Mountain Lion (*Puma concolor*)

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for mountain lion 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 Description

Mountain lions are a keystone species (Yap et al. 2019), and the one terrestrial apex predator left in the Golden Gate Biosphere (GGB) region (Vuln. Assessment Reviewer, pers. comm., 2023). Mountain lions occupy a variety of habitats, including riparian zones, coastal chaparral and scrub, and other areas with rugged terrain and dense brush for cover and breeding (Ahlborn 1988; Vuln. Assessment Worksheets, pers. comm., 2022). The primary prey base for mountain lions consists of approximately 70% black-tailed deer (*Odocoileus hemionus columbianus*), in addition to a variety of other prey such as livestock (e.g., goats [*Ovis aries*] and sheep [*Capra aegagrus hircus*]), wild boar (*Sus scrofa*), domestic cats (*Felis catus*), and raccoons (*Procyon lotor*; Ahlborn 1988; Yap et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). Mountain lions possess substantial home ranges (Yap et al. 2019), with size estimates varying from 70 km^2 (27 mi^2) to 350 km^2 (135 mi^2; Grigione et al. 2002; Vuln. Assessment Worksheets, pers. comm., 2022).

Mountain lions within the GGB region are generally considered part of the North Central Coast population; however, the mountain lions located in Marin and Sonoma counties in the most northern reach of the GGB region belong to the North Coast population (FIgure 1; Yap et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). Although they are not yet officially listed as threatened or endangered under the California Endangered Species Act (CESA), there have been petitions to list the southern/central coast populations of mountain lions under the CESA (Yap et al. 2019; Mountain Lion Foundation 2019), and in April 2020 they were granted temporary protected status (Cougar Conservancy n.d.). Mountain lions are also classified as specially protected mammals under the California Wildlife Protection Act of 1990, as some populations in the state are at risk of extirpation due to habitat loss (Benson et al. 2016; CDFW 2023; CNDDB 2023).

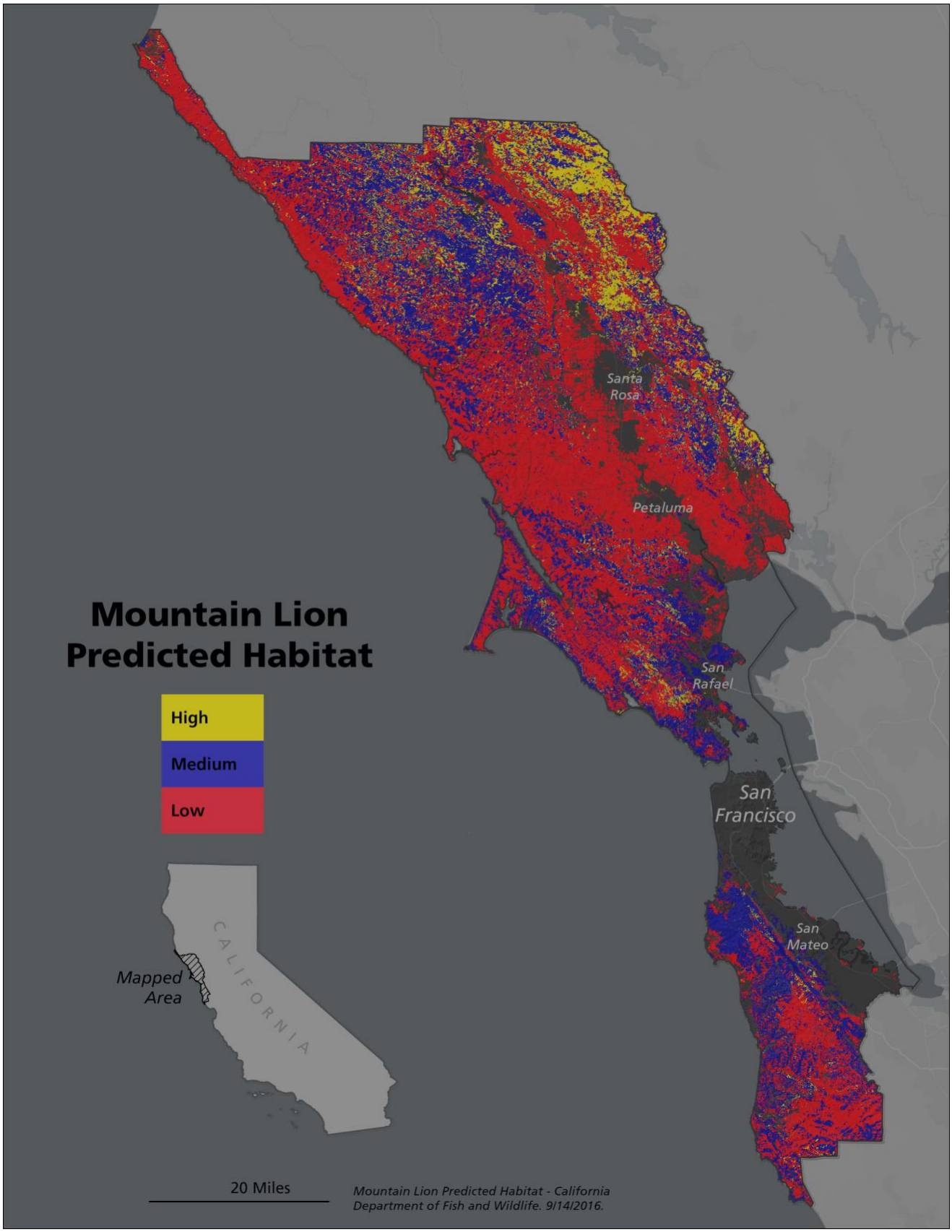

Figure 1. Mountain lion predicted habitat within the GGB region (map provided by the National Park Service).

Species Vulnerability → Moderate *(high confidence)*

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

The vulnerability of mountain lions to climate change arises from a combination of direct physiological impacts, changes in prey availability, habitat fragmentation, and human-wildlife conflicts. Warmer temperatures, extreme heat events, altered precipitation patterns, and drought are likely to significantly affect mountain lions by influencing their movement patterns, behavior, and the distribution and density of their prey. These climate stressors and disturbances can disrupt ecosystem balance and impact the survival and reproductive success of mountain lions. Additionally, the effects of climate change may be exacerbated by non-climate stressors that increase competition for resources, inter-species range conflicts with other predators, disruptions to migration corridors, and disease susceptibility.

Although mountain lions can traverse long distances and thrive in diverse habitats, human-induced habitat loss and fragmentation may restrict their movement and the availability of suitable habitats, resulting in limited population connectivity and reduced genetic variability. Furthermore, mountain lions' territorial and solitary nature and extensive home range restrict their abundance in any one location, which could impede their ability to seek refuge in available climate refugia. Inherent traits that could contribute to the resilience of mountain lion populations include their generalist habitat preferences, diverse diets, and year-round reproductive capabilities. Conservation efforts focused on preserving and enhancing habitat connectivity, promoting the maintenance of viable prey populations, and minimizing human-wildlife conflicts can also support the adaptive capacity of mountain lions in the face of climate change.

Sensitivity and Exposure → Moderate *(moderate confidence)*

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

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

- **Warmer temperatures and more intense and/or frequent heat waves** may increase the challenges that mountain lions face due to reduced prey availability, habitat loss, and potential increases in their interactions with humans. Given that annual temperatures are likely to increase (Flint et al. 2023) and heat waves are likely to become more frequent and extreme (Gershunov & Guirguis 2012; Pierce et al. 2018), mountain lion populations may shift toward coastal areas (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, temperature changes can alter the distribution and abundance of prey species such as black-tailed deer, which may travel to cooler habitats to escape high temperatures (Dellinger et al. 2020). This could change the hunting patterns of mountain lions by requiring them to either follow their prey to new habitats or cope with increased resource competition where prey abundance decreases significantly within their usual hunting range (Villepique et al. 2015; Stoner et al. 2018, 2021; Vuln. Assessment Worksheets, pers. comm., 2022). Rising temperatures and more frequent extreme heat events can also cause physiological stress and dehydration in mountain lions, leading them to seek cooler areas with access to water resources (Fuller et al. 2016). This may alter the mountain lion's territory and increase the potential for human-animal conflicts, especially if they seek refuge in urban areas (Benson et al. 2016, 2021). Mountain lions do, however, live in hotter and drier climates in other regions (e.g., southern California and the American southwest), and their large home ranges and ability to move may suggest that they could adapt to these changes and travel to access water and other resources (Vuln. Assessment Worksheets, pers. comm., 2022).
- **Changes in the amount and timing of precipitation** can profoundly impact mountain lions and their prey by affecting water availability, forage availability, prey distribution and behavior, habitat quality, and disease dynamics. Shifts in precipitation timing, such as changes in the timing of seasonal rainfall or increased frequency of intense rainfall events, can disrupt the natural cycles, distribution, abundance, and behaviors of prey species like deer (Morin et al. 2021). For example, changes in precipitation influence vegetation productivity, which can impact forage availability for herbivores and subsequently affects the abundance and behavioral predictability of the prey base for mountain lions (Townsend 2018; Stoner et al. 2018, 2021; Morin et al. 2021). This can influence mountain lions' home range size and distribution as they travel to follow their prey (Grigione et al. 2002). Similarly, water scarcity due to decreased precipitation can also force mountain lions and their prey to expand their range in search of adequate water sources, thus influencing their movement, distribution, and predator-prey interactions (Harris et al. 2020; Jones et al. 2022). A decrease in precipitation, particularly during summer, can also increase the frequency and severity of wildfires, degrading mountain lion habitats (Littell et al. 2009). Furthermore, changes in precipitation patterns can influence the prevalence, abundance, and transmission of pathogens, which can have cascading effects on mountain lions' health and population dynamics (Foley et al. 2013).

- **Increased frequency and/or severity of drought** may cause mountain lions to modify their predation patterns (diet and behaviors), concentrate around human-provided water sources, and expand their range into urban areas. Increased drought conditions may decrease abundances of black-tailed deer, making it more challenging for mountain lions to obtain their main prey (Stoner et al. 2018, 2021; Vuln. Assessment Worksheets, pers. comm., 2022). Crowding around increasingly-limited water sources could also be detrimental to mountain lion populations as it may drive disease transmission (Hofmeister & Hemert 2018). As water resources become scarcer, mountain lions and their prey may move further into human-populated areas in search of resources, increasing the potential for human-wildlife conflicts (Schloss et al. 2012; Vickers et al. 2015).

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

- **Increases in the risk of large and high-intensity wildfires** could reduce habitat availability and suitability, cause direct injury and mortality to prey species, and alter the ecological dynamics within the mountain lion's home range (Innes & U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory 2013; Dellinger et al. 2020; Blakey et al. 2022). Mountain lions often avoid burned areas, which can lead them to venture into unfamiliar territories, raising the odds of encounters with urban areas and humans (Blakey et al. 2022). Additionally, navigating an altered and fragmented landscape may lead to other behavioral changes as they manage the competing demands of acquiring food, breeding, and avoiding conflicts with conspecifics (Blakey et al. 2022; Vuln. Assessment Worksheets, pers. comm., 2022). This situation could be particularly harmful if they cross roads and highways searching for refuge (Blakey et al. 2022). However, mountain lions are highly mobile, resulting in low direct mortality from wildfire events (Vuln. Assessment Worksheets, pers. comm., 2022).
- **Diseases** like feline immunodeficiency virus (FIV), puma lentivirus, and feline panleukopenia virus can impact mountain lions' physiological well-being and viability. These effects could be exacerbated by climate stressors and disturbances as well as the stress induced by habitat loss and fragmentation (Foley et al. 2013). Mountain lions can transmit FIV through interactions with infected individuals, such as infected prey (e.g., house cats; Lee et al. 2017). While there is little evidence supporting associations between FIV and increased mortality in mountain lions, the infection may lower fecundity and weaken immune systems, which increases their risk of contracting other diseases (Reynolds et al. 2019).

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

In response to changing environmental conditions, mountain lions can adapt their predation patterns by altering their choice of prey species (Townsend 2018; Stoner et al. 2018), a crucial ability given their energetic ties to consuming large prey (Carbone et al. 1999). This adaptive behavior could allow them

to maintain a food source even as climate-driven reductions in forage reduce abundance of their usual prey (mule deer [*Odocoileus hemionus hemionus*] and black-tailed deer; Stoner et al. 2018; Morin et al. 2021; Vuln. Assessment Worksheets, pers. comm., 2022). The degree to which this impact is significant may be influenced by the differences in deer abundance across the GGB region (e.g., in Marin County, deer are considered overabundant; Furnas et al. 2020). If climate change were to reduce deer density to the extent that the diet of mountain lions must shift, they may turn more frequently to unprotected domestic animals in or near urban areas, making them increasingly vulnerable to human-caused mortality (Riley et al. 2021). Pressure may also be increased on prey species that are better-adapted to more arid conditions, such as bighorn sheep (*Ovis canadensis*). Where vegetation cover is significantly reduce, mountain lion hunting behavior may be limited by the availability of cover needed to successfully stalk prey (Blakey et al. 2022; Gaynor et al. 2022).

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** has substantial implications for mountain lions, and climate change can further compound the effects. As human populations and urban areas expand, mountain lions face habitat loss and fragmentation (Yap et al. 2019), which can restrict their movements and access to resources such as water (Vickers et al. 2015; Vuln. Assessment Worksheets, pers. comm., 2022). Encroachment of development into mountain lion habitats enhances the likelihood of human-wildlife conflicts, which can lead to direct mortality (e.g., vehicle strikes) and increase the risk of disease transmission due to more frequent interactions with domesticated animals (Riley et al. 2003; Vickers et al. 2015; Blakey et al. 2022). The energetic costs associated with avoiding humans can also play a role in shaping the spatial ecology of mountain lions as it can cause increased energy expenditures as they move through the landscape, limiting the size of the home ranges they can maintain (Nickel et al. 2021). Continued land-use change could further threaten mountain lions' survival, with some of California's local populations already at risk of extirpation (Benson et al. 2016; Gustafson et al. 2019; Dellinger et al. 2020).
- **Agricultural practices** can lead to habitat loss and fragmentation, reduced prey availability and accessibility, human-wildlife conflicts, pesticide exposure, and disruption of movement corridors for mountain lions (Stoner et al. 2018). Changes in land use for agriculture expansion (e.g., land clearing for farming and grazing) results in changes in vegetation composition, reduced forage availability for mountain lion prey species, and increased competition between livestock and native ungulates for food resources (Sommer et al. 2007; Schieltz & Rubenstein 2016). This could threaten the abundance and distribution of mule and black-tailed deer, which make up a significant part of the mountain lion’s diet. Additionally, conflicts can arise when mountain lions target livestock as potential prey (McManus et al. 2015; Miller et al. 2016;

Dellinger et al. 2021). The economic losses for farmers and ranchers can result in mountain lions being perceived as threats and subject to depredation permits or other control measures (Dellinger et al. 2021).

- Mountain lions can be exposed to **pollutants and poisons** indirectly when they consume prey that have ingested these chemicals. For instance, rodenticides contain anticoagulant compounds that can accumulate in the food chain when carnivores such as mountain lions consume exposed prey (Riley et al. 2004; Rattner et al. 2014; Yap et al. 2019). Industrial pollutants (e.g., heavy metals) and other environmental contaminants can also find their way into mountain lion habitats, particularly as mountain lion ranges increasingly overlap with urban areas (Murray et al. 2019). When mountain lions consume prey contaminated with these poisons, they can suffer from impacts ranging from internal bleeding and immune system suppression to direct mortality (Rattner et al. 2014; Serieys et al. 2015).
- **Roads and highways** act as barriers that restrict the ability of mountain lions to access suitable habitats, food sources, and reproductive partners. This fragmentation can lead to changes in movement patterns, habitat loss, isolation of populations, and restriction of gene flow (Dickson et al. 2005; Vickers et al. 2015; Thomassen et al. 2018; Yap et al. 2019). Roads also increase the risk of vehicle collisions, which can result in direct injuries or fatalities for mountain lions (Vickers et al. 2015; Blakey et al. 2022) and are a primary contributor to mortality among North Central Coast mountain lion populations (Riley et al. 2014; Vickers et al. 2015; Yap et al. 2019). Notably, the California Department of Fish & Wildlife partially attributes mountain lion population declines in this region to the adverse effects of roads (Yap et al. 2019).
- **Fire exclusion and suppression** disrupts natural fire regimes crucial for maintaining healthy ecosystems in California, where most vegetation types are adapted to periodic fires (Keeley & Safford 2016). In the absence of fire, plant communities may transition to more fire-sensitive species, and they frequently become dense with shrubs and small trees (Stuart & Stephens 2006; McIntyre et al. 2015). This can negatively impact herbivore populations, affecting the availability of prey for mountain lions. Dense forests are also significantly more vulnerable to high-intensity fires due to the accumulation of potential fuels (Lorimer et al. 2009), increasing the potential for mortality of prey species (Vuln. Assessment Worksheets, pers. comm., 2022).
- **Livestock grazing** has both direct and indirect impacts on mountain lions. Directly, mountain lions may consider livestock as potential prey, leading to conflicts with ranchers and possibly retaliatory killings allowed by depredation permits from the California Department of Fish and Wildlife (Yap et al. 2019; Dellinger et al. 2021; Vuln. Assessment Worksheets, pers. comm., 2022). Indirectly, livestock grazing can modify vegetation and habitat structure, reducing forage availability for deer and increasing competition between deer and livestock (Sommer et al. 2007; Schieltz & Rubenstein 2016). This competition is intensified during resource-scarce periods and droughts (Sommer et al. 2007), which can impact mountain lions' prey availability during these high-stress events.

Adaptive Capacity → Moderate *(high confidence)*

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

Species extent, status, connectivity, and dispersal ability → Moderate (high confidence)

The San Francisco Bay Area contains areas of high human density with relatively rare mountain lion occurrences (Fifield et al. 2015). In Sonoma County, statewide habitat selection models estimate that there are approximately 75 mountain lions (Vuln. Assessment Worksheets, pers. comm., 2022). The North Central Coast population (within the counties of Alameda, Contra Costa, San Mateo, Santa Clara, and Santa Cruz) is estimated to be somewhere between 33 to 66 individuals (Yap et al. 2019). While there is a fair amount of contiguous protected land within these counties and much of the San Francisco Bay Area, there are limited partitions between these lands and areas of human habitation (Townsend 2018), occasionally leading to the occurrence of mountain lions on private land (Vuln. Assessment Worksheets, pers. comm., 2022). Most private land parcels are small, resulting in situations where an individual mountain lion's home range can encompass over 10,000 of these private parcels (Vuln. Assessment Worksheets, pers. comm., 2022). It is estimated that there are approximately 165,350 to 170,085 km^2 (6,3841 to 6,5670 mi^2) of suitable habitat for mountain lions in the state of California (Dellinger et al. 2020), though mountain lion use of suitable habitat and population density varies across the state (Zeller et al. 2017; Dellinger et al. 2020).

Mountain lions possess high mobility, enabling them to navigate diverse landscapes and adapt to shifting environmental circumstances (Schloss et al. 2012). Nevertheless, land-use conversion, road and highway construction, and increased urbanization have resulted in habitat loss and fragmentation that significantly impact dispersal ability and prey/habitat availability (Vickers et al. 2015; Bay Area Open Space Council 2019; Vuln. Assessment Worksheets, pers. comm., 2022). Natural barriers such as the San Francisco Bay can also restrict the movements of mountain lions within the GGB region (Vuln. Assessment Worksheets, pers. comm., 2022). These natural and human-caused barriers can significantly impact mountain lion population connectivity and the movement of individuals, limiting their ability to access potential climate refugia (Schloss et al. 2012). However, mountain lions can adapt their movement patterns in response to climate stressors and barriers, which can lead to an expansion of their range to novel habitats in order to find needed resources (Schloss et al. 2012; Dunford et al. 2020; Zanin et al. 2021). For instance, mountain lions have demonstrated the ability to navigate through developed areas (Stoner et al. 2021), as evidenced by recent sightings of dispersing young males in urban San Francisco (Bay Area Open Space Council 2019; Vuln. Assessment Worksheets, pers. comm., 2022).

Intraspecific/life history diversity → Moderate (high confidence)

The mountain lion population within the GGB region is considered a "sink" with low genetic diversity and some level of inbreeding (Bay Area Open Space Council 2019; Yap et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). San Francisco Bay and Delta populations have low gene flow attributed to historical population declines, habitat fragmentation, and human activities, factors that have resulted in restricted gene flow, genetic isolation, and low genetic diversity (Ernest et al. 2003; Doyle et al. 2015; Vickers et al. 2015; Benson et al. 2016; Zeller et al. 2017; Yap et al. 2019; Dellinger et al. 2020). Inbreeding can reduce offspring's survival, reproductive efficiency, and overall fitness (Nonaka et al. 2019), which may impact their ability to withstand future climate stressors and disturbances (Yap et al. 2019). Gene flow is also essential to promote local adaptation in species, and the resulting genetic variation from this process is essential for population viability (Kardos et al. 2021). Further genetic monitoring and safeguarding genome-wide genetic variation may be a crucial conservation practice for species such as mountain lions (Riley et al. 2014; Kardos et al. 2021). These practices can advance understanding of the factors impacting a population's genetic diversity and persistence. They can help prevent inbreeding depression, which may aid the population's potential for adaptation to environmental changes, particularly in light of increasing habitat loss (Riley et al. 2014; Kardos et al. 2021).

It is noteworthy, however, that mountain lions display considerable diversity in their behavioral responses as a species group. For example, while they prefer hunting deer (Yap et al. 2019), they exhibit a wide range of prey utilization (Allen et al. 2015). Additionally, mountain lions can travel long distances and inhabit diverse habitats, enabling them to shift geographically in response to the availability of resources (e.g., food, water, shelter) or climate refugia (Schloss et al. 2012). Mountain lions also thrive in various climates and reproduce at any time of the year (Yap et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). This, along with their generalist habitat preferences, diverse diets, and exceptional mobility, may contribute to their resilience in the face of climate change impacts (Noss et al. 1996).

Resistance and recovery → Moderate (high confidence)

Habitat connectivity and quality, prey availability, and the ecosystem dynamics of mountain lions' habitat could be greatly impacted by climate stressors and disturbances, potentially affecting their survival and reproductive success (Schloss et al. 2012). Anthropogenic disturbances (e.g., land-use conversion, urban expansion, building more roads/highways) may also exacerbate the impacts of climate stressors on mountain lions, influencing their ability to recover (Benson et al. 2016; Blakey et al. 2022). Further fragmentation, loss, and degradation of mountain lion habitat can also lead to population declines (Noss et al. 1996; Dellinger et al. 2020), which may cause inbreeding within populations (Riley et al. 2014, 2021; Benson et al. 2016), further limiting their genetic diversity (Kardos et al. 2021) and threatening their overall fitness and adaptive capacity (Yap et al. 2019).

Mountain lions can, however, adapt to a variety of habitats and alter their home range, allowing them to resist some impacts of changing climate conditions (e.g., decreased prey availability, drought impacting water availability) and to move to new locations (Noss et al. 1996; Sommer et al. 2007; Schloss et al. 2012; Stoner et al. 2021). Even though it is rare and not preferred, mountain lions can persist in urbanized areas after a disturbance event that has detrimental impacts on areas they usually occupy (e.g., high-intensity wildfire; Riley et al. 2021; Blakey et al. 2022). Additionally, their varied diets can promote survival if their primary food source (i.e., deer) is significantly reduced by the effects of climate changes such as drought (Sommer et al. 2007; Townsend 2018; Stoner et al. 2018, 2021; Morin et al. 2021).

Management potential → High (high confidence)

Mountain lions often evoke strong positive and negative reactions due to their high profile and position at the center of many conservation initiatives (Yap et al. 2019; Dellinger et al. 2020; Vuln. Assessment Worksheets, pers. comm., 2022). For example, the public often views mountain lions positively due to their charismatic nature and crucial role as top predators in maintaining the health of ecosystems (Vuln. Assessment Worksheets, pers. comm., 2022). However, though attacks by mountain lions are rare, some individuals fear them, with particular concern for the safety of outdoor pets and livestock that can be taken as prey (Vuln. Assessment Worksheets, pers. comm., 2022). The California Department of Fish and Wildlife (CDFW) plays a significant role in the management of mountain lions, and there have been legislative advancements in protecting them (CDFW 2023; CNDDB 2023). The Mountain Lion Foundation is a California-based organization that actively advocates for mountain lion protection, especially in the legislative arena (Vuln. Assessment Worksheets, pers. comm., 2022). There have been petitions to list mountain lion populations in Southern California and along the central coast of California (i.e., the Central Coast North Population, including San Francisco, San Mateo, and peninsula populations) as “endangered” or “threatened” under the California Endangered Species Act (CESA; Yap et al. 2019; Vuln. Assessment Worksheets, pers. comm., 2022). As of the summer of 2023, the CDFW is conducting a status review of these populations, and an official decision regarding their CESA designation has not yet been made (CDFW 2023).

Managers face various challenges in addressing and coping with the impacts of climate change on mountain lions. Climate adaptation and conservation management strategies should aim to increase and maintain habitat connectivity through the protection and maintenance of wildlife corridors as well as reduce pressure from non-climate stressors, such as human land use and residential and commercial development (Ordeñana et al. 2010; Keeley et al. 2018; Yap et al. 2019). However, there is a strong interest in maintaining corridors to promote mountain lion movement and genetic diversity in the region (Vuln. Assessment Worksheets, pers. comm., 2022), as they may help increase adaptive capacity to climate change's impacts by facilitating movement between populations and allowing them to travel to food and water resources, breeding sites, and climatically suitable habitats (Schloss et al. 2012; Riley et al. 2014; Zanin et al. 2021). However, these measures can be costly (Vuln. Assessment Worksheets,

pers. comm., 2022). It is worth noting that about half of California's available suitable habitat for mountain lions is currently unprotected and susceptible to development (Dellinger et al. 2020). Given the significance of this unprotected land as potential mountain lion habitat, there is an opportunity to consider protections that could help create and maintain wildlife corridors, enhance landscape connectivity, and mitigate additional fragmentation, thus supporting the persistence of mountain lion populations in the region (Ernest et al. 2003; Riley et al. 2014; Keeley et al. 2018). Collaboration with the California Department of Fish and Wildlife to adjust deer hunting quotas to ensure an adequate abundance of prey for mountain lions could discourage depredation of other animals, such as livestock (Vuln. Assessment Worksheets, pers. comm., 2022). Additionally, implementing non-lethal methods (e.g., translocation, light–sound devices, night enclosures, electric or non-electric fences) to discourage mountain lion depredations on livestock is possible, but the effectiveness of these methods vary (Miller et al. 2016) and they require financial resources from livestock operators, which may prove challenging to obtain (Breitenmoser et al. 2005; McManus et al. 2015; Miller et al. 2016).

Recommended Citation

EcoAdapt. 2024. Mountain lion (*Puma concolor*): 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).

Literature Cited

Ahlborn G. 1988. Life history account for mountain lions. Page in Zeiner DC, Laudenslayer Jr. WF, Mayer KE, White M, editors. California's Wildlife. Vol. I-III. California Department of Fish and Game, Sacramento, CA. Available from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=2607&inline (accessed August 29, 2023).

Allen ML, Elbroch LM, Casady DS, Wittmer HU. 2015. Feeding and spatial ecology of mountain lions in the Mendocino National Forest, California. California Fish and Game **101**:51–65.

Bay Area Open Space Council. 2019. The Conservation Lands Network 2.0 Report: A regional conservation strategy for the San Francisco Bay Area. Bay Area Open Space Council, Berkeley, CA. Available from https://www.bayarealands.org/wp-content/uploads/2019/10/CLN%202.0%20Final%20Report.Web.pdf.

Benson JF, Abernathy HN, Sikich JA, Riley SPD. 2021. Mountain lions reduce movement, increase efficiency during the Covid-19 shutdown. Ecological Solutions and Evidence **2**:e12093.

Benson JF, Mahoney PJ, Sikich JA, Serieys LEK, Pollinger JP, Ernest HB, Riley SPD. 2016. Interactions between demography, genetics, and landscape connectivity increase extinction probability for a small population of large carnivores in a major metropolitan area. Proceedings of the Royal Society B: Biological Sciences **283**:20160957.

Blakey RV, Sikich JA, Blumstein DT, Riley SPD. 2022. Mountain lions avoid burned areas and increase risky behavior after wildfire in a fragmented urban landscape. Current Biology **32**:4762–4768.

Breitenmoser U, Angst C, Landry J-M, Breitenmoser-Würsten C, Linnell JDC, Weber J-M. 2005. Non-lethal techniques for reducing depredation. Pages 49–71 in Woodroffe R, Thirgood S, Rabinowitz A, editors. People and Wildlife. Cambridge University Press, New York, NY.

Carbone C, Mace GM, Roberts SC, Macdonald DW. 1999. Energetic constraints on the diet of terrestrial carnivores. Nature **402**:286–288.

CDFW. 2023. Mountain Lions in California. Available from https://wildlife.ca.gov/Conservation/Mammals/Mountain-Lion/FAQ#56231953-laws-and-regulations (accessed July 1, 2023).

CNDDB. 2023. State and federally listed endangered and threatened animals of California. California Natural Diversity Database (CNDDB). California Department of Fish and Wildlife, Biogeographic Data Branch, Sacramento, CA.

Cougar Conservancy. (n.d.). Listing At-Risk Cougar Populations Under California's ESA. Available from https://cougarconservancy.org/ca-endangered-species-act#:~:text=petition%20to%20list%20southern%20%26%20central,the%20California%20Endangered%20Species%20Act.

Dellinger JA et al. 2020. Using mountain lion habitat selection in management. The Journal of Wildlife Management **84**:359–371.

Dellinger JA, Cordova R, Macon DK, Rudd JL. 2021. Temporal trends and drivers of mountain lion depredation in California, USA. Human–Wildlife Interactions **15**:162–177.

Dickson BG, Jenness JS, Beier P. 2005. Influence of vegetation, topography, and roads on cougar movement in southern California. The Journal of Wildlife Management **69**:264–276.

Doyle JM, Hacking CC, Willoughby JR, Sundaram M, DeWoody JA. 2015. Mammalian genetic diversity as a function of habitat, body size, trophic class, and conservation status. Journal of Mammalogy **96**:564–572.

Dunford CE, Marks NJ, Wilmers CC, Bryce CM, Nickel B, Wolfe LL, Scantlebury DM, Williams TM. 2020. Surviving in steep terrain: A lab-to-field assessment of locomotor costs for wild mountain lions (*Puma concolor*). Movement Ecology **8**:34.

Ernest HB, Boyce WM, Bleich VC, May B, Stiver SJ, Torres SG. 2003. Genetic structure of mountain lion (*Puma concolor*) populations in California. Conservation Genetics **4**:353–366.

Fifield VL, Rossi AJ, Boydston EE. 2015. Documentation of mountain lions in Marin County, California, 2010–2013. California Fish and Game **101**:66–71.

Flint LE, Flint AL, Stern MA. 2023. The Basin Characterization Model – A monthly regional water balance software package (BCMv8) data release and model archive for hydrologic California (ver. 3.0, June 2023). Data release. Available from https://www.usgs.gov/data/basin-characterization-model-a-monthly-regional-water-balance-software-package-bcmv8-data (accessed August 11, 2023).

Foley JE, Swift P, Fleer KA, Torres S, Girard YA, Johnson CK. 2013. Risk factors for exposure to feline pathogens in California mountain lions (*Puma concolor*). Journal of Wildlife Diseases **49**:279–293.

Fuller A, Mitchell D, Maloney SK, Hetem RS. 2016. Towards a mechanistic understanding of the responses of large terrestrial mammals to heat and aridity associated with climate change. Climate Change Responses **3**:10.

Furnas BJ, Landers RH, Paiste RG, Sacks BN. 2020. Overabundance of black-tailed deer in urbanized coastal California. The Journal of Wildlife Management **84**:979–988.

Gaynor KM, McInturff A, Brashares JS. 2022. Contrasting patterns of risk from human and non-human predators shape temporal activity of prey. Journal of Animal Ecology **91**:46–60.

Gershunov A, Guirguis K. 2012. California heat waves in the present and future. Geophysical Research Letters **39**:L18710.

Grigione MM, Beier P, Hopkins RA, Neal D, Padley WD, Schonewald CM, Johnson ML. 2002. Ecological and allometric determinants of home-range size for mountain lions (*Puma concolor*). Animal Conservation **5**:317–324.

Gustafson KD et al. 2019. Genetic source–sink dynamics among naturally structured and anthropogenically fragmented puma populations. Conservation Genetics **20**:215–227.

Harris GM, Stewart DR, Brown D, Johnson L, Sanderson J, Alvidrez A, Waddell T, Thompson R. 2020. Year-round water management for desert bighorn sheep corresponds with visits by predators not bighorn sheep. PLOS ONE **15**:e0241131.

Hofmeister EK, Hemert CRV. 2018. Effect of climate change on disease spread in wildlife. Pages 247–254 in Miller RE, Lamberski N, Calle P, editors. Fowler's Zoo and Wild Animal Medicine, Volume 9. Elsevier. Available from https://pubs.er.usgs.gov/publication/70198103 (accessed March 9, 2020).

Innes RJ, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. 2013. *Odocoileus hemionus* In: Fire Effects Information System, [Online]. Available from https://www.fs.usda.gov/database/feis/animals/mammal/odhe/all.html.

Jones AS, Rubin ES, Clement MJ, Harding LE, Mesler JI. 2022. Desert bighorn sheep habitat selection, group size, and mountain lion predation risk. The Journal of Wildlife Management **86**:e22173.

Kardos M, Armstrong EE, Fitzpatrick SW, Hauser S, Hedrick PW, Miller JM, Tallmon DA, Funk WC. 2021. The crucial role of genome-wide genetic variation in conservation. Proceedings of the National Academy of Sciences **118**:e2104642118.

Keeley ATH et al. 2018. Migration corridors as adaptation to climate change: Why, how, and what next. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CNRA-2018-001. California Natural Resources Agency, Sacramento, CA.

Keeley JE, Safford HD. 2016. Fire as an ecosystem process. Pages 27–45 in Mooney HA, Zavaleta E, editors. Ecosystems of California. University of California Press, Oakland, CA.

Lee J et al. 2017. Feline immunodeficiency virus cross-species transmission: Implications for emergence of new lentiviral infections. Journal of Virology **91**:e02134-16.

Littell JS, McKenzie D, Peterson DL, Westerling AL. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications **19**:1003–1021.

Lorimer CG, Porter DJ, Madej MA, Stuart JD, Veirs SD, Norman SP, O'Hara KL, Libby WJ. 2009. Presettlement and modern disturbance regimes in coast redwood forests: Implications for the conservation of old-growth stands. Forest Ecology and Management **258**:1038–1054.

McIntyre PJ, Thorne JH, Dolanc CR, Flint AL, Flint LE, Kelly M, Ackerly DD. 2015. Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. Proceedings of the National Academy of Sciences **112**:1458–1463.

McManus JS, Dickman AJ, Gaynor D, Smuts BH, Macdonald DW. 2015. Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. Oryx **49**:687–695.

Miller JRB, Stoner KJ, Cejtin MR, Meyer TK, Middleton AD, Schmitz OJ. 2016. Effectiveness of contemporary techniques for reducing livestock depredations by large carnivores: Human-carnivore coexistence. Wildlife Society Bulletin **40**:806–815.

Morin A, Chamaillé-Jammes S, Valeix M. 2021. Climate effects on prey vulnerability modify expectations of predator responses to short- and long-term climate fluctuations. Frontiers in Ecology and Evolution **8**:601202.

Mountain Lion Foundation. 2019, June 25. Petition Filed to List Mountain Lions under CESA. Available from https://mountainlion.org/2019/06/25/petition-filed-to-list-mountain-lions-under-cesa/.

Murray MH, Sánchez CA, Becker DJ, Byers KA, Worsley-Tonks KE, Craft ME. 2019. City sicker? A meta-analysis of wildlife health and urbanization. Frontiers in Ecology and the Environment **17**:575–583.

Nickel BA, Suraci JP, Nisi AC, Wilmers CC. 2021. Energetics and fear of humans constrain the spatial ecology of pumas. Proceedings of the National Academy of Sciences **118**:e2004592118.

Nonaka E, Sirén J, Somervuo P, Ruokolainen L, Ovaskainen O, Hanski I. 2019. Scaling up the effects of inbreeding depression from individuals to metapopulations. Journal of Animal Ecology **88**:1202–1214.

Noss RF, Quigley HB, Hornocker MG, Merrill T, Paquet PC. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology **10**:949–963.

Ordeñana MA et al. 2010. Effects of urbanization on carnivore species distribution and richness. Journal of Mammalogy **91**:1322–1331.

Pierce DW, Kalansky JF, Cayan DR. 2018. Climate, drought, and sea level rise scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment. Publication Number: CNRA-CEC-2018-006. California Energy Commission, Sacramento, CA.

Rattner BA, Lazarus RS, Elliott JE, Shore RF, van den Brink N. 2014. Adverse outcome pathway and risks of anticoagulant rodenticides to predatory wildlife. Environmental Science & Technology **48**:8433–8445.

Reynolds JJH, Carver S, Cunningham MW, Logan KA, Vickers W, Crooks KR, VandeWoude S, Craft ME. 2019. Feline immunodeficiency virus in puma: Estimation of force of infection reveals insights into transmission. Ecology and Evolution **9**:11010–11024.

Riley SPD, Foley J, Chomel B. 2004. Exposure to feline and canine pathogens in bobcats and gray foxes in urban and rural zones of a national park in California. Journal of Wildlife Diseases **40**:11–22.

Riley SPD, Sauvajot RM, Fuller TK, York EC, Kamradt DA, Bromley C, Wayne RK. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology **17**:566–576.

Riley SPD, Serieys LEK, Pollinger JP, Sikich JA, Dalbeck L, Wayne RK, Ernest HB. 2014. Individual behaviors dominate the dynamics of an urban mountain lion population isolated by roads. Current Biology **24**:1989–1994.

Riley SPD, Sikich JA, Benson JF. 2021. Big cats in the big city: Spatial ecology of mountain lions in Greater Los Angeles. The Journal of Wildlife Management **85**:1527–1542.

Schieltz JM, Rubenstein DI. 2016. Evidence based review: Positive versus negative effects of livestock grazing on wildlife. What do we really know? Environmental Research Letters **11**:113003.

Schloss CA, Nuñez TA, Lawler JJ. 2012. Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. Proceedings of the National Academy of Sciences **109**:8606–8611.

Serieys LEK, Lea A, Pollinger JP, Riley SPD, Wayne RK. 2015. Disease and freeways drive genetic change in urban bobcat populations. Evolutionary Applications **8**:75–92.

Sommer ML, Barboza RL, Botta RA, Kleinfelter EB, Schauss ME, Thompson JR. 2007. Habitat guidelines for mule deer: California woodland chaparral ecoregion. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies. Available from https://wafwa.org/wp-content/uploads/2020/08/HabitatGuidelines_MuleDeer_CA.pdf (accessed July 3, 2023).

Stoner DC, Ditmer MA, Mitchell DL, Young JK, Wolfe ML. 2021. Conflict, coexistence, or both? Cougar habitat selection, prey composition, and mortality in a multiple-use landscape. California Fish and Wildlife Journal **107**:147–172.

Stoner DC, Sexton JO, Choate DM, Nagol J, Bernales HH, Sims SA, Ironside KE, Longshore KM, Edwards TC. 2018. Climatically driven changes in primary production propagate through trophic levels. Global Change Biology **24**:4453–4463.

Stuart JD, Stephens SL. 2006. North Coast bioregion. Pages 147–169 in Sugihara NG, van Wagtendonk JW, Fites-Kaufmann J, Shaffer KE, Thode AE, editors. Fire in California's ecosystems. University of California Press, Berkeley, CA.

Thomassen HA, Harrigan RJ, Delaney KS, Riley SPD, Serieys LEK, Pease K, Wayne RK, Smith TB. 2018. Determining the drivers of population structure in a highly urbanized landscape to inform conservation planning. Conservation Biology **32**:148–158.

Townsend SE. 2018. The Marin wildlife picture index project: Diversity, occupancy and trends in biodiversity, fall 2014–summer 2017. Wildlife Ecology and Consulting, Oakland, CA.

Vickers TW, Sanchez JN, Johnson CK, Morrison SA, Botta R, Smith T, Cohen BS, Huber PR, Ernest HB, Boyce WM. 2015. Survival and mortality of pumas (*Puma concolor*) in a fragmented, urbanizing landscape. PLOS ONE **10**:e0131490.

Villepique JT, Pierce BM, Bleich VC, Andic A, Bowyer RT. 2015. Resource selection by an endangered ungulate: A test of predator-induced range abandonment. Advances in Ecology **2015**:1–19.

Yap T, Cummings B, Rose JP. 2019. A petition to list the Southern California/Central Coast evolutionarily significant unit (ESU) of mountain lions as threatened under the California Endangered Species Act (CESA). Center for Biological Diversity, Tucson, Arizona, USA and the Mountain Lion Foundation, Sacramento, California, USA.

Zanin M, Palomares F, Mangabeira Albernaz AL. 2021. Effects of climate change on the distribution of felids: Mapping biogeographic patterns and establishing conservation priorities. Biodiversity and Conservation **30**:1375–1394.

Zeller KA, Vickers TW, Ernest HB, Boyce WM. 2017. Multi-level, multi-scale resource selection functions and resistance surfaces for conservation planning: Pumas as a case study. PLOS ONE **12**:e0179570.