CLIMATE CHANGE VULNERABILITY ASSESSMENT

Torrey Pines State Natural Reserve

Evaluating the vulnerability of the Torrey Pine, the Western Snowy Plover, and the coastal bluff ecosystem

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ABSTRACT

Climate change is expected to significantly alter coastal ecosystems through rising temperatures, altered precipitation patterns, increased wildfire risk, and accelerating sea level rise. Coastal Southern California is particularly vulnerable to these changes. This climate change vulnerability assessment evaluates the vulnerability of three conservation targets within Torrey Pines State Natural Reserve in San Diego County, California: the Torrey Pine (*Pinus torreyana*), the Western Snowy Plover (*Charadrius nivosus nivosus*), and the coastal bluff ecosystem.

Using a desk-based assessment informed by existing scientific literature and regional climate projections, this study evaluates the sensitivity, exposure, and adaptive capacity of each target. Results suggest that the Torrey Pine and coastal bluff ecosystem exhibit high vulnerability due to their restricted distributions, drought sensitivity, and erosion risk. The Western Snowy Plover shows moderate-to-high vulnerability because of habitat loss associated with sea level rise and coastal disturbance. These findings highlight the importance of proactive climate adaptation planning and habitat protection to support long-term ecosystem resilience within the reserve.

TORREY PINE	WESTERN SNOWY PLOVER	COASTAL BLUFF ECOSYSTEM
High	Moderate–High	High
Restricted range, drought and pest sensitivity	Sea level rise, nest flooding, disturbance	Erosion, drought stress, limited retreat

Introduction

Climate change is widely recognized as one of the defining environmental challenges of the twenty-first century. Rising global temperatures, altered precipitation patterns, increasing wildfire activity, and accelerating sea level rise are already affecting ecosystems worldwide (IPCC, 2021). Coastal ecosystems are particularly vulnerable because they experience both terrestrial and marine climate stressors simultaneously, including warming temperatures, intensified storms, ocean acidification, and shoreline erosion (USGCRP, 2018).

California's coastline is especially sensitive to these impacts due to high population density, limited coastal habitat, and projected sea level rise along the Pacific coast (California Ocean Protection Council, 2018). Although climate risks to coastal ecosystems are increasingly recognized, relatively few localized climate change vulnerability assessments (CCVAs) have been conducted for individual protected areas in California.

Torrey Pines State Natural Reserve in San Diego County contains one of the rarest pine species in North America and a unique coastal landscape including coastal sage scrub, sandy beaches, and eroding coastal bluffs (California State Parks, 2023). These ecosystems may be particularly sensitive to climatic change, yet their vulnerability has not been comprehensively assessed using a formal CCVA framework.

This study addresses that gap by evaluating the climate vulnerability of three ecological targets within Torrey Pines State Natural Reserve—Torrey Pine (*Pinus torreyana*), the Western Snowy Plover (*Charadrius nivosus nivosus*), and the coastal bluff ecosystem—through analysis of their sensitivity, exposure, and adaptive capacity using existing scientific literature and regional climate projections.

Figure 1. Torrey Pines State Natural Reserve, San Diego County, California.

Sensitivity of Targets

Sensitivity refers to the degree to which a species or ecosystem is affected by climatic changes due to biological traits, ecological characteristics, or environmental dependencies (Foden & Young, 2016).

Torrey Pine *(Pinus torreyana)*

The Torrey Pine is highly sensitive to climate change due to its extremely restricted distribution and specialized habitat requirements. The species occurs naturally in only two locations worldwide: Torrey Pines State Natural Reserve and Santa Rosa Island in Channel Islands National Park (Ledig & Conkle, 1983). Increasing temperatures and reduced soil moisture in Southern California may weaken trees, reduce seedling survival, and limit regeneration (IPCC, 2021; Williams et al., 2020).

Figure 2. The Torrey Pine occurs naturally in only two locations worldwide.

Torrey Pines depend on a maritime-influenced climate where coastal fog provides supplemental moisture, and changes in fog patterns could reduce water availability and stress populations (Williams et al., 2008). The species' narrow ecological niche and relatively small population size increase vulnerability to disturbances such as drought, wildfire, and pest outbreaks (Pacifici et al., 2015).

Warmer temperatures may also increase susceptibility to bark beetle infestations (Bentz et al., 2010), while invasive plant species can compete with native vegetation and alter fire regimes (Keeley & Syphard, 2016). Overall, the Torrey Pine exhibits high sensitivity to climate change due to its limited range and ecological specialization.

Western Snowy Plover *(Charadrius nivosus nivosus)*

The Western Snowy Plover demonstrates moderate to high sensitivity to climate change because it depends on specialized coastal habitats for nesting and feeding. The species feeds on small invertebrates along sandy beaches and intertidal zones, and climate-driven changes to coastal food webs may affect prey availability (Galbraith et al., 2002).

Figure 3. Snowy Plovers nest on open sand above the high tide line.

Snowy Plovers require open sandy beaches above the high tide line for nesting, habitats increasingly threatened by coastal development and environmental change (U.S. Fish and Wildlife Service, 2007). Storm surges and flooding events may inundate nests and reduce reproductive success. Although the species occurs along much of the Pacific coast, suitable nesting habitat is limited and the Pacific Coast population remains relatively small.

Invasive vegetation such as ice plant can also alter beach habitats by increasing vegetation cover and making nesting areas unsuitable.

Coastal Bluff Ecosystem

The coastal bluff ecosystem at Torrey Pines includes sandstone cliffs and coastal sage scrub vegetation that support diverse plant and wildlife communities. These ecosystems depend on seasonal rainfall and are vulnerable to drought and heat stress, which may reduce plant productivity and alter vegetation composition (Keeley & Syphard, 2016).

Figure 4. Sandstone bluffs and coastal sage scrub within the reserve.

Coastal bluffs are naturally limited to narrow strips of coastline, and urban development restricts their ability to migrate inland. Increased erosion, landslides, and vegetation stress may destabilize bluff habitats. Many coastal sage scrub species have narrow ecological tolerances related to temperature and moisture conditions, making them sensitive to environmental change. Invasive plant species and altered fire regimes may further threaten native vegetation.

Exposure of Targets

Exposure refers to the extent to which species or ecosystems experience climatic changes in their environment (Foden & Young, 2016). Southern California has already experienced substantial warming, and projections indicate that temperatures may increase by approximately 2–4°C by the end of the century depending on greenhouse gas emissions scenarios (IPCC, 2021). Higher temperatures increase evapotranspiration and reduce soil moisture, intensifying drought conditions across Mediterranean-climate ecosystems (Williams et al., 2020). These conditions may weaken Torrey Pine populations and alter vegetation communities within the coastal bluff ecosystem.

Climate models also project greater variability in precipitation patterns, including fewer but more intense rainfall events (IPCC, 2021). Reduced precipitation combined with rising temperatures may increase drought stress, while intense storms may destabilize coastal cliffs and accelerate erosion. Climate change is also expected to increase wildfire frequency and intensity across California due to hotter temperatures and longer fire seasons (Abatzoglou & Williams, 2016).

Coastal ecosystems within the reserve face additional exposure to sea level rise. Projections estimate that sea levels along the California coast could rise between approximately 0.5 and 1.5 meters by 2100 (California Ocean Protection Council, 2018). Rising seas increase coastal erosion and may reduce sandy beach habitat used by Western Snowy Plovers for nesting. As sea levels rise, beaches may become compressed between the ocean and fixed coastal infrastructure, a process known as coastal squeeze (California Coastal Commission, 2015). Coastal bluffs are particularly exposed because rising seas and stronger storms can accelerate cliff retreat (Hapke & Reid, 2007).

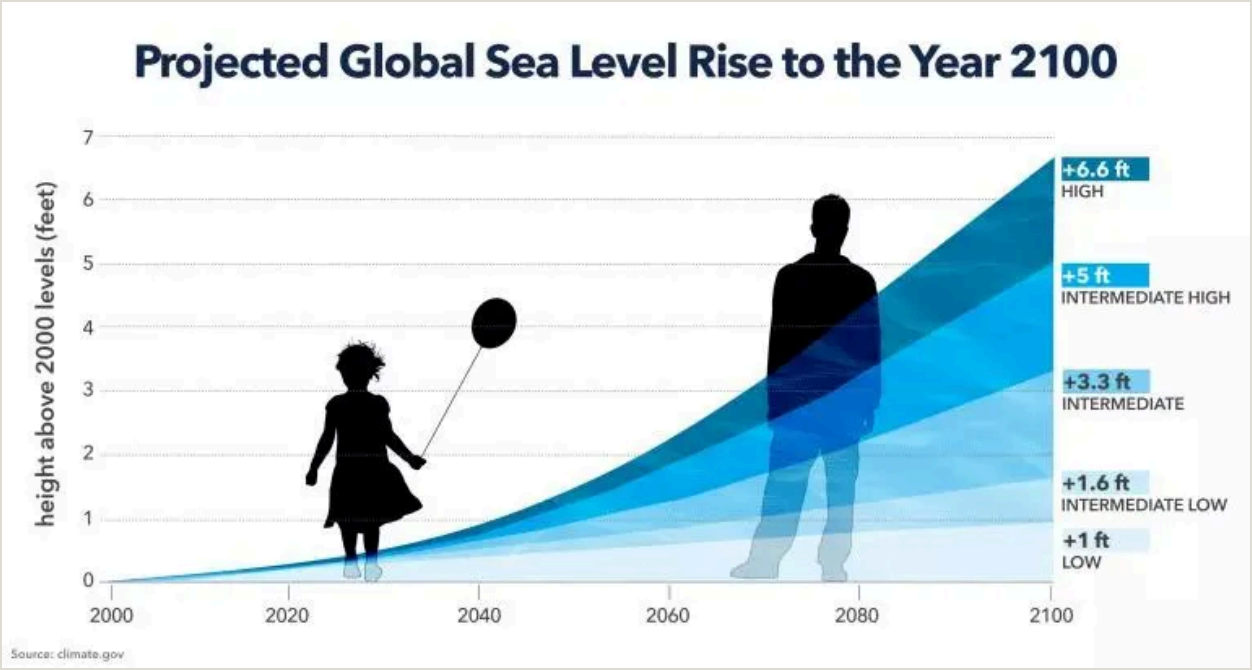

Figure 5. Projected global sea level rise to the year 2100 across emissions scenarios.

Adaptive Capacity of Targets

Adaptive capacity refers to the ability of species or ecosystems to adjust to climatic changes in ways that reduce potential impacts (Foden & Young, 2016).

Torrey Pine

The Torrey Pine exhibits moderate adaptive capacity. Genetic variation exists within the species, which may allow some individuals to tolerate changing environmental conditions (Ledig & Conkle, 1983). However, seed dispersal distances are limited, restricting the species' ability to migrate to new habitats as climate conditions shift. Conservation programs such as reforestation and seed banking may help maintain genetic diversity and support population resilience.

Western Snowy Plover

The Western Snowy Plover demonstrates moderate adaptive capacity due to its mobility and existing conservation programs. Unlike plants, birds can relocate nesting sites along different sections of coastline if suitable habitat remains available. Active conservation

efforts, including monitoring and habitat protection, have supported population recovery in some regions (U.S. Fish and Wildlife Service, 2007).

Coastal Bluff Ecosystem

The coastal bluff ecosystem has relatively low adaptive capacity. Unlike mobile species, ecosystems cannot easily relocate in response to climate change. Coastal development further limits inland migration of bluff habitats. As sea levels rise and erosion increases, these ecosystems may experience long-term habitat loss.

Other Stressors

In addition to climate-driven impacts, several non-climatic stressors may influence the vulnerability of the conservation targets evaluated in this assessment, including poaching, human–wildlife interaction, pollution, and interspecific interactions. Poaching is not considered a significant stressor for the Torrey Pine, Western Snowy Plover, or the coastal bluff ecosystem because Torrey Pines State Natural Reserve is protected and actively managed by California State Parks. However, human disturbance may affect Western Snowy Plover nesting sites, as beach recreation can disrupt breeding behavior (U.S. Fish and Wildlife Service, 2007). Pollution from urban runoff may also affect coastal habitats and alter invertebrate communities that serve as prey for shorebirds (National Research Council, 2009). In addition, climate change may intensify interspecific interactions by increasing competition for limited resources and facilitating the spread of invasive plant species within coastal sage scrub habitats (Keeley & Syphard, 2016).

Overall Vulnerability

Climate change vulnerability is determined by the interaction of sensitivity, exposure, and adaptive capacity (Foden & Young, 2016). Species or ecosystems that are highly sensitive and highly exposed to climate stressors but possess limited adaptive capacity are considered the most vulnerable.

CONSERVATION TARGET	SENSITIVITY	EXPOSURE	ADAPTIVE CAPACITY	OVERALL	KEY DRIVERS
Torrey Pine	High	High	Moderate	**High**	Restricted distribution, drought stress, wildfire, bark beetle outbreaks
Western Snowy Plover	Moderate–High	High	Moderate	**Moderate–High**	Sea level rise, habitat loss, nest flooding, human disturbance
Coastal Bluff Ecosystem	High	High	Low	**High**	Coastal erosion, sea level rise, drought stress, limited inland migration

Table 1. Overall vulnerability of conservation targets at Torrey Pines State Natural Reserve.

The Torrey Pine exhibits high overall vulnerability due to its restricted distribution and sensitivity to drought, wildfire, and pests. Climate projections indicate increasing drought frequency and wildfire risk in Southern California (IPCC, 2021; Williams et al., 2020), which could significantly affect the long-term viability of Torrey Pine populations.

The Western Snowy Plover demonstrates moderate to high vulnerability due to exposure to sea level rise and coastal habitat loss. Although the species can relocate nesting sites along the coast, the availability of suitable habitat may decline as sea levels rise and human disturbance increases.

The coastal bluff ecosystem is assessed as having high vulnerability because it is exposed to both terrestrial and marine climate stressors and has limited capacity to adapt. Rising sea levels and increased wave energy may accelerate coastal erosion and lead to long-term habitat loss (Hapke & Reid, 2007).

Overall, the Torrey Pine and coastal bluff ecosystem appear to be the most vulnerable targets within Torrey Pines State Natural Reserve. The Western Snowy Plover also faces substantial risks due to habitat loss from sea level rise and disturbance. These findings highlight the importance of integrating climate considerations into conservation planning to maintain ecosystem resilience within the reserve.

Level of Confidence

The level of confidence in this assessment is moderate due to uncertainties associated with climate projections and ecological responses. While scientific research consistently indicates that Southern California will experience rising temperatures, increased drought frequency, greater wildfire risk, and sea level rise during the twenty-first century (IPCC, 2021; USGCRP, 2018), the exact magnitude and timing of these changes remain uncertain. Additional uncertainty arises from the ecological responses of species and ecosystems to climate stressors, which may involve complex interactions among drought, wildfire, invasive species, and human disturbance (Foden & Young, 2016). Because this study relies on existing literature and regional climate projections rather than field data, it should be interpreted as a preliminary vulnerability assessment.

Conclusion

This climate change vulnerability assessment evaluated the sensitivity, exposure, and adaptive capacity of three conservation targets within Torrey Pines State Natural Reserve: the Torrey Pine, the Western Snowy Plover, and the coastal bluff ecosystem. The analysis indicates that the Torrey Pine and coastal bluff ecosystem exhibit relatively high vulnerability due to restricted distributions, drought stress, and erosion risk. The Western Snowy Plover faces moderate to high vulnerability due to exposure to sea level rise and coastal habitat loss. These findings suggest that climate change may significantly affect both terrestrial and coastal ecosystems within the reserve over the coming decades.

The results of this assessment highlight the importance of climate-informed management strategies that reduce sensitivity, limit exposure to environmental change, and enhance adaptive capacity. While specific management actions are beyond the scope of this study, protecting critical habitats, maintaining ecological connectivity, and incorporating climate considerations into conservation planning may help support long-term ecosystem resilience. As climate impacts intensify along California's coast, localized vulnerability assessments can provide valuable guidance for protected area management and adaptation planning.

Figure 6. The reserve's beach and bluff interface, where terrestrial and marine climate stressors meet.

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