Freshwater Marshes

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for freshwater 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

Freshwater marshes are non-tidally influenced wetlands that are perennially or seasonally inundated. They are characterized by anaerobic soils, and typically either lack vegetation or support plant communities dominated by hydrophytes (water-loving plants; Duffy et al. 2016). The hydroperiod of freshwater marshes largely determines their ecological character, and is influenced by the extent to which excess water (precipitation exceeding evaporation) is available and the proportion of their water sources that are comprised of runoff and groundwater (Mitsch & Gosselink 2007). In central California, the hydroperiod of freshwater marshes is most often seasonal, with alternating wet and dry periods creating a dynamic environment that facilitates nutrient cycling, plant growth, and fluctuations in how these systems are used by wildlife (Duffy et al. 2016).

The diverse landscapes across California’s central coast support high abundance and diversity of wetlands, including freshwater marshes (Duffy et al. 2016). While classic freshwater marshes (i.e., perennial depressional wetlands that support monocots such as cattails [*Typha* spp.]) are not naturally abundant in most of the Golden Gate Biosphere (GGB) region (Howell et al. 2007; Baumgarten et al. 2021), there are a wide variety of wetland types that support freshwater marsh vegetation, including seasonally ponded or saturated depressions, low-gradient dune slacks and creeks, sag ponds, groundwater-fed slope wetlands, and even a few natural lakes such as Pelican and Mud Lakes at Point Reyes (San Francisco Estuary Institute 2018; Baumgarten et al. 2021; Vuln. Assessment Worksheets, pers. comm., 2022). Among the most well-known wetland sites in Marin County are Olema Marsh, Ledum Swamp, Chileno Valley, wetlands at F and AT&T Ranches, Rock Springs and Potrero Meadows, Tennessee Valley, Muir Beach, and Rodeo Valley. In Sonoma County, the Laguna de Santa Rosa, Pitkin Marsh, Ledson Marsh, and Cunningham Marsh are notable freshwater features (Vuln. Assessment Worksheets, pers. comm., 2022). In San Mateo County, Pescadero Marsh is another large freshwater wetland (Potter 2013).

One of the key characteristics of wetlands is their ability to support multiple types and heights of hydrophytic vegetation, which provide physical structure and habitat for a variety of wildlife species (Mitsch & Gosselink 2007; Duffy et al. 2016). Vascular plants in freshwater marshes can be grouped into emergent macrophytes that are rooted in sediment but extend above the water surface; floating-leaved hydrophytes rooted in sediment with leaves that float on the water surface; and free-floating plants that move along the water surface (Mitsch & Gosselink 2007). Common emergent macrophytes in freshwater wetlands within the GGB region include tall species such as native and non-native cattail, bulrush (*Schoenoplectus* spp.), bur-reed *(Sparganium* spp.), and slough sedge (*Carex obnupta*); intermediate-sized species such as small-fruited bulrush (*Bolboschenus maritimus*) and Pacific rush (*Juncus effusus*); and many smaller emergents such as spikerush (*Eleocharis macrostachya*), Pacific oenanthe (*Oeananthe sarmentosa*), seep-monkeyflower (*Erythranthe guttata*), water smartweed (*Persicaria amphibia*), and various smaller sedge (*Carex*) and rush (*Juncus*) species (Kramer 1988; Leppig 2018; Vuln. Assessment Worksheets, pers. comm., 2022). Common floating-leaved hydrophytes include hydrocotyle (*Hydroctle* spp.), and non-rooting species such as mosquito fern (*Azolla pinnata*) and duckweed (*Lemna minor*) that float on the surface (Vuln. Assessment Worksheets, pers. comm., 2022). Fault sag ponds in Point Reyes National Seashore support freshwater marsh species often associated with vernal pools such as Lobb's aquatic buttercup (*Ranunculus lobbii*), considered a rare plant species (Williams 2009) .

Freshwater wetlands in this region are host to a wide range of aquatic macroinvertebrates, amphibians, birds and mammals, including protected native species such as the California red-legged frog (*Rana aurora draytonii*), western pond turtle (*Actinemys marmorata pallida*) and tri-colored blackbird (*Agelaius tricolor*; Grossinger et al. 2007). They can also serve as important stopover or seasonal features for migratory birds (Page et al. 1999; Baumgarten et al. 2021). Other important ecosystem services provided by freshwater wetlands include nutrient cycling, water filtration, groundwater recharge, flood control, and carbon sequestration (Mitsch et al. 2015; Duffy et al. 2016).

Fine-scale vegetation maps for San Mateo, Marin, and Sonoma Counties were used to identify 11 vegetation classes that generally represent freshwater marsh associations within the GGB region (Tukman Geospatial et al. 2018), which occupy a combined total of 20,400 acres (Figure 1, Table 1). Of that, 58% (11,836 acres) is protected, with the largest area of protected lands managed by the U.S. Fish and Wildlife Service (3,791 acres; Table 2).

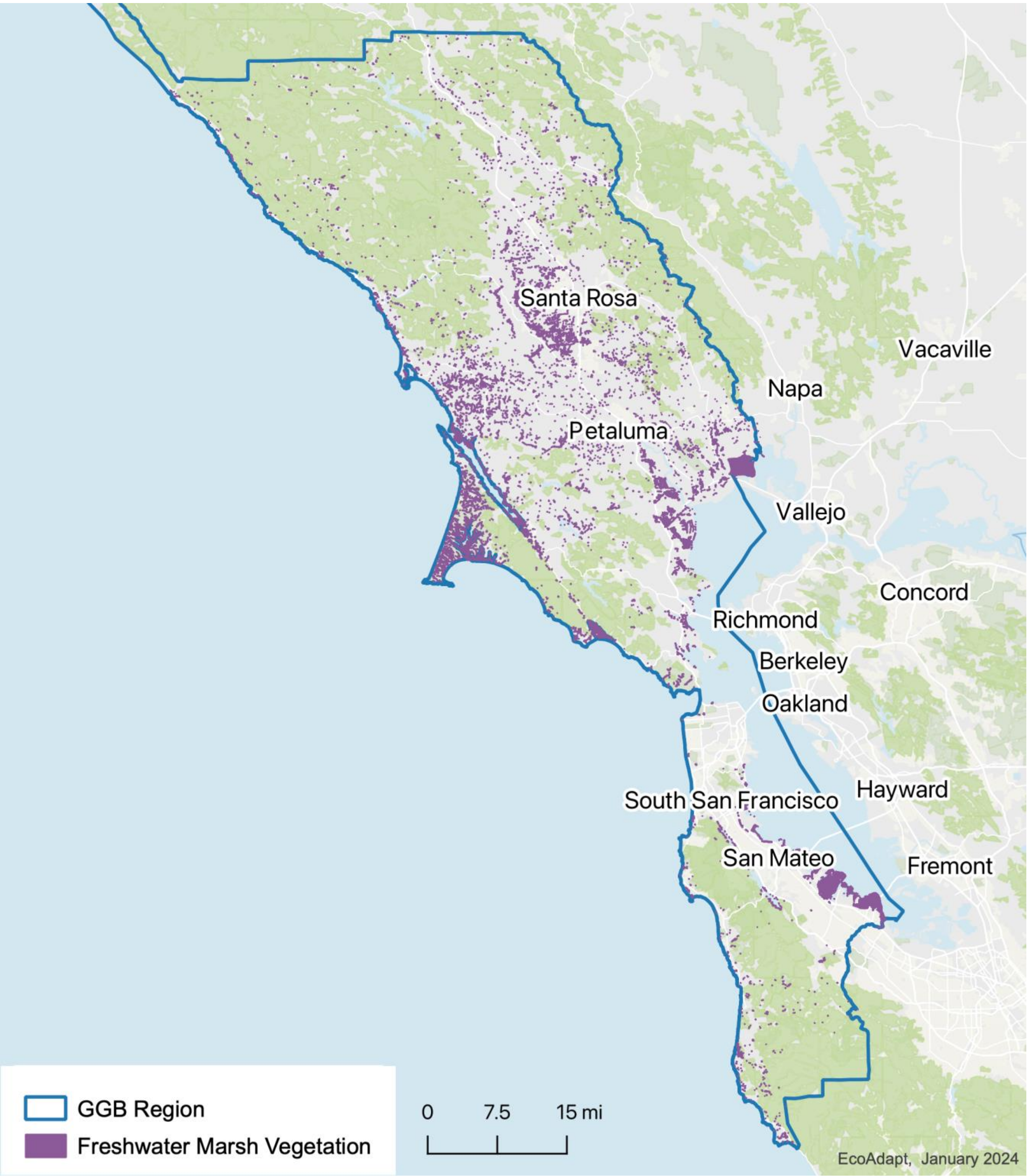

Figure 1. Distribution of vegetation map classes that likely represent freshwater marsh communities within the GGB region, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Table 1. Vegetation map classes included in the definition of freshwater marshes for the purposes of this project, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Vegetation Map Class
Arid West Freshwater Emergent Marsh Group
Californian Vernal Pool / Swale Bottomland Group
Carex serratodens Provisional Alliance
Juncus arcticus (var. *balticus*, *mexicanus*) Alliance
Mudflat/Dry Pond Bottom Mapping Unit
Rhododendron columbianum - Gaultheria shallon / Carex obnupta Association
Vancouverian Freshwater Wet Meadow & Marsh Group
Vancouverian Lowland Marsh, Wet Meadow & Shrubland Macrogroup
Western North America Vernal Pool Macrogroup
Western North American Freshwater Aquatic Vegetation Macrogroup
Western North American Freshwater Marsh Macrogroup

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
United States Fish and Wildlife Service	3,791
National Park Service – Point Reyes National Seashore	2,236
California Department of Fish and Wildlife	1,899
Other protected lands	1,219
Marin County Parks	785
California Department of Parks and Recreation	490
California State Lands Commission	377
Sonoma County Regional Parks Department	255
San Francisco – Public Utilities Commission	175
National Park Service – Golden Gate National Recreation Area	156
Audubon Canyon Ranch	102
Marin Municipal Water District	71
Sonoma Land Trust	67
Midpeninsula Regional Open Space District	66
Sonoma County Agricultural Preservation and Open Space District	64
Peninsula Open Space Trust	45

San Mateo County Parks and Recreation Department	34
United States Army Corps of Engineers	4
The Conservation Fund – California	1
TOTAL	**11,836**

Ecosystem Vulnerability → High *(moderate 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

Freshwater marshes are sensitive to climate stressors and disturbances that alter hydrologic and thermal regimes, including changes in patterns of precipitation and runoff, increased drought, warmer water temperatures, heat waves, sea level rise, increased storms, and wildfire. These changes are likely to impact water levels, hydroperiods, and water quality, altering habitat suitability for many wildlife and plant species and driving changes in wetland structure and function. In addition, non-climate stressors can exacerbate habitat sensitivity by altering wetland and pond hydrology, water quality, and connectivity.

The area of freshwater marshes in the GGB region decreased significantly between the 19th and 21st centuries due to filling, draining, and drowning for reservoir construction. In addition to the loss of large areas of freshwater marshes, many remaining systems have also been degraded through nutrient and sediment inputs. These fragmented and/or degraded systems are particularly vulnerable to the impacts of climate change. However, management activities such as maintaining or restoring natural hydrologic regimes, retaining water within the system, managing vegetation, reducing nutrient inputs, and protecting floodplains may increase the climate resilience of these habitats.

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)*

- Rising **air temperatures** and **heat waves** can increase evapotranspiration, causing loss of both surface water and groundwater from the system (Mitsch & Gosselink 2007; Condon et al. 2020), particularly in inland marshes where the persistence of surface water results from the balance between precipitation and evapotranspiration (Mitsch & Gosselink 2007). Rising air temperatures and heat waves can also contribute to **increased water temperatures and decreased dissolved oxygen** in the water, which together with reduced water levels can stress or kill wetland vegetation and aquatic fauna (Duarte et al. 2012; Verberk & Bilton 2013; Short et al. 2016) and lead to declines in aquatic biodiversity. Increased water temperatures may also alter sex ratios of certain fish (Geffroy & Wedekind 2020). Warmer temperatures, along with rising carbon dioxide, can increase macrophyte growth in wetlands (Salimi et al. 2021), but these factors can also negatively impact macrophytes through mechanisms such as eutrophication that reduce light penetration and hamper emergent plant growth (Short et al. 2016). Analyses of pollen in soil profiles suggest that during the early Holocene, when the climate became hotter and drier, many wetland features that existed in Point Reyes appear to have been converted to a different wetland type (e.g., pond to seasonal wetland) or to an upland system (e.g., wetland to grassland; Anderson 2005), suggesting that this could occur again as the climate changes. In particular, the greatest changes are expected along wetland margins because these areas tend to have the shortest hydroperiod and can vary between wet or dry in any given year (Vuln. Assessment Reviewer, pers. comm., 2023).
- **Changes in the amount and timing of precipitation** and associated **alterations in stream flows** may have significant impacts on freshwater wetlands, most of which rely on surface water runoff or a combination of surface and groundwater. Increases in overall annual precipitation or more intense precipitation over short periods of time could damage wetlands by flooding, which could lead to increased erosion and sediment inputs as well as increases in polluted runoff from surrounding areas (Records et al. 2014; Stern et al. 2020). These impacts are most likely to occur in stream-adjacent wetlands, but may be somewhat reduced in the Bay and Delta region where there are extensive hydrologic controls associated with irrigation and urbanization (Parker & Boyer 2019). In contrast, decreases in precipitation could cause wetlands to shrink (Reiter et al. 2018) or, for some small wetlands, to dry up completely. Decreased or more episodic stream flows can cause disconnection between river and wetland systems, reducing ecological services provided by freshwater wetlands such as nutrient cycling and provision of wildlife habitat (Ardón et al. 2013; Wilson et al. 2022). Some freshwater wetlands may also shift from carbon sinks to carbon sources because of changing flow regimes (Salimi et al. 2021). Groundwater-fed wetlands may be less immediately impacted by precipitation declines, but eventually are likely to be adversely affected by reduced groundwater recharge (Havril et al. 2018). Finally, shifts in the timing and seasonality of precipitation may disrupt the lifecycles of aquatic organisms such as amphibians, which have

evolved with precipitation patterns that are becoming more variable and extreme as the with climate changes (Walls et al. 2013).

- **Declines in soil moisture** and **increased drought** are likely to negatively impact the extent and persistence of wetland features (Condon et al. 2020; Wilson et al. 2022), particularly as increases in groundwater extraction and surface water diversions place additional stress on water supplies during periods of drought (Russo & Lall 2017; Thomas & Famiglietti 2019). For instance, during the extreme 2012–2016 drought, both climatic drying and reductions in surface water allocations significantly impacted wetlands and associated ecological services such as habitat provision for migratory birds (Lund et al. 2018; Reiter et al. 2018). Changes from anaerobic to aerobic soils as a result of drying can shift plant communities towards more upland species and drive alterations in microbial soil assemblages, including increases in aerobic soil respiration and carbon emissions (Silver et al. 2004).
- **Sea level rise** poses a significant threat to freshwater wetland systems by moving saline waters further inland, increasing salinity in low-lying coastal wetlands. This process can stress wetland plants, leading to shifts toward salt-tolerant species (Parker et al. 2011; Short et al. 2016; Parker & Boyer 2019; Osland et al. 2022). Sea level rise can also drive saltwater intrusion into coastal aquifers, inundating wetland systems and increasing salinity (Hoover et al. 2017). Sea level rise impacts can be compounded by other climate changes such as drought, whereby drying wetlands can be more susceptible to saltwater incursion that stresses or damages wetland vegetation and alters ecological functions such as nutrient cycling (Ardón et al. 2013). Some wetlands in the Bay area have room for landward migration, particularly in the less developed North Bay, but in other areas there are significant constraints to migration such as mountainous topography and transformative land uses such as agriculture and urbanization (Heberger et al. 2009; Thorne et al. 2015; Parker & Boyer 2019).

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

- Freshwater wetlands are sensitive to **increases in storm frequency/intensity and associated flooding**, which can alter inundation frequency and variability and cause substantive changes in wetland ecosystems. Increases in the frequency and intensity of flooding can lead to impacts such as erosion, sedimentation, increases in pollutant loads, shifts in vegetative assemblages, or system conversion from freshwater marsh to shallow pond or lake (Kirwan & Guntenspergen 2015), and these could be exacerbated by additional climate stressors such as warming temperatures (Sun et al. 2022).
- The **frequency and intensity of wildfire** in wetlands is highly dependent on hydroperiod and system productivity, which influence fuel availability and moisture (Bixby et al. 2015). Seasonally-inundated marshes are more likely to burn during the dry season compared to perennial marshes. Both perennial and seasonal wetlands may be influenced by increases in

large, uncharacteristically-severe fires in upland areas within the same watershed, as loss of upland vegetation typically mobilizes nutrients, increases runoff and erosion, and alters microclimates in the short-term (Coombs & Melack 2013; Bixby et al. 2015; Jager 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 and commercial development** and associated infrastructure such as **roads, highways and trails** are a primary driver of wetland loss and conversion in the GGB region, which has a long history of urbanization (Baumgarten et al. 2018, 2021). Housing, manufacturing, and roads have all contributed to the draining, ditching, and paving of freshwater marshes, leading to extensive losses where wetlands are converted to upland areas. For example, researchers documented an 84% loss of non-tidal wetlands associated with development in the Petaluma River watershed from the late 19th through 20th centuries, including the loss of extensive areas of freshwater marsh (Baumgarten et al. 2018). Lengthening and straightening of channels to improve navigation, increase drainage, and facilitate mosquito control have left a legacy of simplified stream systems and loss of associated wetlands (Baumgarten et al. 2018). The impacts of roads and associated traffic on freshwater wetlands are many, and include fragmentation, water quality and sediment impacts due to pollution from road runoff, noise and light pollution, hydrologic disconnection, soil compaction and erosion, movement of invasive species, and barriers to dispersal and migration of wetland-associated species such as fish and amphibians (Trombulak & Frissell 2000; National Research Council 2005). All these stressors reduce the resilience of wetland systems, increasing their vulnerability to climate changes (Dwire et al. 2018).
- **Agriculture** and **livestock grazing** have significant impacts on wetlands, and many watersheds within the GGB region contain significant agricultural and grazing activities (Nicely et al. 2007; Grossinger et al. 2007; Baumgarten et al. 2018). The impacts of these activities accelerated during the late 19th and 20th century (Grossinger et al. 2007) as thousands of acres of tidal and freshwater wetlands throughout the region were diked and drained for agriculture (Baumgarten et al. 2018, 2021). As a result, many low-lying, former wetland areas have oxidized and subsided, creating areas that are increasingly vulnerable to inundation from sea level rise (Deverel et al. 2010). Livestock also directly impact wetland habitat by increasing erosion and sedimentation and trampling sensitive vegetation (Morris & Reich 2013). In some areas, the creation of irrigation ponds may introduce new depressional wetlands into the landscape, but these typically provide relatively little value in terms of ecosystem services (Vuln. Assessment Reviewer, pers. comm., 2023).
- Upstream land uses, including agriculture and urban development, can contribute **pollution** that impacts freshwater wetlands, which tend to be in low-lying areas that collect runoff and

sediments from upstream or up-slope land uses (Mitsch & Gosselink 2007). While wetlands have the capacity to absorb anthropogenically-derived pollutants and are often employed as a solution for treatment of polluted runoff (Díaz et al. 2010; Malaviya & Singh 2012), there are limits to the toxins they can take up and remain healthy. In addition, ingested and bioaccumulative contaminants can cause impacts to fish and wildlife that inhabit these systems (Cohen et al. 2001; Reynolds & Ryan 2018).

- The San Francisco Bay-Delta region is one of the most hydrologically extensive and interconnected water systems in the world, with a complex network of **canals, water diversions, and dams** on both major tributaries that feed the Bay and Delta as well as many smaller creek systems throughout the region (Lund 2016; Baumgarten et al. 2021). On average, the flow that currently reaches the San Francisco Bay is less than 50% of its historic flow prior to the creation of this extensive hydrologic infrastructure (The Bay Institute 2016). Major reductions in freshwater supply to streams and wetlands, decreased water quality, and upstream shifts in the salinity mixing zone of the Bay are all symptoms of the region-wide alterations in flow, and have caused significant repercussions for the Bay's ecology (The Bay Institute 2016). These impacts are likely to be exacerbated by sea level rise, storms that affect the amount and timing of runoff from local tributaries, and increasing temperatures that drive evaporation and drought (Ackerly et al. 2012; Vuln. Assessment Reviewer, pers. comm., 2023).
- **Invasive species** present a serious threat to freshwater wetlands by altering ecosystem structure, reducing biodiversity of native plant species, modifying food webs, and impacting nutrient cycling (Zedler & Kercher 2004; Preston et al. 2012). Problematic invasive vegetation in freshwater wetlands of the GGB region include emergent aquatic plants such as water primrose (*Ludwigia hexapetala*, *L. grandiflora*), parrot's feather (*Myriophyllum aquaticum*), and hydrilla, among others (Okada et al. 2009; Duffy et al. 2016; Vuln. Assessment Reviewer, pers. comm., 2023). Facultative invasive species, which can occur in wetland and non-wetland ecosystems, also cause widespread impacts to biodiversity in disturbed seasonal freshwater marshes in the GGB region. These include cape ivy (*Delairea odorata*), tall fescue (*Festuca arundinacea*), velvet grass (*Holcus lanatus*) , and others (Vuln. Assessment Reviewer, pers. comm., 2023). Additional wetland species such as floating aquatic fern (*Salvinia* sp.) and South American spongeplant (*Limnobium laevigatum*) are not yet extensively found in the GGB region but are known from other areas of California and are highly likely to spread into freshwater wetlands of this area (Anderson & Akers 2011; Cal-IPC 2023). Several invasive animals are also highly impactful in freshwater wetlands of the region, including New Zealand mudsnails (*Potamopyrgus antipodarum*), bullfrogs (*Lithobates catesbeianus*), green sunfish (*Lepomis cyanellus*), bass (*Morone saxatilis*), and mosquitofish (*Gambusia affinis*; Lawler et al. 1999; Preston et al. 2012; Vuln. Assessment Reviewer, pers. comm., 2023).

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 (high confidence)

Most freshwater marshes in the GGB region are severely limited both in extent and continuity. While this is partly because the topography of the coastal range limits wetland extent, human land-use conversion to agriculture and development has also led to extensive draining, conversion and fragmentation of these systems over the past decades to centuries (Grossinger et al. 2007; Baumgarten et al. 2018, 2021; Vuln. Assessment Worksheets, pers. comm., 2022). In addition to the loss of many freshwater marshes, these land use changes continue to create barriers to ecosystem continuity in remaining wetlands. For instance, roads and developed areas restrict both the hydrologic connectivity of wetland systems and the movement of wildlife that depends on them (National Research Council 2005). Roads can also facilitate the introduction of invasive species, which further stresses native species and ecosystem function (Anderson 2019). Dams, water diversions, flood control structures, and buried stream segments are widespread throughout the region (Baumgarten et al. 2021), and have created barriers to movement for many aquatic species, particularly migratory fish and amphibians (Quiñones & Moyle, Peter 2014; Leitwein et al. 2017; Moyle et al. 2017; NPS 2019).

Ecosystem diversity → High (moderate confidence)

Freshwater wetlands are aquatic ecosystems with diverse structural characteristics that support very high plant and animal diversity (Hails 1996; Duffy et al. 2016), providing critically-important habitat features for birds, amphibians, fishes, and invertebrates (Gardali et al. 2012; Howard et al. 2015; Baumgarten et al. 2021). These include rare, uncommon, or range-restricted wetland plant species, many of which are likely to be particularly vulnerable to climate-driven changes in hydrological regime that exceed their tolerance to drought or inundation. A significant number of wetland species are at the southern limit of their distribution in the GGB region, increasing their vulnerability to climate change; these include Pacific reedgrass (*Calamagrostis nutkaensis*), Lyngbye's sedge (*Carex lyngbyei*), skunk cabbage (*Lysichiton americanus*), bogbean (*Menyanthes trifoliata*), western false asphodel (*Tofieldia occidentalis*), and dwarf bilberry (*Vaccineum caespitosum*; Vuln. Assessment Reviewer, pers. comm., 2023). Within the GGB region, numerous other rare and endangered plants and animals are associated with freshwater marshes (Baumgarten et al. 2018, 2021), including freshwater wetland-obligate plants such as Sonoma alopecurus (*Alopecurus aequalis* var. *sonomensis*), marsh sandwort (*Arenaria paludicola*), western lily (*Lilium occidentale*), and Pitkin marsh lily (*Lilium pardalinum* ssp. *pitkinense*; Vuln. Assessment Worksheets, pers. comm., 2022). Increasing temperatures, sea level rise, and increasing variability and shifts in precipitation regimes associated with climate change are expected to intensify the impacts of these stressors to freshwater marshes and the wildlife that rely on them (Parker et al. 2011; Gardali et al. 2012).

Resistance and recovery → Low (moderate confidence)

Historical and current patterns of land use in the GGB region significantly constrain freshwater wetlands, reducing their ability to resist or recover from environmental stressors and severe disturbances. In particular, the dependence of these aquatic ecosystems on retaining water in order to support the vegetative communities that depend on them increases their vulnerability to more extended dry seasons and increased drought (Poff et al. 2002; Luković et al. 2021). Wetland systems supported primarily by surface water inputs are less resistant than groundwater-dominated wetlands to changes in precipitation and warming temperatures, largely because groundwater maintains cooler temperatures (Winter 2000; Poff et al. 2002). However, over longer periods of time even groundwater-fed wetlands are likely to experience significant impacts due to the impacts of warming on evapotranspiration and groundwater storage (Condon et al. 2020). Wetland-dependent species including fish and amphibians are already stressed by multiple factors including habitat loss and invasive species, and projected changes in precipitation (e.g., increased variability) are likely to create additional challenges to resistance and recovery (Herbold et al. 2018; Kupferberg et al. 2022; McDevitt-Galles et al. 2022).

Management potential → Moderate (high confidence)

For many decades, freshwater marshes were viewed primarily as a breeding ground for mosquitoes and/or as nuisances that needed to be removed to make way for agriculture and development. Currently, there is increasing recognition that freshwater wetlands are important for a variety of functions including biodiversity, stormwater attenuation and flood storage, and water quality (Grossinger et al. 2007; Duffy & Kahara 2011; Baumgarten et al. 2018, 2021). Freshwater marshes are also increasingly valued by the public for their beauty and recreational opportunities. Birdwatchers, in particular, tend to advocate for wetlands because of their importance as habitat for a variety of bird species (Duffy & Kahara 2011; Audubon Society 2023). Wetlands also receive regulatory protection both federally through the Federal Clean Water Act of 1972 (33 U.S.C. §§1251-1387), and in the state of California (State of California 2019). Significant funding is available for restoration in the Bay Area, as well as more broadly across the state for wetland restoration efforts, including through state climate Investment funding (CA Department of Fish and Wildlife n.d.). However, it is critical to protect high-quality remnant wetlands in addition to restoring degraded wetlands. It may also be advantageous to look for mitigation opportunities that allow wetland creation associated with future projects, though creating appropriate hydrology is challenging and requires careful site selection that considers historical context, what the landscape is capable of supporting, and how it will continue to function in the face of climate change (Vuln. Assessment Reviewer, pers. comm., 2023).

Management activities designed to reduce climate vulnerability in freshwater wetlands often focus on restoring natural hydrology, retaining water within the system, and managing vegetation through grazing, mowing, and control of invasive species (Zedler 2000). Reducing nutrient inputs to wetlands and ponds can help minimize eutrophication and limit the risk of harmful algal blooms, particularly during periods of drought (Paerl et al. 2020). Adherence to good grazing practices can mitigate erosion and trampling impacts and create significant water quality and ecological benefits including reduced erosion, carbon sequestration, and controlling invasive plants (Bay Area Open Space Council 2019). Acquiring and restoring modified historic floodplains and wetlands will prevent continued habitat loss, protecting potential refugia and enabling aquatic systems to recover from disturbances (Baumgarten et al. 2021). Management and restoration of riparian buffers is also critical to protect freshwater wetlands and associated aquatic systems (e.g., connecting streams) from upland land uses and climate changes such as increasing temperatures (Broadmeadow & Nisbet 2004; Justice et al. 2017). In addition to reducing the impacts of climate stressors and disturbances, climate-informed management of these freshwater marshes would also benefit conservation target species (i.e., frogs, fish, wading birds), maintain high biodiversity across the landscape, and provide the public with important water resources and recreational benefits (Duffy & Kahara 2011; Duffy et al. 2016).

Monitoring and assessment are important to support identification and prioritization of management activities. The One Tam 2016 Peak Health report notes that protected wetland features in Marin County are in need of increased efforts to inventory and monitor these important landscape features (Edson et al. 2016). Tools that can assist with this include the Wetland and Riparian Area Monitoring Plan (WRAMP) toolkit (https://www.mywaterquality.ca.gov/monitoring_council/wetland_workgroup/) and the California Rapid Assessment Method (CRAM) for wetland monitoring (https://www.sfei.org/projects/california-rapid-assessment-method-cram).

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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