Riparian Forests and Woodlands

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for riparian forests and woodlands 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

Riparian forests and woodlands are areas of transition between uplands and streams, lakes, or wetlands, and are generally located along current or former stream corridors (Collins 2016). In the Golden Gate Biosphere (GGB) region, streams are generally low-lying and are characterized by rain-dominated hydrologic regimes (i.e., not fed by snowmelt from mountainous areas), with variable flows and frequent disturbances (Gasith & Resh 1999; Power et al. 2016). Unregulated stream systems are dynamic, and in mid-and low-gradient streams, channel meandering and flooding events can create areas of new substrate that may be colonized by riparian vegetation such as willows (*Salix* spp.; Stella et al. 2013). Farther from the floodplain, riparian forests can develop, comprised of a diverse mix of trees, shrubs, and understory plants that in the GGB region may include coast redwood (*Sequoia sempervirens*), bigleaf maple (*Acer macrophyllum*), box elder (*Acer negundo*), red alder (*Alnus rubra*), white alder (*Alnus rhombifolia*), Fremont cottonwood (*Populus fremontii*), California bay laurel (*Umbellularia rhombifolia*), and various oaks (*Quercus* spp.; Orr & Merrill 2018; CNPS 2023). Shrub layer plants include willows (also occasionally in the tree layer), California blackberry (*Rubus ursinus*), blue elderberry (*Sambucus mexicana*), Pacific poison-oak (*Toxicodendron diversilobum*), and California wild rose (Rosa californica; RHJV 2004; CNPS 2023).

Riparian forests provide important ecosystem services, including bank stabilization, flood attenuation, interception of pollutants, and wildlife habitat (Klapproth & Johnson 2009; Baumgarten et al. 2021). They also regulate in-stream conditions through shading and inputs of organic matter that serve as both food and habitat for aquatic fauna (Broadmeadow & Nisbet 2004; Power et al. 2016; Bay Area Open Space Council 2019). Historically, floodplain-associated forests and woodlands were more abundant in the region, but significant changes in land use have eliminated many of these features over time (Van Dyke & Wasson 2005; Baumgarten et al. 2021).

Fine-scale vegetation maps for San Mateo, Marin, and Sonoma Counties were used to identify 19 vegetation classes that generally represent riparian forests and woodlands within the GGB region (Tukman Geospatial et al. 2018), which occupy a combined total of 130,021 acres (Figure 1, Table 1).[1] Of that, 28% (36,204 acres) is protected, with the largest area of protected lands managed by the National Park Service at Point Reyes National Seashore (9,154 acres; Table 2).

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[1] This map and total acreage represents all areas categorized as the map classes listed in Table 1, which is based on datasets from the 2018 Marin Countywide Fine Scale Vegetation Map (Tukman Geospatial et al. 2018). Some of the *Umbellularia californica* Mapping Units displayed on this map may occur in an upland (non-riparian) setting, as insufficient data exists to accurately distinguish upland stands from those that are present in areas that function as riparian. As a result, total acreage may overestimate the extent of this ecosystem within the region.

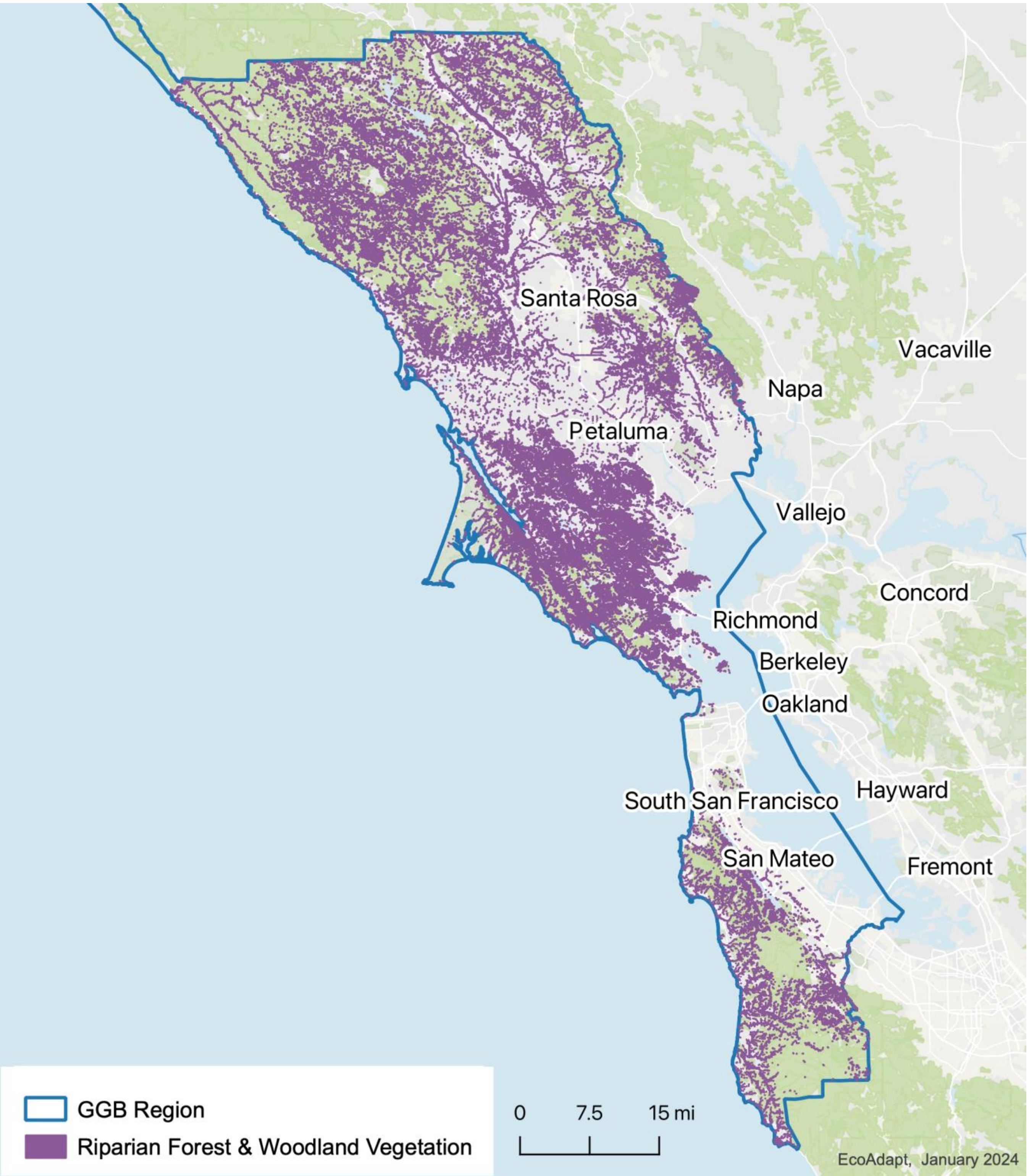

Figure 1. Distribution of vegetation map classes that likely represent riparian forests and woodlands within the GGB region, derived from fine scale vegetation maps for San Mateo, Marin, and Sonoma Counties (Tukman Geospatial et al. 2018).

Table 1. Vegetation map classes likely to represent riparian forests and woodlands 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
Acer macrophyllum – Alnus rubra Alliance
Acer macrophyllum Mapping Unit
Acer negundo / (*Rubus ursinus*) Association
Alnus rhombifolia Alliance
Fraxinus latifolia Alliance
Juglans hindsii and Hybrids Special Stands and Semi-Natural Alliance
Populus fremontii – Fraxinus velutina – Salix gooddingii Alliance
Populus trichocarpa Alliance
Quercus agrifolia / *Salix lasiolepis* Association
Salix exigua Alliance
Salix gooddingii – Salix laevigata Alliance
Salix hookeriana – Salix sitchensis – Spiraea douglasii Alliance
Salix lasiolepis Alliance
Salix lucida ssp. *lasiandra* Association
Southwestern North American Riparian Evergreen and Deciduous
Southwestern North American Riparian/Wash Scrub Group
Umbellularia californica Mapping Unit
Vancouverian Coastal Riparian Scrub Group
Vancouverian Riparian Deciduous Forest Group

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**
National Park Service – Point Reyes National Seashore	9,154
California Department of Parks and Recreation	6,811
Marin Municipal Water District	3,843
Marin County Parks	3,210
Other protected lands	2,626
San Francisco – Public Utilities Commission	2,174
Midpeninsula Regional Open Space District	1,804
National Park Service – Golden Gate National Recreation Area	1,324

United States Army Corps of Engineers	940
The Conservation Fund – California	709
Sonoma County Regional Parks Department	698
Peninsula Open Space Trust	659
Sonoma County Agricultural Preservation and Open Space District	529
Audubon Canyon Ranch	511
Sonoma Land Trust	427
United States Bureau of Land Management	300
San Mateo County Parks and Recreation Department	299
California Department of Fish and Wildlife	167
California State Lands Commission	19
TOTAL	**36,204**

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

Riparian forest and woodland ecosystems are vulnerable to a number of climate stressors and climate-driven changes in disturbance regimes that affect hydrology and vegetative structure and function, including warmer temperatures, changes in precipitation, increased drought, wildfire, and flooding, among others. Non-climate stressors such as land-use conversion and development, dams/flood control, water diversions, and invasive species have driven fragmentation and degradation of the health and integrity of riparian forest systems in the GGB region since European settlement began to significantly alter the landscape in the late 18th century. Because riparian systems are so constrained by development, particularly in more urban areas, protecting what remains and mitigating stressors such as invasive species and water diversions is a high priority in the context of climate change. Riparian systems are also challenged by lack of broad public understanding of their functions and value, though constituent groups such as birders are important allies in generating support for management efforts. The proximity of these systems with wetlands, which often have a measure of regulatory protection and receive substantial attention and resources for restoration, may benefit riparian systems as well.

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.*

Modeling of climate-driven changes in the future distribution of California bay laurel and coast live oak by Ackerly et al. (2015) found that these vegetation associations, which are commonly found in riparian forests and woodlands in the GGB region, are not expected to experience significant declines under a range of potential future conditions (Figure 2). Rather, California bay laurel communities may expand under hot/wet climate scenarios, particularly in the southern and more inland portions of the GGB region. In the northern portions of the project area, coast live oak may expand under the drier scenarios, with little change projected under wetter scenarios and in the southern part of the region.

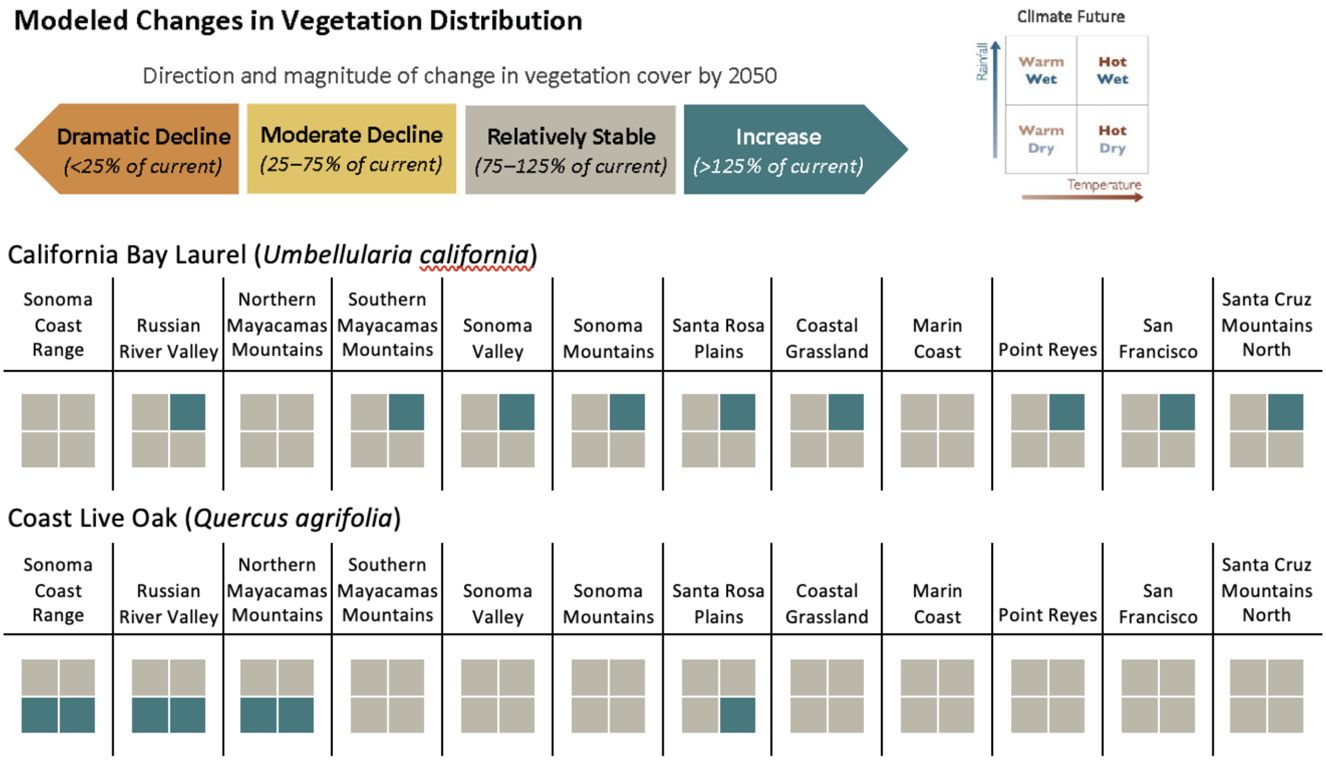

Figure 2. Projected trends in vegetation distribution by mid-century (~2050) within landscape units overlapping the GGB region, based on results from Ackerly et al. (2015). The four squares refer to a range of possible climate futures that vary with respect to temperature and precipitation, with the top and bottom squares representing wetter and drier scenarios, respectively, and the left and right squares representing scenarios projecting average annual temperature increases of greater than and less than 4.5°C, respectively. The color of the squares indicates the direction and magnitude of change in vegetation cover by 2050, with orange representing dramatic declines (less than 25% of current cover present), yellow representing moderate declines (25–75% of current), gray representing relatively stable cover (75–125% of current), and green represents increases (more than 125% of current).

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

- **Increasing air temperatures** enhance evapotranspiration rates, reducing water availability in riparian systems and impacting vegetation by reducing plant growth and increasing mortality (Perry et al. 2012). These climatic changes may drive shifts in riparian communities towards drought-tolerant species (including invasive species) and reductions in plant biodiversity (Catford et al. 2013; Kominoski et al. 2013).
- **Changes in precipitation patterns** can impact riparian forests by altering the timing and amount of water availability. Decreased precipitation can reduce the amount of water in streams, potentially leading to the loss of riparian vegetation (Portela et al. 2023). Drier conditions can also result in the reduction or elimination of scouring flows, particularly in regulated systems, which alter patterns of erosion and sediment deposition and can lead to vegetation encroachment (Gasith & Resh 1999; Janssen et al. 2020). Increased precipitation can cause flooding, erosion of stream banks, and damage and loss of riparian vegetation that result in reduced plant biodiversity (Garssen et al. 2017).
- **Increased drought** is associated with extreme reductions in the amount of water available to riparian vegetation that lead to decreases in plant growth and increases in mortality, particularly when droughts are persistent or repeated (Portela et al. 2023). Higher moisture stress in riparian areas could drive shifts towards more drought-tolerant and/or non-native species that replace those with high water needs such as cottonwoods and willows (Perry et al. 2012). Severe drought can have particularly significant impacts, particularly lower in watersheds where the effects of reduced flows are compounded by withdrawals to supply irrigation and drinking water (Stewart et al. 2020).
- Riparian forest systems are adapted to a dynamic and changing hydrology. However, changes in precipitation patterns, temperature and drought are likely to result in **altered stream flows**, with increasing variability and shifts in the onset and seasonality of drying and flooding likely to impact both the establishment and persistence of riparian forests (De Dios Miranda et al. 2009). For example, a study modeling the effects of climate change on riparian vegetation in southern Portugal rivers (which also experience a Mediterranean climate) suggest that future changes may result in reduced extent of riparian vegetation and the loss of pioneer and early-successional stages (Rivaes et al. 2013).
- **Sea level rise** will increase salinity, leading to upstream migration of tidal wetlands and loss of freshwater riparian vegetation (Hopkinson et al. 2008; Bay Area Open Space Council 2019).

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

- **Climate-driven changes in wildfire** driven by factors such as increased summer aridity and delayed onset of winter precipitation (Williams et al. 2019) are likely to increase plant mortality in riparian forests and woodlands, although vegetation losses tend to be less than in surrounding upland forests due to higher moisture content in riparian zones (Arkle & Pilliod 2010). However, wildfire impacts can be significant where fuel loads are high, particularly for lower-order streams in steep terrain (Hunsaker & Long 2014). Wildfire can also lead to increases in runoff and erosion that follow rain events on bare and damaged soils in burned areas (Shakesby & Doerr 2006). These impacts are likely to occur more often due to projected increases in the frequency and intensity of extreme rainfall under climate change, resulting in destruction of riparian vegetation and increased debris flows into and along stream channels (Cannon & DeGraff 2009). Wildfire can also have cascading effects on aquatic insects and predator-prey dynamics in riparian systems (Cooper et al. 2015). For example, severely burned areas were associated with greater rates of aquatic insect emergence and level of predator activity documented in an Idaho river system (Malison & Baxter 2010).

- Although flooding is a key disturbance regime in riparian systems, **increases in the severity of flooding** could impact riparian vegetation, particularly in systems that are already degraded or experiencing stress. Uncharacteristically severe floods (i.e., those that go significantly beyond the natural hydrologic variation these systems can tolerate) have the potential to lead to bank erosion and/or collapse, which in turn can result in damage or loss of riparian vegetation (Bendix & Hupp 2000). However, larger floods have the potential to distribute nutrients and seeds further into floodplains, which can support growth of riparian vegetation (Garssen et al. 2017).
- **Increases in severe storms** would be likely to increase direct loss of riparian trees from windthrow and breakage (Usbeck et al. 2010; Saad et al. 2017). Coastal storms can also intersect with sea level rise to exacerbate flooding impacts near the mouths of rivers (Odigie & Warrick 2017).

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.

- Significant **changes in land use,** particularly in the most densely populated areas of the San Francisco Bay Area, have led to widespread development in watersheds, with impacts that include deforestation and fragmentation, soil compaction, water withdrawals, and increases in impervious surfaces (Connor et al. 2002; Rickman & Connor 2003; Gonzales & Ajami 2017). These changes alter the functioning of watershed and stream processes, including provision of wildlife habitat, the ability to absorb and regulate stormwater runoff, and groundwater recharge (Paul & Meyer 2001; Riley et al. 2005).
- Historic and ongoing **agricultural practices** such as land clearing and soil compaction set the stage for gully formation that can eliminate riparian habitat where stream systems undergo severe degradation and channel incision (Swanson et al. 1989). Both agriculture and **livestock**

grazing also increase water demand for crop irrigation and animals, contributing to water withdrawals that reduce instream flows (Kiparsky & Gleick 2003) and compound drought impacts and associated water deficits (AghaKouchak et al. 2018). Livestock also impact streambanks and riparian areas where they congregate, trampling soils and vegetation and contributing to bank erosion and channel incisions (Belsky et al. 1999).

- Significant modifications have been made to many streams in the GGB region in association with **flood control structures, dams, and water diversions**, particularly in more urban areas where flooding is a concern for life and property. These modifications disconnect floodplains from mainstem rivers, reduce channel complexity, and contribute to channel incision resulting from sediment starvation, ultimately reducing riparian health and function (Kondolf & Curry 1986; Tockner & Stanford 2002; Opperman et al. 2009; Stella et al. 2013). Damming can also alter groundwater discharge patterns from riparian zones into the channel, resulting in higher instream temperatures (Hucks Sawyer et al. 2009). Flood control and water level regulation can also facilitate the establishment and spread of invasive species (Stella et al. 2013). Groundwater extraction may reduce the amount of water available to riparian vegetation (Scott et al. 1999), and climate change is likely to lead to increased groundwater use (Alam et al. 2019).
- **Invasive species** can outcompete native species, reducing the biodiversity and function of riparian ecosystems (Lambert et al. 2010). Invasive plant species that are problematic in riparian systems of the GGB region include Japanese knotweed (*Fallopia japonica*), Cape ivy (*Delairea odorata*), English ivy (*Hedera helix*), giant reed (*Arundo donax*), periwinkle (*Vinca major*), Himalayan blackberry (*Rubus armeniacus*) and, in estuarine riparian systems, cordgrass (*Spartina alterniflora*, *S. densiflora*), as well as bullfrogs (*Lithobates catesbeianus*), red-eared sliders (*Tachema scripta elegans*) and invasive fish including largemouth bass (*Micropterus salmoides*) and carp (*Cyprinidae* family), particularly in reservoirs (Herrera & Dudley 2003; Richardson 2003; Farrell et al. 2016; Baumgarten et al. 2021; Kupferberg et al. 2022; CDFW 2023). These invasive species can create significant changes across riparian communities. For example, giant reed is known to have reduced the diversity and abundance of stream-associated invertebrates where it displaced native vegetation in riparian systems of central California (Herrera & Dudley 2003). Giant reed also increases wildfire risk, and it exhibits rapid growth and increased post-fire dominance in burned areas compared to native riparian vegetation (Coffman et al. 2010). However, impacts of invasive species with climatic changes are complex, and not necessarily only additive. Modeling of bullfrog and California red-legged frog (*Rana aurora draytonii*) populations suggested that winter flooding events, which are likely to become stronger and more frequent in the region (Flint & Flint 2012), have greater negative impacts on bullfrogs, which may benefit native frogs (Doubledee et al. 2003).

Sensitivity to other factors → Moderate *(moderate confidence)*

- Climate-driven reductions in anadromous fish populations are likely to have cascading impacts on riparian vegetation through reduced inputs of marine-derived nutrients (Dennert et al. 2023). Currently, anadromous salmonids (*Oncorhynchus* spp.) and Pacific lamprey (*Entosphenus tridentatus*) transfer nitrogen and other plant nutrients from marine to riverine ecosystems when they spawn and die. Reductions in this nutrient subsidy could result in diminished vegetative growth, altered community diversity, and changes to food webs.

Adaptive Capacity → Low *(moderate 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)

Riparian areas in the GGB region are severely degraded and constrained by stressors such as land use conversion, particularly in the more densely populated areas around San Francisco Bay (Nicely et al. 2007; Quinones & Moyle 2014). Extensive land use changes and direct modifications to stream systems have occurred since European settlement in the late 18th century, leading to loss of wetlands and riparian vegetation, spread of invasive species, and consequent shifts in vegetation assemblages (Baumgarten et al. 2021). Many floodplains and riparian areas have been disconnected from mainstem streams and rivers, reducing their ability to provide wildlife habitat (Quiñones & Moyle, Peter 2014) and store floodwaters (Fritz et al. 2018). Despite these impacts, many riparian vegetative communities do continue to provide important ecosystem services (Baumgarten et al. 2021). As the climate changes, corresponding changes in stream and riparian habitats may differentially affect species that depend on them depending on how their ability to move into newly-suitable areas, with range-restricted endemic species being particularly vulnerable to population declines and extirpation (Rogers et al. 2020).

Ecosystem diversity → Moderate (moderate confidence)

Streams in the GGB region support diverse vegetation communities, including willow-oak forest, oak-dominated forest and scrub, and oak and bay riparian forests, as well as an array of understory species (Baumgarten et al. 2018, 2021; CNPS 2023). These, in turn, support hundreds of mammals, birds, amphibians and reptiles (RHJV 2004). The upper reaches of riparian habitats, which often coincide with areas less intensively developed for human use, tend to be more intact and less subject to disturbances such as noise and human activity, and these are of particular importance to migratory passerines (RHJV 2004; Riensche et al. n.d.). This interdependency between wildlife and less disturbed vegetative communities is likely to increase in importance as climate change continues to impact riparian systems.

Resistance and recovery → Moderate (moderate confidence)

Riparian systems with intact hydrological regimes are dynamic and adapted to recover from a variety of disturbance regimes over time (Bendix & Hupp 2000; Broadmeadow & Nisbet 2004; Barron-Gafford et al. 2021; Portela et al. 2023). However, recovery is challenged by both climate-driven changes and non-climate stressors (Swanson et al. 1989; Caldwell et al. 2012; Colloff et al. 2016). Factors such as fragmentation, loss of riparian vegetation, and changes in hydrologic regimes limit resistance to climate change in riparian systems, and may prevent post-disturbance recovery (Bêche et al. 2009; Jones et al. 2010; Quiñones & Moyle, Peter 2014; Baumgarten et al. 2021). For example, ongoing deterioration of riparian forest health may occur as a result of non-climate stressors that lead to channel incision and associated declines in the level of the water table, combined with increased drought and longer dry seasons associated with climate change (Stella et al. 2013).

Riparian forests are a critical transitional zone between aquatic and terrestrial habitats and are recognized for their many ecological functions including habitat provision, flood attenuation, erosion control, and storage and release of water between stream channels and upland areas (Broadmeadow & Nisbet 2004; Klapproth & Johnson 2009; Baumgarten et al. 2021). Riparian systems can function as important refugia for aquatic organisms during periods of environmental stress by providing pools and low-velocity backwaters, and thermal refugia such as areas of high groundwater input and shaded areas (Sedell et al. 1990; Ebersole et al. 2001). These important functions make a strong argument for the roles of active conservation, stewardship and restoration to help riparian systems resist climate and non-climate stressors and recover from stressful events (Seavy et al. 2009; Lennox et al. 2011; Baumgarten et al. 2021).

Management potential → Moderate (moderate confidence)

The functions provided by riparian ecosystems are likely to become even more important in the face of changing climate conditions, including increased temperatures and hydrologic variability (Karamouz et al. 2011). Given that riparian ecosystems in the GGB region are already fragmented and degraded, the highest management priority may be to protect remaining intact areas (Vuln. Assessment Worksheets, pers. comm., 2022). Management practices that enhance the structure and function of riparian systems may help limit the impacts of climate change and increase the likelihood of recovery following disturbances, even in degraded areas. These include enhancing forest structural diversity (Portela et al. 2023), restoring variable flow regimes in areas impacted by dams and water diversions (Poff & Zimmerman 2010), reconnecting floodplains with mainstem channels (Justice et al. 2017), controlling invasive species to increase riparian health and function (Baumgarten et al. 2021), and reducing water withdrawals to maintain or increase stream flows that support riparian areas, particularly during periods of high temperatures and drought (Caldwell et al. 2012). Climate change may also necessitate increased flexibility (e.g., changes in timing) of restoration efforts due to greater uncertainty and climatic variability (Perry et al. 2015).

Support for climate-informed management of riparian ecosystems is challenged by lack of public awareness of their importance as a natural resource (Vuln. Assessment Worksheets, pers. comm., 2022). An important exception may be their value to birders and bird conservation organizations (Ballard et al. 2004). Climate-driven declines in the extent of riparian systems also have the potential to highlight their value to the public in terms of recreational and wildlife observation opportunities, as well as respite from heat (Colloff et al. 2016). The close association between riparian systems and wetlands affords them some measure of regulatory protection at state and local levels (State of California 2019), though the rules around setbacks and buffers can be inconsistent across jurisdictions (Vuln. Assessment Worksheets, pers. comm., 2022). Because significant resources are being allocated in this region towards wetland restoration (Breaux et al. 2005; Vuln. Assessment Worksheets, pers. comm., 2022), integration of riparian forests and woodlands into these projects would greatly benefit these ecosystems.

Recommended Citation

EcoAdapt. 2024. Riparian forests and woodlands: Climate change vulnerability assessment summary for the Golden Gate Biosphere region. EcoAdapt, Bainbridge Island, WA.

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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