Serpentine Endemic Rare Plants

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for serpentine endemic rare plants 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.

Species Group Description

Serpentine endemic rare plants are uniquely adapted to serpentine habitats, characterized by soils that are derived from the weathering of ultramafic rocks, particularly serpentinite and peridotite (Kruckeberg 1985; Williams 2016). Serpentine soils exert a profound influence on the plant diversity that can flourish in them as they are typically deficient in nutrients (e.g., nitrogen, phosphorous, potassium, calcium) and harbor high and often toxic concentrations of elements such as magnesium and iron as well as a variety of heavy metals (Safford et al. 2005; O'Dell & Rajakaruna 2011; Williams 2016; NPS 2019; Safford & Miller 2020). Additionally, these soils are frequently shallow and rocky with diminished water-holding capacity, further contributing to an ecologically stressful environment that often results in restricted plant growth and sparse vegetation cover (O'Dell & Rajakaruna 2011). Serpentine soils, however, do support many specialized plant species adapted to thrive in these challenging conditions, including rare and endemic species (O'Dell & Rajakaruna 2011; Safford & Miller 2020). Notable serpentine endemic rare species within the Golden Gate Biosphere (GGB) region include: Presidio manzanita (*Arctostaphylos montana* ssp. *ravenii*), Presidio clarkia (*Clarkia franciscana*), Marin western flax (*Hesperolinon congestum*), Franciscan manzanita (*Arctostaphylos franciscana*), fountain thistle (*Cirsium fontinale var. fontinales*), Tiburon mariposa lily (*Calochortus tiburonensis*), Baker's manzanita (*Arctostaphylos bakeri* spp. *bakeri*), white-rayed pentachaeta (*Pentachaeta bellidiflora*), and San Mateo thorn mint (*Acanthomintha duttonii*; NPS 2019; Vuln. Assessment Worksheets, pers. comm., 2022; Calflora 2023). These species rank as 1B.1 on the California Rare Plant Rank scale, meaning they are rare and seriously threatened in California and elsewhere (CNPS 2023). They are also listed as threatened or endangered at the federal level (CNPS 2023).

The GGB region contains a variety of serpentine habitats that all host serpentine endemic rare species, including barrens, conifer forests, grasslands, chaparral, and scrub (Figure 1; UNESCO 2016; Vuln. Assessment Worksheets, pers. comm., 2022). In contrast to the majority of California, the North Coast range (which encompasses most of the GGB region) exhibits significantly elevated occurrences of serpentine endemic species, with 127 serpentine endemic taxa identified in this area (Safford & Miller 2020).

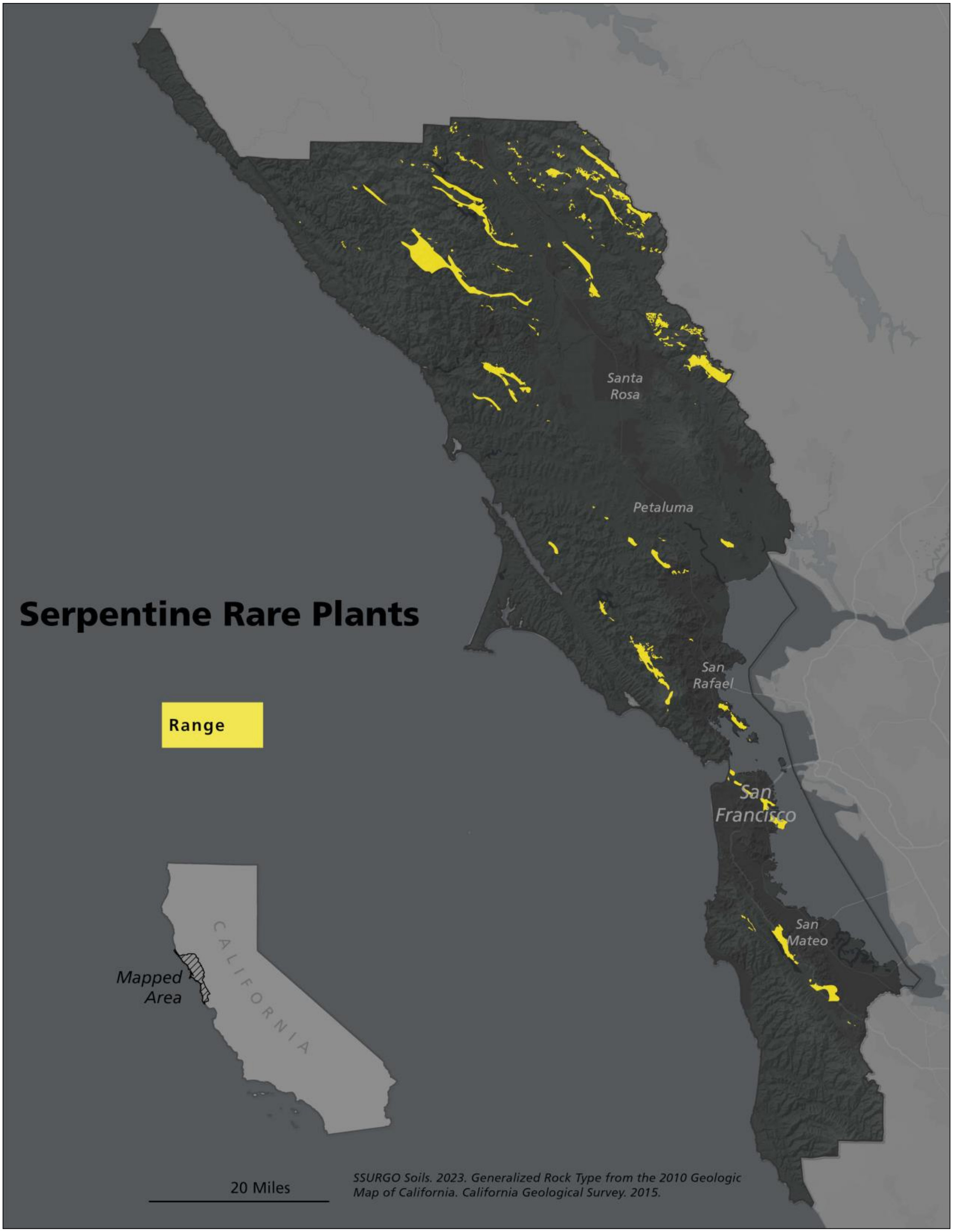

Figure 1. The range of serpentine rare plants within the GGB region, as indicated by the presence of serpentine soils (map provided by the National Park Service).

Species Vulnerability → Moderate *(moderate confidence)*

Vulnerability is evaluated by considering the species group's sensitivity and exposure to various climate and non-climate stressors as well as the species group'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 species vulnerability

Serpentine endemic rare plants exhibit sensitivity to climate changes and disturbances, including changes in air temperature, heat waves, interannual precipitation variability, drought, and wildfire. These factors can impact plant growth, nitrogen deposition, availability of refugia, invasive species introductions and establishment, and habitat fragmentation. Non-climate stressors such as fire exclusion and suppression, pollution, and development can amplify the detrimental impacts of climate change, potentially resulting in the decline of rare plant species.

Limited connectivity, exacerbated by various stressors, can hinder endemic species dispersal and threaten habitat integrity. However, this isolation can also drive selective pressures promoting adaptation and diversification in serpentine endemics, enhancing their resilience to thrive in harsh environments. Although they are resistant to many environmental stressors, human disturbances may impede the ability of serpentine rare endemic species to recover from the impacts of climate change, particularly given their restricted dispersal capacity. To address these challenges, climate-informed conservation and management strategies are likely to focus on minimizing human-induced disturbances and mitigating the introduction of non-native species. Furthermore, a concerted effort should be made to identify and safeguard potential climate refugia, and the utilization of native seed banks could prove useful in assisting species recovery following major disturbances.

Sensitivity and Exposure → Moderate *(moderate confidence)*

***Sensitivity** is a measure of whether and how a species group 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 a species group 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 a species group is less vulnerable.*

Sensitivity and future exposure to climate factors → Moderate *(low confidence)*

- **Increased air temperature and heat waves** are likely to influence the growth of serpentine specialists, though overall these species are likely well-adapted to resist the negative impacts of this climate stressor. Serpentine species exhibit functional traits that may confer reduced sensitivity to rising temperatures, including relatively large root systems, dwarfed/small stature, and xeromorphic foliage adaptations that aid survival in arid environments (Damschen et al. 2012). Additionally, certain serpentine species that inhabit areas near or directly beneath canopy cover are less sensitive to increased air temperatures compared to those in open understories (Harrison et al. 2020). However, heat waves and elevated temperatures may also lead to the local extinctions of endemic plant species, especially for disconnected populations inhabiting discontinuous habitats (e.g., island-like distributions; Ackerly 2003; Harrison & Noss 2017). Increased temperatures may also exacerbate moisture stress in this already water-limited environment, reducing plant growth rates and threatening their survival and reproductive output (Tadros 1957).

- **Changes in precipitation patterns**, such as decreased annual precipitation and longer, drier dry seasons, may benefit serpentine endemic species. Harsh soil conditions in serpentine substrates hinder non-serpentine species' growth and survival, especially during dry spells (Kruckeberg 1954; Gram et al. 2004; Harrison & Noss 2017; Rossington et al. 2018). These conditions reduce competition from non-serpentine species, turning habitats such as dry serpentine outcrops into potential refugia for serpentine species (Kruckeberg 1954; Gram et al. 2004; Brady et al. 2005; Rossington et al. 2018; Vuln. Assessment Worksheets, pers. comm., 2022). Conversely, increased precipitation during the wet season can make it easier for non-native/non-serpentine species to become established, increasing competition for resources and potentially resulting in displacement of serpentine endemics. Over time, the distribution of serpentine endemic rare species may shift toward drier areas where competitive pressure from non-serpentine species is reduced (Rossington et al. 2018). Because serpentine species are adapted to nitrogen-deficient soils, increases in nitrogen deposition (i.e., from industrial, road, or other urban sources) resulting from increased runoff during and after heavy rain events can also affect serpentine plant communities, with wetter years favoring non-native species by enhancing seed production and growth (Huenneke et al. 1990; Eskelinen & Harrison 2014). In the absence of abundant non-native species, however, native serpentine forbs have been known to respond positively to the addition of macronutrients (i.e., nitrogen and phosphorus; Huenneke et al. 1990). If their thresholds for tolerances are not crossed, serpentine species may be able to withstand potential increases in macronutrient concentrations under wetter conditions. Increased precipitation may also lead to more ground litter due to increased biomass production from native and non-native grasses, resulting in a decline in the richness of endemic forbs that generally require lower light and temperature levels for germination (Weiss 1999).
- **Increased drought** beyond historical norms and stress thresholds may pose challenges to the survival of serpentine species and impact species richness and diversity (Damschen et al. 2010; Copeland et al. 2016). While serpentine endemic rare plants have evolved specialized adaptations to thrive in environments characterized by low water availability (e.g., reduced leaf sizes; O'Dell & Rajakaruna 2011). For instance, several *Arctostaphylos* species have been found

to have a strong resistance to cavitation stress and retain a “safety margin,” particularly maritime and transitional species (Jacobsen & Pratt 2013). However, soil moisture is a crucial factor that influences distribution at the local level (Rossington et al. 2018), contributing to reproductive isolation that can result in further adaptation to the serpentine ecological niche and/or changing environmental conditions over time (Yost et al. 2012; Rossington et al. 2018). However, some serpentine species, such as fountain thistle (which is limited to seeps and springs) may be particularly sensitive to extreme and/or prolonged drought (Vuln. Assessment Worksheets, pers. comm., 2022).

Drought can disrupt the timing of critical life cycle events, such as flowering and seed production (Rossington et al. 2018). Failure to flower and set seeds during periods of drought can impact species' reproductive success. Over time, this has the potential to drive selection for earlier flowering in serpentine species, resulting in shorter life cycles and facilitating early reproductive activity before periods of high drought (Rossington et al. 2018). During severe drought conditions, the fitness and survival of non-serpentine species on these sites may be impacted more than those well-adapted to serpentine soils (Rossington et al. 2018), potentially reducing resource competition for serpentine endemics.

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

- While **climate-driven changes in wildfire regimes** have the potential to pose challenges for serpentine endemic rare plants, the effects of fire on serpentine plant communities overall tend to be less pronounced compared to those in non-serpentine environments. However, non-serpentine species might persist longer due to the slow pace of recovery inherent to serpentine species (Harrison et al. 2003; Safford & Harrison 2004, 2008). This delayed recovery can be attributed to the low-nutrient characteristics of serpentine soils, which can restrict plant recruitment and growth (Harrison et al. 2003; Safford & Harrison 2004, 2008). Within serpentine grassland ecosystems, fire may benefit native plants by increasing germination and flowering as well as species richness and forb cover (Hernández et al. 2021). Fires that take place early in the growing season before non-native seeds disperse may help to reduce the presence of non-natives on serpentine soils and enhance native species’ cover (Hernández et al. 2021). Fire can also play a part in removing litter buildup (Safford & Harrison 2004), promoting the growth of serpentine endemic forb species (Hernández et al. 2021). Although unlikely, too-frequent fire would have a highly detrimental effect on rare serpentine manzanitas that are obligate seeders and need sufficient intervals between fire to reproduce (Parker et al. 2021).

Dependency on habitat and/or other species → High *(high confidence)*

Populations of rare endemic species in serpentine areas have developed unique traits that make them highly adapted to their microhabitats, which are essential for survival (Ackerly 2003; O’Dell & Rajakaruna 2011; Damschen et al. 2012). These species are strongly dependent on specific environmental conditions, and in order to maintain their habitat, management strategies such as grazing are necessary in certain ecosystems (e.g., serpentine grasslands subject to nitrogen deposition pressure) to prevent the domination of non-native annual grasses (Weiss 1999). Continual grazing has been shown to be effective in protecting biodiversity in these communities and is particularly crucial for the survival of pollinators such as the Bay checkerspot butterfly (*Euphydryas Editha bayensis*), whose larvae depend on these habitats (Weiss 1999).

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 species** such as yellow starthistle (*Centaurea solstitialis*), barbed goatgrass (*Aegilops triuncialis*) and purple false brome (*Brachypodium distachyon*) can grow within serpentine habitats of the San Francisco Bay Area despite the harsh conditions and nutrient scarcity of serpentine soils (Williams 2016), as these invasive plants can also grow within serpentine areas in their native ranges (California Invasive Plant Council 2023). Both barbed goatgrass and purple false brome contain high levels of silica, which lead to persistent thatch buildup that can affect the availability of open areas for serpentine plant germination and growth (DiTomaso et al. 2013). The presence of invasive species has traditionally been associated with the displacement of native rare species in specific habitats (Dukes & Mooney 2004; NPS 2019) and can profoundly impact ecosystem structure, soil chemistry, community productivity, and water availability (Ehrenfeld 2003; NPS 2019). Within ecosystems characterized by nutrient deficits, such as serpentine systems, nutrient availability affects how likely habitats are to be invaded (Huenneke et al. 1990). For example, increased nitrogen deposition often leads to increased invasion by exotic non-serpentine species, displacing native serpentine plants and associated pollinators (Huenneke et al. 1990; Weiss 1999; Vallano et al. 2012; Eskelinen & Harrison 2014; Hernández et al. 2019).
- **Pollution from developed areas and associated roads and highways** can have a profound impact on serpentine endemics. Air pollution from urban areas with high traffic and industrial activities can lead to nitrogen deposition that threatens the biodiversity of serpentine habitats by promoting the growth of annual grasses and weeds (including non-native species; Weiss 1999; Williams 2016; Hernández et al. 2019). This can reduce open ground cover by increasing litter and lead to a decline in species that do not survive well under these conditions (Williams 2016). In addition to contributing to air pollution, roads and highways can fragment natural habitats, disrupting ecological connectivity between species populations. They are also associated with higher levels of human use that can cause damage (e.g., trampling) in areas that may contain rare species (Weiss 1999).
- **Fire exclusion/suppression** can disrupt the natural balance of serpentine ecosystems. Serpentine species are well-adapted to periodic fire events (Jules et al. 2011), and some

species, such as endemic manzanitas, are obligate seeders that require fire for reproduction (Parker et al. 2021). Fire can help maintain ecological balance by promoting seed germination, stimulating new growth, and reducing competition from non-native species (Jules et al. 2011), and therefore the exclusion of fire impacts these processes. Fire exclusion in serpentine grasslands may also increase litter that can lead to the decline of serpentine forb species by limiting their light availability (Elam et al. 1998; Hernández et al. 2021). The survival of some rare endemic species, like the Baker's manzanita, can be threatened by shading from late-successional species that become established where fire is suppressed (Elam et al. 1998). In the absence of fire, fuel also accumulates via the dry litter vegetation and other dead plant material (Hernández 2021; Hernández et al. 2021), potentially resulting in more intense wildfires when they do occur.

Adaptive Capacity → Low *(moderate confidence)*

***Adaptive capacity** is the ability of a species group 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 species group will be less likely to cope with the adverse effects of climate change, thus increasing the vulnerability of the species group.*

Species group extent, integrity, connectivity, and dispersal ability → Low (moderate confidence)

Serpentine endemic flora displays notable geographical confinement and scarcity, attributed to the constrained distribution of serpentine soils and their inherent competitive disadvantage when confronted with species adapted to more productive soils (Kruckeberg 1954, 1985; Anacker et al. 2013; Williams 2016). There are pockets or islands of suitable serpentine habitat throughout California and the San Francisco Bay Area, but connectivity among these is limited (Vuln. Assessment Worksheets, pers. comm., 2022). This contributes to habitat fragmentation, particularly in the context of additional stressors that impact habitat availability and integrity and restrict species dispersal, such as land-use conversion, roads, exotic species, and geologic features (Anacker et al. 2013). Such factors can lead to the isolation of plant species communities, which for serpentine endemics has facilitated a selective pressure that promotes adaptation and diversification (Kruckeberg 1985; Ackerly 2003; Brady et al. 2005). This gives serpentine species an advantage over more generalist species that may not be able to adapt to future changing climate conditions (Damschen et al. 2012). However, rare endemic species do have a heightened vulnerability to extirpation due to the impacts of climate change when compared to both non-endemic native plants and introduced species (Manes et al. 2021). This vulnerability can be attributed to their reduced population size and limited genetic diversity, which makes them less resilient to environmental changes (Işik 2011; Manes et al. 2021). As a result, rare endemic species can be susceptible to extirpation following a single stochastic event like a major fire or disease outbreak (Manes et al. 2021).

Intraspecific/life history diversity → Moderate (moderate confidence)

The diversity of serpentine endemic rare plants and the habitats they reside in are shaped by various environmental factors, including topography, coastal proximity, latitude, microclimate, and the coexistence of other plant species (Harrison et al. 2000). These factors contribute to the establishment of a rich assemblage of native plant species, many of whom are adapted to thrive within specific microhabitats across the broader serpentine landscape. Due in part to the varying specialized adaptations of different serpentine endemic populations to their microhabitats, these species display substantial genetic divergence (Ackerly 2003; O'Dell & Rajakaruna 2011; Konečná et al. 2020). This divergence is attributed to the imperative need for these species to adapt to the inherently harsh conditions of their native serpentine environment as well as the fragmentation serpentine communities experience within California and more locally in the San Francisco Bay Area (Ackerly 2003; O'Dell & Rajakaruna 2011; Vuln. Assessment Worksheets, pers. comm., 2022).

Resistance and recovery → Moderate (low confidence)

While the resistance of serpentine species to environmental stressors such as drought is relatively high (Eskelinen & Harrison 2014), their ability to recover from disturbances is significantly reduced by human impacts on their natural habitat (Vuln. Assessment Worksheets, pers. comm., 2022). For example, low dispersal capacity in isolated populations, together with habitat fragmentation and loss as a result of human activities, may significantly impact their ability to access new suitable habitats (Matthies et al. 2004; Anacker et al. 2013; NPS 2019). Furthermore, rare serpentine endemic species tend to be slow-growing (Anacker 2014) due to the elevated concentrations of heavy metals and limited nutrient availability in serpentine habitats (Harrison et al. 2006; Anacker et al. 2011). This slow growth can hinder their capacity to rebound following a disturbance event by limiting successful recolonization and increasing competition from faster-growing non-serpentine species (Harrison et al. 2006). However, serpentine endemic rare plants often possess distinctive characteristics that can help them respond effectively to subtle fluctuations in environmental conditions, including expansive root systems, compact stature, and xeromorphic foliage (Damschen et al. 2012). Adaptations such as higher investment in growing an extensive root system as compared to above-ground stems and leaves ("shoots") can increase nutrient and water uptake efficiency when needed, such as during periods of extreme drought (O'Dell & Rajakaruna 2011).

Management potential → Low (moderate confidence)

The overall public value of serpentine endemic species in the San Francisco Bay Area is variable depending on the location of the species and whether there are conflicting land-use priorities where humans would like to expand urban development (Vuln. Assessment Worksheets, pers. comm., 2022). Generally, the value for these species among those who recreate in serpentine habitats is high (Vuln. Assessment Worksheets, pers. comm., 2022). There is good regulatory support for these species, and most serpentine habitats within the San Francisco Bay Area contain at least one species listed as a species of concern (Vuln. Assessment Worksheets, pers. comm., 2022). However, financial support for conserving or managing these species could be better. Depending on funding availability and organizational support, regional managers may need more support in initiating new projects for serpentine endemic rare plants (Vuln. Assessment Worksheets, pers. comm., 2022).

Within the GGB region, efforts have already been made to manage serpentine habitats and protect rare plant species. For example, the Presidio site within the Golden Gate National Reserve underwent a restoration project at two serpentine sites to expand and restore Presidio clarkia (UNESCO 2016). Additionally, public resources such as Calflora (http://www.calflora. org) have integrated research regarding serpentine endemism into their database (e.g., Safford and Miller 2020) by providing the California Rare Plant Ranks for species with an affinity for serpentine habitats (including rare serpentine species identified by the California Native Plant Society) as well as distribution maps. Managers can use the CalFlora tool to guide conservation planning and resource management (Calflora 2023).

Moving forward, climate-informed conservation and management efforts toward endemic serpentine species may aim to maintain and prioritize current populations of rare endemic species, minimize human-caused disturbances that would damage habitats, and mitigate invasions from non-native species. Strategies such as identifying and protecting potential climate refugia, managing nutrient deposition, and controlling invasive species could help maintain existing populations (Damschen et al. 2012; Harrison & Noss 2017). Using native seed banks may also prove crucial to assist species recovery after significant disturbances such as extreme wildfires (Kiss et al. 2018; Hernández et al. 2021). Efforts to restore degraded serpentine habitats involve a suite of strategic approaches, including the controlled application of prescribed fire, targeted soil property manipulations, and the restoration of natural hydrological processes (Safford & Harrison 2008). Additionally, partnerships between land managers, non-profits, state agencies, and collaborative networks such as the Golden Gate Biosphere Network may be pivotal in safeguarding serpentine rare endemic species in the GGB region (NPS 2019). Further research efforts regarding serpentine endemic species and the impacts of climate change could include sustained and standardized monitoring of implemented conservation and adaptation initiatives and expanded investigation of how environmental changes and climatic variables will influence species population dynamics (NPS 2019).

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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