Appendix K

The Role of Natural Habitat in Coastal Vulnerability and Adaptation Planning within the Greater Monterey County Region

September 2012

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To support decision-makers in their efforts to manage coastal resources in our changing world, The Natural Capital Project and the Center for Ocean Solutions have engaged with the Greater Monterey County Integrated Regional Water Management (GMC IRWM) planning team to assess the effects of coastal adaptation strategies and climate scenarios on the ecosystem services provided by coastal and nearshore environments. This project 1) assessed the physical vulnerability of the coast to hazards such as erosion and inundation, and 2) assessed the vulnerability of relevant infrastructure, land use types and coastal communities. This assessment can be used to identify areas for future analysis and inform project prioritization and funding. Analysis of these vulnerabilities was developed through the use of the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) decision support tool—a family of tools to map and value the goods and services provided by nature. The Coastal Vulnerability[1] model was utilized for this project.

Introduction

The impacts from climate change to California's coast are evident in Monterey County. As noted in the *Climate Change Handbook for Regional Water Planning*,[2] sea level rise will impact the shoreline in many ways such as the increased severity of coastal erosion, the increased likelihood of coastal structure failure, and the increased likelihood of the inundation of coastal infrastructure due to storm surge. These sea level rise impacts may be enhanced by a potential increase in storm wave intensity.

In spite of these increased impacts, human activity in the ocean and along the coast continues to grow. Faced with a changing climate and this growing intensity of human activities, coastal communities must understand how development and modifications of the biological and physical environment can affect their exposure to storm-induced erosion, flooding, and inundation, both now and in future sea level rise scenarios. The InVEST Coastal Vulnerability model produces a qualitative estimate of such exposure. The model maps the location and vulnerability of populations, land use, and infrastructure near coastlines using a Vulnerability Index, which differentiates areas with relatively high or low exposure to erosion and inundation during storms. In addition, the Index can highlight the protective services offered by natural habitats—such as wetlands, dunes, and kelp forests—to coastal populations.

Methods

The Vulnerability Index produced by the Coastal Vulnerability model is the qualitative estimate of exposure to erosion and flooding. It is based on seven physical and biological characteristics of the region—geomorphology, natural habitats, relief, wave exposure, wind exposure, surge potential, and sea level change—which are ranked according to their potential for increasing or decreasing coastal hazards (Figure 1). The Coastal Vulnerability model can be used to qualitatively assess where the protective role

[1] http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/#marine-models
[2] United States Environmental Protection Agency Region 9, and California Department of Water Resources (US EPA and DWR). 2011. Climate Change Handbook for Regional Water Planning. Availablehttp://www.water.ca.gov/climatechange/CCHandbook.cfm

of natural habitats has the capacity to reduce the vulnerability of coastal communities and infrastructure. The model does not take into account coastal processes that are unique to a region, nor does it predict long- or short-term changes in shoreline position or configuration.

This analysis included two other qualitative indices, an Erosion Index and an Inundation Index, combining the physical and biological variables from the Vulnerability Index that contribute to erosion or wind-generated surge respectively. The Erosion Index combines the geomorphology, wave exposure, and natural habitat rankings. The Inundation Index combines the relief, wind exposure, surge potential, sea level rise, and natural habitat rankings. The Inundation Index accounts *only* for variables that might affect wind-generated surge (wind induced rise of the water level) and does *not* include effects of inundation from wave run-up (which is dependent on beach foreshore slope and offshore wave characteristics) or flooding from inland sources. Data for the model were collected from various sources (Table 1).

Table 1: Data inputs for InVEST Coastal Vulnerability model

Data inputs	**Data source**
Geomorphology	NOAA Digital Coast; Coastal Sediment Management Group website
Relief	National Map Seamless Server USGS
Dunes	Coastal Sediment Management Group website
Wetland	National Wetlands Inventory
Kelp	California Department of Fish and Game
Sea level change	California Interim Guidelines
Wind and wave exposure	Scripps Institute of Oceanography, Coastal Data Information Program

In the GMC IRWM region (Figure 2) the InVEST tool assessed the physical vulnerability to coastal hazards under three climate and two habitat scenarios using the Vulnerability Index, Erosion Index, and Inundation Index. By pairing each of the three climate scenarios with the two habitat scenarios, the analysis evaluated six total scenarios. This information was supplemented with data on prime agriculture on the coast (using the California Farmland Monitoring and Mapping data) and coastal communities (using US 2010 Census data at the census block group scale). The climate scenarios follow the State of California Sea-Level Rise Interim Guidance Document:[3] 1) Baseline (Year 2000 sea level), 2) 14 inches by 2050, and 3) 55 inches by 2100. The habitat types included in the two habitat scenarios are 1) the current distribution of high (≥ 5 m) and low (< 5 m) dunes, emergent marsh (National Wetland Inventory data), and kelp (composite layer of Department of Fish Game aerial survey data 2000-2010), and 2) none of these habitats (Figure 3). These habitats were chosen according to their ability to protect the coast from erosion and flooding.

To map and interpret the Vulnerability Index values the GMC region coastline was divided into 50 m^2 segments and classified as highest, medium high, medium low or lowest vulnerability based on the quartiles of the full distribution of Vulnerability Index values (across all coastline segments for all six scenarios) (Table 2). This process was repeated to classify the Erosion and Inundation Indices respectively based on the quartiles of the full distribution of the Erosion Index and Inundation Index values across the different scenarios (Table 2). The Erosion and Inundation Indices are not additive.

[3] Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT). 2010. State of California Sea-Level Rise Interim Guidance Document. http://www.opc.ca.gov/2011/07/sea-level-rise-task-force-interim-guidance-document/

However, they can suggest where erosion or wind-generated surge is the more important factor driving the Vulnerability Index.

Table 2: Quartile distribution of erosion, inundation, and vulnerability indices

	Erosion Index	Inundation Index	Vulnerability Index
Lowest	<1.34	<1.8	<3.06
Medium low	1.34–1.83	1.8–2.83	3.06–5.10
Medium high	1.83–2.36	2.83–4.24	5.10–9.58
Highest	>2.36	>4.24	>9.58

Although there is very limited water infrastructure spatial data for the GMC IRWM region, locations of people and agricultural land can suggest where the greatest concentration of water infrastructure is located. To assess the vulnerability of populations to coastal hazards, coastal segments with the highest Vulnerability Index values were selected. Then the ArcGIS Focal Statistics tool determined the average number of people at each of these 50 m^2 segments within a 1 km distance inland. To assess the vulnerability of prime farmland to coastal hazards, coastal segments with the highest vulnerability were selected and used to determine the number of segments within 1 km of prime farmland. In addition, available water infrastructure data were mapped for the Northern GMC region and used to determine the number of water infrastructure within 1 km of the highest vulnerability sections of the coast.

Results

Impact of Sea Level Rise on Vulnerability

The model results suggest that physical vulnerability of the GMC IRWM coastal region will increase with sea level rise (Figures 4, 5, 6 and 7), with a more than 25% increase in coastal segments that are in the highest vulnerability category with a 55-inch rise in sea level, even with habitat protection (Table 3). Associated with this increase in physical vulnerability with sea level rise is a higher percentage of people and prime agricultural land that will be highly vulnerable to erosion and flooding (Tables 4 and 5). Our analysis of the limited water infrastructure data available in the Northern GMC region suggests that with a 55-inch rise in sea level without habitat protection more than 40% of infrastructure within 1 km of the coast is within 1 km of the highest vulnerability sections of the coast (Figure 8). This analysis would benefit from the inclusion of comprehensive and specific water infrastructure data.

Table 3: Percent of highest vulnerability segments of the coast

Scenario	2000 Sea Level	14” Sea Level Rise	55” Sea Level Rise
With habitat	8%	26%	36%
Without habitat	16%	29%	40%

Table 4: Percent of coastal segments within 1 km of “Prime Agricultural” land with highest vulnerability values

Scenario	2000 Sea Level	14” Sea Level Rise	55” Sea Level Rise
With habitat	23%	33%	35%
Without habitat	32%	33%	37%

Table 5: Percent of people within 1 km of the coast that are within l km of the highest vulnerability segments (number of people within 1 km of highest vulnerability coastal segments).

Scenario	2000 Sea Level	14" Sea Level Rise	55" Sea Level Rise
With habitat	14% (10,000)	46% (32,000)	51% (36,000)
Without habitat	37% (26,000)	49% (34,000)	54% (39,000)

Key message: The Coastal Vulnerability model results suggest that sea level rise predicted through 2100 will lead to an increase in vulnerability, and a greater than 25% increase in coastal segments that are in the highest vulnerability category.

The Role of Natural Habitat in Mitigating Vulnerability

One strategy to reduce vulnerability is to protect the habitats that play a role in protecting infrastructure and people, such as wetlands and dunes. The InVEST Coastal Vulnerability model results indicate that habitats play the greatest protective role for communities and prime agriculture in the areas with the highest vulnerability—Moss Landing, Marina and Seaside (Figure 4, 5, 6, 7). These analyses suggest prioritizing areas within this region for habitat conservation and restoration. The results also suggest that wetland areas in the Elkhorn Slough and Salinas River region are particularly important for reducing vulnerability.

In the Northern GMC IRWM region, the presence of the highest vulnerability segments in the outer coastal region appears to be generally driven by erosion factors in the model. However, many of the Erosion Index values in this area increase from medium low to highest erosion ranking without the protective services the dune habitat in this region (Figure 9). These results suggest a focus on protecting and restoring dunes, which can protect inland communities from flooding.

Higher vulnerability segments in Elkhorn Slough and the Salinas River appear to be generally driven by wind-generated surge. However, the effect of wind-generated surge is increased without the protective services of wetland habitats in this region. (Figure 10). Wetlands attenuate waves and stabilize shorelines for protection against surge.[4] It is important to note that inundation due to storm surge is a complex function of wave size, wave speed, shore topography, shore geography, and slope of the ocean bottom. The Inundation Index only accounts for wind-generated surge, and does not account for wave run-up. The Inundation Index also does not account for inland flooding. However, the *Climate Change Handbook for Regional Water Planning* states that increased storm severity will lead to more severe floods,[5] suggesting that these wetland regions would be even more vulnerable to flooding than just by wind-generated surge.

Key Message: Coastal Vulnerability model results suggest that coastal habitats will play a key role in reducing the vulnerability of people and prime agricultural land to coastal erosion and flooding.

[4] Shepard CC, Crain CM, Beck MW (2011) The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. PLoS ONE 6(11): e27374. doi:10.1371/journal.pone.0027374

[5] United States Environmental Protection Agency Region 9, and California Department of Water Resources (US EPA and DWR). 2011. Climate Change Handbook for Regional Water Planning. Page 4-12

Summary and Next Steps

Many response strategies regarding coastal water infrastructure development and defense are made without the benefit of both climate change and coastal protection effects on a broad range of benefits that people expect and need from well-functioning coastal ecosystems. In order to strategically shape decisions about coastal adaptation in ways that meet coastal defense objectives while also protecting or restoring coastal habitats and the full suite of services those habitats provide to people, communities must understand the costs and benefits of different adaptation responses.

The InVEST Coastal Vulnerability model results suggest that coastal habitats will play a key role in reducing the vulnerability of people and prime agricultural land to coastal erosion and flooding. Nature-based approaches to adaptation aim to preserve and restore coastal habitats such as wetlands, dunes and kelp with an outcome that is possibly less costly and less damaging to coastal ecosystems while also more resilient and flexible—allowing for adaptive management in the context of a changing climate.

Future work should focus on a few of the most vulnerable areas and habitats to examine the effects of climate change impacts and alternative adaptation strategies (e.g., restoration and conservation, relocation or retreat, infrastructure investment) and the costs and benefits associated with these adaptation approaches. Ultimately this information can be used to inform the design and execution of IRWM projects to address climate adaptation considerations and support the sustainability of local ecosystems and the benefits provided to people.

Summary:

- Coastal Vulnerability model results suggest that sea level rise predicted through 2100 will lead to an increase in vulnerability and a more than 25% increase in coastal segments that are in the highest vulnerability category.
- Coastal Vulnerability model results suggest that coastal habitats will play a key role in reducing the vulnerability of people and prime agricultural land to coastal erosion and flooding.
- In order to fully evaluate water infrastructure vulnerability and adaptation strategies, comprehensive water infrastructure data must be collected and analyzed for vulnerability to climate change.
- Future work should evaluate the costs and benefits of alternative adaptation strategies such as restoration and conservation, relocation or retreat, or infrastructure investment.

The Role of Natural Habitat in Coastal Vulnerability and Adaptation Planning
Figures

Rank	Very Low	Low	Moderate	High	Very High
	1	2	3	4	5
Geomorphology	Rocky High Cliff, Concrete Armoring	Medium Cliff, Small Seawalls, Wood Armoring	Low Cliff, Alluvial Plain	Cobble Beach, Estuary, Lagoon, Bluff	Barrier Beach, Sand Beach, Mud Flat, Delta
Relief	>90th Percentile	>75th Percentile	Average Value	>25th Percentile	>10th Percentile
Natural Habitats	Coastal Forest	High Dune, Marsh	Low Dune	Seagrass, Kelp	No Habitat
Sea Level Change	2000 Sea Levels		14" Sea Level Rise		55" Sea Level Rise
Wind Exposure	<10th Percentile	<25th Percentile	Average Value	<75th Percentile	<90th Percentile
Wave Exposure	<10th Percentile	<25th Percentile	Average Value	<75th Percentile	<90th Percentile
Surge Potential	<10th Percentile	<25th Percentile	Average Value	<75th Percentile	<90th Percentile

Figure 1. **Data Inputs for Coastal Vulnerability Model**. Using various input datasets for each of the seven biological and physical variables (Table 1), the tool generates absolute values for each of the variables (e.g., distance to shelf, average elevation in meters, wave power) for each 50 m^2 segment of GMC IRWM region coastline. The tool then ranks each segment of coastline for each variable from very low exposure (Rank=1) to very high exposure (Rank=5) to coastal hazards. Ranks for geomorphology and habitats are absolute and depend on categorical variables. Ranks for the other five variables are relative and depend on the distribution of values for all coastline segments. The tool then estimates exposure to coastal hazards for each shoreline segment:

$$\text{Vulnerability Index} = \sqrt{\frac{R_{\text{Habitats}} R_{\text{Geomorphology}} R_{\text{Relief}} R_{\text{SLR}} R_{\text{Wind}} R_{\text{Waves}} R_{\text{Surge Potential}}}{7}}$$

where *R* is rank, and subscripts for each rank indicate one of the seven variables. The value of seven is derived from the number of variables.

In those segments of shoreline where man-made armoring structures (e.g., sea walls, rock walls, revetments) were identified as geomorphic features we used a two-step process to account for the structures. First, structures were categorized as either concrete or wood. Second, those segments of the shoreline backed by concrete coastal structures were assigned a rank of 1 and those segments of the shoreline backed by wood armoring structures were assigned a rank of 2.

For more specific information about the model please see: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/#marine-models.

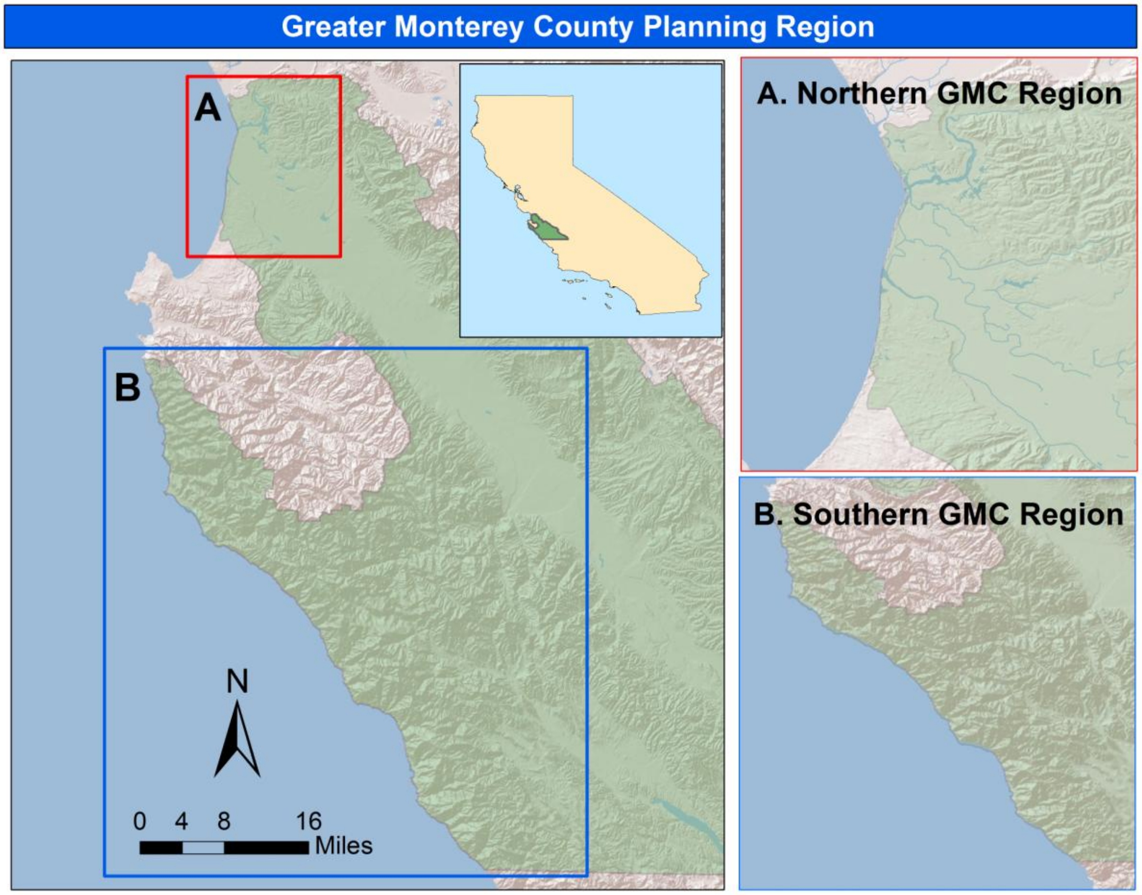
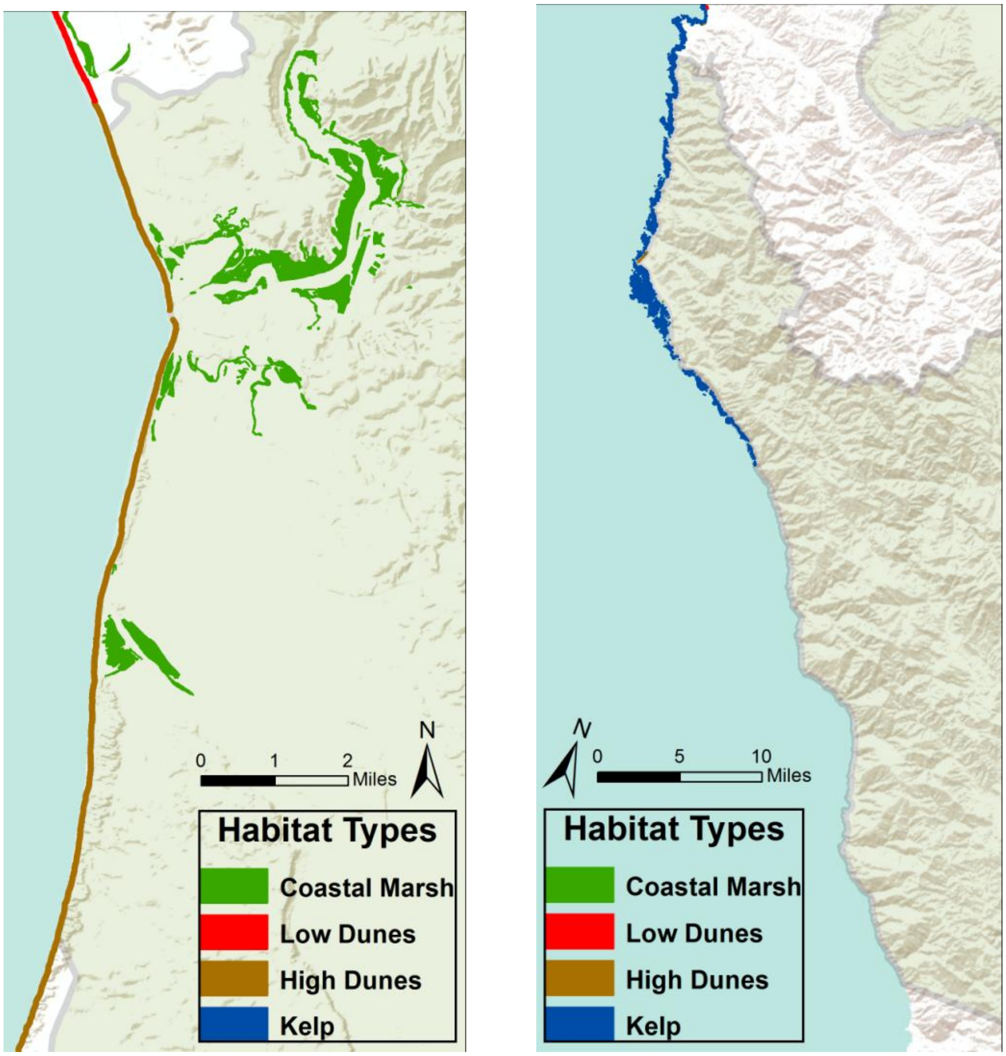
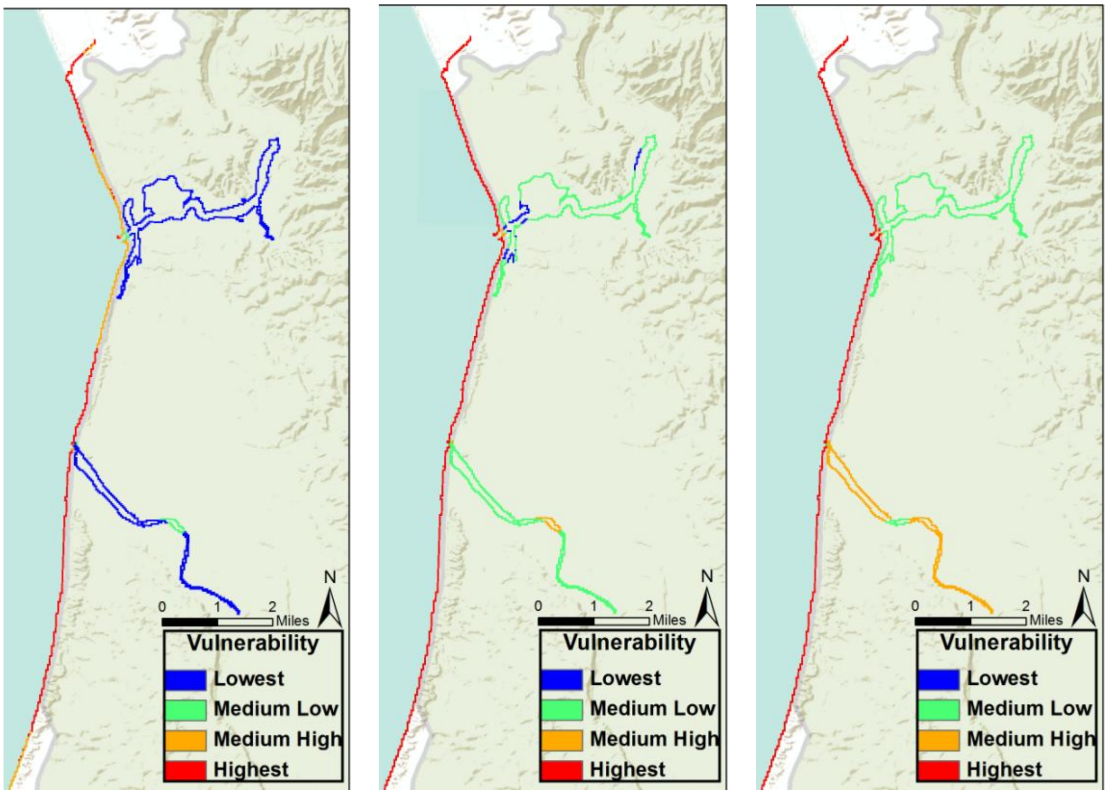


Figure 2. Greater Monterey County IRWM Planning Region. The Greater Monterey County Integrated Regional Water Management (IRWM) region includes the entirety of Monterey County exclusive of the Pajaro River Watershed IRWM region and the Monterey Peninsula, Carmel Bay, and South Monterey Bay IRWM region established under Proposition 50. Inset Map A outlined in red is the Northern GMC region. Inset Map B outlined in blue is the Southern GMC region.



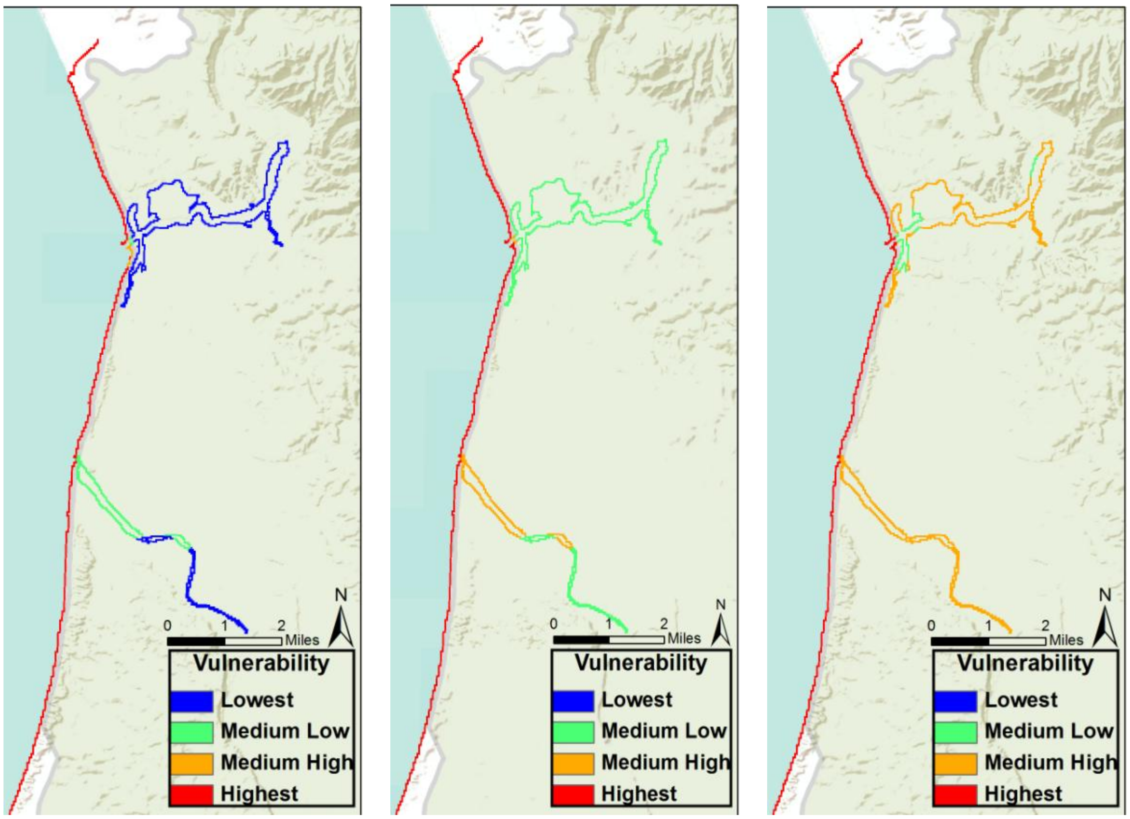
A. Northern GMC Region **B. Southern GMC Region**

Figure 3. Habitat layers used in analysis. Habitat GIS layers used in the analysis in the northern and southern Greater Monterey County Integrated Regional Water Management planning regions. See Table 1 and text for more information on data layers.



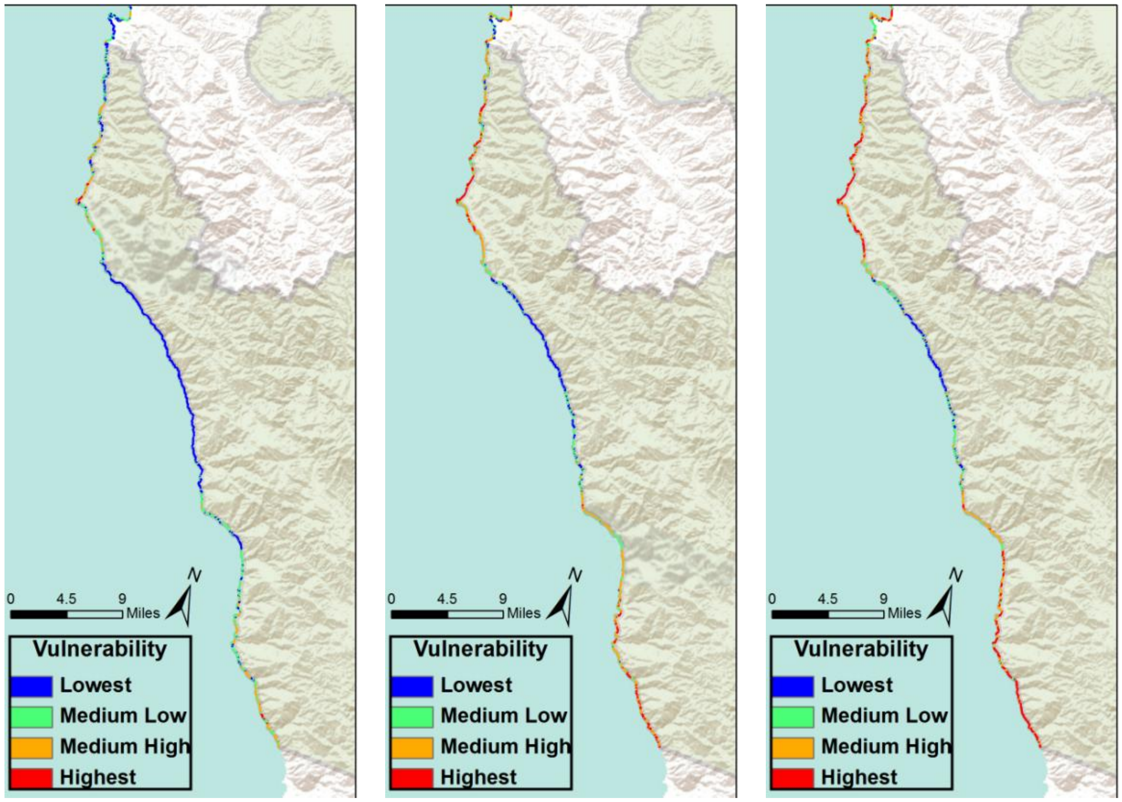
A. Year 2000 Sea Level **B. 14-inch Sea Level Rise** **C. 55-inch Sea Level Rise**

Figure 4. Impact of sea-level rise on vulnerability with habitat protection. Distribution of Vulnerability Index ranks at three different sea level rise scenarios with habitat protection in the northern section of the Greater Monterey County Integrated Regional Water Management planning region. Segments are 50 m^2. See Table 2 for quartile distributions for the Vulnerability Index.



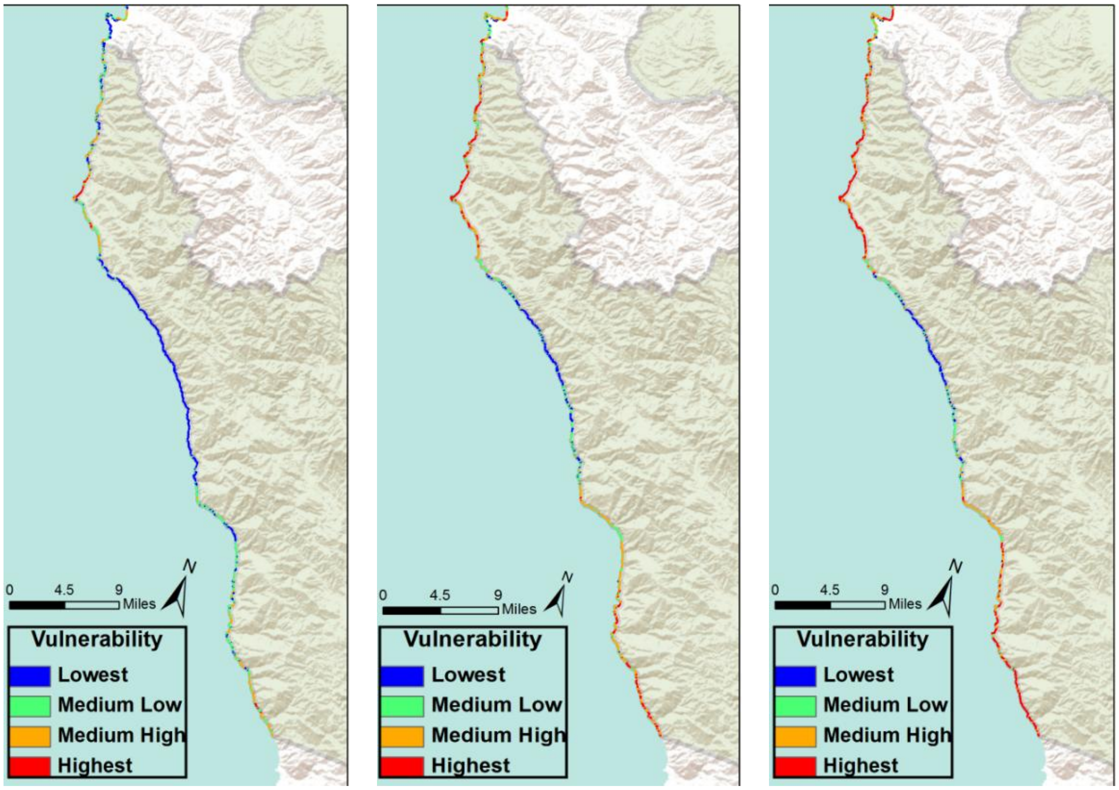
A. Year 2000 Sea Level **B. 14-inch Sea Level Rise** **C. 55-inch Sea Level Rise**

Figure 5. Impact of sea level rise on vulnerability with habitat loss. Distribution of Vulnerability Index ranks at three different sea level rise scenarios with habitat loss in the northern section of the Greater Monterey County Integrated Regional Water Management planning region. Segments are 50 m^2. See Table 2 for quartile distributions for the Vulnerability Index.



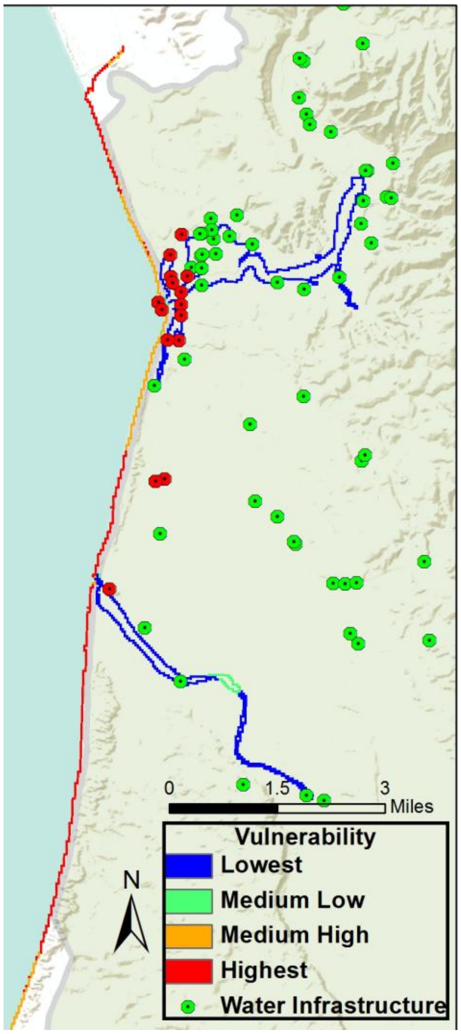
A. Year 2000 Sea Level **B. 14-inch Sea Level Rise** **C. 55-inch Sea Level Rise**

Figure 6. Impact of sea level rise on vulnerability with habitat protection. Distribution of Vulnerability Index ranks at three different sea level rise scenarios with habitat protection in the southern section of the Greater Monterey County Integrated Regional Water Management planning region. Segments are 50 m^2. See Table 2 for quartile distributions for the Vulnerability Index.

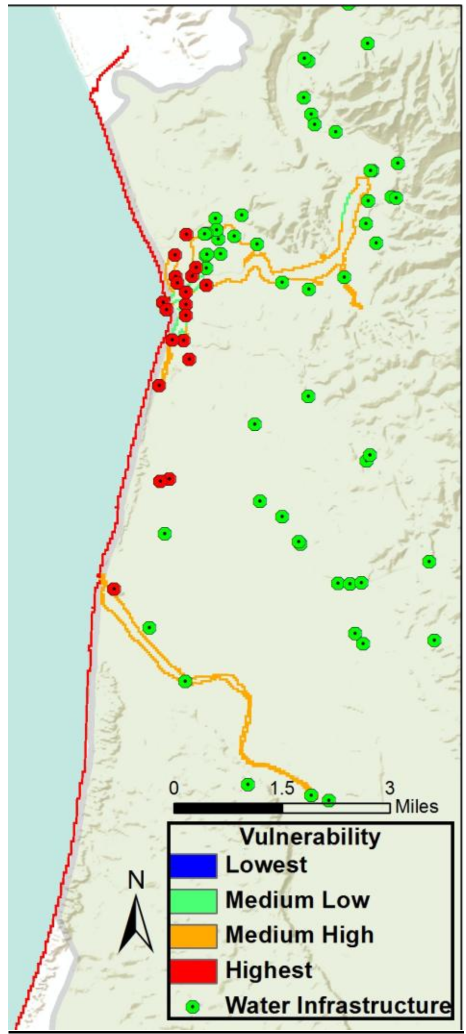


A. Year 2000 Sea Level **B. 14-inch Sea Level Rise** **C. 55-inch Sea Level Rise**

Figure 7. Impact of sea level rise on vulnerability with habitat loss. Distribution of Vulnerability Index ranks at three different sea level rise scenarios with habitat loss in the southern section of the Greater Monterey County Integrated Regional Water Management planning region. Segments are 50 m^2. See Table 2 for quartile distributions for the Vulnerability Index.

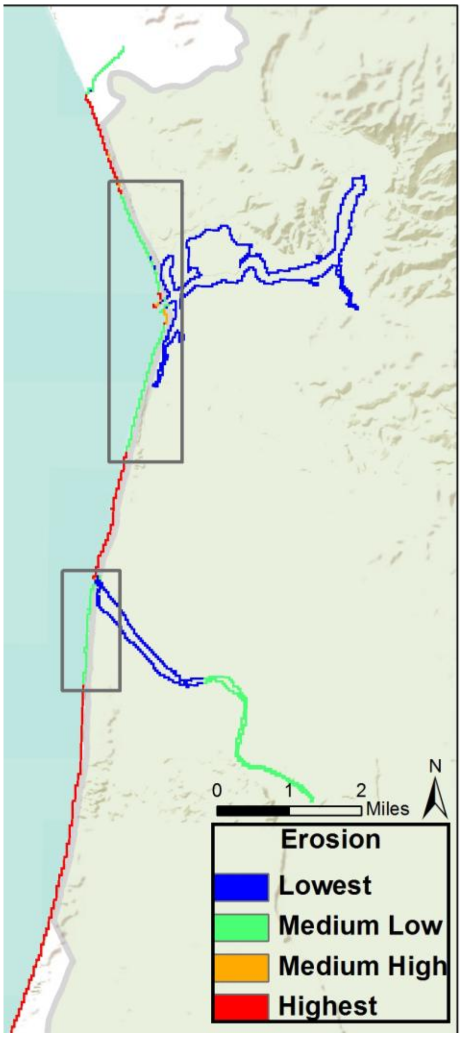


A) Year 2000 Sea Level with Habitat Protection

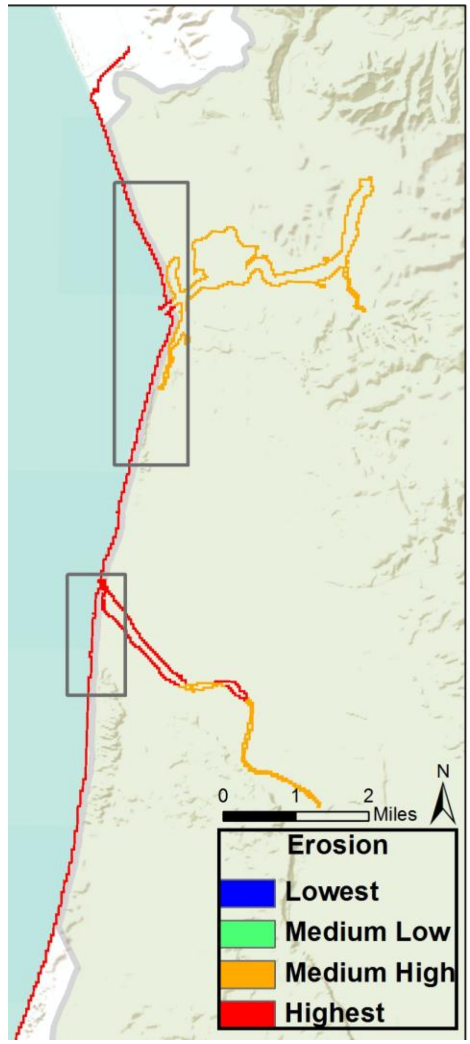


B) 55-inch Sea Level Rise with Habitat Loss

Figure 8. Vulnerability and water infrastructure. Distribution of a sample of water infrastructure (e.g., culverts, pipes, bridges) in the Northern GMC Region. The two images represent two different scenarios: A) Year 2000 sea level with habitat protection and B) 55-inch sea level rise with habitat loss. The red infrastructure is within 1 km of the highest Vulnerability Index value segments of the coastline. In (B) more than 40% of infrastructure within 1 km of the coast is within 1 km of the highest vulnerability sections of the coast. Segments are 50 m^2. See Table 2 for quartile distributions for the Vulnerability Index.

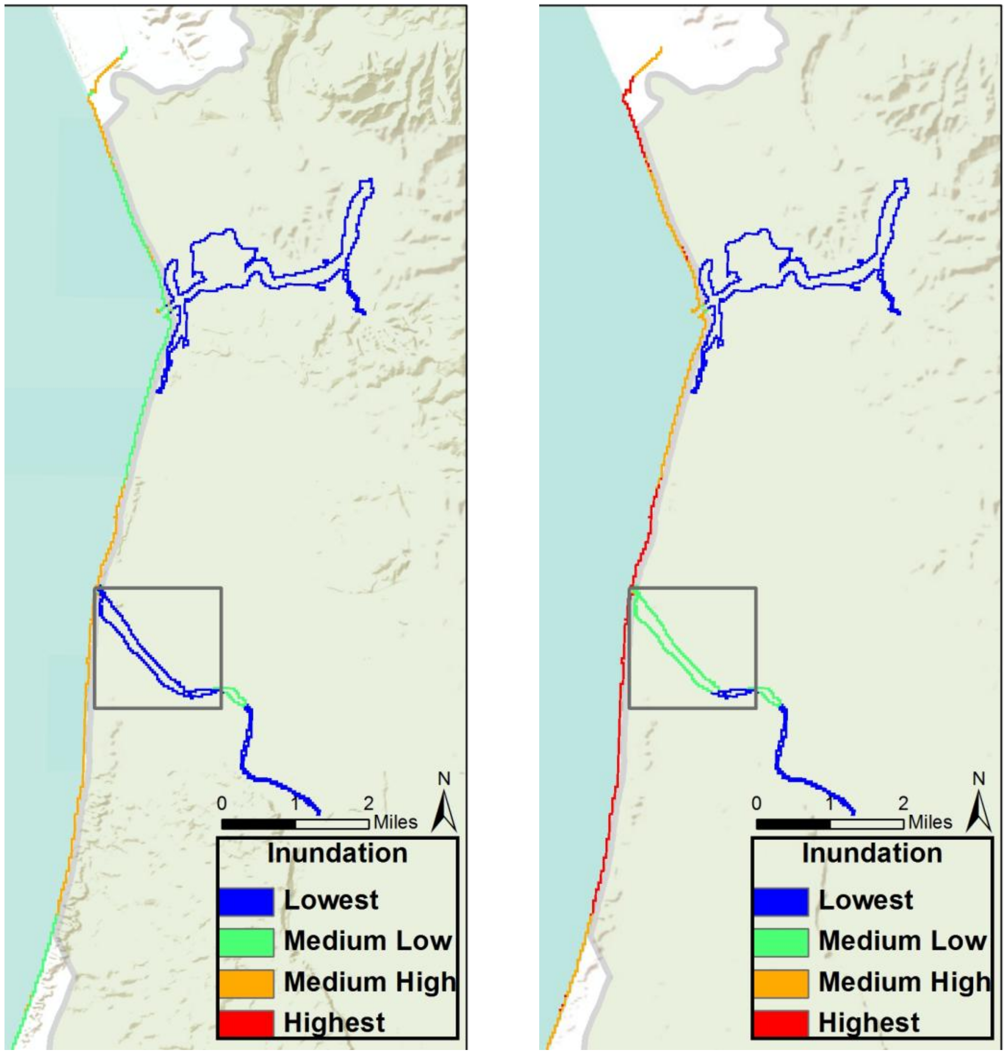


A. Erosion with Habitat Protection at Year 2000 Sea Level



B. Erosion without Habitat Loss at Year 2000 Sea Level

Figure 9. Effects of habitat on Erosion Index. Distribution of Erosion Index ranks along the northern GMC region at year 2000 sea levels in two scenarios: A) with habitat protection and B) with habitat loss. Note that the Erosion Index values of the boxed regions increase from medium low to highest erosion ranking without the protective services of habitat. See Table 2 for quartile distributions for all indices. Segments are 50 m^2.



A. Erosion with Habitat Protection at Year 2000 Sea Level

B. Erosion with Habitat Loss at Year 2000 Sea Level

Figure 10. Effect of habitat on Inundation Index. Distribution of Inundation Index ranks along the northern GMC region at year 2000 sea levels in two scenarios: A) with habitat protection and B) with habitat loss. Note that the Inundation Index values of the boxed region are increased without protective services from habitat. See Table 2 for quartile distributions for all indices. Segments are 50 m^2.