely a 5-10 year process

Montara and Pillar Point

SEA STARS

RESULTS-AT-A-GLANCE

Climate Stressors

- Increased Water Temperature
- Sea Level Rise
- Ocean Acidification

Non-Climate Stressors

- Loss of Food Source
- Habitat Damage
- Disease

Adaptive Capacity

- Ecological Capacity = Moderate
- Social Capacity = Moderate
- Combined Capacity = Moderate

Ecological Strengths

Spatial Extent
Value & Importance

Social Strengths

Stakeholder Relationships
Existing Mandate

Final Vulnerability Scores

	RISK	ADAPTIVE CAPACITY	VULNERABILITY
INCREASED WATER TEMPERATURE	EXTREME	MODERATE	HIGH
OCEAN ACIDIFICATION	MODERATE	MODERATE	MODERATE
SEA LEVEL RISE	MODERATE	MODERATE	MODERATE

Recommended Strategies

Build a Science to Management Working Group

Cost: Low

Efficacy: High

Investigate Resilient Genotypes for Potential Outplanting

Cost: High

Efficacy: Unknown

Identify Climate Refugia and Apply Area-Based Protections

Cost: High

Efficacy: High

Sea Stars in Montara State Marine Reserve and Pillar Point State Marine Conservation Area

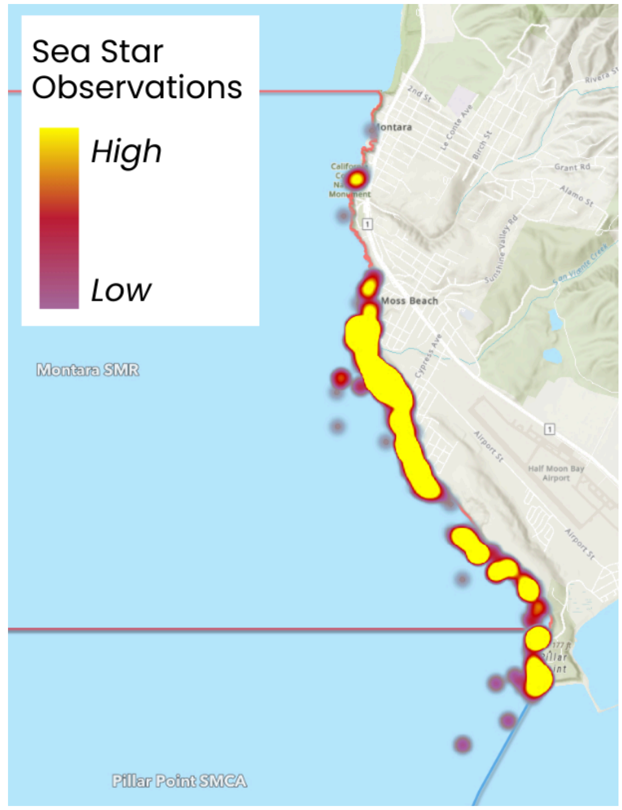

Figure 16. All [iNaturalist observations](#) of sea stars (accessed on November 24, 2024) on the Montara SMR and Pillar Point SMCA coastline.

Sea star populations in both Montara SMR and Pillar Point SMCA are fairly similar, with some key differences. Montara SMR has more diversity and higher populations of sea star species than Pillar Point SMCA (Figure 16). Anecdotally, experts believe that high harbor seal populations in Montara may impact sea stars; harbor seals haul-out on exposed reefs in turn tearing up species and habitat in the process. Data from iNaturalist indicate that ochre and bat stars are the most frequently identified species at both of these areas (accessed November 2024). Since 2005, iNaturalist reports 2,045 sea star sightings in Montara SMR. In Pillar Point SMCA, iNaturalist data goes back as far as 2013, indicating 91 observations of sea stars.

Sea Star Wasting Disease

Sea Star Wasting Disease (SSWD) has affected over 20 species of sea stars along the U.S. West Coast, including those in the San Mateo region ([Konar et al., 2019](#)). During the completion of this assessment, the exact cause was unclear; since then, the culprit has been identified as *Vibrio pectenicida* strain FHCF-3 ([Prentice et al., 2025](#)). With this new discovery, much more research must be conducted to understand the pathogen. Existing research may still offer insights about the disease and suggest its behavior under climate risks.

Laboratory studies from before this discovery found that cooler temperatures slow disease progression, though affected stars ultimately succumb to the disease (MARINe, September 18, 2023 Update). The 2014–2016 marine heat wave likely exacerbated SSWD by elevating water temperatures (Harvell et al., 2019).

Larger, more rugose species, such as sunflower stars (*Pycnopodia helianthoides*), appear particularly vulnerable, while smoother species like bat stars (*Patiria miniata*) and leather stars (*Dermasterias imbricata*) show milder symptoms (MARINe, 2023). For example, mottled stars (*Evasterias troschelii*) exhibit disease progression similar to ochre stars, likely due to shared physical traits (MARINe, 2023).

The Sunflower Star population was decimated along the U.S. West Coast from SSWD (Schiebelhut et al., 2024). But in 2023, MARINe and their monitoring partners recorded five observations in California, the highest count in nearly a decade (MARINe, September 5, 2024 Update).

Long-term monitoring by MARINe (2012–2023) at Pillar Point SMCA and Montara SMR has documented SSWD in several species, including giant pink sea stars, ochre sea stars, and sunflower stars (MARINe, 2023). MARINe and their partners are continuing to observe sunflower stars in small numbers in specific locations, offering a glimmer of hope for the potential resilience or recovery of certain populations. Continued monitoring and research are essential to understanding SSWD and mitigating its impact on marine ecosystems.

Stressors

The three climate stressors identified by participants for sea stars included increased water temperature, ocean acidification, and sea level rise. All three stressors were determined to have an “almost certain” climate risk likelihood, with the assessment yielding a greater than 50% probability.

Climate Stressors

Increased Water Temperature

Elevated water temperatures, particularly during marine heat waves like the 2014–2016 "Warm Blob," significantly stress sea stars and contribute to the severity of SSWD. The timing of peak population declines in sea stars aligns with periods of anomalously warm sea surface temperatures, suggesting a strong correlation between warming and disease outbreaks (Harvell et al., 2019). Increased temperatures may exacerbate SSWD by intensifying metabolic demands and promoting microbial activity, which reduces oxygen availability in the water—a potential stressor for sea stars. Additionally, SSWD impacts have been more intense in southern regions compared to northern areas, indicating a temperature gradient in disease severity (Miner et al., 2018). Modeling studies further support this link, with findings showing a strong association between sea surface temperature and mortality rates among affected populations (Aalto et al., 2020). These findings highlight the vulnerability of sea stars to rising temperatures and underscores the need to address climate change to mitigate further population declines.

Ocean Acidification

Ocean acidification, driven by increased carbon dioxide (CO_2) absorption by seawater, presents a significant stressor to sea stars, potentially contributing to the severity of SSWD (Wahltinez et al., 2023). By 2100, pH is expected to decrease by 0.3 to 0.4 units (Orr et al., 2005). Decreased pH levels can disrupt the physiology of sea stars, particularly their ability to regulate calcium carbonate structures essential for their skeletal support (Collard et al., 2013; National Research Council, 2010). While some studies, such as one exposing *Asterias rubens* from the western Baltic Sea to elevated pCO_2, found no significant impact on survival or calcification rates, there were notable declines in feeding and growth rates under acidified conditions (Appelhans et al., 2014). Reduced feeding compromises energy intake, which is vital for reproduction, regeneration, and immune function, further weakening sea stars and potentially increasing their susceptibility to SSWD.

Sea Level Rise

Sea level rise inundation models indicate an increase in water height of 300-400 cm in key sea star habitat (UC Berkeley, 2016). This poses a significant threat to sea stars and their prey species by fundamentally altering the intertidal zone habitat. As rising waters encroach upon existing rocky shores, the vertical space available for intertidal species becomes compressed (Figure 17). This is problematic for mussels, a primary food source for sea stars, which require specific tidal zones for optimal growth and survival (Morris et al., 1980; Petes et al., 2008). In Montara SMR and Pillar Point SMCA, this is particularly challenging as there is not much available space to allow for the natural inland migration of the intertidal zone, making the habitat for mussels increasingly limited. This reduction in mussel populations can have cascading effects on the food chain, directly impacting sea star populations that rely on them for sustenance. The compression of these habitats also forces sea stars and their prey into smaller areas, thus intensifying competition and predation pressures while making both species more vulnerable to other environmental stressors.

Figure 17. All [iNaturalist observations](#) of sea stars (accessed on November 24, 2024) and predicted sea level rise, indicating likely inundation of key intertidal habitat.

The three non-climate stressors included in this RVA were loss of food sources, habitat damage, and disease. Loss of food sources and disease worsen with climate change, while climate change is not necessarily a compounding factor in regards to habitat damage.

Non-Climate Stressors

Loss of Food Source

Loss of food sources can significantly impact sea star populations in marine environments. When food sources become scarce due to illegal harvesting in protected areas like Pillar Point SMCA, sea stars may struggle to find adequate nutrition. This can affect their growth, reproduction, and overall population stability. Unfortunately, illegal harvesting of mussels is not uncommon in Pillar Point SMCA, particularly because it is directly adjacent to unprotected areas where harvesting is allowed. This close proximity leads some visitors to unknowingly harvest mussels in protected areas.

Habitat Damage

Harbor seals, particularly in Montara SMR, can impact sea star populations through various ecological interactions. While direct predation on sea stars by harbor seals is not common, their presence and activities in protected areas can indirectly affect sea star populations through trophic cascades and habitat modification. Specifically in Montara SMR, harbor seals are known to haul-out on exposed reefs, damaging sea star habitat, as well as habitat for key prey species (e.g., mussels).

Disease

Disease outbreaks pose a significant threat to tidepool ecosystems, particularly affecting keystone species like sea stars. The recent SSWD outbreak serves as a stark example, causing one of the largest marine disease events ever recorded. Research suggests that environmental stress factors, such as warming waters, may exacerbate disease outbreaks, highlighting the complex interactions between climate and non-climate stressors.

Cumulative Risk & Consequence

The cumulative consequence from climate stressors and non-climate stressors was found to be *major* for increased water temperature and *minor* for ocean acidification and sea level rise. All non-climate stressors were exacerbated by increased water temperatures, in that water temperature can reduce the diversity and abundance of food sources. Additionally, warmer temperatures tend to draw more people to the beach, leading to increased habitat damage. This will be further exacerbated by sea level rise, which will narrow the amount of available beach space and result in more extreme space conflicts. The overall stress from increased temperatures and ocean acidification can reduce species resilience to pathogens, increasing the risk of marine disease outbreaks. Preliminary research indicates that leather stars may be more vulnerable to ocean acidification and marine disease outbreaks than purple or mottled stars (Finley, n.d.). Additionally, rising water levels may connect more tidepools spatially, leading to easier disease transmission between individual pools.

Adaptive Capacity

The ecological potential for adaptive capacity for sea stars is Moderate (3.2). The only Superior (5) ecological factor was determined to be the value and importance of sea stars, as they are the “charismatic megafauna” of tidepools–everyone knows what they are and are excited to see them. Biodiversity and past evidence of recovery were the ecological factors that scored lowest for adaptive capacity (poor = 2). Recovery to SSWD has been slow, and populations are still not fully rebounded to previous abundance. Initial evidence of a genetic response to SSWD shows promising adaptations that could provide more long-term resilience, however this is still yet to be fully understood. Biodiversity was scored as Poor (2) because this region is less biodiverse than nearby areas. Ochre sea stars are the primary sea star species in the area, and it is very rare to see other species.

The social adaptive capacity for sea stars is Moderate (3.5). Stakeholder relationships and existing mandate received Superior (5) scores. Stakeholders are very well engaged and interested in sea stars, especially through the docent program. Similar to the other assets, participants perceive the MPA mandate as strong and unlikely to change. Responsiveness, ability to learn and change, and proactive management received the lowest scores (2). Participants perceived that science is not always incorporated into management decisions and that decision-making is often reactionary. For example, many participants felt that SSWD was not efficiently managed in a proactive manner. There is strong science and monitoring occurring in the region through community science programs and academic research, but the connection to management could be strengthened. Enforcement scored low because with only three wardens for the entire county, enforcement capacity is extremely low.

Adaptive capacity averaged across both ecological and social factors is Moderate (3.4).

Vulnerability

The vulnerability for increased water temperature is High, and vulnerability for ocean acidification and sea level rise is Moderate (Figure 18).

SEA STARS	RISK	ADAPTIVE CAPACITY	VULNERABILITY
INCREASED WATER TEMPERATURE	EXTREME	MODERATE	HIGH
OCEAN ACIDIFICATION	MODERATE	MODERATE	MODERATE
SEA LEVEL RISE	MODERATE	MODERATE	MODERATE

Figure 18. Final risk, adaptive capacity, and vulnerability scores for sea stars, on a scale from Low to Extreme.

Recommended Strategies

Drawing on the full list of brainstormed strategies from the third exercise, workshop participants identified multiple approaches and strategies for increasing the adaptive capacity of sea stars in Montara SMR and Pillar Point SMCA. These were determined to have varying levels of efficacy and costs. All brainstormed strategies are available in Appendix B.

Build a Science to Management Working Group

Low Cost | High Efficacy

The primary goal is to increase science-management relationships through a working group model, aiming to create a space for the creation and implementation of solutions.

- **Leader and potential partners**
    - MPACN
    - Pacific Coast Ocean Restoration Initiative
    - The Nature Conservancy
    - Universities
    - California Department of Fish and Wildlife
    - California State Parks
    - California Ocean Protection Council
    - California Ocean Science Trust

- **Monitoring & evaluation criteria**
    - Identification of group leader/facilitator
    - Group roster
    - Regular meetings and opportunities to share information
    - Identification of actionable solutions

- **Funding/costs -** Funding would need to be procured for the following items:
    - Facilitator
    - Shared online space (website, Esri hub, shared google document)
    - Costs for in person meeting (optional)
    - Stipends for participation (optional)

- **Existing or needed management mechanisms**
    - Management mechanisms aren't necessary for the group
    - Adaptive management would be helpful for implementing their solutions
    - Agency support for managers to participate

- **Timeline:** Could be established in a year

Investigate Resilient Genotypes for Potential Outplanting

High Cost | Unknown Efficacy

Investigation of sea star genotypes that are more temperature and disease-resistant would allow the potential outplanting of those genotypes in the region. This would help facilitate a more resilient generation of sea star communities, contributing to long-term species resilience and adaptation.

- **Leader and potential partners**
    - MARINe Lab at University of California, Santa Cruz
    - PISCO Lab at Oregon State University
    - National Marine Sanctuaries
    - Monterey Bay Aquarium
    - California Department of Fish and Wildlife
    - California State Parks
    - California Ocean Protection Council
    - California Ocean Science Trust
    - Regional partners in Oregon, Washington, and Mexico

- **Monitoring & evaluation criteria**
    - Identification of genotypes that are resistant
    - Journal article
    - Feasibility analysis investigating possible impacts for outplanting in San Mateo region
    - Outplanting of new genotypes
    - Prevalence of sea stars with greater resistance to stressors
    - Increased and more successful sea star recruitment throughout the region

- **Funding/costs -** Funding would need to be procured for the following items:
    - Research and experiments
    - Animal husbandry
    - Researcher costs
    - Monitoring to evaluate impacts once outplanted
    - Publishing costs

- **Existing or needed management mechanisms**
    - State and federal support for outplanting, which would require

coordination across:
        - California Department of Fish and Wildlife
        - US Fish and Wildlife Service
        - NOAA
        - Army Corps of Engineers

- **Timeline:** Long-term, around 10 years in total
    - Finding genotypes: 2-3 years
    - Feasibility analysis: 2-3 years
    - Outplanting: 1-3 years
    - Ongoing monitoring: 5+ years

Identify Climate Refugia and Apply Area-Based Protections

High Cost | High Efficacy

The final strategy involves identifying areas that serve as refugia for sea stars from warming ocean waters. Once identified, these refugia areas could be given stronger protections. In extreme cases, sea stars could also be moved to refugia areas to avoid mass mortality.

- **Leader and potential partners**
    - California Department of Fish and Wildlife
    - California State Parks
    - California Ocean Protection Council
    - California Ocean Science Trust
    - University researchers

- **Monitoring & evaluation criteria**
    - Identification of refugia from warming ocean waters
    - Increased or added protections for refugia
    - Monitoring of sea stars in refugia zones
    - Training docents to assess conditions and move sea stars if needed

- **Funding/costs -** Funding would need to be procured for the following items:
    - Research to identify refugia (in situ monitoring and modeling)
    - Likely some sort of public process if adding protections
    - Monitoring costs
    - Docent training materials

    - Hosted docent training

- **Existing or needed management mechanisms**
    - Unsure - this would require a larger exploration of laws/management requirements
    - Possibly add protections and strengthen enforcement

- **Timeline:** Likely a 5-10 year process

Next Steps

Throughout this pilot RVA, workshop participants noted several potential next steps to continue climate adaptation planning efforts and expand the application of this methodology.

The strategies identified through this pilot are ripe for implementation. The information provided in this report may be a catalyst for the creation of more in-depth project design, which could be leveraged for identifying and procuring additional funding support. Through this process, the collaborative may leverage overlaps between identified strategies for cost savings and a more integrated approach. For example, identifying climate refugia for both tidepools and sea stars could potentially be undertaken within the same project. This presents an opportunity for integrated research and planning efforts, given that both assets share the intertidal environment and face similar climate stressors like warming waters and sea level rise.

The results from this pilot highlight the benefit of undertaking the RVA process, as well as several lessons learned that can be applied in future iterations. Vulnerability assessments for California's MPAs have been a consistent recommendation from regional and statewide forums, and leveraging this method would allow for state-wide consistency and coordination throughout the process. Securing funding to help offset costs of participation was recognized as essential for enabling these future activities. This would allow for the provision of stipends for participants, as well as hosting workshops in-person.

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Appendix A. Regional Climate Summary

Before conducting the RVA, it's important to establish a common understanding of climate impacts in the MPA. This document outlines the expected impact of climate change in the San Mateo area, as a baseline for future RVA drafting. Throughout the actual RVA, we will conduct more in-depth assessments specific to the chosen assets.

Definitions

- **Parameter:** An environmental pressure or challenge directly linked to climate change that may affect the resilience and functioning of a habitat or species.
- **Change to date**: Any changes that have already occurred in this parameter at your site. If there are no data with respect to change from historic conditions, briefly synopsize the current condition (e.g. current average annual water temperature at the site is….).
- **Direction and range of projected change**: Anticipated changes in this parameter at your site. Include a time frame associated with described projection (e.g. water temperature will increase between 1.5 and 5°C by 2050).
- **Trends in projected change**: Simplify the projection to indicate the big patterns relevant to management (e.g. increasing water temperatures will continue over the next century, with greatest warming in summer months, exacerbated by increasingly common cessation of upwelling).
- **Confidence**: The level of confidence of the projected change (e.g. High, 95%, very likely).
- **Map**: Use this column to refer to any associated maps or graphics that can be available for RVA participants.

Water Temperature

Water temperature can be measured as both Sea Surface Temperature (SST) and sub-surface temperature. SST refers to the temperature of the top layer of the ocean, typically measured at about 1 meter below the surface. It is influenced by factors such as solar radiation, wind, and ocean currents and is critical for studying climate patterns, marine ecosystems, and weather phenomena like hurricanes. Sub-surface temperature, on the other hand, measures the temperature below the immediate surface, typically in deeper layers of the ocean, providing insight into ocean circulation, heat distribution, and subsurface processes that affect marine life and climate.

Change to Date	**Increased** by approximately 0.6°C to 1°C in the past 100 years
Direction and range of projected change	Depending on emission scenarios: **SST** 2050: 1.5°C to 2°C (moderate) 2100: increase by 2°C to 3°C (moderate). Could exceed 4°C under high emission scenario Warming is more intense at surface so there will also be an increase in stratification **Subsurface warming** Projected warming changes at 300 m depth (~2°C) and warming of ~1°C to 500 m or more.
Trends in projected change	**Increase**. The magnitude of increase depends on future global emission pathways and mitigation measures
Confidence	**Very high**

Sea Level Rise

Sea level rise is the long-term increase in the average height of the ocean's surface, primarily due to climate change. This rise is driven by two main factors: the melting of ice sheets and glaciers, and the molecular expansion of seawater as it warms. Sea level rise poses significant risks to coastal communities, ecosystems, and infrastructure, leading to increased flooding, erosion, and habitat loss.

Change to Date	**Increased** by 0.19 meters in the past 100 years. 1.99 mm/year
Direction and range of	2050: 0.3-0.6 m 2100: 1.0 - 2.1 m

projected change	Extreme: 3.1 m
Trends in projected change	**Increase.**
Confidence	**Very high.**
Map	• NOAA Tides and Currents - Sea Level Trends • Cal-Adapt - Sea Level Rise • NOAA Sea Level Rise Viewer

Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of oxygen present in water, essential for the survival of aquatic organisms such as fish, invertebrates, and microorganisms. It enters water through diffusion from the atmosphere, photosynthesis by aquatic plants, and mixing from wave action. The level of DO is a key indicator of water quality, and low levels (hypoxia) can lead to dead zones where marine life cannot survive. Factors that affect DO levels include water temperature, photosynthesis, respiration, decomposition, water movement, and nutrient pollution.

Change to Date	Over the past century, DO levels off California's coast have experienced significant declines, primarily driven by climate change and nutrient pollution. Studies indicate that DO in deep waters off Central California has decreased by as much as 40% in recent decades, largely due to increased water temperatures and reduced mixing, which limit oxygen replenishment. The rise in nutrient runoff has also contributed to more frequent hypoxic events, leading to negative impacts on marine life and ecosystems.
Direction and range of projected change	Significant decrease in DO below the surface mixed layer. Changes to the depth of the hypoxic layer is projected to shoal up to 150 m in offshore waters and 60-70 m in nearshore waters.

Trends in projected change	**Decrease**
Confidence	**Very high**. Projected trends based on multiple climate and oceanographic models (ROMS-GFDL and ROMS-IPSL)

Currents

Ocean currents are large-scale movements of seawater driven by factors such as wind, the Earth's rotation (Coriolis effect), and differences in water density due to temperature and salinity. These currents play a critical role in regulating global climate by redistributing heat, influencing weather patterns, and transporting nutrients and marine life across vast distances. Ocean currents are categorized into surface currents, primarily wind-driven, and deep currents, driven by temperature and salinity differences.

Change to Date	**Variable.** Have shown variability over time due to oceanic and atmospheric changes. Intensification of upwelling has affected the strength and direction of currents
Direction and range of projected change	By 2050, coastal current patterns are expected to shift due to changing wind patterns, increasing SST and ocean stratification. By 2100, altered ocean circulation patterns are projected
Trends in projected change	**Increased seasonal variability.** California current strength is likely to increase in northern region but will experience seasonal variability with stronger spring upwelling and weaker summer upwelling, resulting from changes in wind and ocean temperature patterns
Confidence	**Moderate to high** for short term projections (2050). More uncertainty in long term projects beyond 2050 - based on greenhouse gas emissions and potential ice sheet collapses

Upwelling/Mixing

Upwelling is the process where deep, cold, and nutrient-rich water rises to the ocean surface, typically driven by wind patterns that push surface waters away from the coast. This nutrient influx supports the growth of phytoplankton, forming the base of the marine food web and enhancing the productivity of fisheries. Upwelling regions are vital for global marine ecosystems but are also sensitive to changes in climate and ocean circulation patterns.

Change to Date	**Increase/strengthening** of upwelling/mixing
Direction and range of projected change	Further increase/strengthening of coastal upwelling under a high emission scenario.
Trends in projected change	**Increasing.**
Confidence	**Moderate**.

Precipitation

Precipitation is any form of water, such as rain, snow, sleet, or hail, that falls from clouds to the Earth's surface. Precipitation is a key component of the water cycle, replenishing freshwater supplies and influencing weather patterns and ecosystems.

Change to Date	**Increased variability and severity.** Precipitation in California has shown high variability, with both dry and wet years becoming more extreme. San Mateo has experienced periods of extreme drought alternating with intense storms, such as the bomb cyclones of recent years. Average annual precipitation is 24-28 inches in San Mateo.

	Major droughts have occurred multiple times over the last century, with the most recent notable drought spanning from 2011 to 2017, resulting in a **58% precipitation deficit** in some parts of California
Direction and range of projected change	2050: Little or no overall change in average annual precipitation. Increase in extreme precipitation events by 10-20%. Winter precipitation will increase by 5-10% compared to the 20th century. 2100: number of dry years will increase; more extreme precipitation events.
Trends in projected change	**Increasing.** Heavy precipitation events; dry years will become drier and wet years will become wetter
Confidence	**Moderate to high.** Future average precipitation is difficult to predict because precipitation in California is known to be highly variable from year-year.
Map	• Cal-Adapt - Precipitation • Cal -Adapt- Extreme Precipitation Events

Ocean Acidification

Ocean acidification is the process by which seawater becomes more acidic due to increased absorption of carbon dioxide (CO_2) from the atmosphere. As CO_2 dissolves in seawater, it forms carbonic acid, lowering the pH and reducing the availability of carbonate ions, which are essential for marine organisms like corals and shellfish to build their calcium carbonate shells and skeletons. This phenomenon poses a significant threat to marine ecosystems, disrupting food chains and biodiversity, particularly in sensitive habitats like coral reefs.

Change to Date	**Increasing**. Ocean acidification is increasing as CO2 in the ocean increases (declining pH). The ocean absorbs

	approximately 30 percent of the CO2 released into the atmosphere each year. Long term data for California waters is limited; however, the existing data has a similar trend to a long term dataset collected in Hawaii at the same time points. Research using core samples of foraminifera shells from the seafloor off Santa Barbara shows that acidity in coastal waters has increased at nearly **twice the rate** of the global ocean average
Direction and range of projected change	2050: acidification is expected to lower the pH by approximately **0.1 to 0.2 units**. 2100: Projections for the future indicate that, under the IPCC's RCP8.5 scenario (high emissions), ocean pH could decrease by **0.3 to 0.4 units** along the California coast The upwelling that occurs along this coast, which brings CO_2-enriched water to the surface, is expected to intensify the acidification process, particularly during periods of stronger Pacific Decadal Oscillations.
Trends in projected change	**Increase**.
Confidence	**High.** The use of foraminifera shells for a long-term record provides precise historical trends, while modern models that combine observed pH levels with CO_2 emissions scenarios strengthen future projections.

Turbidity

Turbidity refers to the cloudiness or haziness of water caused by the presence of suspended particles such as silt, clay, organic matter, algae, or microorganisms. It is a key indicator of water quality, with high turbidity reducing light penetration, affecting photosynthesis in aquatic plants, and potentially harming marine life. Turbidity can increase due to natural processes like erosion and runoff, as well as human activities like construction, agriculture, and pollution.

Change to Date	**Variable.** Spiking during extreme weather events and erosion episodes.
Direction and range of projected change	Increased turbidity - linked to more intense storms and changes in sediment transport
Trends in projected change	**Increasing.** Exact quantitative projects are limited
Confidence	**Moderate**

Wave Action & Coastal Erosion

Coastal erosion is the gradual loss of land along coastlines due to the action of waves, tides, currents, and wind. It is often accelerated by human activities such as construction, sand mining, and the removal of natural barriers like vegetation, as well as by rising sea levels and storm surges linked to climate change. Coastal erosion can lead to the loss of habitats, property damage, and increased vulnerability of coastal communities to flooding and other hazards. When combined with factors like rising sea levels and storm surges, intensified wave action can accelerate coastal erosion, resulting in significant loss of land and altering coastal ecosystems.

Change to Date	**Increased by 0.4-0.6 meters** per year in certain vulnerable portions of the coast
Direction and range of projected change	2050: with projected sea-level rise scenarios ranging from 0.5 to 1 meter, erosion rates could increase by up to 50% from current levels. 2100: severe erosion - The average bluff erosion in San Mateo County could extend landward by more than 60-80 meters by 2100 if no mitigation efforts are implemented
Trends in projected	**Increasing.** Rising water levels and increased storm activity will increase coastal erosion

change	
Confidence	**Moderate to High**
Map	Our Coast Our Future

Salinity

Salinity is the concentration of dissolved salts in water.. It plays a crucial role in determining the physical and chemical properties of water bodies, influencing factors such as density, buoyancy, and the behavior of marine organisms. Variations in salinity occur due to processes like evaporation, precipitation, river inflow, and ocean currents, affecting ecosystems and the distribution of species in both marine and freshwater environments.

Change to Date	**Variable.** Salinity has fluctuated due to multiple factors and regional climate patterns over the last 100 years. Natural variability, such as upwelling events and freshwater input from rivers, plays a significant role. However, recent decades have seen more consistent trends linked to climate change, with some evidence of decreased salinity during El Niño events due to increased freshwater influx.
Direction and range of projected change	By 2050 and 2100, projections show potential variability in salinity driven by climate-induced changes in freshwater input and ocean circulation
Trends in projected change	**Variable.** The trends in salinity changes along the California coast remain influenced by climate variability. Under scenarios of increased greenhouse gas emissions, projections suggest that upwelling—critical to nutrient and oxygen cycles—could intensify, which might increase salinity in some regions. However, higher freshwater inflows from rainfall and runoff could lead to localized decreases in salinity. The specific trend in San Mateo remains subject to regional factors like changes in river outflow and the balance between evaporation and

	precipitation.
Confidence	**Moderate**

Storm Severity & Frequency

Storm severity refers to the intensity of a storm, which can be measured by factors such as wind speed, rainfall amounts, and potential for damage or destruction. Storm frequency indicates how often storms occur in a given area over a specific time period, reflecting patterns in weather systems and climate conditions. Both storm severity and frequency are influenced by various factors, including climate change, which can lead to more intense and frequent storms, resulting in increased risks to communities, ecosystems, and infrastructure.

Change to Date	**Significant increase** in extreme storm events since the mid-20th century, with trends suggesting more intense storms leading to greater flooding risks
Direction and range of projected change	Increasing intensity and frequency of storms As the climate warms, years with many atmospheric river storms become more frequent in most climate-change projections, but the average number of such storms per year is not projected to change much. Increases in intensity will result in more severe flood events. Average number of storms per year not projected to change much
Trends in projected change	**Increase**. Predicted to increase in severity
Confidence	**Moderate**

Harmful Algal Blooms

Harmful algal blooms (HABs) are rapid increases in the population of certain algae species in water bodies, often resulting in the production of toxins that can harm marine life, human health, and ecosystems. These blooms can occur in both freshwater and marine environments, typically triggered by factors such as nutrient pollution, warm temperatures, and stagnant water conditions. HABs can lead to significant ecological and economic consequences, including fish kills, shellfish poisoning, and negative impacts on tourism and recreation.

Change to Date	**Shifts in distribution, increased abundance, and increased toxicity.** HABs in California have significantly increased in frequency and intensity over the past few decades. Reports indicate that occurrences rose from approximately 100 incidents in 2016 to over 600 by 2021. Although comprehensive data spanning the full century is limited, it's noted that specific species, such as *Pseudo-nitzschia*, which produces domoic acid, have been monitored since the late 20th century and are more frequently detected. Recent high-profile blooms in 2015, 2022, and 2023 underscore a rising trend
Direction and range of projected change	2050 and 2100: Increased frequency and intensity **Warmer Water Temperatures**: Higher temperatures promote the growth of algal species **Nutrient Runoff**: Increased nutrient availability from both agricultural and urban runoff is linked to bloom occurrences **Deteriorating Ocean Conditions**: Changes in oceanographic conditions, including stratification and circulation patterns, are likely to influence HAB dynamics
Trends in projected change	**Increasing**. Intensification of upwelling and predicted increase in nitrate
Confidence	**Moderate**

ENSO/PDO

El Niño-Southern Oscillation (ENSO) is a climate phenomenon characterized by periodic fluctuations in ocean temperatures and atmospheric conditions in the central and eastern Pacific Ocean, impacting global weather patterns. It has three phases: El Niño, which involves warmer ocean temperatures and can lead to increased rainfall in some regions; La Niña, marked by cooler ocean temperatures and typically resulting in drier conditions; and the neutral phase, where conditions are average. The Pacific Decadal Oscillation (PDO) is a longer-term climate pattern that describes variations in sea surface temperatures in the North Pacific Ocean, occurring over decades and influencing regional climate and marine ecosystems, often interacting with ENSO events to modulate their effects.

Change to Date	**Variable**. ENSO has exhibited variability over the last century, with significant impacts on climate patterns in California. Studies show that both El Niño and La Niña events have become more intense and frequent in the past few decades, largely due to climate change. For example, the strong El Niño events in the late 20th century (e.g., 1982-1983, 1997-1998) led to increased rainfall and flooding along the California coast, influencing hydrological cycles and ecosystem dynamics
Direction and range of projected change	Projections indicate that El Niño events may become stronger, while the impacts on La Niña are less certain.
Trends in projected change	**Increasing**. Significant intensification of El Nino events
Confidence	**High**. Studies have consistently shown correlations between ENSO phases and weather impacts in California, particularly in terms of flooding and drought patterns

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Appendix B. Strategy Development

All strategies brainstormed during the Strategy Development phase of the project.

Vulnerability	Approach	Strategy	Cost	Efficacy
Harbor Seals				
All	Increase Adaptive Capacity	Community engagement - public engagement and outreach about safe viewing, especially during key seasons. Share material from MMC. Work to co-develop materials and resources. Trainings on how to message with the public. Leverage existing programs; language accessible, culturally relevant programming	Low to Medium	High
All	**Increase Adaptive Capacity**	**Increase city engagement and education with wildlife; build stewardship**	**Low to Medium**	**High**
All	Increase Adaptive Capacity	Increase partnerships/collaboration with watershed management, agricultural folks, land managers for pollution management - not necessarily putting things in place, but the goal is to lead to that	Low	Medium to High
All	**Increase Adaptive Capacity**	**Increase monitoring of haul out areas and look into proactive protections for areas that seals may shift to. Dynamic management - close areas off so seals have space to haul out in new areas. More proactive**	**High**	**High**

		management (elephant seal example) Elephant seal monitoring updates		
All	Increase Adaptive Capacity	Limit access to southern beaches to provide sanctuary spaces for harbor seals (elephant seal example) - Precedent for temporary/seasonal closure of haul outs in La Jolla	High	Unknown
Increased Ocean Temperature (Low)	Reduce Consequence	Increase docent presence and enforcement to ensure that increased beach visitation and coastal squeeze doesn't negatively impact harbor seals	Medium	High
Increased Ocean Temperature (Low)	Reduce Consequence	Create visitor limits (ex: 100 people at once) within protected areas to reduce space conflicts	High	High
Sea Level Rise (Moderate)	Reduce Consequence	Work with land-trust to maintain and secure haul-out areas. Work with officials to set barriers to reduce public recreation in vulnerable areas proactively as conditions change (Bluffs) - proactive protections and management. Recovering impacted haul out areas - hands on construction	High	High
Sea Level Rise (Moderate)	Reduce Consequence	Place artificial haul outs - harbor seals have used these in the past in a harbor setting, but they were removed	High	Unknown
Sea Level	Reduce	Explore commercial fishing gear recommendations to	High	Low

Rise (Moderate)	Consequence	reduce entanglement		
Tidepools				
All	Increase Adaptive Capacity	Manage human activity and access - limit access when stressors are particularly high. People can still access, just not when it's highly vulnerable. Cost for enforcement, monitoring, community engagement. Similar model as with harbor seals.	High	High
All	**Increase Adaptive Capacity**	**Increase docents during low tides. Cost for training, advertising. Can call rangers for backup. Cost for MPA Training, resources, interpretive guide, etc.**	**Medium**	**High**
All	Increase Adaptive Capacity	Increase enforcement through state rangers (CDFW)	High	High
All	Increase Adaptive Capacity	Increase education resources/signs for visitors	Medium	Medium
All	Increase Adaptive Capacity	Restrict the number of visitors to tidepools - similar to Hanauma bay example. Could push people to less protected areas as a result. Would need more enforcement	High	High
All	Increase Adaptive	Reintroduction of sea stars (and other critical species?) to restore community composition	High	Unknown

	Capacity			
All	Increase Adaptive Capacity	Manger created/informed climate adaptation plan per species	High	Medium
Sea Level Rise (Moderate)	Reduce Consequence	Protect landward migration zones for habitat shifting (moving infrastructure)	High	Unknown
Sea Level Rise (Moderate)	Reduce Consequence	Create artificial habitat	High	Unknown
Increased Daytime Air Temperature (Moderate) and Increased Ocean Temperature (Moderate)	**Reduce Consequence**	**Identify natural refugia - areas less exposed to temperature/stress. Protect these refugia. Better understand the system at this location and where community composition is likely to resist.**	**High**	**High**
Increased Daytime Air Temperature (Moderate)	Reduce Consequence	Restore algae	Medium	Unknown

Sea Stars				
All	Increase Adaptive Capacity	Prevent disease transmission through inoculation/breeding of healthy populations	High	High
All	**Increase Adaptive Capacity**	**Increase science-management relationships - working group model (TNC PCOR?). Create a space for solution making**	**Low**	**High**
All	Increase Adaptive Capacity	Manager driven climate adaptation plan (could apply to all assets). Use science to create proactive management plans. Efficacy depends on funding to implement the plan	High	Medium-High
Increased Ocean Temperature (High)	**Reduce Consequence**	**Investigate genotypes that are more temperature/disease-resistant; culture and outplant those genotypes?**	**High**	**Unknown**
Increased Ocean Temperature (High)	Reduce Consequence	Culture and outplant	High	Unknown
Increased Ocean Temperature (High)	**Reduce Consequence**	**Identify refugia for sea stars specifically and protect those areas, or explore the possibility of moving sea stars to those areas as a last ditch situation. Would require exploration of laws/management requirements**	**High**	**High**

Sea Level Rise (Moderate)	Reduce Consequence	Protect landward migration zones to allow for habitat shifting as waters rise	High	Unknown
Sea Level Rise (Moderate)	Reduce Consequence	Build up reefs to keep up with sea level rise	High	Unknown