Tidal Marshes

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for tidal marshes in the Golden Gate Biosphere (GGB) region of California. The following information is based on stakeholder input provided during and following a winter 2022 vulnerability workshop as well as sources from the scientific literature.

Ecosystem Description

Tidal marshes are prevalent within the Golden Gate Biosphere (GGB) region, where they are situated along the shores of the San Francisco Bay and its estuaries. These marshes are formed at the interface of saltwater and brackish water ecosystems and are heavily influenced by tidal fluctuations (Parker et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). They are often associated with lagoons, creeks, and streams, and are characterized by flat, low-lying terrain (Kennish 2001; Parker et al. 2011; Krause et al. 2020; Vuln. Assessment Worksheets, pers. comm., 2022). Vegetation structure within tidal marshes exhibits a discernible zonal pattern, which is determined by exposure to varying water levels and fluctuations in salinity (Parker et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). Dominant plant species include California cordgrass (*Spartina foliosa)* and pickleweed (*Salicornia pacifica*), which is usually found at higher elevations within the marsh (Callaway et al. 2011; Palaima 2012). Tidal marshes play a crucial role in supporting many species, including migratory and resident birds such as song sparrow (*Melospiza melodia*), San Francisco common yellowthroat (*Geothlypis trichas sinuosa*), marsh wren (*Cistothorus palustris*), black rail (*Laterallus jamaicensis*), and Ridgway's rail (*Rallus obsoletus*; Spautz et al. 2006; Casazza et al. 2016; Nur et al. 2018). They also provide habitat for fish, invertebrates, and small mammals (Spautz et al. 2006; Takekawa et al. 2011; Smith et al. 2014; Feyrer et al. 2021), aid in mitigating coastal flooding and erosion, and help improve water quality (Kennish 2001; Krause et al. 2020).

Fine-scale vegetation maps for San Mateo, Marin, and Sonoma Counties were used to identify 11 vegetation classes that generally represent tidal marshes within the GGB region (Tukman Geospatial et al. 2018), which occupy a combined total of 18,416 acres (Figure 1, Table 1). Of that, 65% (12,015 acres) is protected, with the largest area of protected lands managed by the California Department of Fish and Wildlife (4,032 acres; Table 2).

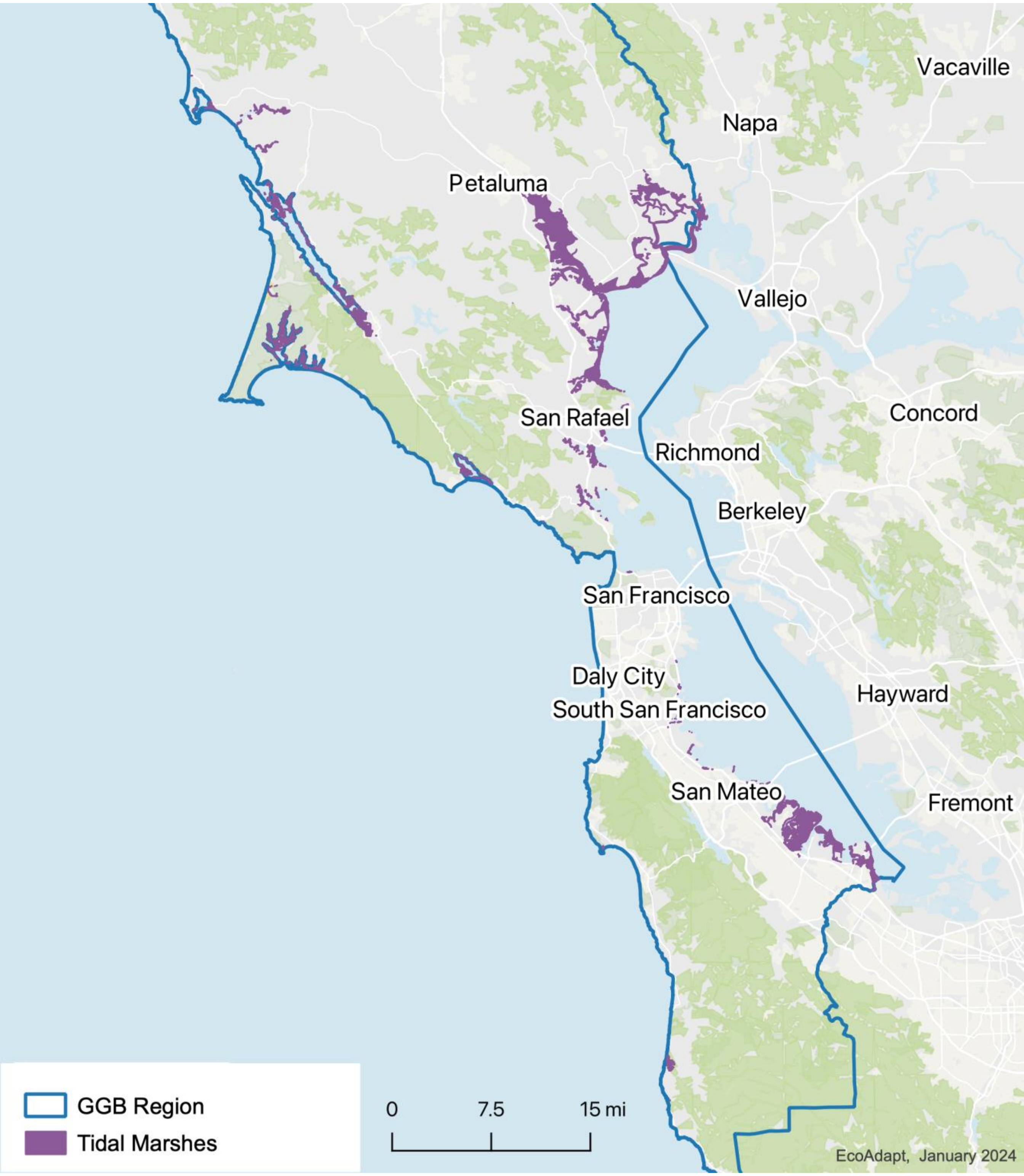

Figure 1. Distribution of vegetation map classes that likely represent tidal marshes within the GGB region, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Table 1. Vegetation map classes likely to represent tidal marshes within the GGB region, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Vegetation Map Class
Atriplex prostrata – Cotula coronopifolia Semi-Natural Alliance
Bolboschoenus maritimus Alliance
Distichlis spicata Alliance
Grindelia stricta Provisional Association
Lepidium latifolium – (*Lactuca serriola*) Semi-Natural Alliance
North American Pacific Coastal Salt Marsh Macrogroup
Sarcocornia pacifica (*Salicornia depressa*) Alliance
Spartina foliosa Association
Tidal Panne
Triglochin maritima Association
Zostera (*marina*, *pacifica*) Pacific Aquatic Alliance

Table 2. Total protected acres in the GGB region by land management agency, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Land Management Agency	**Protected Acres**
California Department of Fish and Wildlife	4,032
United States Fish and Wildlife Service	2,441
Other protected lands	2,281
California State Lands Commission	1,551
Marin County Parks	499
National Park Service – Point Reyes National Seashore	473
California Department of Parks and Recreation	298
Midpeninsula Regional Open Space District	121
Peninsula Open Space Trust	112
Audubon Canyon Ranch	84
San Francisco – Public Utilities Commission	52
Sonoma County Regional Parks Department	43
United States Army Corps of Engineers	11
National Park Service – Golden Gate National Recreation Area	9
San Mateo County Parks and Recreation Dept.	7
Sonoma Land Trust	1
TOTAL	**12,015**

Ecosystem Vulnerability → High *(high confidence)*

Vulnerability is evaluated by considering the ecosystem's sensitivity and exposure to various climate and non-climate stressors as well as the ecosystem's adaptive capacity (i.e., ability to cope with these stressors), and is given a ranking of low, moderate, or high. The confidence ranking represents confidence in the accuracy of the ranking based on available scientific knowledge, and is similarly ranked on a scale from low to high.

Summary of ecosystem vulnerability

Tidal marshes within the San Francisco Bay Area represent unique and ecologically-valuable ecosystems vulnerable to the multifaceted impacts of climate change. One of the most significant challenges tidal marshes face is sea-level rise, which threatens to inundate and erode these ecosystems and affects hydrology, species composition, and ecological functioning. This is of particular concern where infrastructure and land-use change block the way for inland marsh migration, which results in the gradual narrowing and eventual loss of tidal marshes (a process known as coastal squeeze). Elevated water temperatures and precipitation-driven changes in salinity may also affect the growth and distribution of key plant species that are vital for marsh stabilization. Additionally, extreme weather events such as storms, flooding, and prolonged droughts could expose tidal marshes to more significant erosion and physical disturbance potentially resulting in plant mortality and hydrological changes. Tidal marshes within the GGB region are heavily impacted by non-climate stressors that compound the effects of climate change, including rapid urbanization, pollution, roads, invasive species, and water diversions. These stressors have resulted in tidal marsh loss and fragmentation, reduced water quality, and degradation of marsh hydrology and native plant communities, among other impacts.

Although a significant proportion of tidal marshes within the GGB region have been lost or degraded due to development and hydrological changes associated with human activities, there is some potential for inland marsh migration in areas without obstructions. Tidal marshes also support high structural diversity, promoting ecosystem health and stability through varied ecological interactions, vital resources, and shelter for numerous species, which may support their adaptive capacity. Management actions that maintain and enhance plant diversity in tidal marshes are important for strengthening ecosystem resilience, maintaining crucial ecological functions, and limiting invasive species establishment. Additionally, managers should consider employing strategies that support marsh migration in response to sea level rise.

Sensitivity and Exposure → High *(moderate confidence)*

Sensitivity *is a measure of whether and how an ecosystem is likely to be affected by a given change in climate factors, climate-driven changes in disturbance regimes, and non-climate stressors. By contrast,* ***exposure*** *is a* *measure of how much change in these factors an ecosystem is likely to experience. Sensitivity and exposure are combined here into one score representing both components of vulnerability, with high scores corresponding to increased vulnerability and low scores suggesting an ecosystem is less vulnerable.*

Sensitivity and future exposure to climate factors → High *(moderate confidence)*

- **Sea level rise** impacts tidal marshes by influencing salinity levels, sediment deposition, flooding regimes, and species composition (Callaway et al. 2007). As sea levels rise, tidal marshes become inundated with salt water more frequently and for longer durations, potentially leading to increased erosion and shifts in the boundary between upper and lower marsh vegetation. Over time, this is likely to result in conversion of low marsh to open water and mud flats, reducing marsh size (Callaway et al. 2007; Craft et al. 2009; Stralberg et al. 2011; Schile et al. 2014; Buffington et al. 2021). However, some tidal marshes, if unobstructed by development or other human activities, may be able to migrate landward as sea levels rise (Craft et al. 2009; Osland et al. 2022). Sea level rise will also alter soil salinity, driving shifts in plant composition towards more salt-tolerant species that may impact marsh-dependent wildlife such as birds (Callaway et al. 2007; Stralberg et al. 2011). Saltwater intrusion can impede the decomposition of marsh substrates, which has the potential to modify the rate of carbon sequestration (Parker et al. 2011; Palaima 2012; Mo et al. 2019). This may result in changes in nutrient cycling and the accessibility of organic matter for marsh plants, ultimately impacting ecosystem productivity (Parker et al. 2011; Mo et al. 2019) and species abundance and distribution (Callaway et al. 2007; Parker et al. 2011).
- **Changes in precipitation patterns** can have complex and far-reaching impacts on tidal marsh ecosystems. An influx of freshwater due to increased precipitation can reduce salinity, potentially altering species composition (Spautz et al. 2006; Fagherazzi et al. 2012). Increases in precipitation can also increase runoff that may be high in nutrient concentrations from upland areas, and elevate sediment loads in water bodies (Craft et al. 2009; Palaima 2012). By contrast, decreased precipitation may reduce sediment input, slowing marsh accretion rates (Craft et al. 2009; Palaima 2012). These alterations have the potential to affect primary production, microbial communities, invertebrate activity, and the marsh's food web, potentially also affecting carbon and nutrient pools within the ecosystem (Li et al. 2020; Gilby et al. 2021).
- **Drought** is associated with decreased freshwater inputs within tidal marshes, impacting the growth and survival of marsh plants (Parker et al. 2011; Palaima 2012). Drought also leads to shifts in salinity levels within tidal systems, impacting the composition and distribution of marsh vegetation by favoring salt-tolerant species (Parker et al. 2011). Generally, native tidal marsh plants are better adapted to withstand dry conditions than non-native species, giving them a competitive advantage during drought events (Palaima 2012; Casazza et al. 2016; Wigginton et al. 2020). For example, studies documented the dieback of the invasive non-native perennial

pepperweed (*Lepidium latifolium)* in tidal marshes during an extreme, multi-year drought from 2012 to 2015 in California (Casazza et al. 2016; Wigginton et al. 2020).

- **Rising water temperatures** can disrupt the balance of tidal marsh ecosystems by driving shifts in plant distribution and composition, which alter habitat availability and food resources for marsh-dependent species (Cherry & Battaglia 2019; Colombano et al. 2021). Increased water temperatures can also accelerate organic matter decomposition in marsh soils, which releases more carbon dioxide into the atmosphere (Kirwan et al. 2014). This decay rate, however, can increase soil elevation in tidal marshes and may help to mitigate loss or degradation due to sea level rise and coastal squeeze (Kirwan et al. 2014).
- **Altered streamflow** can lead to shifts in sediment loads, water quality, and species composition within tidal marsh ecosystems (Roman et al. 2002; Smith et al. 2014; Stern et al. 2020). Increased precipitation and more frequent/intense storms are expected to increase sediment loads, resulting in the transportation of harmful pollutants and reducing the amount of light that enters the water, which poses a threat to the survival of benthic organisms (Stern et al. 2020). However, increased sediment loads could also help maintain marsh elevation and reduce the effects of erosion associated with storm surge and sea level rise (Stern et al. 2020; Thorne et al. 2022). Changes in freshwater streamflow can impact marsh salinity levels, with increased flow leading to reduced salinity and low flows increasing it, both of which can have an impact on the survival of species intolerant to these changes (Parker et al. 2011; Stern et al. 2020).

Sensitivity and future exposure to climate-driven changes in disturbances → High *(high confidence)*

- **Storms and related impacts (e.g., wind, flooding)** can cause erosion, altered hydrology and sediment deposition, saltwater intrusion, and disruption of ecosystem processes within tidal marshes (Cherry & Battaglia 2019; Houttuijn Bloemendaal et al. 2021). Although marshes act as natural buffers against storm surges by absorbing and dissipating wave energy (Palaima 2012), more intense and/or frequent storms as a result of climate change might result in significant increases in erosion, particularly along marsh edges, potentially making marshes even more vulnerable to damage (Cherry & Battaglia 2019). Increases in storms may also alter plant-sediment feedback loops critical for maintaining marsh elevation and mitigating subsidence via the accumulation of organic material and vertical sediment accretion (Baustian & Mendelssohn 2018; Pannozzo et al. 2021).

Sensitivity and current exposure to non-climate stressors → High *(high confidence)*

Non-climate stressors can exacerbate ecosystem sensitivity to changes in climate factors and disturbance regimes, and/or can be exacerbated by these changes.

- **Residential/commercial development** along the coast can limit inland migration of tidal marshes as sea levels rise, leading to reduced marsh size via coastal squeeze (Palaima 2012; Vuln. Assessment Worksheets, pers. comm., 2022). Impermeable surfaces located in urban areas, such as roads, can transfer contaminants by facilitating increased water flow to nearby marsh areas where it significantly impacts water quality (Arnold & Gibbons 1996). Encroachment and the introduction of pollutants associated with urban development can also influence the ability of tidal marshes to provide essential ecosystem services such as water filtration, shoreline protection, and habitat for wetland species (Johnson et al. 2013; Mitsch et al. 2015; Novoa et al. 2020). Tidal marshes located near urban areas tend to have lower species diversity and richness compared to those in more rural areas, which is often associated with reduced ecosystem resilience (Johnson et al. 2013; Novoa et al. 2020).

- **Dams and water diversions** can have profound impacts on watershed connectivity and wetland dynamics, causing alterations to the tidal range and currents that then lead to changes in stratification and sediment transport, which in turn can contribute to erosion (Jaffe et al. 2007; Kirwan & Megonigal 2013; Figueroa et al. 2022). Dams trap sediment and limit its delivery to tidal marshes, which may lead to subsidence and the gradual conversion of marsh into open water, reducing habitat availability for marsh-dependent species (Jaffe et al. 2007; Dusterhoff et al. 2023). These impacts are amplified by rising sea levels and altered streamflow that influence erosion and inundation, further decreasing the persistence and survival of marsh species (Callaway et al. 2007; Jaffe et al. 2007; Parker et al. 2011; Stern et al. 2020). Removing dams to reconnect previously divided watersheds and reestablish water flow to tidal marshes can allow them to utilize sediment resources in the upper watershed, which helps maintain and improve marsh integrity (Dusterhoff et al. 2023).

  For tidal marshes in the San Francisco Bay region, diking in the late 1800s for agriculture, grazing, commercial salt production, and urban development caused significant loss of marsh extent, though the rate of loss was reduced following the passage of the Clean Water Act in the 1970s that protected marshes from diking (Callaway et al. 2011).

- **Invasive species** can significantly impact tidal marshes in the San Francisco Bay Area (Callaway et al. 2011). Climate changes such as rising sea levels that alter hydrology and salinity affect the types of plants that can survive, often allowing invasive species a competitive advantage that drive further changes in plant community composition (Morris et al. 2002; Craft et al. 2009; Schile et al. 2011). However, notable dieback of invasive species during drought events has been observed, and this could create opportunities for native species to reestablish (Palaima 2012; Casazza et al. 2016; Wigginton et al. 2020). One of the current major concerns is the invasion of non-native Spartina species such as smooth cordgrass (*S. alterniflora*) into tidal marshes (Callaway et al. 2011). This species hybridizes with the native cordgrass species, and unless controlled can spread aggressively thereby reducing the presence of native species (Rosso et al. 2005). Smooth cordgrass and its hybrids have also resulted in habitat loss for salmon and oysters, as well as economic losses for human communities and industries that rely on these species (Brusati 2008; ONMS 2010).

Non-native European green crabs (*Carcinus maenas*) and Japanese mud snails (*Batillaria attramentaria*) prey on and outcompete native tidal marsh species for resources (Dewar et al. 2008). This predator-induced stress and reduced access to resources, coupled with the stress caused by fluctuations in water temperatures and salinity due to sea level rise could further impact native species survival under a changing climate (Craft et al. 2009; Callaway et al. 2011; Kirwan et al. 2014; Cherry & Battaglia 2019; Colombano et al. 2021).

- **Livestock grazing** can directly and indirectly influence wetland ecosystems. In tidal marshes, direct consequences include alterations in vegetation height, increased soil compaction, and trampling, which in turn affect marsh surface elevation and soil carbon content (Yang et al. 2017). However, the impact of livestock grazing on marsh accretion rates is contingent upon livestock species (e.g., cattle, sheep, goats) and stocking densities, with higher densities resulting in lower cumulative accretion rates (Tesauro 2001). Indirectly, livestock grazing can modify the structure of the soil food web by altering microorganism biomass and nematode species abundance (Veen et al. 2010). Impacts to the food web tend to be greatest in high marsh areas, where grazing is concentrated (Nolte et al. 2015).
- **Pollutants** such as those found in wastewater (e.g., nitrogen and phosphorus) degrade tidal marshes, increasing the vulnerability of some marshes to sea level rise (Krause et al. 2020). This is attributed to the accumulation of below-ground biomass that occurs with increased nutrient deposition, which reduces peat stability and plant root strength in low-elevation marshes and reduces their ability to withstand erosion (Deegan et al. 2012; Wong et al. 2015; Krause et al. 2020). An influx of pollutants also increase ammonia and sulfide levels in the marsh and adjacent sloughs and channels, which promotes harmful algal blooms that are toxic to plants and aquatic organisms (Wasson et al. 2017; Krause et al. 2020; Colombano et al. 2021). The resulting plant die-offs exacerbate erosion, coastal instability, and subsidence, increasing the possibility that the marsh will eventually be converted into mudflats or open water (Krause et al. 2020).
- **Roads, highways, and trails** create physical barriers that disrupt water flow and wildlife movement (Coffin 2007; Li et al. 2020). This fragmentation isolates populations of plants and animals, which impedes their access to crucial resources and can ultimately reduce genetic diversity and reproductive success if different populations are unable to mix (Trombulak & Frissell 2001). Roads also put animals at risk of vehicle-related mortality (Forman & Alexander 1998; Coffin 2007). In addition to habitat fragmentation, roads have far-reaching impacts on the physical and chemical environment in tidal marshes. They can alter soil conditions and water patterns, potentially leading to changes in vegetation composition (Coffin 2007). Moreover, roads introduce pollutants into marsh ecosystems through vehicle emissions, contributing to water quality degradation (Coffin 2007). Roads and highways can also promote the dispersal of exotic species and increase human utilization of these areas, leading to futher

degradation and potentially contributing to long-lasting detrimental effects on tidal marsh biodiversity and functioning (Simmons et al. 2010).

Adaptive Capacity → Low *(high confidence)*

Adaptive capacity *is the ability of an ecosystem to respond to or cope with climate change impacts with minimal disruption. High adaptive capacity corresponds to lower overall climate change vulnerability, while low adaptive capacity means that the ecosystem will be less likely to cope with the adverse effects of climate change, thus increasing the vulnerability of the ecosystem.*

Ecosystem extent, integrity, and continuity → Low (moderate confidence)

The San Francisco Bay Estuary once contained the largest contiguous tidal marsh system on the Pacific coast of the United States (Josselyn 1983; Stralberg et al. 2011; Takekawa et al. 2011), though over 90% of the wetlands that existed in the Bay Area are now degraded or gone (Callaway et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). Urbanization is a significant contributing factor to the degradation and loss of these wetlands, variably impacting their structural and functional integrity throughout the region (Casazza et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022). Marsh continuity is also compromised as most exist in isolated and fragmented patches and are surrounded by urban development (Casazza et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022). Other changes that impact marsh integrity include altered salinity, changes in hydrology, exposure to pollutants, and the presence of invasive species (Tsao et al. 2009; Archbald & Boyer 2014).

Many barriers to dispersal exist for species that are dependent on tidal marsh habitats, including land use conversion, roads, dams, water diversions, and geological features like coastal cliffs (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, factors such as increased/decreased salinity and inundation can act as barriers as they influence species productivity as well as accessibility and suitability of areas for species to survive (Schile et al. 2011). However, existing transition zones around the edges of tidal marshes could provide refuge for mobile species during high tide events (WRA 2019; Vuln. Assessment Reviewer, pers. comm., 2023). These zones can serve as corridors, connecting tidal marshes to upland areas that may be suitable habitats for these species to migrate to at higher elevations (WRA 2019). Creating and maintaining transition zones has been an adaptive strategy used in revegetation programs, such as the Corte Madera four-acre tidal marsh restoration project in Corte Madera in Marin County (WRA 2019; Vuln. Assessment Reviewer, pers. comm., 2023). This project included planting transitional vegetation such as shrubs and seeding native grasses and shrub species at the upland edge of the marshes to improve these areas as places of refuge for marsh species (WRA 2019).

Ecosystem diversity → High (high confidence)

Within tidal marshes, high structural diversity contributes to the overall health and stability of the ecosystem by supporting nutrient dynamics, invasion resistance, and habitat availability for various species (Josselyn 1983; LaRue et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). However, some wetland areas in this region exhibit a lack of physical complexity, such as straight tidal channels (Williams & Faber 2001; Zedler et al. 2001; Callaway et al. 2011). Additionally, many sites in the San Francisco Bay Area that were restored in the 1980s and 1990s have limited biological diversity due to the time required to establish native species and develop the complexity characteristic of more mature marshes (Williams & Faber 2001; Zedler et al. 2001; Callaway et al. 2011).

Plant diversity in tidal marshes is limited by waterlogged soils, high salinity levels, and frequent inundation, which contribute to harsh conditions not suitable for many generalist species (Watson & Byrne 2009; Palaima 2012). In some locations, it is likely that rising sea levels may further limit diversity as less salt-tolerant species in high marsh areas are replaced by low marsh vegetation (Watson & Byrne 2009). Higher plant diversity within tidal marshes can support productivity and nutrient retention and help to retain ecosystem functions as well as limit the establishment of invasive species, increasing resilience in the face of climate change (Zedler et al. 2001; Callaway et al. 2011).

Tidal marshes support a diverse group of animals ranging from invertebrates (the polychaete worm *Capitella capitata;* yellow shore crab [*Hemigrapsus oregonensis*]; beach hopper [*Traskorchestia traskiana*]), fish (topsmelt [*Atherinops affinis*]; arrow goby [*Clevelandia ios*]), birds (song sparrows, San Francisco common yellowthroat, black rail, Ridgeway's rail), and mammals (Suisun shrew [*Sorey sinuosus*]; salt marsh harvest mouse [*Reithrodontomys raviventris halicoetes*]; Josselyn 1983; Spautz et al. 2006; Smith et al. 2014; Casazza et al. 2016). The varying hydrology of these marshes can impact species movement, from fish nurseries to the availability of foraging grounds for mammals (Morris et al. 2002; Craft et al. 2009; Findlay & Fischer 2013; Neubauer 2013). The range of animal species present in the habitat can also be contingent on the composition and diversity of tidal marsh vegetation (Stralberg et al. 2010). The loss of plant species sensitive to increased salinity may impact the presence and diversity of the animal species that depend on them (Josselyn 1983; Watson & Byrne 2009; Palaima 2012).

Resistance and recovery → Low (high confidence)

Due to their high degree of dynamism and adaptability, tidal marsh habitats have historically withstood moderate ecological and anthropogenic disturbances (Colombano et al. 2021). However, the compounding effects of climate change and non-climate stressors may lead to significant challenges to their ability to persist (Wang et al. 2019; Colombano et al. 2021). For example, coastal squeeze, caused by rising sea levels and increased land development along coastlines, poses a growing threat to tidal wetlands (Torio & Chmura 2013; Wang et al. 2019). This occurs where barriers designed to protect inland areas from sea level rise block or reduce tidal flows and prevent marshes from migrating to adjacent uplands (Torio & Chmura 2013; Wang et al. 2019). Wetlands that cannot move inland will shrink or completely disappear as rising sea levels submerge vegetation and drive the transition of marsh into mudflats or open water (Torio & Chmura 2013; Krause et al. 2020). However, it is possible for unobstructed tidal marshes to migrate in response to changing conditions (Wang et al. 2019). In these instances, gains as a result of marsh migration to higher elevations may offset the loss of lowland marshes impacted by inundation from sea level rise (Morris et al. 2002; Wang et al. 2019; Colombano et al. 2021).

Elevated carbon dioxide (CO_2) levels may also enhance the resilience of marsh ecosystems to sea level rise by facilitating below-ground plant growth that increases surface elevation (Langley et al. 2009, 2013; Wang et al. 2019). This is most pronounced under high salinity and continuous flooding/inundation conditions, where marshes face more significant environmental stressors (Langley et al. 2009, 2013). However, the degree of this CO_2-induced benefit is contingent upon other factors such as nitrogen pollution and human impacts that contribute to habitat degradation (Langley et al. 2009).

Management potential → Moderate (high confidence)

Tidal marshes in the San Francisco Bay Area are valued by the public for recreational opportunities such as bird watching (Vuln. Assessment Worksheets, pers. comm., 2022). In recent years, they are increasingly gaining recognition by the public as essential players in future coastline protection against rising sea levels and coastal erosion (Callaway et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). Tidal marshes and wetlands in general have a high level of societal support, which is evident by the availability of funding and regulatory backing for wetland conservation in the Bay Area (Vuln. Assessment Worksheets, pers. comm., 2022). However, when it comes to active management of these ecosystems, the managers tasked with preserving and maintaining tidal marshes in light of a changing climate often face limitations in their capacity, mainly due to insufficient resources and funding (Vuln. Assessment Worksheets, pers. comm., 2022).

There are a number of restoration efforts already underway in the Bay Area that target the conservation and restoration of tidal marshes (Callaway et al. 2011). For example, the South Bay Salt Pond Restoration Project (SBSPRP) endeavors to restore 15,100 acres of former commercial salt ponds to tidal wetlands to enhance wildlife habitat, increase wildlife-friendly public access, and contribute to flood risk management in the area (South Bay Salt Pond Restoration Project 2023). In 2018, Phase 2 of this project began to build higher-ground transitional areas to provide a space for wildlife seeking refuge as sea levels rise (South Bay Salt Pond Restoration Project 2023). Tidal marsh restoration projects covering vast coastal areas, such as the SBSPRP, have highlighted the challenges of this work (e.g., needed resources for invasive species management) and the importance of public involvement and support (Callaway et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). However, they also provide a good example of explicit consideration of climate change in planning for tidal marsh restoration efforts, which is critical (Callaway et al. 2007; Thorne et al. 2015; Vuln. Assessment

Worksheets, pers. comm., 2022). It is also important that project planning includes ongoing monitoring to support adaptive management, a multi-stressor framework to gain insight into the timing and magnitude of changes, and a collaborative approach between academic scientists and on-the-ground managers (Williams & Faber 2001; Colombano et al. 2021).

The implementation of other strategies, such as updating development guidelines to require a certain percentage of open/green space for new coastal development, may also help promote tidal marsh conservation (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, the identification of tools to identify areas where impacts such as coastal squeeze are likely to be most severe, alongside a thorough examination of their causes and consequences, is essential to promote policies that encourage effective utilization and protection of coastal wetlands (Torio & Chmura 2013; Silva et al. 2020). This research can benefit and advance priority setting for local coastal restoration efforts and funding allocation (Silva et al. 2020).

Recommended Citation

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Further information on the Golden Gate Biosphere Region Climate Adaptation Project is available on the project page (www.ecoadapt.org/goto/GGBRClimateProject).

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