Coastal Prairie

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for coastal prairie 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

Coastal prairie is a native grassland community found in the central and northern regions of California, near shorelines and on hills, bluffs, terraces, and valleys (Holland 1986; Stromberg et al. 2001; Ford & Hayes 2007; Steers & Spaulding 2013; Vuln. Assessment Worksheets, pers. comm., 2022). Coastal prairie vegetation associations are closely linked to Pacific coastal climates (Corbin et al. 2005; Everard et al. 2010), as well as topographic position, and are sustained by disturbances such as fire and grazing (Ford & Hayes 2007). They are sometimes further categorized into bald hills prairies, which are found on drier coastal ridges, and coastal terrace prairies, which occur on marine terraces in relatively moister settings (Holland 1986; Stromberg et al. 2001; Vuln. Assessment Worksheets, pers. comm., 2022).

Coastal prairies are characterized by dense perennial grasses and a variety of forb species. Dominant perennial bunchgrasses may include purple needlegrass (*Stipa pulchra*), Idaho and red fescue (*Festuca idahoensis, F. rubra*), and California oatgrass (*Danthonia californica*; Stromberg et al. 2001; Ford & Hayes 2007; Steers & Spaulding 2013; CNPS 2023). They host many annual and perennial forbs, including native wildflowers like California poppies (*Eschscholzia californica*) and seaside daisies (*Erigeron glaucus*; Ford & Hayes 2007; Vuln. Assessment Worksheets, pers. comm., 2022). Coastal prairie is also habitat for numerous sensitive plant species such as federally-endangered Sonoma spineflower (*Chorizanthe valida*), golden larkspur (*Delphinium luteum*), and Hickman's potentilla (*Potentilla hickmanii*) (E. Wrubel, pers. comm., 2023). These diverse grasslands also support a variety of mammals, birds, and invertebrates, many of which are rare or endangered (Stromberg et al. 2001; Ford & Hayes 2007; Steers & Spaulding 2013).

Prominent areas of coastal prairie within the GGB region include Point Arena, Fort Ross, Salt Point, Sea Ranch, the Sonoma Coast, Point Reyes National Seashore, the Marin Headlands, and the San Mateo coast (e.g., Mori Point; Kraft et al. 2007; Steers & Spaulding 2013). Coastal prairies are considered rare throughout California and are labeled endangered plant communities by the California Natural Diversity Database (Minnich 2008). These ecosystems are also categorized as sensitive by the California Department of Fish and Wildlife (CDFW 2023b) and the California Coastal Commission (Ford & Hayes 2007).

Ecosystem Vulnerability → Moderate *(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

Coastal prairies are sensitive to climate stressors and changes in disturbance regimes that cause shifts in species distribution, composition, and overall ecosystem health, including changes in precipitation patterns, increased drought, heat waves, sea level rise and storm surge, altered wildfire regimes, and increased pests and pathogens. Changes in these factors are likely to influence plant growth and nutrient availability, potentially increasing the dominance of non-native species, and drive shifts in community composition and ecosystem distribution. Invasive exotic species represent a significant stressor for coastal prairies, as they outcompete and exclude native species and contribute to altered fire regimes. Fire exclusion and suppression have also resulted in degradation of these systems via woody plant encroachment, and other non-climate stressors such as urban development and agriculture have contributed to significant loss and fragmentation of coastal prairies within the region. If these threats are not addressed, they could reduce the ability of coastal prairie to adapt to climate change over time.

Coastal prairies in the GGB region have declined dramatically as a result of human land uses, which together with woody vegetation encroachment and the introduction of invasive species have fragmented and degraded remnant prairies. Coastal prairies generally have high species richness, which can promote stability and the maintenance of ecosystem services even during stressful environmental changes. Additionally, many native plant species in coastal prairies are well-adapted to disturbances such as wildfire, grazing, and drought. However, the resilience of this ecosystem can be compromised when degraded (e.g., following invasion by non-native and woody species) or subjected to severe disturbances (e.g., overgrazing). Climate-informed management efforts that may enhance the ability of this system to cope with change include restoration plantings, the use of prescribed fire to maintain appropriate burn intervals, mechanical removal of woody plants to mitigate encroachment, and public education to promote stewardship.

Sensitivity and Exposure → Moderate *(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 → Moderate *(moderate confidence)*

- **Changes in the amount and timing of precipitation** can have effects on the productivity, abundance, and distribution of plant species within coastal prairie ecosystems (Fenn et al. 2010; Pfeifer-Meister et al. 2016; Del Vecchio et al. 2018; Kiss et al. 2018). Changes in precipitation influence soil moisture levels, which are crucial for plant growth and nutrient availability (Fenn et al. 2010). Coastal prairies are characterized by competition for moisture, with invasive annual species generally outcompeting native perennials in areas with low levels of soil moisture, while native perennials tend to be more successful in high-moisture environments (Everard et al. 2010). Many native coastal prairie species have been found to utilize condensed water from fog, which helps them survive during the dry summer months (Corbin et al. 2005). However, estimates suggest that the frequency of summer fog has decreased by 33% since the early 20th century (Johnstone & Dawson 2010), and these trends may continue in the future. Decreases in moisture availability would likely limit reduce the recruitment of late-successional woody species from adjacent scrub habitats, with benefits for the integrity of coastal prairie ecosystems (Da Silva & Bartolome 1984; Williams & Hobbs 1989; Ford & Hayes 2007). Conversely, during times of increased precipitation, species such as coyote brush (*Baccharis pilularis*) are likely to expand into coastal prairies during wetter periods, which may cause a decline in grassland forbs due to increased competition (Da Silva & Bartolome 1984; Williams et al. 1987; Williams & Hobbs 1989; Ford & Hayes 2007; Kidder 2015; Pfeifer-Meister et al. 2016).
- **Increases in extended periods of severe drought** may lead to changes in grassland species composition, including a shift in dominance toward invasive annual species (Everard et al. 2010; Pfeifer-Meister et al. 2016), as well as reduced herbaceous cover, species richness, and productivity (Copeland et al. 2016). However, many coastal prairie species have evolved adaptations to cope with periodic droughts (Corbin et al. 2005; Vuln. Assessment Worksheets, pers. comm., 2022; Luong et al. 2023b). For instance, bunchgrasses have developed deep roots that increase access to water, and many species, including California oatgrass, purple needlegrass, and red and Idaho fescue, can mitigate summer drought stress through the uptake of condensed moisture from fog (Corbin et al. 2005; Emery 2016; Vuln. Assessment Worksheets, pers. comm., 2022; Luong et al. 2023b).
- **Heat waves** occur as punctuated disturbances, and can cause rapid, severe desiccation of plant tissues. They affect plant populations by killing off seedling cohorts, or disrupting flowering or fruiting cycles. Heat extremes can cause more damage to grasslands than milder, year-round increases in surface temperature, especially during drought periods (White et al. 2000; Van Peer et al. 2004).
- **Sea level rise and storm surge** are likely to contribute to the erosion of coastal ecosystems, including the coastal bluffs where many prairies occur (Garner et al. 2015; Vuln. Assessment Worksheets, pers. comm., 2022). Over time, erosion associated with sea level rise and storm

surge has the potential to reduce ecosystem extent (Garner et al. 2015). For instance, the endangered coast yellow leptosiphon (*Leptosiphon croceus*) residing on the Vallemar Bluff in Moss Beach (San Mateo County) is vulnerable to erosion, and further loss of their habitat threatens their future survival (CDFW 2023a). The effects of coastal erosion are particularly concerning in areas where development such as houses or roads has already narrowed habitat for rare species such as the yellow leptosiphon (Vuln. Assessment Worksheets, pers. comm., 2022; CDFW 2023a).

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

- **Altered wildfire regimes** have the potential to significantly impact the future persistence of coastal prairie ecosystems (Ford & Hayes 2007). Coastal prairies are historically adapted to fire (Ford & Hayes 2007; Stromberg et al. 2007; Chambers et al. 2019), which benefits native species by reducing competition with woody plant species, releasing nutrients, and increasing access to sunlight (D'Antonio et al. 2002; Vuln. Assessment Worksheets, pers. comm., 2022). Fires can also help limit the expansion of some invasive species; this is the case for ripgut brome (*Bromus diandrus*), as their seeds appear more susceptible to direct contact with flames compared to the seeds of native species (Sweet et al. 2008; Monaco et al. 2016). Historically, a combination of natural fires and cultural burning practices helped maintain the mosaic pattern of coastal prairie and coastal scrub ecosystems in the San Francisco Bay Area (Ford & Hayes 2007; Keeley et al. 2011; Vuln. Assessment Worksheets, pers. comm., 2022). However, fire exclusion and suppression has resulted in the succession of coastal prairie to coastal scrub species in many areas (Vuln. Assessment Worksheets, pers. comm., 2022).
- **Pests and pathogens** can influence plant species abundance and composition in coastal prairie habitats (Malmstrom et al. 2005a; MacDonald et al. 2012; Karunarathna et al. 2021). Periods of increased precipitation could influence the presence and spread of fungal pathogens, which are associated with decreased species diversity (Karunarathna et al. 2021). Additionally, diseases that reduce the population of native species may provide invasive plants with an advantage, potentially leading to a shift in dominant vegetation toward non-natives (D'Antonio & Vitousek 1992; Malmstrom et al. 2005b). Invasive annual grasses are also known to contribute to the spread of non-native diseases such as barley and cereal yellow dwarf viruses. These are spread via aphid vectors to native perennial grasses, which can lose as much as 30% of their vegetative and reproductive vigor when infected (Malmstrom et al. 2005b). The fungal pathogen *Stemphylium solani* is also prevalent in coastal prairies of central California and can lead to leaf necrosis and early senescence of native clover species, impacting their survival (Gilbert & Parker 2010). The *Lupine anthracnose* disease, which is caused by the fungus *Colletotrichum lupini*, is known to destroy the host plant populations of the endangered mission blue butterfly (*Icaricia icarioides missionensis*), and is believed to have contributed to the decline of this species in the

San Francisco Bay Area (Ford & Hayes 2007; MacDonald et al. 2012). The presence of *L. anthracnose* can be attributed to uncharacteristically wet winter and spring seasons (Vuln. Assessment Worksheets, pers. comm., 2022), which provide the optimal conditions for disease development (e.g., prolonged leaf wetness; Velásquez et al. 2018).

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.

- **Invasive plants** drive declines in native species through competition for essential resources (e.g., water, sunlight, nutrients), in part due to their ability to thrive in a wide range of environmental conditions, reproduce quickly, and disperse efficiently (D'Antonio & Vitousek 1992; Levine & D'Antonio 1999; Dukes & Mooney 2004; Corbin & D'Antonio 2004; Vilà et al. 2011; Pfeifer-Meister et al. 2016; Luong et al. 2023b). In the San Francisco Bay Area, native bunchgrasses such as purple needlegrass and California oatgrass are experiencing population declines due in part to the competitive pressure of invasive species during their seedling growth stages (Corbin & D'Antonio 2004; Luong & Loik 2021; Luong et al. 2023b). Invasive plants can also alter soil composition in coastal prairies, leading to increased nitrogen concentrations and reduced soil moisture, which, in turn, affects nutrient cycling and native plant species composition (D'Antonio & Vitousek 1992; Ehrenfeld 2003; Parker & Schimel 2010). Invasive plant species can also disrupt fire regimes by altering fuel type and availability (D'Antonio & Vitousek 1992; Hobbs & Huenneke 1992; Brooks et al. 2004; Diez et al. 2012; Chambers et al. 2019; Fusco et al. 2019; Sample et al. 2022), with negative consequences for native plants and wildlife (Bachen et al. 2018; Mayfield et al. 2021).
- **Residential and commercial development** has significant effects on coastal prairie extent and continuity, and is considered one of the greatest threats to their persistence (Alberti 2005; Ford & Hayes 2007; Reed et al. 2011). Fragmentation due to development and urban sprawl decreases species richness and leads to reduced gene flow in isolated populations, which can result in declines in genetic diversity and increased vulnerability to environmental changes (Trombulak & Frissell 2001; Grimm et al. 2008; Elmqvist et al. 2016). Fragmentation can also cause the extirpation of native species from their traditional coastal prairie habitats (e.g., the Ohlone tiger beetle ([*Cicindela ohlone*]; Bartolome et al. 2004, 2014).
- **Agricultural development** is associated with increased pollution and disruptions to native species composition (Ford & Hayes 2007). Native plant communities are unlikely to remain intact on lands that have been continually fertilized, irrigated, or cultivated, even in the soil seed bank. Generally, the center of these fields lack native grasses, and any dispersal that does occur does so slowly and along the field's borders (Stromberg & Griffin 1996; Ford & Hayes 2007). Even where farmers converted agricultural fields back into open grasslands, they often have few species characteristic of natural grasslands (Ford & Hayes 2007).

- Coastal prairies are dependent on fire to maintain ecosystem structure and biodiversity (Buisson et al. 2006; Ford & Hayes 2007; Stromberg et al. 2007; Archer et al. 2017), and **fire exclusion and suppression** can pose a direct threat to native species in these ecosystems by creating conditions that allow invasive species to proliferate (Moyes et al. 2005; Monaco et al. 2016). For instance, thatch accumulation can impede the growth of native forbs by limiting sunlight exposure and reducing soil temperature, which provides a competitive advantage to invasive species (D'Antonio et al. 2002; Eviner 2014) such as ripgut brome (Moyes et al. 2005; Monaco et al. 2016). Fire exclusion can also result in soil nutrient depletion that limits germination and/or seed production of fire-dependent species (D'Antonio et al. 2002). In the absence of fire, encroachment of woody plants such as coyote brush and Douglas-fir (*Pseudotsuga menziesii*) often occurs within coastal prairies, which over time can result in type conversion of grasslands to shrublands or woodlands (Ford & Hayes 2007; Stromberg et al. 2007; Vuln. Assessment Worksheets, pers. comm., 2022).
- **Roads and highways** influence coastal prairie structure and species composition (Coffin 2007), and create barriers that disrupt wildlife movement and dispersal (Forman & Alexander 1998; Coffin 2007). In the San Francisco Bay Area, Highway 1 cuts through coastal prairie ecosystems along the coastline (Vuln. Assessment Worksheets, pers. comm., 2022). Fragmentation such as this can isolate plant and animal populations, affecting genetic diversity and reproductive success and likely reducing resilience to climate change (Spellerberg 1998; Trombulak & Frissell 2001). The presence of roads can also increase vehicle-related mortality in animals that depend on coastal prairie habitats, such as the endangered San Francisco garter snake (*Thamnophis sirtalis tetrataenia*; Coffin 2007; Halstead et al. 2011).
- **Livestock grazing** in coastal prairies can be an effective method to prevent shrub encroachment (Ford & Hayes 2007), maintain vegetation structure (Bartolome et al. 2014), and reduce invasive grasses (Hayes & Holl 2003). However, the success of this strategy depends on that timing, frequency, duration, and intensity of grazing. If not managed properly, grazing can have significant negative impacts on coastal prairies (Stahlheber & D'Antonio 2013; Bartolome et al. 2014). For example, grazing late in the season can harm the survival of some perennial grasses, with potential impacts on prairie species composition. Grazing can also sometimes result in an increase in non-native forb species (Stahlheber & D'Antonio 2013).
- **Recreational activities** such as hiking, biking, and off-road vehicle use can harm native species through trampling and impacts to competition dynamics (Bartolome et al. 2004; Wolf et al. 2017; Luong et al. 2023b, 2023a). This is especially likely when these activities cause frequent, significant soil disturbances (Luong et al. 2023b), though the degree of impact from these activities can vary across species. For example, in coastal prairies, disturbances can benefit purple needlegrass growth but negatively influence its ability to reproduce due to an increase in culm sterility (Luong et al. 2023b). By contrast, native California oatgrass generally maintains growth and reproductive capability along regularly-disturbed paths used for foot and bike

traffic (Luong et al. 2023b). This, however, is also true for some invasive species (e.g., *Dactylis glomerata*), which may give them a competitive advantage in areas where higher concentrations of native species are negatively impacted by these disturbances (Luong et al. 2023b).

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)

California has lost nearly 99% of its native grasslands since early European settlement, including a 90–95% loss of the original extent of coastal prairie (Noss & Peters 1995; Vuln. Assessment Worksheets, pers. comm., 2022). In the San Francisco Bay Area, urbanization in the late 19th century resulted the loss of over 20% of San Francisco's coastal prairie, and the remaining areas continue to be subject to developmental pressure that fragments and degrades these ecosystems (Ford & Hayes 2007; Vuln. Assessment Worksheets, pers. comm., 2022). Smaller patches of prairie, in particular, are usually composed of perennial grasses and are thought to be more vulnerable to the impacts of climate change due to their isolation and species homogeny (Ackerly et al. 2010; Vuln. Assessment Worksheets, pers. comm., 2022). Coastal prairie ecosystems in the San Francisco Bay Area also contain numerous barriers to wildlife dispersal (e.g., agricultural areas, roads, geologic features) that can limit the movements of animals, restrict access to vital resources, and isolate populations, potentially affecting their ability to reproduce (Ford & Hayes 2007; Vuln. Assessment Worksheets, pers. comm., 2022).

Ecosystem diversity → High (high confidence)

Coastal prairies are diverse ecosystems characterized by a high degree of heterogeneity in structure and composition, which is influenced by fluctuations in soil moisture (Stromberg et al. 2001; Steers & Spaulding 2013; Pfeifer-Meister et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022). These ecosystems support high plant diversity, including 80 species that are endemic to California (Stromberg et al. 2001; Ford & Hayes 2007). Annual forb species, in particular, contribute to the high overall biodiversity of this system (Stromberg et al. 2001; Ford & Hayes 2007; Lesage et al. 2022), and wetter sites near the coast tend to be more species-rich compared to prairies located farther inland (Ford & Hayes 2007). The overall diverse species composition of these prairies may promote stability and maintenance of ecosystem services such as pollination, even during stressful environmental changes (Tilman & Downing 1994). However, fragmentation as a result of development and roads can isolate populations, reducing genetic exchange and biodiversity (Trombulak & Frissell 2001; Coffin 2007;

Grimm et al. 2008; Elmqvist et al. 2016), and this may decrease the ability of the ecosystem to maintain productivity as the climate changes (Tilman & Downing 1994; Isbell et al. 2015; Vuln. Assessment Worksheets, pers. comm., 2022).

Coastal prairies are also home to a wide variety of herbivores and pollinators that depend on the ecosystem's diverse plant resources for food, shelter, and nesting materials (Stromberg et al. 2001; Evens et al. 2006; Ford & Hayes 2007). These include many sensitive species such as the San Francisco garter snake, Ohlone tiger beetle, California red-legged frog (*Rana draytonii*), mission blue butterfly, Myrtle's silverspot butterfly (*Speyeria zerene myrtleae*), Callippe silverspot butterfly (*Speyeria callippe callippe*), and Bay checkerspot butterfly (*Euphydryas editha bayensis*; Stromberg et al. 2001; Ford & Hayes 2007; Halstead et al. 2011; Steers & Spaulding 2013; Luong et al. 2023a; CNDDB 2023).

Resistance and recovery → Moderate (moderate confidence)

Coastal prairie vegetation exhibits considerable resistance to moderate disturbances such as drought, grazing, and fire (Corbin et al. 2005; Buisson et al. 2006; Vuln. Assessment Worksheets, pers. comm., 2022). In fact, coastal prairies are dependent on disturbances to maintain ecosystem structure and biodiversity and prevent woody and non-native species encroachment (D'Antonio et al. 2002; Hayes & Holl 2003; Buisson et al. 2006; Stromberg et al. 2007; Archer et al. 2017; Lesage et al. 2022). Without fire, for example, thatch buildup may result in native forb species failing to germinate, potentially contributing to their decline (D'Antonio et al. 2002; Hayes & Holl 2003; Ford & Hayes 2007).

Coastal prairie species also have adaptive traits that allow them to persist during and after disturbances (Bartolome et al. 2004, 2014). For example, seedbanks of annual species remain viable for extended periods of time, allowing germination to occur when there are favorable environmental conditions. This aids in species recovery and survival following disturbances (e.g., fire) and in response to climate variability (Bartolome et al. 2014). However, the resilience of these ecosystems can be compromised when subjected to severe disturbances such as overgrazing or extensive tillage, which can lead to the depletion of native perennial propagules and increase vulnerability to invasion by woody and non-native species (Lesage et al. 2022; Vuln. Assessment Worksheets, pers. comm., 2022).

Management potential → Low (moderate confidence)

Coastal prairies are often overlooked in favor of more famous natural landmarks such as redwoods, but they do hold value to the public for tourism during super blooms as well as for botanists, bird watchers, and indigenous tribal interests (Vuln. Assessment Worksheets, pers. comm., 2022). Coastal prairies have received regulatory support in the form of protection from the Federal Coastal Zone Management Act of 1972 (16 U.S.C. § 1451) and the California Coastal Act of 1976 (Division 20 of the California Public Resources Code), which impose restrictions on shoreline development that reinforce the importance of conserving these ecosystems. Societal support is also growing for practices such as controlled burns that could help maintain the integrity of coastal prairies (Vuln. Assessment Worksheets, pers. comm., 2022). Nonetheless, despite their dedication and contributions,

organizations like the California Native Grassland Association and the California Native Plant Society remain relatively small and underrecognized in their efforts to conserve coastal prairies (Vuln. Assessment Worksheets, pers. comm., 2022).

To maintain the balance between coastal prairie and coastal scrub habitats, management techniques such as the mechanical removal of coyote brush and Douglas-fir as well as invasive species, along with the systematic use of prescribed fires, can prove to be effective (Ford & Hayes 2007; Monaco et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022). Prescribed fires are a valuable tool for reducing annual grass and invasive species thatch cover, particularly in late spring when heavy cover can hinder the growth of native plants (Fenn et al. 2010; Monaco et al. 2016; Luong & Loik 2021). Coastal prairies are, however, already very impacted by invasive species and it is difficult for managers to eradicate them once they have become established (Vuln. Assessment Worksheets, pers. comm., 2022). Overall, the capacity of managers to implement climate-informed strategies is limited by resource availability and staff capacity (Vuln. Assessment Worksheets, pers. comm., 2022). Implementation of small-scale restoration and conservation efforts are often more feasible, as regional or landscape-scale interventions are much more complex and time-intensive (Luong & Loik 2021; Vuln. Assessment Worksheets, pers. comm., 2022).

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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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