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Riordan, Erin C.
Rundel, Philip W.

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Evaluating the Future Role of the University of California Natural Reserve System for Sensitive Plant Protection under Climate Change

ERIN C. RIORDAN* AND PHILIP W. RUNDEL

DEPARTMENT OF ECOLOGY AND EVOLUTIONARY BIOLOGY

UNIVERSITY OF CALIFORNIA, LOS ANGELES, CALIFORNIA 90095 USA

*EMAIL FOR CORRESPONDENCE: ERIORDAN@UCLA.EDU

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Executive Summary

Description

Protected areas are critical for conserving California's many sensitive plant species but their future role is uncertain under climate change. Climate-driven species losses and redistributions could dramatically affect the relevance of protected areas for biodiversity conservation this century. Focusing on the University of California Natural Reserve System (NRS), we predicted the future impact of climate change on reserve effectiveness with respect to sensitive plant protection. First, we evaluated the historical representation of sensitive plant species in the NRS reserve network by compiling species accounts from checklists, floras, and spatial queries of occurrence databases. Next, we calculated projected climate change exposure across the NRS reserve network for the end of the 21st century (2070–2099) relative to baseline (1971–2000) conditions under five future climate scenarios. We then predicted statewide changes in suitable habitat for 180 sensitive plant taxa using the same future climate scenarios in a species distribution modeling approach. Finally, from these predictions we evaluated suitable habitat retention at three spatial scales: individual NRS reserves (focal reserves), the NRS reserve network, and the surrounding mosaic of protected open space. Six reserves—Sagehen Creek Field Station, McLaughlin Natural Reserve, Jepson Prairie Reserve, Landels-Hill Big Creek Reserve, Sedgwick Reserve, and Boyd Deep Canyon Desert Research Center—were selected as focal reserves for analyses.

Main Findings

A considerable proportion of California's sensitive plants have historical representation in the NRS reserve network

- At the time of this report, over 2,300 vascular plant taxa have a California Rare Plant Rank (CRPR) status, 406 of which are state or federally listed
- NRS reserves comprise less than 1% of the state's total land area yet represent as much as 16% (373 minimum rank taxa) of all CRPR vascular plants
- Many sensitive plants have been recorded in large parks associated with the NRS (97 taxa in Yosemite National Park; 105 taxa in Anza-Borrego Desert State Park), increasing the total number of sensitive plants historically represented in the greater NRS network to 526 taxa
- Over 70% (1,637 taxa) of all CRPR vascular plants in California have been recorded within 50 km of an NRS reserve or associated park

Projected climate change exposure varied by climate model and reserve geographic location

- Projections for precipitation were highly variable across climate models
- Overall, reserves in central and northern California had greater exposure to increased precipitation while those in southern California had greater exposure to decreased precipitation
- Exposure to warming was greatest for reserves in the Sierra Nevada and East of the Sierra Nevada and lowest for those along the coast
- Climatic water deficit (CWD), a measure of drought stress experienced by plants, increased across all reserves, even under scenarios of increased precipitation, with reserves in the Sierra Nevada and East of the Sierra Nevada having particularly high exposure

By the end of this century, we predict climate change will drive considerable loss in suitable habitat for many of California's sensitive plant species

- 25 of 180 species modeled had no geographic overlap between modeled baseline and future suitable habitat under three or more climate scenarios
- Assuming species are unable to migrate to future suitable habitat (no dispersal), an additional 73 species (41%) were at severe risk with 80–99% predicted loss in suitable habitat
- Dispersal could alleviate risk for some species – 53 species (30%) were at decreased risk with net habitat gain under future climate scenarios, assuming they are able to reach, establish, and persist in newly suitable habitat
- Even under an optimistic dispersal scenario, 62 species (34%) were still at severe risk

Climate-driven habitat loss and redistribution affected sensitive plant representation in the NRS

- Focal reserves retained suitable habitat for less than 40% of modeled sensitive plant species under future climate scenarios
- Species retention increased as the extent of the area protected expanded to include the entire NRS reserve network and surrounding protected open space
- Allowing dispersal had little effect on species retention within individual focal reserves but increased representation in the NRS reserve network and surrounding open space

Conclusions

Historically, the NRS has played an important conservation role protecting California's sensitive plant species. Because many reserves are located in areas rich in sensitive species, the NRS is well positioned to continue playing a key role in rare plant research and conservation, both locally and regionally. While we predict climate-driven habitat loss and species redistributions will negatively affect sensitive species representation within individual NRS reserves, many species may retain suitable habitat in the NRS network as a whole and in surrounding protected open space. Managing for species persistence and redistribution under climate change will likely require increased cooperation and partnerships among neighboring protected areas and open space as well as better integration of social, conservation, and ecological research. With a long history of research, stewardship, and stakeholder engagement, the NRS is well positioned to take the lead in both supporting the research needed to improve our understanding of the ecological effects of climate change and developing more dynamic and collaborative trans-boundary management strategies.

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Introduction

Climate change poses a considerable threat to protected areas effectiveness for biodiversity conservation. Protected areas are fixed geographically, often delimited from a static snapshot of biodiversity and climate (Gaston et al. 2006), yet their conservation targets are dynamic with complex responses to environmental change. Scientists are already observing the effects of climate change at all levels of ecological organization—from populations to species, communities to ecosystems (McCarty 2001, Walther et al. 2002, Parmesan 2006). Under rapidly changing climate, species must acclimate (Nicotra et al. 2010), adapt (Davis and Shaw 2001), or migrate to stay within their climatic tolerance (Walther et al. 2005, Thomas 2010, Chen et al. 2011), else face extinction (McLaughlin et al. 2002, Urban 2015). If protected area value is defined by effectiveness of biodiversity representation and ability to buffer processes threatening species persistence (Margules and Pressey 2000, Gaston et al. 2006), climate-driven range shifts and extinctions could have a large impact on the future role and relevance of protected areas for conservation (Araújo et al. 2004, Araújo et al. 2011, Monzón et al. 2011). Indeed, across the country, climate-driven population declines, disease expansions, and species redistributions have already affected the conservation value of protected areas (Monzón et al. 2011).

Species distribution models (SDMs) are an important tool for conservation planning in the context of climate change (Schwartz 2012, Guisan et al. 2013). These models relate species occurrences and environmental predictors to model species ranges and map suitable habitat (Guisan and Thuiller 2005, Elith and Leathwick 2009). When combined with future climate scenarios, SDMs can be used to predict range shifts and changes in species composition and diversity in response to climate change (e.g., Loarie et al. 2008). A number of such applications indicate a loss of protected area effectiveness with climate-driven species redistributions (Araújo et al. 2004, Hannah et al. 2007, Araújo et al. 2011). On the other hand, protected areas that maintain suitability for many species or facilitate range expansions and protect newly suitable habitat for colonization may gain conservation value under climate change (Hole et al. 2009, Thomas et al. 2012, Thomas and Gillingham 2015). Furthermore, climate change could provide opportunities for protected areas to develop more dynamic (Monzón et al. 2011) and collaborative management strategies (Belote et al. 2017, Monahan and Theobald 2018) to help safeguard biodiversity.

In California, protected areas are critical to buffer biodiversity from human threats (Klausmeyer and Shaw 2009). As a global biodiversity hotspot (Myers et al. 2000), California's remarkable biodiversity and endemism are heavily threatened by human activities (Schwartz et al. 2006, Underwood et al. 2009). Of the 5,327 native plant species and over 6,500 native minimum rank taxa occurring in the state, 35% are considered sensitive and 25% are considered rare, threatened, or endangered in California (CNPS 2018). A large proportion (57%) of sensitive plants in California are also endemic, occurring nowhere else in the world. Climate change is expected to heavily impact California's native flora (Hannah et al. 2012, Thorne et al. 2016), potentially driving large habitat losses for two thirds of all endemic (Loarie et al. 2008) as well as many rare (Anacker et al. 2013, Beltran et al. 2014) plant species. A loss of sensitive species from protected areas could have huge implications for future biodiversity conservation in the state.

Study Objectives

Focusing on the University of California Natural Reserve System (NRS), we predicted the impact of projected climate change on reserve effectiveness with respect to sensitive plant protection. The NRS was originally established in 1965 to provide natural environments for research, education, and public service and has since expanded to an extensive network of 39 reserves that is the world's largest university operated reserve system (Fiedler et al. 2013). With properties spanning all major ecoregions and representing much of the state's biodiversity, stewardship plays a central role in the mission of the NRS. However, information about the potential effects of climate change on reserve effectiveness is needed to help guide decision-making and ensure continued conservation relevance in the decades to come. First, we evaluated the historic representation of sensitive vascular plant species in the NRS by compiling species accounts from reserve checklists, floras, and spatial queries of occurrence databases. Next, we calculated projected climate change exposure across the NRS reserve network for the end of the 21st century (2070–2099) relative to baseline (1971–2000) using five future climate scenarios. We then predicted statewide changes in suitable habitat under the same five scenarios for 180 endemic sensitive plant taxa using a species distribution modeling approach. From these predictions we evaluated suitable habitat retention at three spatial scales: individual NRS reserves, the NRS reserve network, and the surrounding mosaic of protected open space.

Methods

UC Natural Reserve System and Protected Area Ownership

The Natural Reserve System's reserve network encompasses over 756,000 acres and serves as a gateway to more than a million additional acres of public land (Fig.1, Table 1). We selected six focal reserves representing important habitats in California to evaluate future sensitive plant protection across spatial scales. These reserves were Sagehen Creek Field Station in the Sierra Nevada; McLaughlin Natural Reserve in the North Coast Ranges; Jepson Prairie Reserve, a remnant natural prairie with vernal pools in the southern Sacramento Valley; Landels-Hill Big Creek Reserve in the central coast Santa Lucia Mountains; Sedgwick Reserve in southern California's Santa Ynez Valley; and Boyd Deep Canyon Desert Research Center on the western edge of the Colorado Desert. Boyd Deep Canyon Desert Research Center encompasses a major drainage system extending from the Santa Rosa Mountains to the desert lowlands.

The NRS network includes land owned by the University of California and land owned by external partners (e.g., private landowners, land trusts, state park systems) but managed by the NRS. We consider the NRS reserve network as all parcels of land either owned by or having a legal agreement with the NRS. We categorized land ownership of surrounding protected open space within 50 km of NRS reserves based on agency-level distinction from the California Protected Area Database (CPAD 2017) (Table 2). CPAD is a spatial database of over 49 million acres of protected lands owned and managed by over 1,000 unique entities. These entities span federal, state, county, city, special district, nonprofit, and private designations and encompass large blocks of open space (e.g., National Parks, National Forests, and BLM land) as well as smaller open spaces such as county and neighborhood parks (Fig. 2). Two large parks, Anza-Borrego Desert State Park and Yosemite National Park have use agreements with the NRS. We summarized sensitive species for these associated parks as part of a "greater" NRS network. Given their large size external management by state and federal agencies, however, we included them as part of the protected open space matrix in habitat retention analyses rather than treating them as NRS reserves.

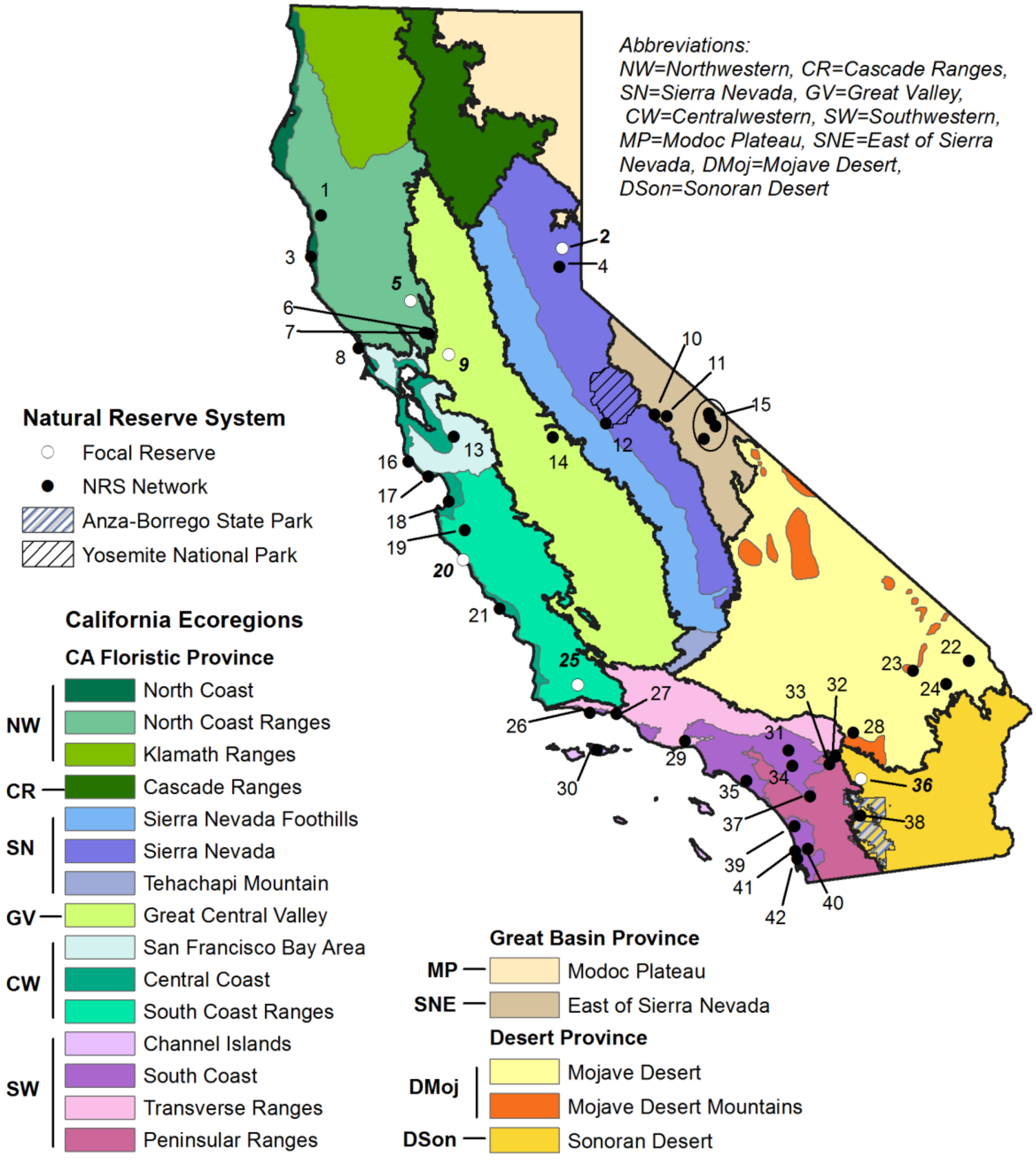


Figure 1. NRS reserve locations by California ecoregion. Focal reserves are indicated by white circles and italic numbers. Ecoregions are modified from Baldwin et al. (2012).

Table 1. List of NRS reserves. Numbers correspond to Figure 1, focal reserves are highlighted.

Reserve Name	**Campus**	**Acreage**	**Elevation (m)**
1-Angelo Coast Range Reserve	Berkeley	7835	378–1290
2-Sagehen Creek Field Station	Berkeley	9000	1800–2650
3-Jenny Pygmy Forest Reserve	Berkeley	70	180
4-Chickering American River Reserve	Berkeley	16875	1830–2470
5-McLaughlin Natural Reserve	Davis	6940	379–888
6-Quail Ridge Reserve	Davis	2500	134–462
7-Stebbins Cold Canyon Reserve	Davis	638	91–762
8-Bodega Marine Reserve	Davis	545	0–58
9-Jepson Prairie Reserve	Davis	1566	2–8
10-VESR* - Valentine Camp	Santa Barbara	154	2437–2605
11-VESR* - Sierra Nevada Aquatic Research Laboratory	Santa Barbara	56	2149–2160
12-Yosemite Field Station**	Merced	--	1220
13-Blue Oak Ranch Reserve	Berkeley	3259	454–870
14-Merced Vernal Pools and Grassland Reserve	Merced	6561	85–177
15-White Mountains Research Center	Los Angeles	45	1252–4342
16-Año Nuevo Island Reserve	Santa Cruz	10	0–13
17-Younger Lagoon Reserve	Santa Cruz	72	0–15
18-Fort Ord Natural Reserve	Santa Cruz	609	21–58
19-Hastings Natural History Reservation	Berkeley	2373	467–953
20-Landels-Hill Big Creek Reserve	Santa Cruz	4328	0–1067
21-Kenneth S. Norris Ranch Marino Reserve	Santa Barbara	500	0–216
22-Sacramento Mountains Reserve	Riverside	591	700–915
23-Sweeney Granite Mountains Desert Research Center	Riverside	3600	1128–2071
24-Old Woman Mountains	Riverside	265	821–1085
25-Sedgwick Reserve	Santa Barbara	5896	290–790
26-Coil Oil Point Natural Reserve	Santa Barbara	170	0–12
27-Carpenteria Salt Marsh Reserve	Santa Barbara	230	−1–3
28-Burns Piñon Ridge Reserve	Irvine	306	1080–1300
29-Stunt Ranch Santa Monica Mountains Reserve	Los Angeles	310	392–472
30-Santa Cruz Island Reserve	Santa Barbara	46090	0–742
31-Box Springs Reserve	Riverside	160	506–745
32-Oasis de Los Osos	Riverside	160	400–700
33-James San Jacinto Mountains Reserve	Riverside	30	1623–1692
34-Motte Rimrock Reserve	Riverside	715	482–605
35-San Joaquin Marsh Reserve	Irvine	202	2–3
36-Boyd Deep Canyon Desert Research Center	Riverside	6122	9–2657
37-Emerson Oaks Reserve	Riverside	241	439–640
38-Steele/Burnand Anza-Borrego Desert Research Center***	Irvine	78	182
39-Dawson Los Monos Canyon Reserve	San Diego	234	67–179
40-Elliott Chaparral Reserve	San Diego	183	230–290
41-Scripps Coastal Reserve	San Diego	844	–15–113
42-Kendall-Frost Mission Bay Marsh Reserve	San Diego	21	–0.6–3

*VESR Valentine Eastern Sierra Reserve

**Use agreement with Yosemite National Park provides an additional 761,000 acres with 641–3997 m elevation range

***Use agreement with Anza-Borrego Desert State Park provides an additional 615,000 acres with 18–1888 m elevation range

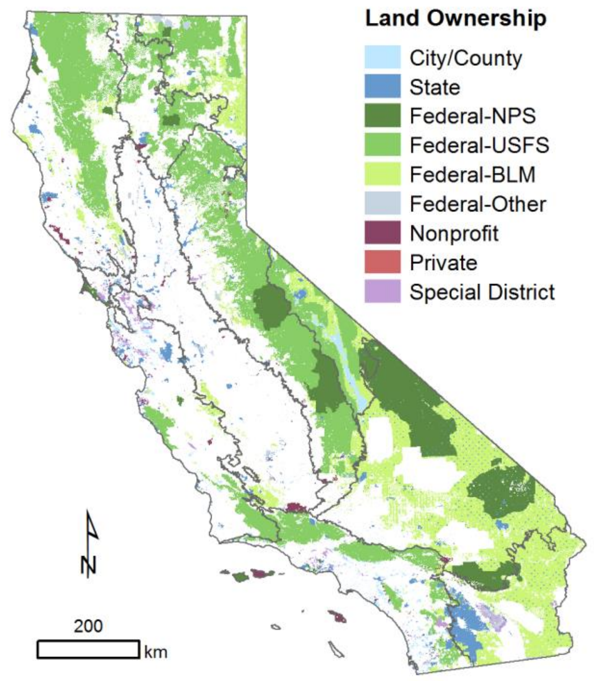


Figure 2. California protected open space ownership. Ownership is based on CPAD.

Table 2. Ownership of protected open space surrounding the NRS. Acreage of protected land within 50 km of NRS reserves.

Agency	Acreage
Federal - USFS	6,386,649
Federal - BLM	4,029,687
Federal - NPS	2,459,145
State - CDPR	1,175,264
State - CDFW	465,351
City	458,929
Special District	446,953
County	312,024
Nonprofit	290,743
State - Other	265,724
Federal - USFWS	112,612
Federal - Other	90,619
Federal - US Military/Defense	8,156
Private	3,373

USFS US Forest Service; BLM Bureau of Land Management; NPS National Park Service; CDPR California Department of Parks and Recreation; CDFW California Department of Fish and Wildlife; USFW US Fish and Wildlife Service

NRS Sensitive Plant Species

We identified sensitive plants of conservation concern using California Rare Plant Ranks (CRPR, see Glossary) from the California Native Plant Society's Inventory of Rare and Endangered Plants (CNPS 2018). We compiled occurrence data for 2,192 CRPR plant taxa from the following sources: the Consortium of California Herbaria (CCH 2014), California Natural Diversity Database (CNDDB 2013), and CalPhotos (CalPhotos 2013). Although many of these taxa include varieties and subspecies, for simplicity we use the term "species" rather than the more appropriate terms "taxa" and "taxon." We compiled a list of sensitive plant species on NRS reserves from checklists, floras, and spatial queries of occurrence data (Appendix 1). We updated taxonomy following The Jepson eFlora (JFP 2018) and created a synonymy for CRPR plant species based on synonyms listed in the Jepson Online Interchange, Calflora, USDA PLANTS, and the Integrated Taxonomic Information System. We then summarized the number of sensitive plant species by CRPR rank and NRS reserve. For the White Mountain Research Center, we compiled species observations with 2 miles of the Crooked Creek, Barcroft, and Summit stations. Because the NRS provides access to and supports research in nearby areas rich in sensitive plants, we included CRPR summaries for the following parks and regions: Año Nuevo State Park, Granite Mountains, White Mountains, Anza-Borrego Desert State Park and Yosemite National Park. Our compiled NRS sensitive plant list is not exhaustive and may include dubious occurrences, taxonomic uncertainties, and misidentifications. Sensitive species are likely underrepresented, as many reserves lack thorough checklists or floras. Some historical observations may represent extirpated species rather than extant populations. Finally, CRPR assignments reflect the status at the time of the report (CNPS 2018) and may change with future assessments (see Appendix 1).

Climate Data

We calculated 30-year averages for baseline (1971–2000) and future (2070–2099) climate surfaces from the California Basin Characterization Model (BCM; Flint et al. 2013) in order to evaluate projected climate change exposure across NRS reserves and predict suitable habitat for sensitive plant species. The BCM applies a monthly regional water-balance model to simulate hydrologic response to climate at 270 m spatial resolution. It provides 18 future climate projections spanning a range of general circulation models (GCMs; see Glossary) and emission scenarios. From these, we selected projections from five GCMs assuming a high future emission concentration pathway, the Representative Concentration Pathway (RCP) 8.5 (Fig. 3, Appendix 2). RCP scenarios (IPCC 2013) are based on radiative forcing, defined as the cumulative measure of all human greenhouse gas emissions, expressed in Watts per square meter. The high concentration pathway scenario (RCP 8.5) is projected to reach a radiative forcing of 8.5 $W \cdot m^{-2}$ in 2100 (IPCC 2013) and most closely tracks the current global emissions trajectory.

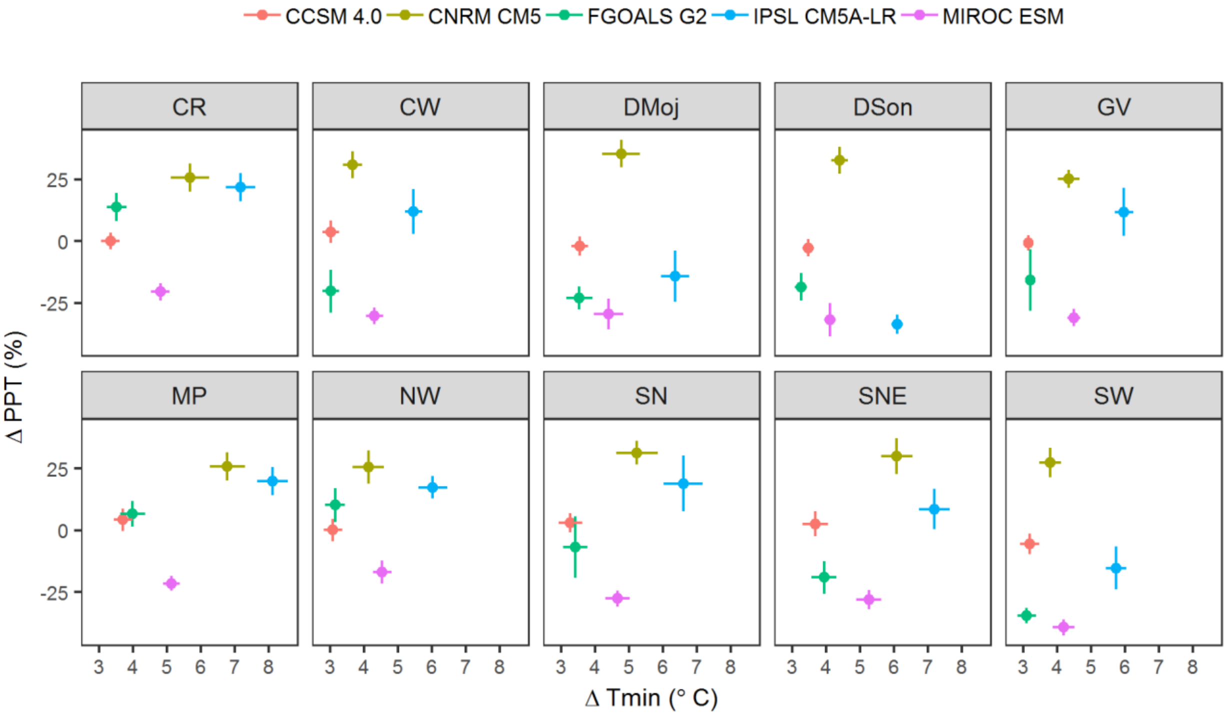


Figure 3. Projected change in regional climate. Mean ± SD change in climate projected for 2070–2099 relative to 1971–2000 summarized by geographic region. Tmin = minimum winter temperature; PPT = annual precipitation. Region abbreviations: CR Cascade Range, CW Centralwestern, DMoj Mojave Desert, DSon Sonoran Desert, GC Great Central Valley, MP Modoc Plateau, NW Northwestern, SN Sierra Nevada, SNE East of Sierra Nevada, SW Southwestern. See Appendix 2 for climate exposure maps.

Species Distribution Modeling

Species occurrence data and environmental predictors

We identified 317 candidate plant species to model that occur within 50 km of one or more focal reserves. Candidate species were endemic to California, had a CRPR status 1B (rare, threatened, or endangered) or 4 (uncommon), and had at least 20 unique occurrence locations. To ensure occurrence data quality we only used records collected after 1900 having less than 10 km georeference uncertainty (Graham et al. 2008) and excluded records annotated as cultivated or planted. We identified georeference errors and corrected where possible using the following steps. First, we checked that the county name listed on the record matched the mapped county based on the georeferenced latitude and longitude. We then verified the location of any occurrence having baseline (1971–2000) mean annual temperature or annual precipitation values exceeding 5 standard deviations from the species mean. Finally, we visually checked any geographic outliers to confirm the georeferenced location reasonably matched the written location description of the record.

We calculated 19 bioclimatic variables (Bioclim; Nix 1986) representing annual trends, seasonality, and extremes from BCM baseline and future climate data. We selected a subset of variables for modeling (Table 3) that minimized collinearity (all pairwise Pearson's r < 0.8) and are known drivers of western US plant distribution (Stephenson 1998, Rehfeldt et al. 2006). Climatic water deficit, the evaporative demand not met by available water, measures climate stress experienced by plants (Stephenson 1990, 1998). It is calculated as the difference between potential evapotranspiration—the amount of water that could potentially evaporate or transpire from vegetation given unlimited water—and actual evapotranspiration—the evaporative water loss from vegetation based on actual water availability (Flint and Flint 2012). Because many of California's rare and endemic plants are edaphic specialists (Harrison 2013) we included two soil variables, parent geology and soil depth. Soil data were obtained from the BCM and were originally based on SSURGO soil data produced by the USDA Natural Resources Conservation Service (NRCS).

Table 3. Environmental predictors used in species distribution models.

Variable	Description
CWD	Climatic Water Deficit
T_{SEAS}	Temperature Seasonality
T_{MAX}	Maximum Temperature of Warmest Month
T_{MIN}	Minimum Temperature of Coldest Month
PPT_{SEAS}	Precipitation Seasonality
PPT_{SUMMER}	Precipitation of Warmest Quarter
PPT_{WINTER}	Precipitation of Coldest Quarter
Geology	Parent Geology
Soil Depth	Depth to bedrock

Modeling approach

We used the modeling algorithm Maxent (Phillips et al. 2006), a maximum entropy method for modeling species distributions from occurrence (presence-only) data. We chose Maxent for its high performance with small sample sizes (Elith et al. 2006, Hernandez et al. 2006, Pearson et al. 2007) typical of rare species. For each species, we modeled the relationship between species presence and baseline (1971–2000) climate and soil using a targeted background sampled within 100 km of species occurrences (see Appendix 3 for detailed modeling methods). This species-environment relationship was then projected onto each of five future climate scenarios for the end of the century (2070–2099) to predict the spatial distribution of future suitable habitat in California. We assumed two dispersal scenarios to estimate future habitat loss (no dispersal) and gain (full dispersal). Under the no dispersal scenario, future habitat was restricted to areas that were also suitable under baseline climate. The full dispersal scenario allowed gains in future suitable habitat within 100 km of historical species occurrences. We did not include suitable habitat beyond 100 km as it is unlikely that sensitive species will be able to disperse beyond 100 km in the time period considered without human intervention and there are a number of factors that must be considered in assisted migrations that are beyond the scope of this report (see Aitken and Whitlock 2013). We evaluated model performance using four-fold cross validation to estimate two metrics, the area under the receiver operating characteristic curve (AUC) and the True Skill Statistic (TSS).

Assessing Projected Climate Change Effects

Climate exposure

Climate exposure was calculated as the difference between late 21st century (2070–2099) and baseline (1971–2000) 30-year averages for the following variables: annual precipitation (PPT), minimum winter (December–February) temperature, maximum summer (June–August) temperature, and climatic water deficit (CWD). Precipitation exposure was calculated as the percent difference relative to baseline. We summarized exposure for California regions (Geographic Subdivisions in Baldwin et al. 2012) and NRS reserves as the mean ± standard deviation of pixels for each climate variable and climate scenario. For reserves encompassing less than three pixels of data, we summarized climate variables within a 540 m radius circle from the reserve center (Kendall-Frost Mission Bay Marsh Reserve, Scripps Coastal Reserve, White Mountains Research Center). Año Nuevo Island Reserve was excluded from climate exposure analyses due to lack of coverage by BCM data. We report climate exposure as the median and range (minimum–maximum) across the five climate scenarios.

Sensitive plant habitat suitability

For each climate and dispersal scenario, we mapped predicted future habitat as: stable (suitable under baseline and future climate), loss (suitable under baseline climate, unsuitable under future climate), or gain (unsuitable under baseline climate, suitable under future climate). We also mapped consensus areas where at least three climate models showed spatial agreement in predicted future habitat (consensus scenario; Fig. 4). We then calculated the percent overlap in baseline and future habitat, as well as the percent gain, loss, and net change in future habitat relative to baseline for the end of the century. Species were assigned a climate change risk category based on the net change in suitable habitat under the consensus scenario.

NRS effectiveness for sensitive species protection

For each focal reserve, we counted the total number of sensitive plant species with: baseline suitable habitat in the reserve (R), complete future loss of suitable habitat from the reserve (L), and future gain of suitable habitat in the reserve (new colonizers; G). From these counts we calculated the reserve turnover in sensitive species (Thuiller et al. 2005):

$$T = 100 \times (L + G)/(R + G)$$

We also calculated habitat retention in focal reserves as the percent of species with baseline suitable habitat that retained habitat under future climate and dispersal scenarios. We then evaluated habitat retention of focal species with scale: (1) individual focal reserve, (2) the NRS network, and (3) surrounding protected open space within a 50 km radius of the NRS network. Species counts, turnover, and percent habitat retention were summarized as the consensus and the range (min–max) across the five future climate scenarios. The associated parks Yosemite National Park and Anza-Borrego Desert State Park and public land of the White Mountains Research Center (National Forest and Los Angeles Department of Water and Power) were considered part of the surrounding protected open space in habitat retention calculations.

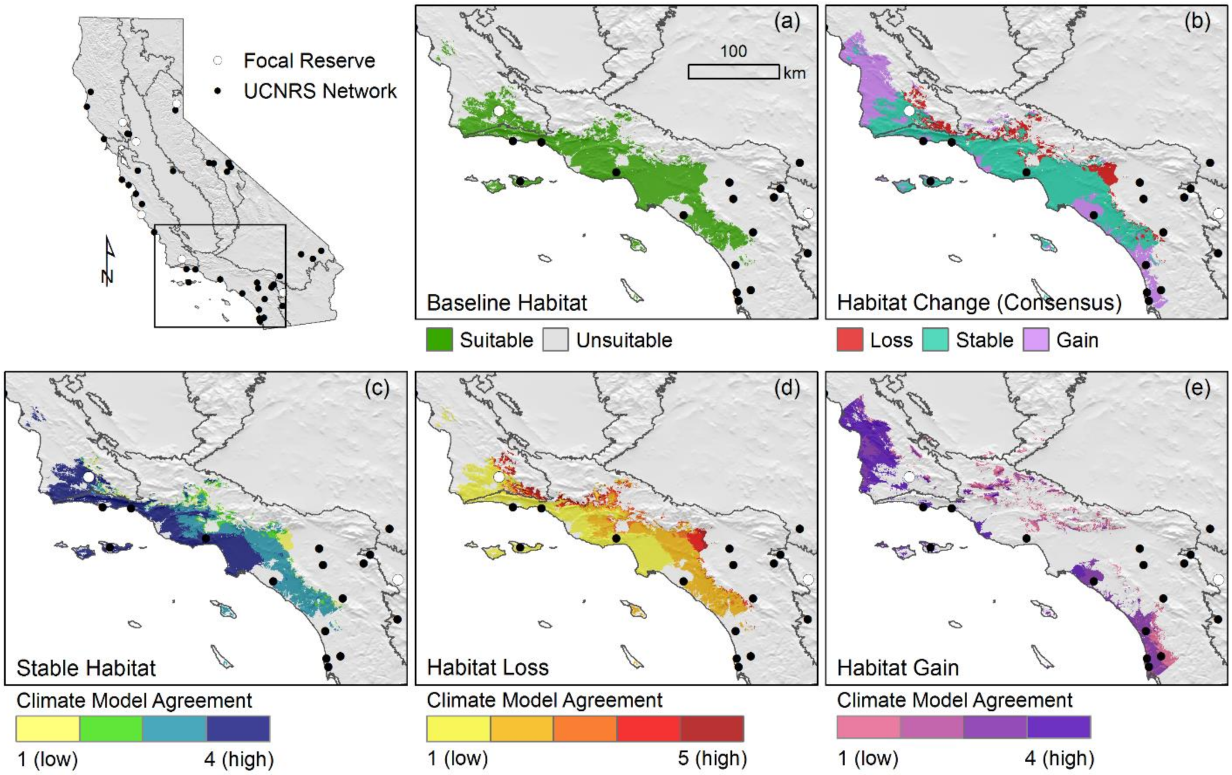


Figure 4. Predicted suitable habitat for Catalina mariposa lily. Maps of (a) baseline (1971–2000) and (b-e) future (2070–2099) suitable habitat for the Catalina mariposa lily (*Calochortus catalinae*). Consensus habitat change (b) show areas of spatial agreement in habitat change (loss, stable, gain) under three or more future climate scenarios. Climate model agreement maps (c-e) show spatial agreement of predicted future habitat across all five future climate scenarios ranging from 1 (no agreement) to 5 (full agreement).

Results

Historical Status of Sensitive Plants in the NRS

Over 2,300 vascular plant taxa have a special conservation status in California, 50% of which are rare, threatened, or endangered throughout their range (CRPR 1B) and 26% of which are uncommon or have limited distributions and warrant regular monitoring (CRPR 4) (Table 4). Over 1,300 CRPR taxa are endemic to California, the majority of which have a CRPR 1B status. An additional 20% are rare, threated, or endangered in California but more common outside the state (CRPR 2B). Geographic regions with high densities of CRPR 1B and CRPR 4 plants include the North Coast, Central Coast, San Francisco Bay Area, Channel Islands, Mojave Desert Mountains, and Southwestern California (Fig. 5). Mountainous areas in the northern and eastern interior (Klamath Ranges, Cascade Ranges) and Great Basin Province (Modoc Plateau, East of the Sierra Nevada) are particularly high in CRPR 2B taxa.

Historically, NRS reserves represent a considerable proportion of California's sensitive vascular plants, comprising less than 1% of the state's total land area but representing as much as 16% (373 minimum rank taxa) of the state's CRPR taxa (Table 4). Many sensitive plants have been observed in large parks associated with the NRS (97 taxa in Yosemite National Park; 105 taxa in Anza-Borrego Desert State Park), increasing the total number of sensitive plants represented in the greater NRS network to 526 taxa. Although some species are only known from historical collections and thus may have been extirpated from reserve boundaries, these numbers likely underrepresent the total number of sensitive plants within the NRS network given that many reserves lack comprehensive plant inventories. Indeed, over 70% of all CRPR taxa in California occur within 50 km of an NRS reserve or associated park (Table 4, Fig. 6).

Reserves with some of the greatest numbers of CRPR taxa are Santa Cruz Island Reserve, McLaughlin Natural Reserve, and Boyd Deep Canyon Desert Research Center (Table 5). These reserves are among the largest in the NRS and have high geologic, topographic and climatic diversity. McLaughlin Natural Reserve is known for its geologic diversity including unusual edaphic habitats like serpentine derived soils. Many of the CRPR taxa found on McLaughlin are edaphic specialists, such as Hall's harmonia (*Harmonia hallii*; CRPR 1B). Collectively, Boyd Deep Canyon Research Center and the Deep Canyon Transect, which span a major elevational gradient from the Colorado Desert to the Santa Rosa Mountains, represent 38 sensitive plant species—from the federally endangered Coachella Valley milk-vetch (*Astragalus lentiginosus* var. *coachellae*; CRPR 1B.2) in the desert dunes to shaggy haired alumroot (*Heuchera hirsutissima*; CRPR 1B.3) in the upper elevations of the mountains. The NRS also provides access to and supports research in nearby areas rich in sensitive plant species. The White Mountains have 110 sensitive plant taxa (Morefield 2016), 45 of which have been recorded within two miles of the Crooked Creek, Barcroft, and Summit stations of the White Mountains Desert Research Center.

Forty eight of California's 195 state or federally listed plants have been observed within the greater NRS network including Yosemite National Park and Anza-Borrego Desert State Park. Key reserves for listed plant species are Santa Cruz Island Reserve, Jepson Prairie Reserve, Merced Vernal Pools and Grassland Reserve, and many coastal reserves including Ford Ord Natural Reserve (Table 6). Many of the listed species on Santa Cruz Island Reserve are island endemics such as the federally threatened island rush rose (*Helianthemum greenei*; CRPR 1B.2) and federally endangered Santa Cruz Island fringepod (*Thysanocarpus conchuliferus*; CRPR 1B.2). Jepson Prairie and Merced Vernal Pools and Grassland reserves protect critical vernal pool habitat and associated listed species like Colusa grass (*Neostapfia colusana*; CRPR 1B.1). Fort Ord Natural Reserve protects a stand of threatened maritime chaparral and two associated listed plants, seaside bird's beak (*Cordylanthus rigidus* ssp. *littoralis*; CRPR 1B.1) and Monterey gilia (*Gilia tenuiflora* ssp. *arenaria*; CRPR 1B.2).

Table 4. State- and NRS system-wide counts of sensitive plant species. Vascular plant counts include historical records of species that may have been extirpated within reserve boundaries. CRPR = California Rare Plant Rank. California Endangered Species Act (CESA): CC = candidate for listing; CR = rare; CT = threatened; CE = endangered. Federal Endangered Species Act (FESA): FC = candidate for listing; FT = threatened; FE = endangered.

		CRPR Status						**CESA**				**FESA**		
	Total	1A	2A	1B	2B	3	4	CC	CR	CT	CE	FC	FT	FE
State	2306	22	7	1154	472	69	582	2	64	22	133	1	52	135
NRS reserves	373	1	0	142	58	12	160	--	4	2	16	--	8	19
Greater NRS network*	526	1	2	196	104	16	207	--	11	2	21	--	9	21
Greater NRS network (50km)**	1637	13	5	825	317	29	448	1	52	20	100	8	38	111

*Total CRPR species in the greater NRS network including Anza-Borrego Desert State Park and Yosemite National Park

**Total CRPR species within 50 km of the greater NRS network including Anza-Borrego Desert State Park and Yosemite National Park

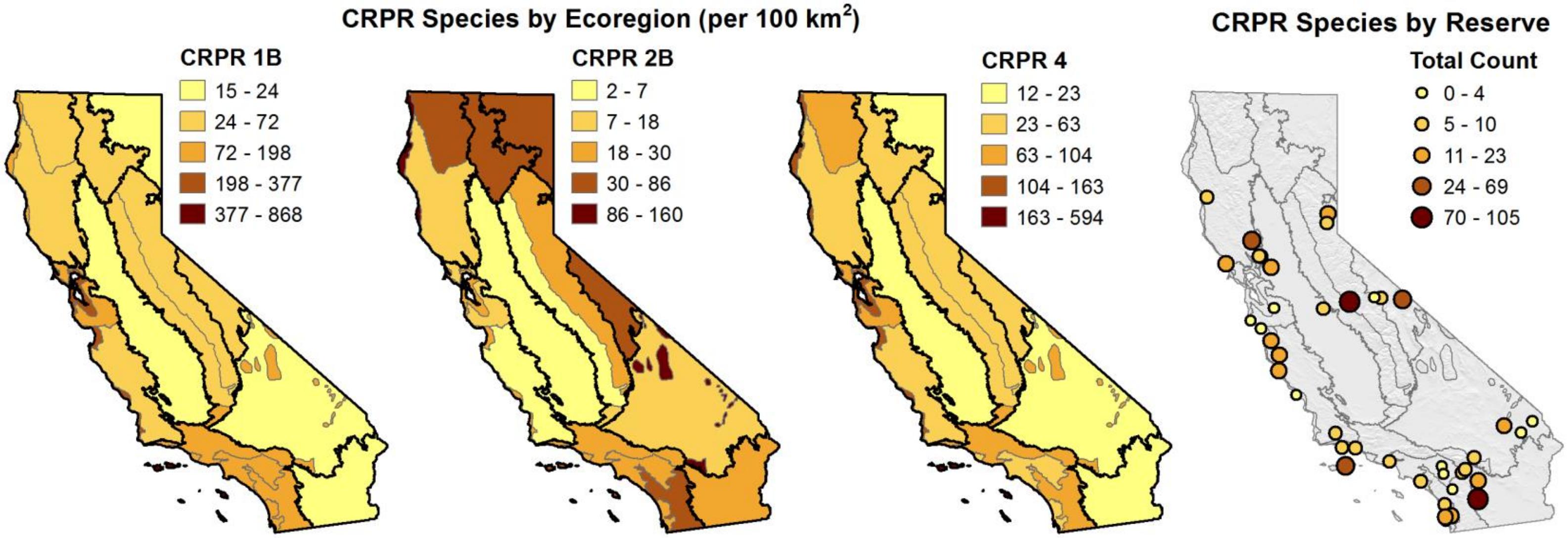


Figure 5. Distribution of sensitive plant species in California. Ecoregion CRPR counts are normalized by ecoregion area. Reserve counts include all CRPR ranks (1A, 1B, 2A, 2B, 3, 4). Ecoregions are modified from Baldwin et al. (2012). CRPR = California Rare Plant Rank.

Table 5. NRS reserve sensitive plant species counts. Counts include historical records of species that may have been extirpated within reserve boundaries. CRPR = California Rare Plant Rank. California Endangered Species Act (CESA): CR = rare; CT = threatened; CE = endangered. Federal Endangered Species Act (FESA): FT = threatened; FE = endangered. See Appendix 1 for global list of CRPR species by reserve.

					CRPR				CESA			FEA	
Region	**Reserve**	Total	1A	2A	1B	2B	3	4	CR	CT	CE	FT	FE
NW	Angelo Coast Range Reserve	8	0	0	0	1	0	7	0	0	0	0	0
CW	Año Nuevo Island Reserve	0	0	0	0	0	0	0	0	0	0	0	0
CW	Blue Oak Ranch Reserve	4	0	0	1	0	0	3	0	0	0	0	0
CW	Bodega Marine Laboratory and Reserve	19	0	0	12	1	1	5	0	0	1	0	2
SW	Box Springs Reserve	3	0	0	0	0	0	3	0	0	0	0	0
DSon	Boyd Deep Canyon Desert Research Center	20	0	0	5	7	1	7	0	0	0	0	0
DMoj	Burns Piñon Ridge Reserve	8	0	0	4	2	0	2	0	0	0	1	0
SW	Carpinteria Salt Marsh Reserve	9	0	0	3	0	2	4	0	0	2	0	2
SN	Chickering American River Reserve	5	0	0	3	0	0	2	0	0	0	0	0
SW	Coal Oil Point Natural Reserve	10	0	0	6	0	1	3	0	1	1	0	1
SW	Dawson Los Monos Canyon Reserve	8	0	0	4	1	0	3	0	0	1	0	0
SW	Elliott Chaparral Reserve	16	0	0	10	0	0	6	1	0	2	1	1
SW	Emerson Oaks Reserve	1	0	0	0	0	0	1	0	0	0	0	0
CW	Fort Ord Natural Reserve	14	0	0	9	0	0	5	0	1	1	1	1
CW	Hastings Natural History Reservation	12	0	0	4	0	0	8	0	0	0	0	0
SW	James San Jacinto Mountains Reserve	6	0	0	2	0	0	4	0	0	0	0	0
NW	Jenny Pygmy Forest Reserve	--	--	--	--	--	--	--	--	--	--	--	--
GV	Jepson Prairie Reserve	23	0	0	15	3	1	4	1	0	3	1	1
SW	Kendall-Frost Mission Bay Marsh Reserve	2	0	0	1	1	0	0	0	0	0	0	1
CW	Kenneth S. Norris Rancho Marino Reserve	3	0	0	2	0	0	1	0	0	0	0	0
CW	Landels-Hill Big Creek Reserve	16	0	0	6	0	2	8	0	0	0	0	0
NW	McLaughlin Reserve	44	0	0	14	0	0	30	0	0	0	0	1
GV	Merced Vernal Pools and Grassland Reserve	7	0	0	5	0	1	1	0	0	3	3	0
SW	Motte Rimrock Reserve	4	0	0	2	0	0	2	0	0	0	0	0
DMoj	Oasis de Los Osos	7	0	0	2	0	0	5	0	0	0	0	0
DMoj	Old Woman Mountains	1	0	0	0	1	0	0	0	0	0	0	0
NW	Quail Ridge Reserve	5	0	0	2	0	0	3	0	0	0	0	1

			CRPR						CESA			FESA	
Region	**Reserve**	Total	1A	2A	1B	2B	3	4	CR	CT	CE	FT	FE
DMoj	Sacramento Mountains Reserve	1	0	0	0	1	0	0	0	0	0	0	0
SN	Sagehen Creek Field Station	13	0	0	3	6	0	4	0	0	0	0	0
SW	San Joaquin Freshwater Marsh Reserve	5	0	0	4	0	0	1	0	0	0	0	0
SW	Santa Cruz Island Reserve	69	1	0	23	1	2	42	2	0	3	2	9
SW	Scripps Coastal Reserve	14	0	0	5	3	0	6	0	0	1	0	1
CW	Sedgwick Reserve	7	0	0	1	0	1	5	0	0	0	0	0
NW	Stebbins Cold Canyon Reserve	6	0	0	2	0	0	4	0	0	0	0	0
DSon	Steele/Burnand Anza-Borrego Desert Research Center	--	--	--	--	--	--	--	--	--	--	--	--
SW	Stunt Ranch Santa Monica Mountains Reserve	7	0	0	1	0	0	6	0	0	1	0	1
DMoj	Sweeney Granite Mountains Desert Research Center	15	0	0	2	6	0	7	0	0	0	0	0
SNE	VESR - Sierra Nevada Aquatic Research Laboratory	8	0	0	0	3	0	5	0	0	0	0	0
SNE	VESR - Valentine Camp	2	0	0	0	0	0	2	0	0	0	0	0
SNE	White Mountains Research Center*	45	0	0	7	25	1	12	0	0	0	0	0
CW	Younger Lagoon Reserve	0	0	0	0	0	0	0	0	0	0	0	0
	Associated Parks												
DSon	Anza-Borrego Desert State Park (ABDSP)	105	0	1	42	31	2	29	4	0	5	1	2
SN	Yosemite National Park (YOSE)	97	0	1	24	29	3	40	4	0	0	0	0
	Nearby Regions and Parks												
CW	Año Nuevo State Park	11	0	0	4	0	1	6	0	0	1	0	0
DSon	Deep Canyon Transect	38	0	0	14	9	1	14	0	0	0	0	1
DMoj	Granite Mountains**	18	0	0	2	8	0	8	0	0	0	0	0
SNE	White Mountains***	110	0	0	15	60	3	32	1	0	0	0	0
	Total NRS reserves only	**373**	**1**	**0**	**142**	**58**	**12**	**160**	**4**	**2**	**16**	**8**	**19**
	Total NRS including ABDSP and YOSE	**526**	**1**	**2**	**196**	**104**	**16**	**207**	**11**	**2**	**21**	**9**	**21**

*CRPR species within 2 miles of Crooked Creek, Barcroft, and Summit Stations

**CRPR species in the Granite Mountains area (André 2006)

***CRPR species in the White Mountains area (Morefield 2016)

Table 6. State and federally listed plant species on NRS reserves. Includes Yosemite National Park and Anza-Borrego Desert State Park. CRPR = California Rare Plant Rank. California Endangered Species Act (CESA): CR = rare; CT = threatened; CE = endangered. Federal Endangered Species Act (FESA): FT = threatened; FE = endangered.

Scientific Name	CRPR	CESA	FESA	Reserve
Acmispon argophyllus var. *niveus*	4.3	CE	--	Santa Cruz Island Reserve
Allium yosemitense	1B.3	CR	--	Yosemite National Park
Arctostaphylos confertiflora	1B.2	--	FE	Santa Cruz Island Reserve
Astragalus lentiginosus var. *coachellae*[*]	1B.2	--	FE	Deep Canyon Transect
Astragalus magdalenae var. *peirsonii*	1B.2	CE	FT	Anza-Borrego Desert State Park
Astragalus pycnostachyus var. *lanosissimus*	1B.1	CE	FE	Carpinteria Salt Marsh Reserve; Coal Oil Point Natural Reserve
Baccharis vanessae	1B.1	CE	FT	Elliott Chaparral Reserve
Berberis nevinii	1B.1	CE	FE	Anza-Borrego Desert State Park
Berberis pinnata ssp. *insularis*	1B.2	CE	FE	Santa Cruz Island Reserve
Boechera hoffmannii	1B.1	--	FE	Santa Cruz Island Reserve
Calochortus dunnii	1B.2	CR	--	Elliott Chaparral Reserve; Anza-Borrego Desert State Park
Carex tompkinsii	4.3	CR	--	Yosemite National Park
Castilleja campestris var. *succulenta*	1B.2	CE	FT	Merced Vernal Pools and Grassland Reserve
Chloropyron maritimum ssp. *maritimum*	1B.2	CE	FE	Carpinteria Salt Marsh Reserve
Chorizanthe pungens var. *pungens*	1B.2	--	FT	Fort Ord Natural Reserve
Cirsium rhothophilum	1B.2	CT	--	Coal Oil Point Natural Reserve
Cordylanthus rigidus ssp. *littoralis*	1B.1	CE	--	Fort Ord Natural Reserve
Crocanthemum greenei	1B.2	--	FT	Santa Cruz Island Reserve
Delphinium hesperium ssp. *cuyamacae*	1B.2	CR	--	Anza-Borrego Desert State Park
Downingia concolor var. *brevior*	1B.1	CE	--	Anza-Borrego Desert State Park
Dudleya brevifolia	1B.1	CE	--	Dawson Los Monos Canyon Reserve; Scripps Coastal Reserve
Dudleya nesiotica	1B.1	CR	FT	Santa Cruz Island Reserve
Erigeron parishii	1B.1	--	FT	Burns Piñon Ridge Reserve
Eriophyllum congdonii	1B.2	CR	--	Yosemite National Park
Erysimum menziesii[**]	1B.1	CE	FE	Bodega Marine Laboratory and Reserve
Galium angustifolium ssp. *borregoense*	1B.3	CR	--	Anza-Borrego Desert State Park
Galium buxifolium	1B.2	CR	FE	Santa Cruz Island Reserve
Gilia tenuiflora ssp. *arenaria*	1B.2	CT	FE	Fort Ord Natural Reserve
Gratiola heterosepala	1B.2	CE	--	Jepson Prairie Reserve

Scientific Name	CRPR	CESA	FESA	Reserve
Helianthus niveus ssp. *tephrodes*	1B.2	CE	--	Anza-Borrego Desert State Park
Lewisia congdonii	1B.3	CR	--	Yosemite National Park
Lilaeopsis masonii	1B.1	CR	--	Jepson Prairie Reserve
Limnanthes alba ssp. *parishii*	1B.2	CE	--	Anza-Borrego Desert State Park
Malacothamnus fasciculatus var. *nesioticus*	1B.1	CE	FE	Santa Cruz Island Reserve
Malacothrix indecora	1B.1	--	FE	Santa Cruz Island Reserve
Malacothrix squalida	1B.1	--	FE	Santa Cruz Island Reserve
Nemacladus twisselmannii	1B.2	CR	--	Anza-Borrego Desert State Park
Neostapfia colusana	1B.1	CE	FT	Jepson Prairie Reserve; Merced Vernal Pools and Grassland Reserve
Orcuttia inaequalis	1B.1	CE	FT	Merced Vernal Pools and Grassland Reserve
Pentachaeta lyonii	1B.1	CE	FE	Stunt Ranch Santa Monica Mountains Reserve
Poa atropurpurea	1B.2	--	FE	Anza-Borrego Desert State Park
Pogogyne abramsii	1B.1	CE	FE	Elliott Chaparral Reserve
Sibara filifolia	1B.1	--	FE	Santa Cruz Island Reserve
Sidalcea keckii	1B.1	--	FE	McLaughlin Reserve; Quail Ridge Reserve
Suaeda californica	1B.1	--	FE	Kendall-Frost Mission Bay Marsh Reserve; Scripps Coastal Reserve
Thysanocarpus conchuliferus	1B.2	--	FE	Santa Cruz Island Reserve
Trifolium amoenum[**]	1B.1	--	FE	Bodega Marine Laboratory and Reserve
Tuctoria mucronata	1B.1	CE	FE	Jepson Prairie Reserve

[*] Occurs on Deep Canyon Transect, not on Boyd Deep Canyon Research Center reserve

[**] Experimentally planted at Bodega Marine Laboratory and Reserve

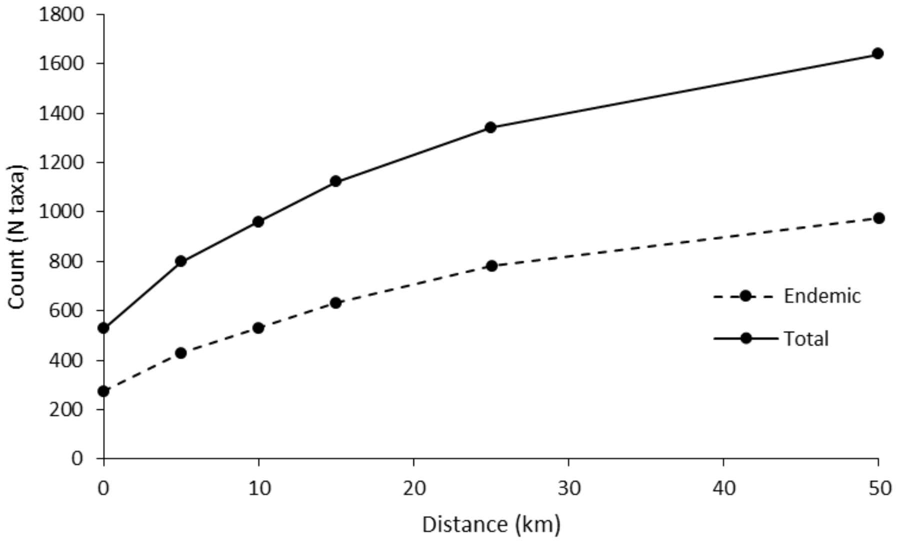


Figure 6. Sensitive plant species by proximity to NRS reserves. Count is the sum of all CRPR rank (1A, 1B, 2A, 2B, 3, 4) species in the greater NRS network including Anza-Borrego Desert State Park and Yosemite National Park).

Climate Exposure

California is projected to warm considerably by the end of the 21st century. State average winter minimum and summer maximum temperatures are projected to increase by 2.2–6.3°C and 2.9–6.5°C respectively by 2070–2099 (relative to 1971–2000) under the high greenhouse gas emissions future we considered (Appendix 2). Projected warming was most pronounced in the interior mountains and desert regions and less severe along the coast (Fig. 3, Appendix 2). Projected annual precipitation varied widely in both magnitude and direction, ranging from a 28% decrease (MIROC ESM) to 29% increase (CNRM CM5) averaged across the state. Two climate models had geographically diverging patterns of precipitation change with increases in the north and decreases in the south. Overall, southern California coast, interior, and desert regions had among the greatest projected decreases in precipitation relative to other parts of the state. Climatic water deficit was projected to increase across all regions, even under scenarios of increased precipitation, indicating a strong control of temperature on water balance and evaporative demand.

The degree of projected future (2070–2099) climate exposure at NRS reserves varied by geographic location and climate model (Fig. 7, Appendix 2). The median (N = 5 climate scenarios) increase in temperature ranged across reserves from 3.3 °C to 5.7 °C (winter minimum temperature) and 3.6 °C to 6.1 °C (summer maximum temperature). Exposure to warming was greatest in reserves in the Sierra Nevada and East of the Sierra Nevada and lowest in coastal reserves. The maximum projected decrease in precipitation ranged from 16 to 44% relative to baseline with reserves located in southwestern California having high exposure to precipitation decreases. The maximum projected increase in reserve precipitation ranged from 17 to 52%, with reserves in western central and northern California having high exposure to precipitation increases. Climatic water deficit was projected to increase across all reserves and climate scenarios (median reserve increase of 99–365 mm) with reserves in the Sierra Nevada and East of the Sierra Nevada (VESR, White Mountains Research Center, Chickering, Sagehen Creek Field Station) having the greatest exposure to increased CWD.

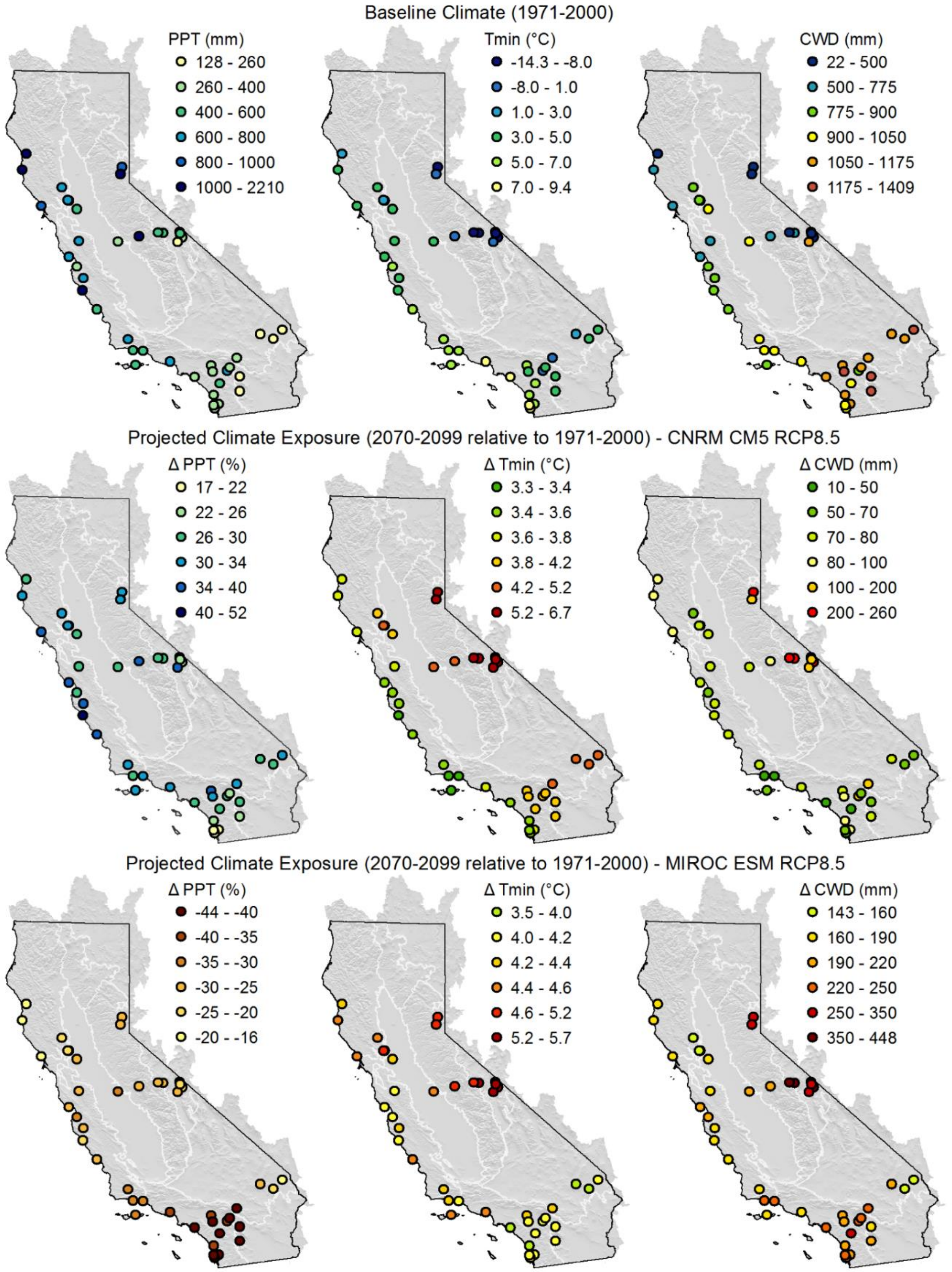


Figure 7. NRS baseline climate and projected future climate exposure. Maps show contrasting wetter (CNRM CM5) and drier (MIROC ESM) precipitation trajectories. PPT = mean annual precipitation; Tmin = winter minimum temperature (December–February); CWD = climatic water deficit.

Sensitive Plant Habitat Suitability

Of the 317 candidate plant species modeled, 266 met minimum model performance criteria. Of these, 166 species had baseline suitable habitat on focal reserves. An additional 14 species ('colonizers') were predicted to gain habitat on focal reserves under at least one future climate scenario. We focused on these 180 species for the report (see Species List). Overall SDM performance was high, both in terms of AUC (0.933 ± 0.036; mean ± standard deviation) and TSS (0.726 ± 0.095; mean ± standard deviation) (Appendix 4). Predicted change in suitable habitat in California varied widely across species and climate models (Fig. 8). Rank 1B (rare, threatened or endangered) and rank 4 (uncommon watch list) species did not differ significantly in predicted suitable habitat loss (P = 0.262; Wilcoxon rank sum test) or gain (P = 0.118; Wilcoxon rank-sum test).

By the end of the 21st century, 25 species were predicted to have no geographic overlap between baseline and future suitable habitat under three or more climate scenarios. Of these, 22 species had no future suitable habitat within 100 km of known species occurrences (Table 7). Assuming species are unable to migrate to future suitable habitat (no dispersal scenario), an additional 73 species (41%) are at severe risk with 80–99% predicted habitat loss and only 33 species (18%) are at low risk with less than 20% habitat loss. Assuming species are able to disperse up to 100 km (full dispersal scenario), predicted gains in suitable habitat may offset some losses. Assuming full dispersal, 53 species (29%) were at decreased risk with a net increase in suitable habitat. Yet, even under this optimistic dispersal scenario, 62 species (34%) are at severe risk with 80–99% predicted habitat loss under three or more future climate scenarios.

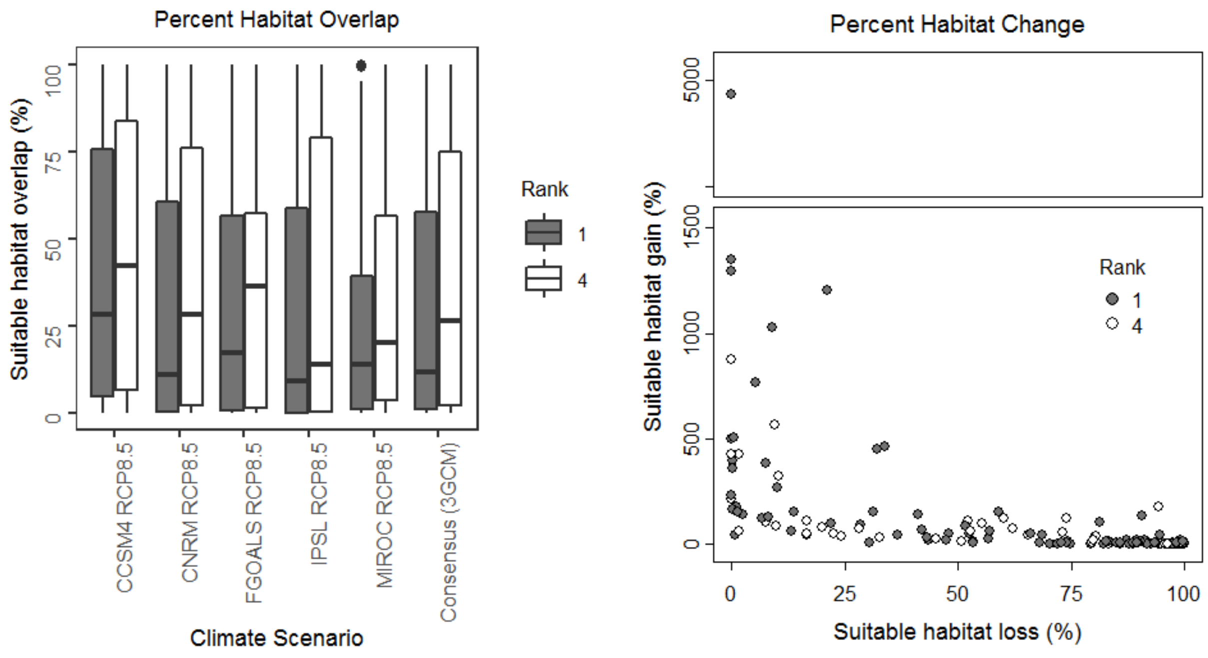


Figure 8. Predicted change in sensitive species suitable habitat in California. (Left) Percent spatial overlap in predicted baseline (1971–2000) and future (2070–2099) suitable habitat by climate scenario. (Right) Species percent gain and loss of suitable habitat was calculated under the consensus scenario. Ranks correspond to CRPR 1B (rare, threatened, or endangered) and CRPR 4 (uncommon watch-list). N=180 modeled plant species.

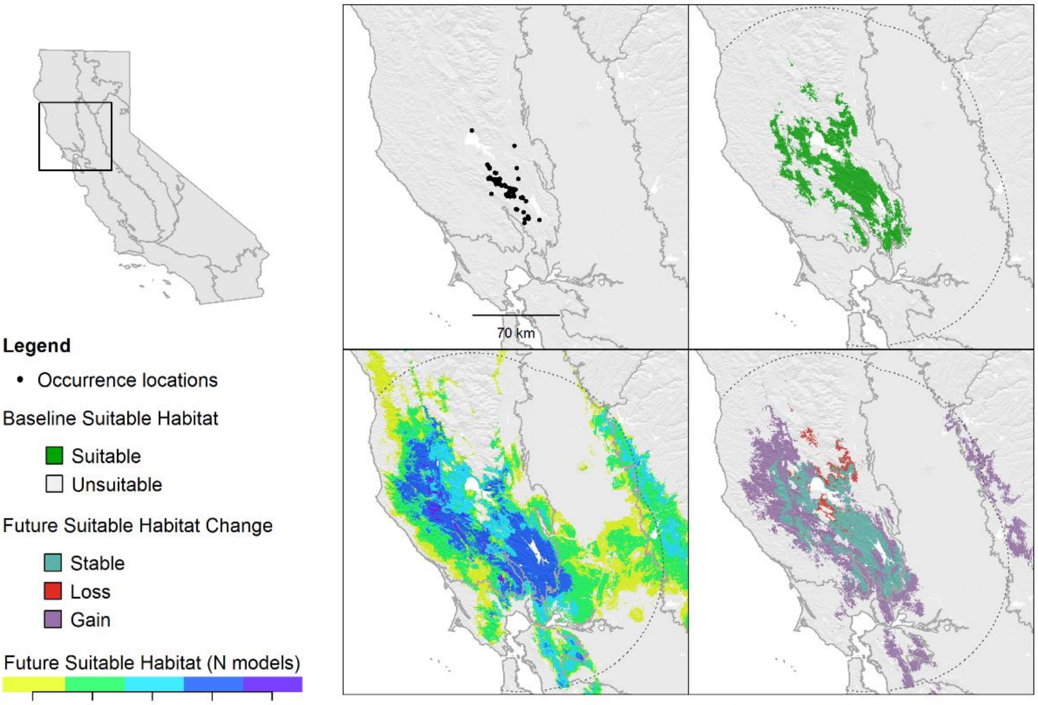
Table 7. Predicted risk of suitable habitat loss for modeled sensitive species. Risk categories are based on the predicted net change in suitable habitat (statewide) for the end of the century (2070–2099) under the consensus scenario. The number of CRPR species is summed by risk category for each dispersal scenario.

Risk Category	Net Habitat Change	No Dispersal	Full Dispersal
Extreme	–100 %	25	22
Severe	–80% to –99%s	73	62
High	–50% to –80%	28	20
Moderate	–20% to –50%	21	13
Low	+20% to –20%	33	10
Somewhat Decreased	+20% to +50%	·	12
Decreased	> +50%	·	41

Perhaps surprisingly, we predicted habitat gains for some species with known edaphic restrictions and narrow ranges such as the dune specialist Coachella Valley milkvetch (*Astragalus lentiginosus* var. *coachellae*) and the following serpentine endemics: serpentine reed grass (*Calamagrostis ophitidis*); Tiburon paintbrush (*Castilleja affinis* var. *neglecta*), swamp larkspur (*Delphinium umbraculorum*) and Hall's harmonia (*Harmonia hallii*) (Appendix 5). This suggests our models may not have captured key habitat requirements related to edaphic specialization for at least some species. For example, two species of western flax found at McLaughlin Reserve, *Hesperolinon drymarioides* (CRPR 1B.2) and *Hesperolinon bicarpellatum* (CRPR 1B.2), are both strict serpentine endemics but had very different predicted change in suitable habitat (Fig. 9, Appendix 4). *Hesperolinon bicarpellatum* had low risk of climate-driven habitat loss with 86% spatial overlap in suitable baseline and future habitat and a predicted habitat gain of 148% under at least three climate scenarios. In contrast, *H. drymarioides* had severe risk of climate-driven habitat loss with only 1% spatial overlap in baseline and future suitable habitat under least three climate scenarios and almost no consensus in predicted habitat gain. Although both species have high affinity for serpentine substrates (Safford et al. 2005), their importance and percent contribution of geology to Maxent models differed. Geology had low contribution to the model of *H. bicarpellatum* but very high contribution to the model of *H. drymarioides*.

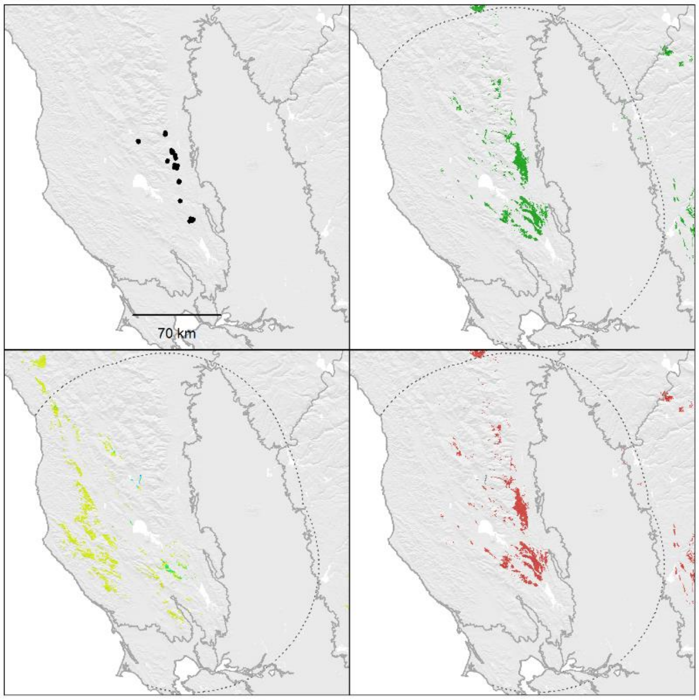
NRS Effectiveness for Sensitive Species Protection

Of the 180 species modeled, 132 had baseline habitat on focal reserves (Table 8). McLaughlin Natural Reserve had the greatest baseline representation of sensitive species (suitable habitat for 44 species). Sagehen Creek Field Station, located on the eastern slope of the northern Sierra Nevada, had the lowest (7 species), due in part to our focus on California endemics and exclusion of sensitive species that also occur outside the state. By the end of the 21st century, we predicted that less than 40% of species would retain suitable habitat within focal reserves (consensus scenario). Sedgwick Reserve had the greatest habitat retention, 52% species retention under the consensus scenario (range: 38–67%), followed by McLaughlin Natural Reserve which had 48% (range: 39–59%). Sagehen Creek Field Station had the lowest retention, 14% (range: 14–43%) of baseline species. Focal reserves accommodated habitat gains for 22 of the 132 baseline species as well as 16 "new" species that were not represented at baseline but gained habitat in reserves under future climate scenarios. Jepson Prairie and McLaughlin reserves had the greatest increase of "new" species. Reserve turnover in sensitive species was high, ranging from 48–86% (no dispersal) and 52–89% (full dispersal) (Table 8; Appendix 6).



two-carpellate western flax | *Hesperolinon bicarpellatum*

CRPR: 1B.2 | CESA: None | FESA: None



drymaria-like western flax | *Hesperolinon drymarioides*

CRPR: 1B.2 | CESA: None | FESA: None

Figure 9. Example of low- and high-risk edaphic specialists. Two western flax species, *Hesperolinon bicarpellatum* and *Hesperolinon drymarioides,* have high serpentine soil affinities and occur on McLaughlin Natural Reserve but differ in their predicted risk of climate-driven habitat loss.

In general, habitat retention for sensitive species increased as the extent of the area protected expanded to include the entire NRS network and surrounding open space (Fig. 10). Sagehen Creek Field Station was the only exception, where species retention did not increase when we considered the NRS network as a whole, but did increase when we considered the surrounding protected open space (mainly USFS lands). Many NRS reserves are located within the vicinity of large contiguous areas of protected open space. Federal lands (USFS, BLM, NPS) followed by state parks were the largest contributors to nearby protected area (Table 2). However, not all species were well retained outside the focal reserves. For example, Landels-Hill Big Creek Reserve and Boyd Deep Canyon Desert Research Center had similar within-reserve species retention under projected climate change. Species at Big Creek had lower habitat retention in surrounding protected areas (78% species retained under a best-case scenario) whereas species at Boyd Deep Canyon Reserve were fully retained in surrounding protected areas.

Dispersal had little effect on species habitat retention at the scale of the individual reserve, but did increase habitat representation in the NRS network and surrounding protected open space (Fig. 10). This suggests that while large climate-driven habitat shifts may cause species losses from within individual reserves, many species will have habitat represented within the greater NRS network and surrounding protected area matrix. Assuming dispersal of up to 100 km, the NRS network accommodated habitat gains for 45 of the 180 sensitive species modeled (consensus scenario). Uncertainty in the spatial distribution of predicted habitat gains across climate models and uncertainty in species' colonization abilities, however, could make incorporating habitat expansions into rare plant management challenging.

Table 8. Predicted species retention and turnover at focal reserves. Baseline is the number of sensitive plant species with suitable habitat on the reserve under baseline climate (1971–2000). Species change is based on habitat suitability at the end of the century (2070–2099) compared to baseline. ND = no dispersal; FD = full (100 km) dispersal. Table values correspond to the consensus scenario and range (min–max) across all five climate scenarios.

Reserve	Baseline	Species Change (N species)			Turnover (%)	
		Loss (ND)	Loss (FD)	Gain (FD)	(ND)	(FD)
Sagehen Creek Field Station	7	6 (4–6)	6 (4–6)	2 (1–4)	86 (57–86)	89 (73–91)
McLaughlin Natural Reserve	44	23 (18–27)	23 (18–27)	10 (4–12)	52 (41–61)	61 (46–70)
Jepson Prairie Reserve	21	13 (12–18)	13 (12–18)	12 (8–20)	62 (57–86)	76 (74–90)
Landels-Hill Big Creek Reserve	32	23 (16–23)	22 (15–23)	5 (3–20)	72 (50–72)	73 (64–78)
Sedgwick Reserve	21	10 (7–13)	10 (7–13)	1 (2–17)	48 (33–62)	50 (39–79)
Boyd Deep Canyon DRC*	21	14 (10–16)	14 (10–16)	1 (1–4)	67 (48–76)	68 (54–78)
Focal Reserve Total	132	82 (68–87)	80 (63–86)	16 (18–30)	62 (51–66)	65 (56–69)

*DRC = Desert Research Center

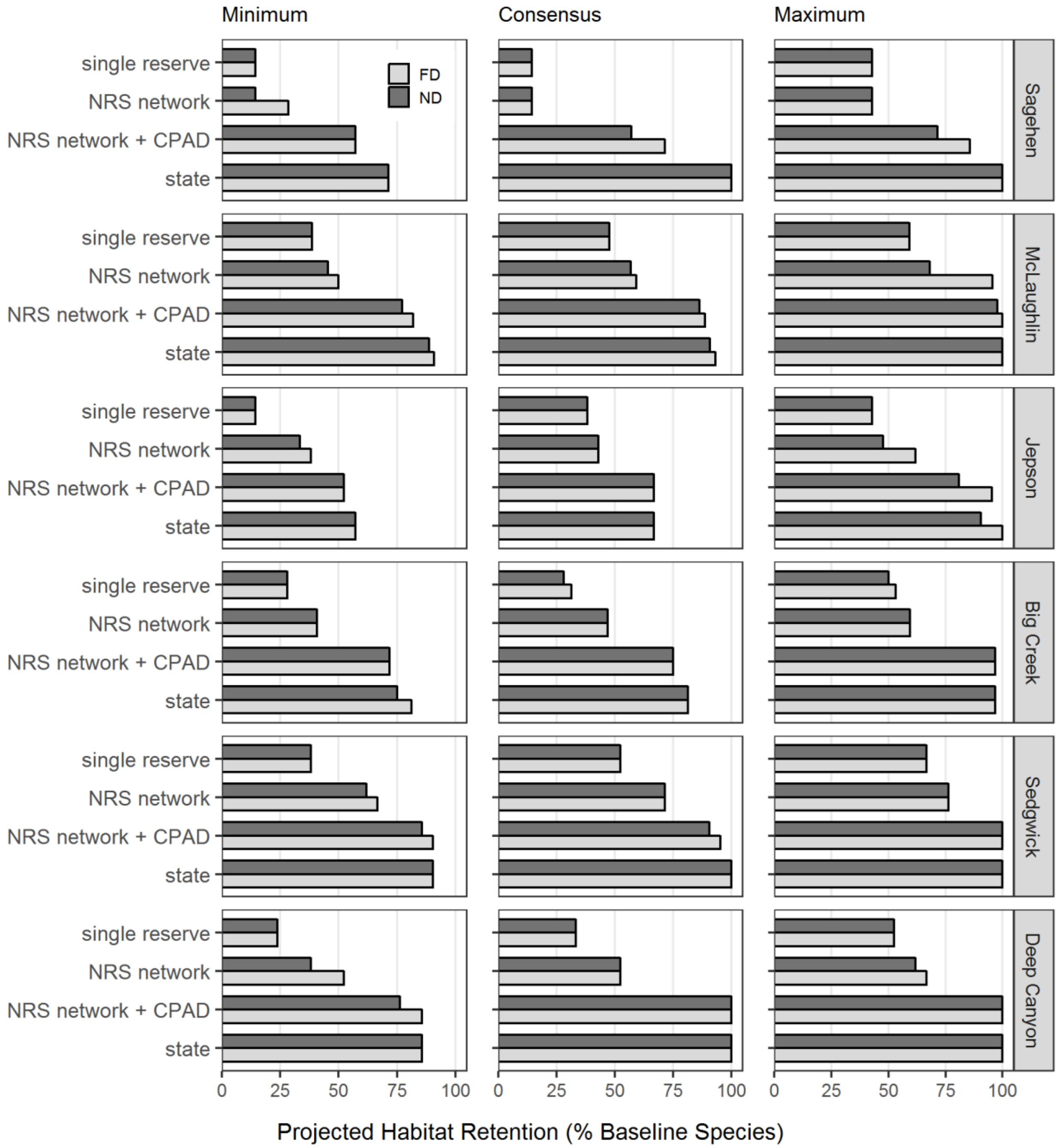


Figure 10. Predicted habitat retention for sensitive plant species. Rows correspond to the sensitive species for each focal reserve. Consensus habitat retention is based on the consensus scenario of spatial agreement of future habitat under three or more future climate scenarios. Minimum and maximum reflect the range in habitat retention across all five climate scenarios. Anza-Borrego Desert State Park and Yosemite National Park are included as part of the surrounding protected open space (CPAD).

Discussion

The NRS plays an important conservation role for native plants, protecting 16% of California’s sensitive vascular plant species in less than 1% of the state’s land area. Small reserves, such as many in the NRS, hold significant conservation value despite the challenges that come with managing small proprieties (e.g., edge effects, small population sizes, destructive trespassing). Even isolated, once-rural parcels of land can provide important protection for rare plants, especially narrow-ranged edaphic endemic species (Parker 2012). Because many of its reserves are located in areas rich in sensitive species, the NRS is well positioned to inform rare plant research and monitoring, both locally and regionally. McLaughlin Natural Reserve has facilitated foundational research on edaphic endemics (e.g., Harrison et al. 2000). Researchers at Sweeney Granite Mountains Desert Research Center have been instrumental in improving the understanding of rare plant diversity and distribution in California’s deserts (André 2014, Moore and André 2014). Such research will become increasingly important to successfully manage for species persistence and biodiversity under climate change.

The vulnerability of the NRS network to climate change will depend on the magnitude and velocity of climate change experienced by reserves(exposure), the sensitivity of species and systems within reserves to climate change (sensitivity), and mechanisms that mitigate both exposure and sensitivity (adaptive capacity) (Füssel and Klein 2006, Glick et al. 2011). Small reserves are at particularly high risk of entirely losing contemporary climate conditions within their boundaries (Loarie et al. 2009, Ackerly et al. 2010). In an analysis of the velocity of projected climate change, Loarie et al. (2009) found that only 8% of protected areas worldwide had climate residence times over 100 years. Reserves with high environmental heterogeneity may be better buffered from climate change impacts, however, such factors are rarely considered when designating protected areas (Ackerly et al. 2010, Carroll et al. 2017). Rather, spatial bias for establishment in extreme environments tend to predispose protected areas to high climate change exposure. Gonzalez et al. (2018) found national parks in the US have experienced and will continue to experience disproportionate exposure to climate change compared to the country as a whole. This is due to the large proportion of park land area located in high latitudes and elevations where warming is occurring at a high rate or in the arid southwest where precipitation has declined sharply (Gonzalez et al. 2018). Similarly, we found greatest projected exposure to warming and increasing climatic water deficit in NRS reserves located at high elevations in the Sierra Nevada and White Mountains and greatest exposure to precipitation declines in southern California.

In accordance with previous studies addressing future protected area effectiveness (Burns et al. 2003, Araújo et al. 2004, Hannah et al. 2007, Araújo et al. 2011), we predict that climate change will negatively impact role of the NRS with respect to sensitive species protection. Protected areas are a cornerstone of biodiversity conservation, safeguarding species and ecosystems from human-driven habitat loss and degradation that would otherwise accelerate species extinctions (Pimm et al. 1995, Ricketts et al. 2005). The effects of climate change, however, are not easily buffered. Many of the rare plants we modeled appear to have high sensitivity to habitat loss with changing climate. These large climate-driven losses and redistribution of suitable habitat, in turn, caused a significant loss in the representation of sensitive plant species from NRS reserves. Indeed, over half of species we modeled had little to no spatial overlap in predicted baseline and future suitable habitat anywhere in the state by the end of the century. We found that dispersal alleviated some risk, resulting in higher habitat retention within the greater NRS network and the surrounding protected open space when species were allowed to disperse into areas of newly suitable habitat. This suggests that NRS reserves could play an important role facilitation and managing for range shifts that may be required for species to keep pace with climate change (e.g., Thomas et al. 2012).

With its long history of research, stewardship, and external partnerships, the NRS is well positioned to take the lead (1) supporting the research needed to improve our understanding of the ecological effects of climate change and (2) developing more dynamic and collaborative trans-boundary management strategies (e.g., Monzón et al. 2011, Monahan and Theobald 2018). The high velocity of plant movement necessary to keep pace with climate change may not be feasible for most species (Corlett and Westcott 2013). Plants unable migrate quickly enough could face local extirpation from reserves and even extinction if they are unable to acclimate or adapt in situ(McLaughlin et al. 2002, Urban 2015). A better understanding of the mechanisms of plant response to climate change and adaptive constraints (Christmas et al. 2016) are needed to determine whether or not more controversial strategies requiring greater human intervention (e.g., assisted migration; Aitken and Whitlock 2013) should be taken to ensure species persistence. Unanticipated biogeographic responses to climate change suggest scientists will need to take a more complex, multifaceted approach that incorporates local scales and natural history (Rapacciuolo et al. 2014). For example, edaphic specialists of infertile soils may be relatively insensitive to climate change (Harrison et al. 2015) and more resilient than our modeling results suggest while species with high habitat fragmentation may have increased extinction risk under climate change (Fahrig 1997, Selwood et al. 2015). The research legacy at the living laboratories of the NRS is ideal for supporting research needed to better understand and manage ecological responses to climate change.

Managing for species persistence and redistribution under climate change requires integrating social, conservation, and ecological research (Bonebrake et al. 2018) as well as increased cooperation and partnerships among neighboring areas (Monahan and Theobald 2018). The close connections the NRS facilitates between reserve managers, scientists, stakeholders, and external conservation organizations and natural resource management agencies are ideal for developing new collaborative, transboundary management approaches. The NRS already contributes to regional planning efforts with diverse partners, from large federal agencies like the US Forest Service to small nonprofits and land trusts. Future efforts may need to include ecologically intact or low human impact areas outside current conservation reserve and protected area matrix (Cox and Underwood 2011, Belote et al. 2017). In addition, the active research at the reserves can help ensure these efforts are based on the most up to date and locally relevant scientific research. Thus, climate change will likely provide not just challenges but also new opportunities for the NRS.

Caveats for Sensitive Species SDMs

Often little is known about the distribution and even basic life histories of rare species. Sparse data and spatial inaccuracies can make modeling rare species particularly difficult (but see Engler et al. 2004, Guisan et al. 2006). Yet, for these same reasons rare species are in the most need of species distribution modeling to support monitoring and conservation efforts – a problem Lomba et al. (2010) call the “rare species modeling paradox.” We recommend applying SDM predictions in concert with expert knowledge about the species natural history, ecological relationships, and population dynamics whenever possible. Modeling assumptions and limitations should be fully recognized and model predictions are best interpreted in terms of climatic suitability and climate stress, not species persistence. Coupled models that integrate population dynamics, physiological tolerances, and/or genetic variation are better equipped to evaluate extinction risk and species persistence under climate change (Franklin et al. 2016) but were beyond the capacity of this report.

The degree to which a species violates model assumptions can result in over- and under-estimation of projected climate change risk (Schwartz 2012). Here we highlight the major assumptions of SDMs with respect to rare species. Further information can be found in a number of comprehensive reviews (Pearson and Dawson 2003, Wiens et al. 2009, Araújo and Peterson 2012, Schwartz 2012, Guisan et al. 2013). First and foremost, SDMs assume a species distribution is limited by the environmental predictors in the model. We included climate and geologic predictors in our sensitive plant models, however, many additional factors influence plant distribution in California, especially biotic interactions and disturbance (wildfire). These factors, along with intrinsic life history traits (longevity, dispersal capacity) affect the degree to which a species is in equilibrium with climate (Araújo and Pearson 2005) – another fundamental assumption of species distribution modeling. Species distribution models assume a species occupies all (climatically) suitable habitat. Climate change, however, can result in disequilibrium with climate (Svenning and Sandel 2013). For example, a long-lived species may continue to persist as an adult in areas where climate has become unfavorable for recruitment. Dispersal barriers or limitation can result in situations where a species is absent despite favorable conditions, such as migration lags under climate change (Pearson and Dawson 2003).

Although we incorporated edaphic conditions into our models, it is likely that our variables for soil depth and parent geology did not adequately represent the full the range of species edaphic requirements. Relationships with parent geology type (e.g., restrictions to serpentine derived soils) were well represented for some species (*Calochortus fimbriatus, Eriogonum nervulosum Hesperolinon drymarioides*), but not others (*Hesperolinon bicarpellatum, Harmonia hallii*, *Streptanthus hesperidis*). We were unable to include additional variables related to edaphic condition that may also be important to plant species, such as soil texture or chemistry (Dubuis et al. 2013). Edaphic specialization and endemism is especially prevalent in California's flora (Harrison 2013). These non-climatic factors will likely pose a constraint to range expansion under climate change (Beauregard and de Blois 2014) even though they were not always well captured in our models. For species where edaphic restrictions are well known, local-scale models that incorporate fine resolution edaphic data (e.g., Gogol-Prokurat 2011) may give more realistic habitat predictions. Unfortunately, such fine scale data were unavailable for the large statewide spatial extent of our study.

Finally, species distribution models assume species niches are conserved (Wiens and Graham 2005), meaning the species-environment relationship does not change in space and time (no adaption). This is especially important to acknowledge when using models to forecast range shifts under scenarios of climate change. Actual species responses will likely be more nuanced than the redistributions we predict. Factors such as habitat fragmentation and niche availability will constrain adaptive capacity (Christmas et al. 2016), leading to differential species responses and vulnerabilities. In California, biogeographic responses to 20th century climate change have been complex and individualistic (Rapacciuolo et al. 2014). Future climate change will bring novel climate combinations that have no present-day analog leading to non-analog communities and unanticipated challenges for conservation (Williams and Jackson 2007). While predictive modeling is a useful tool for conservation planning, adaptive management will become increasingly important as we enter an era of unprecedented environmental change.

Species List

List of modeled sensitive plant species. Taxonomy and California Rare Plant Rank (CRPR) are based on the most recent information at the time of the report (CNPS 2018). California Endangered Species Act (CESA): CR = rare; CT = threatened; CE = endangered. Federal Endangered Species Act (FESA): FE = endangered; FT = threatened.

Scientific Name	Common Name	Family	CRPR	CESA	FESA
Abies bracteata	bristlecone fir	Pinaceae	1B.3		
Allium hickmanii	Hickman's onion	Alliaceae	1B.2		
Allium howellii var. *clokeyi*	Mt. Pinos onion	Alliaceae	1B.3		
Amsinckia lunaris	bent-flowered fiddleneck	Boraginaceae	1B.2		
Antirrhinum subcordatum	dimorphic snapdragon	Plantaginaceae	4.3		
Arabis blepharophylla	coast rockcress	Brassicaceae	4.3		
Arctostaphylos cruzensis	Arroyo de la Cruz manzanita	Ericaceae	1B.2		
Arctostaphylos hookeri ssp. *hookeri*	Hooker's manzanita	Ericaceae	1B.2		
Arctostaphylos hooveri	Hoover's manzanita	Ericaceae	4.3		
Arctostaphylos manzanita ssp. *elegans*	Konocti manzanita	Ericaceae	1B.3		
Arctostaphylos obispoensis	Bishop manzanita	Ericaceae	4.3		
Arctostaphylos pajaroensis	Pajaro manzanita	Ericaceae	1B.1		
Arctostaphylos pilosula	Santa Margarita manzanita	Ericaceae	1B.2		
Arctostaphylos pumila	sandmat manzanita	Ericaceae	1B.2		
Asclepias solanoana	serpentine milkweed	Apocynaceae	4.2		
Astragalus bernardinus	San Bernardino milk-vetch	Fabaceae	1B.2		
Astragalus breweri	Brewer's milk-vetch	Fabaceae	4.2		
Astragalus lentiginosus var. *coachellae*	Coachella Valley milk-vetch	Fabaceae	1B.2		FE
Astragalus macrodon	Salinas milk-vetch	Fabaceae	4.3		
Astragalus nutans	Providence Mountains milk-vetch	Fabaceae	4.3		
Astragalus rattanii var. *jepsonianus*	Jepson's milk-vetch	Fabaceae	1B.2		
Astragalus tener var. *tener*	alkali milk-vetch	Fabaceae	1B.2		
Astragalus tricarinatus	triple-ribbed milk-vetch	Fabaceae	1B.2		FE
Atriplex cordulata var. *cordulata*	heartscale	Chenopodiaceae	1B.2		
Atriplex depressa	brittlescale	Chenopodiaceae	1B.2		
Atriplex persistens	vernal pool smallscale	Chenopodiaceae	1B.2		
Baccharis plummerae ssp. *plummerae*	Plummer's baccharis	Asteraceae	4.3		
Balsamorhiza macrolepis	big-scale balsamroot	Asteraceae	1B.2		
Berberis nevinii	Nevin's barberry	Berberidaceae	1B.1	CE	FE
Blepharizonia plumosa	big tarplant	Asteraceae	1B.1		
Calamagrostis ophitidis	serpentine reed grass	Poaceae	4.3		
Calochortus catalinae	Catalina mariposa lily	Liliaceae	4.2		
Calochortus fimbriatus	late-flowered mariposa lily	Liliaceae	1B.3		
Calochortus palmeri var. *munzii*	San Jacinto mariposa lily	Liliaceae	1B.2		
Calochortus palmeri var. *palmeri*	Palmer's mariposa lily	Liliaceae	1B.2		
Calochortus plummerae	Plummer's mariposa lily	Liliaceae	4.2		
Calochortus simulans	La Panza mariposa lily	Liliaceae	1B.3		
Calochortus umbellatus	Oakland star-tulip	Liliaceae	4.2		
Calycadenia villosa	dwarf calycadenia	Asteraceae	1B.1		
Calystegia subacaulis ssp. *episcopalis*	Cambria morning-glory	Convolvulaceae	4.2		

Scientific Name	**Common Name**	**Family**	**CRPR**	**CESA**	**FESA**
Camissoniopsis hardhamiae	Hardham's evening-primrose	Onagraceae	1B.2		
Carex obispoensis	San Luis Obispo sedge	Cyperaceae	1B.2		
Carlquistia muirii	Muir's tarplant	Asteraceae	1B.3		
Castilleja affinis var. *neglecta*	Tiburon paintbrush	Orobanchaceae	1B.2	CT	FE
Castilleja latifolia	Monterey Coast paintbrush	Orobanchaceae	4.3		
Castilleja rubicundula var. *rubicundula*	pink creamsacs	Orobanchaceae	1B.2		
Caulanthus californicus	California jewelflower	Brassicaceae	1B.1	CE	FE
Caulanthus lemmonii	Lemmon's jewelflower	Brassicaceae	1B.2		
Caulanthus simulans	Payson's jewelflower	Brassicaceae	4.2		
Ceanothus purpureus	holly-leaved ceanothus	Rhamnaceae	1B.2		
Centromadia parryi ssp. *parryi*	pappose tarplant	Asteraceae	1B.2		
Centromadia parryi ssp. *rudis*	Parry's rough tarplant	Asteraceae	4.2		
Chaenactis carphoclinia var. *peirsonii*	Peirson's pincushion	Asteraceae	1B.3		
Chlorogalum pomeridianum var. *minus*	dwarf soaproot	Agavaceae	1B.2		
Chloropyron molle ssp. *hispidum*	hispid bird's-beak	Orobanchaceae	1B.1		
Chloropyron molle ssp. *molle*	soft bird's-beak	Orobanchaceae	1B.2	CR	FE
Chorizanthe breweri	Brewer's spineflower	Polygonaceae	1B.3		
Chorizanthe parryi var. *parryi*	Parry's spineflower	Polygonaceae	1B.1		
Chorizanthe pungens var. *pungens*	Monterey spineflower	Polygonaceae	1B.2		FT
Chorizanthe xanti var. *leucotheca*	white-bracted spineflower	Polygonaceae	1B.2		
Cirsium scariosum var. *loncholepis*	La Graciosa thistle	Asteraceae	1B.1	CT	FE
Clarkia breweri	Brewer's clarkia	Onagraceae	4.2		
Clarkia gracilis ssp. *tracyi*	Tracy's clarkia	Onagraceae	4.2		
Collomia diversifolia	serpentine collomia	Polemoniaceae	4.3		
Cordylanthus rigidus ssp. *littoralis*	seaside bird's-beak	Orobanchaceae	1B.1	CE	
Cordylanthus tenuis ssp. *brunneus*	serpentine bird's-beak	Orobanchaceae	4.3		
Coryphantha alversonii	foxtail cactus	Cactaceae	4.3		
Cryptantha dissita	serpentine cryptantha	Boraginaceae	1B.2		
Deinandra mohavensis	Mojave tarplant	Asteraceae	1B.3	CE	
Delphinium hutchinsoniae	Hutchinson's larkspur	Ranunculaceae	1B.2		
Delphinium parryi ssp. *blochmaniae*	dune larkspur	Ranunculaceae	1B.2		
Delphinium recurvatum	recurved larkspur	Ranunculaceae	1B.2		
Delphinium uliginosum	swamp larkspur	Ranunculaceae	4.2		
Delphinium umbraculorum	umbrella larkspur	Ranunculaceae	1B.3		
Diplacus johnstonii	Johnston's monkeyflower	Phrymaceae	4.3		
Diplacus vandenbergensis	Vandenberg monkeyflower	Phrymaceae	1B.1		FE
Epilobium howellii	subalpine fireweed	Onagraceae	4.3		
Eriastrum harwoodii	Harwood's eriastrum	Polemoniaceae	1B.2		
Eriastrum luteum	yellow-flowered eriastrum	Polemoniaceae	1B.2		
Erigeron miser	starved daisy	Asteraceae	1B.3		
Eriodictyon capitatum	Lompoc yerba santa	Namaceae	1B.2	CR	FE
Eriogonum luteolum var. *caninum*	Tiburon buckwheat	Polygonaceae	1B.2		
Eriogonum nervulosum	Snow Mountain buckwheat	Polygonaceae	1B.2		
Eriogonum nortonii	Pinnacles buckwheat	Polygonaceae	1B.3		
Eriogonum tripodum	tripod buckwheat	Polygonaceae	4.2		
Eriogonum umbellatum var. *torreyanum*	Donner Pass buckwheat	Polygonaceae	1B.2		
Erythranthe nudata	bare monkeyflower	Phrymaceae	4.3		

Scientific Name	Common Name	Family	CRPR	CESA	FESA
Extriplex joaquinana	San Joaquin spearscale	Chenopodiaceae	1B.2		
Frasera neglecta	pine green-gentian	Gentianaceae	4.3		
Fritillaria agrestis	stinkbells	Liliaceae	4.2		
Fritillaria falcata	talus fritillary	Liliaceae	1B.2		
Fritillaria ojaiensis	Ojai fritillary	Liliaceae	1B.2		
Fritillaria pluriflora	adobe-lily	Liliaceae	1B.2		
Galium andrewsii ssp. *gatense*	phlox-leaf serpentine bedstraw	Rubiaceae	4.2		
Galium angustifolium ssp. *borregoense*	Borrego bedstraw	Rubiaceae	1B.3	CR	
Galium angustifolium ssp. *jacinticum*	San Jacinto Mountains bedstraw	Rubiaceae	1B.3		
Galium hardhamiae	Hardham's bedstraw	Rubiaceae	1B.3		
Harmonia hallii	Hall's harmonia	Asteraceae	1B.2		
Harmonia nutans	nodding harmonia	Asteraceae	4.3		
Hesperevax caulescens	hogwallow starfish	Asteraceae	4.2		
Hesperolinon adenophyllum	glandular western flax	Linaceae	1B.2		
Hesperolinon bicarpellatum	two-carpellate western flax	Linaceae	1B.2		
Hesperolinon breweri	Brewer's western flax	Linaceae	1B.2		
Hesperolinon drymarioides	drymaria-like western flax	Linaceae	1B.2		
Hesperolinon tehamense	Tehama County western flax	Linaceae	1B.3		
Heuchera hirsutissima	shaggy-haired alumroot	Saxifragaceae	1B.3		
Holocarpha macradenia	Santa Cruz tarplant	Asteraceae	1B.1	CE	FT
Horkelia cuneata var. *puberula*	mesa horkelia	Rosaceae	1B.1		
Horkelia cuneata var. *sericea*	Kellogg's horkelia	Rosaceae	1B.1		
Horkelia yadonii	Santa Lucia horkelia	Rosaceae	4.2		
Ivesia sericoleuca	Plumas ivesia	Rosaceae	1B.2		
Juglans californica	Southern California black walnut	Juglandaceae	4.2		
Juglans hindsii	Northern California black walnut	Juglandaceae	1B.1		
Juncus luciensis	Santa Lucia dwarf rush	Juncaceae	1B.2		
Lasthenia californica ssp. *macrantha*	perennial goldfields	Asteraceae	1B.2		
Lasthenia conjugens	Contra Costa goldfields	Asteraceae	1B.1		FE
Lasthenia ferrisiae	Ferris' goldfields	Asteraceae	4.2		
Lathyrus jepsonii var. *jepsonii*	Delta tule pea	Fabaceae	1B.2		
Layia heterotricha	pale-yellow layia	Asteraceae	1B.1		
Layia munzii	Munz's tidy-tips	Asteraceae	1B.2		
Layia septentrionalis	Colusa layia	Asteraceae	1B.2		
Legenere limosa	legenere	Campanulaceae	1B.1		
Leptosiphon acicularis	bristly leptosiphon	Polemoniaceae	4.2		
Leptosiphon grandiflorus	large-flowered leptosiphon	Polemoniaceae	4.2		
Leptosiphon jepsonii	Jepson's leptosiphon	Polemoniaceae	1B.2		
Lessingia tenuis	spring lessingia	Asteraceae	4.3		
Lilaeopsis masonii	Mason's lilaeopsis	Apiaceae	1B.1	CR	
Lilium humboldtii ssp. *ocellatum*	ocellated Humboldt lily	Liliaceae	4.2		
Lomatium hooveri	Hoover's lomatium	Apiaceae	4.3		
Lomatium parvifolium	small-leaved lomatium	Apiaceae	4.2		
Lupinus dalesiae	Quincy lupine	Fabaceae	4.2		
Lupinus sericatus	Cobb Mountain lupine	Fabaceae	1B.2		
Madia radiata	showy golden madia	Asteraceae	1B.1		
Malacothamnus aboriginum	Indian Valley bush-mallow	Malvaceae	1B.2		

Scientific Name	**Common Name**	**Family**	**CRPR**	**CESA**	**FESA**
Malacothamnus davidsonii	Davidson's bush-mallow	Malvaceae	1B.2		
Malacothamnus jonesii	Jones' bush-mallow	Malvaceae	4.3		
Malacothrix saxatilis var. *arachnoidea*	Carmel Valley malacothrix	Asteraceae	1B.2		
Microseris paludosa	marsh microseris	Asteraceae	1B.2		
Microseris sylvatica	sylvan microseris	Asteraceae	4.2		
Monardella hypoleuca ssp. *hypoleuca*	white-veined monardella	Lamiaceae	1B.3		
Monardella macrantha ssp. *hallii*	Hall's monardella	Lamiaceae	1B.3		
Monardella palmeri	Palmer's monardella	Lamiaceae	1B.2		
Monardella robisonii	Robison's monardella	Lamiaceae	1B.3		
Monardella viridis	green monardella	Lamiaceae	4.3		
Monolopia gracilens	woodland woolythreads	Asteraceae	1B.2		
Navarretia jepsonii	Jepson's navarretia	Polemoniaceae	4.3		
Navarretia leucocephala ssp. *bakeri*	Baker's navarretia	Polemoniaceae	1B.1		
Navarretia leucocephala ssp. *pauciflora*	few-flowered navarretia	Polemoniaceae	1B.1	CT	FE
Navarretia nigelliformis ssp. *radians*	shining navarretia	Polemoniaceae	1B.2		
Navarretia prostrata	prostrate vernal pool navarretia	Polemoniaceae	1B.1		
Navarretia rosulata	Marin County navarretia	Polemoniaceae	1B.2		
Nemacladus secundiflorus var. *robbinsii*	Robbins' nemacladus	Campanulaceae	1B.2		
Neostapfia colusana	Colusa grass	Poaceae	1B.1	CE	FT
Orcuttia tenuis	slender Orcutt grass	Poaceae	1B.1	CE	FT
Oreostemma elatum	tall alpine-aster	Asteraceae	1B.2		
Perideridia pringlei	adobe yampah	Apiaceae	4.3		
Phacelia stebbinsii	Stebbins' phacelia	Hydrophyllaceae	1B.2		
Piperia yadonii	Yadon's rein orchid	Orchidaceae	1B.1		FE
Plagiobothrys uncinatus	hooked popcornflower	Boraginaceae	1B.2		
Pyrrocoma lucida	sticky pyrrocoma	Asteraceae	1B.2		
Rhynchospora californica	California beaked-rush	Cyperaceae	1B.1		
Ribes victoris	Victor's gooseberry	Grossulariaceae	4.3		
Sagittaria sanfordii	Sanford's arrowhead	Alismataceae	1B.2		
Saltugilia latimeri	Latimer's woodland-gilia	Polemoniaceae	1B.2		
Salvia greatae	Orocopia sage	Lamiaceae	1B.3		
Sidalcea hickmanii ssp. *hickmanii*	Hickman's checkerbloom	Malvaceae	1B.3		
Sidalcea keckii	Keck's checkerbloom	Malvaceae	1B.1		FE
Sidotheca emarginata	white-margined oxytheca	Polygonaceae	1B.3		
Silene occidentalis ssp. *occidentalis*	Western campion	Caryophyllaceae	4.3		
Streptanthus albidus ssp. *peramoenus*	most beautiful jewelflower	Brassicaceae	1B.2		
Streptanthus barbiger	bearded jewelflower	Brassicaceae	4.2		
Streptanthus batrachopus	Tamalpais jewelflower	Brassicaceae	1B.3		
Streptanthus drepanoides	sickle-fruit jewelflower	Brassicaceae	4.3		
Streptanthus hesperidis	green jewelflower	Brassicaceae	1B.2		
Symphyotrichum defoliatum	San Bernardino aster	Asteraceae	1B.2		
Syntrichopappus lemmonii	Lemmon's syntrichopappus	Asteraceae	4.3		
Thermopsis californica var. *argentata*	silvery false lupine	Fabaceae	4.3		
Trifolium hydrophilum	saline clover	Fabaceae	1B.2		
Tropidocarpum capparideum	caper-fruited tropidocarpum	Brassicaceae	1B.1		
Viola tomentosa	felt-leaved violet	Violaceae	4.2		

Glossary

adaptive capacity—Ability of a system to adjust to potential damage, take advantage of opportunities, or respond to consequences (of climate change) (IPCC 2014).

assisted migration—The intentional translocation of individuals within or outside the natural range of a species in order to facilitate adaptation and mitigate maladaptation to climate change (Aitken and Whitlock 2013).

Basin Characterization Model (BCM)—Spatially explicit, regional water balance model that integrates physical watershed characteristics with historical or projected climate data to predict watershed-specific hydrologic responses for the California hydrologic region at high spatial resolution (Flint et al. 2013).

California Protected Area Database (CPAD)—GIS database of California lands that are owned in fee and protected for open space purposes by public agencies or non-profit organizations.

California Rare Plant Rank (CRPR)—California Native Plant Society ranking system for extirpated, rare, threatened, endangered, and uncommon plant species in California (see https://www.cnps.org/rare-plants/cnps-rare-plant-ranks).

CRPR 1A. Presumed extinct or extirpated

CRPR 1B. Rare, threatened, or endangered in California and elsewhere

CRPR 2A. Presumed extirpated in California but common elsewhere

CRPR 2B. Rare, threatened, or endangered in California but more common elsewhere

CRPR 3. Review list of species requiring more information

CRPR 4. Watch list of species limited in distribution or uncommon/infrequent

climate change—Persistent (typically decades or longer) change in the state of climate that can be identified by changes in the mean or variability of its properties (IPCC 2014).

climate exposure—Degree and nature to which a system is exposed to climate change. Exposure refers to extrinsic factors of climate change such as character, magnitude, and rate of change (Glick et al. 2011).

climate model—Numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions with feedback processes, and accounting for all or some of its known properties (IPCC 2014). The climate system can be represented by models of varying complexity. (See **general circulation model**).

climate projection (climate scenario)—Simulated response of the climate system to a future emission or concentration scenario of greenhouse gases and aerosols, typically derived from a climate model (IPCC 2014).

climatic water deficit (CWD)—Measure of drought stress calculated as the evaporative demand that exceeds water availability (Stephenson 1998). In the Basin Characterization Model (BCM) CWD is calculated as the difference between potential evapotranspiration and actual evapotranspiration (Flint et al. 2013).

emission scenario—Plausible representation of future emissions of substances that are radiatively active in the atmosphere (e.g., greenhouse gases, aerosols) based on assumptions about driving forces such as socio-economic development, technology change, and land use (IPCC 2014). Emission scenarios are used with climate models to compute climate change projections (see **Representative Concentration Pathways**).

endemic—Native or restricted to a certain geographic area.

edaphic—Relating to soil, especially as it affects living organisms.

general circulation model (GCM)—Global climate model that reflects the latest scientific understanding of complex physical, chemical, and biological properties of the climate system, as well as their interactions with feedback properties. Coupled atmosphere/ocean/sea-ice general circulation models (also known as AOGCMs) are among the most comprehensive representation of the earth’s climate system (IPCC 2014).

habitat suitability—Degree to which a site supports a particular taxon, typically based on environmental characteristics such as climate.

Maxent—Maximum entropy approach for modeling species distributions from presence-only species occurrence data (Phillips et al. 2006).

mitigation (of climate change)—Human intervention to reduce the source or enhance sink of greenhouse gases that contribute to climate change.

Representative Concentration Pathway (RCP)—Scenario of the emissions and concentrations of greenhouse gases, aerosols, and other radiatively active chemicals, as well as land cover and human land use (IPCC 2014). Concentration pathways define both the trajectory and the long-term concentration level (Moss et al. 2010). Four RCPs extending to 2100 were produced in the Fifth IPCC Assessment Report (IPCC 2013).

> **RCP8.5.** A high concentration pathway for which radiative forcing reaches >8.5 Wm^{-2} by 2100 and continues to rise.

resilience—Capacity of a system to recover, rebound, or recoup from a hazardous event or disturbance.

sensitivity—Degree to which a system is affected, adversely or beneficially, by climate variability and/or change (Glick et al. 2011). Effects may be direct or indirect.

species distribution model (SDM)—Statistical model relating species distributional data (e.g., occurrence at known locations) with environmental information at those locations. These models are typically used in an explanatory way to improve understanding about a species association with environmental characteristics, or to predict a species distribution in space and time (Elith and Leathwick 2009). Modeling methods vary widely depending on the structure of occurrence and environmental data, as well as the modeling objective.

uncertainty—Incomplete knowledge resulting from a lack of information or disagreement about what is known/knowable. Uncertainty can arise from many sources, such as incomplete knowledge of the climate system and uncertainty in projections of future human behavior related to emissions (IPCC 2014).

vulnerability—Propensity of a system to be adversely affected by climate change. Vulnerability is a function of the climate **exposure** experienced by the system, its **sensitivity**, and its **adaptive capacity** (Glick et al. 2011).

Appendix 1. NRS Sensitive Plant List

We compiled the NRS sensitive vascular plant list from reserve checklists, floras, and spatial queries of occurrence data collected between 1900 and 2013. We used the NRS-wide plant list (Haggerty and Mazer 2010) as a starting point for reserve checklists and supplemented with additional information when possible (Table A1.2). Reserves floras and checklists varied in completeness. For example, McLaughlin Natural Reserve had a well-vouchered flora updated in 2017 (Dean 2017), whereas Jenny Pygmy Forest Reserve and Steele/Burnand Anza-Borrego Desert Research Center lacked checklists and occurrences. Our occurrence database contained records for 2,192 sensitive minimum rank taxa (species, subspecies, and varieties) downloaded between 2013 and 2014 from the Consortium of California Herbaria (CCH 2014), California Natural Diversity Database (CNDDB 2013), and CalPhotos (CalPhotos 2013). It does not include data for species added to the CNPS Inventory of Rare and Endangered Plants after 2013 or occurrence observations recorded or digitized after 2013. We cross-checked each reserve observation with distributional information from the inventory (CNPS 2018) to identify dubious species identifications or locations. We also flagged records that were not native to a reserve. For example, there are only three native stands of Monterey pine (*Pinus radiata*) in California, one of which occurs in the Kenneth S. Norris Rancho Marino Reserve in Cambria. All other instances of this species on NRS reserves are naturalized or introduced from cultivation and therefore not of conservation concern. We excluded non-native records from summary counts but included them with flags and annotation in the global list in this appendix. Despite these precautions, our final sensitive plant list may include errors stemming from taxonomic uncertainties, misidentifications, or bad locality data. In addition, some historical observations may represent species extirpations rather than extant populations.

We included information for sensitive plants in the following parks and regions associated with NRS reserves as a resource for researchers: Año Nuevo State Park, Anza-Borrego Desert State Park, Deep Canyon Transect (associated with Boyd Deep Canyon Desert Research Center), Granite Mountains (in the Mojave National Preserve), White Mountains (in the Inyo National Forest) and Yosemite National Park. The White Mountains Research Center provides access for research in surrounding areas owned by the US Forest Service and Los Angeles Department of Water and Power. Reserve acreage only corresponds to buildings and facilities and therefore there are no species “on” the reserve. However, we provided a list of sensitive plants observed within a two mile vicinity of the Crooked Creek, Barcroft, and Summit stations. Because Anza-Borrego Desert State Park and Yosemite National Park have use agreements with the NRS we include a summary count for the ‘greater’ NRS network including species from both parks. The global list of sensitive species for the NRS and associated parks and regions is available as an excel spreadsheet [Appendix 1.xls]. It includes all species with a CRPR ranking (1A, 2, 2B, 3, 4) or legal listing (CESA, FESA) (Table A1.1). Status and taxonomy reflect the most recent information from the Inventory of Rare and Endangered Plants at the time of the report (CNPS 2018). With few exceptions, taxonomy follows Baldwin et al. (2012) with electronic updates (JFP 2018). Species are listed by reserve—those occurring on more than one reserve have multiple entries in the global plant list. Flora and checklist sources are provided in Table A1.2 and in the excel spreadsheet.

Link to download Appendix 1supplemental data:
Erin C. Riordan. 2019. Supplemental information (Appendix 1, Appendix 4, Appendix5) from the report: Evaluating the future role of the University of California Natural Reserve System for sensitive plant protection under climate change. Knowledge Network for Biocomplexity. doi:10.5063/F15X2773.

Table A1.1. California Rare Plant Rank descriptions. Abbreviations: CNPS California Native Plant Society; CRPR California Rare Plant Rank; CDFW California Department of Fish and Wildlife; USFWS United States Fish and Wildlife Services; CESA California Endangered Species Act; FESA Federal Endangered Species Act. Additional information can be found at: https://www.cnps.org/rare-plants/cnps-rare-plant-ranks.

Organization	Ranking	Definition
CNPS	CRPR 1A	Plants presumed extirpated in California and rare or extinct elsewhere
CNPS	CRPR 1B	Plants rare, threatened, or endangered in California and elsewhere
CNPS	CRPR 2A	Plant presumed extirpated in California but more common elsewhere
CNPS	CRPR 2B	Plants rare, threatened, or endangered in California but more common elsewhere
CNPS	CRPR 3	Plants about which more information is needed (review list)
CNPS	CRPR 4	Plants of limited distribution (watch list)
CDFW	CESA CC	State candidate for listing
CDFW	CESA CE	State listed endangered
CDFW	CESA CT	State listed threatened
CDFW	CESA CR	State listed rare
USFWS	FESA FE	Federally listed endangered
USFWS	FESA FT	Federally listed threatened
USFWS	FESA FC	Federal candidate for listing

Table A1.2. Sources for global NRS sensitive species list.

Reserve/Region	Reference
NRS Flora	Haggery, B.P. and S.J. Mazer (2010) Flora of the UC Natural Reserve System. https://ucnrs.org/plant-list/ [accessed September 2018].
Angelo Coast Range	Angelo Coast Range Reserve (unknown date) Plants of Angelo Reserve. http://angelo.berkeley.edu/data/specimen-data/ [accessed November 2018].
Año Nuevo State Park	Merit, M. (unknown date) Plants of Año Nuevo State Park. https://www.inaturalist.org/guides/3231 [accessed November 2018].
Año Nuevo State Park	California State Parks (2008) Final General Plan and Environmental Impact Report. http://www.parks.ca.gov/pages/21299/files/ano%20nuevo_final%20gp%20web%20version.pdf [accessed September 2018].
Año Nuevo State Park	Calflora (2018) What Grows Here Dynamic Plant Lists for Parks in California, by County. http://www.calflora.org/entry/parks-county.html [accessed November 2018].
Anza-Borrego Desert State Park	Dice, J. and L. Hendrickson (2018) Anza-Borrego Desert State Park Rare and Endangered Plant Species List. (Compiled by the authors 8 November 2018).
Blue Oak Ranch Reserve	Blue Oak Ranch Reserve (2017) Vascular Plants of Blue Oak Ranch. (Compiled from S.J. Bainbridge 1996, 1997 and 2008 surveys; updated by K. Andonian 2017).
Bodega Marine Reserve	Bodega Marine Reserve (2012) Vascular Plants of Bodega Head and Bodega Dunes. https://marinescience.ucdavis.edu/sites/g/files/dgvnsk4981/files/inline-files/BMR_PlantList.pdf [accessed September 2018].
Box Springs Reserve	Box Springs Reserve (unknown date) Vascular Plants of Box Springs Reserve. (Compiled from contributions from A.C. Sanders, S. Boyd, F.C. Vasek, W.W. Mayhew, M. Myers and B. Carlson).
Boyd Deep Canyon	Fisher, M. (2015) Deep Canyon Transect Plant Species. https://deepcanyon.ucnrs.org/species-lists/ [accessed October 2018].
Burns Piñon Ridge Reserve	Elvin, M.A., P.A. Bowler, and A.C. Sanders (2006) A Checklist of the Vascular Plants at the University of California Natural Reserve System’s Burns Piñon Ridge Reserve. (Updated by P. Bowler October 2018). http://burns.ucnrs.org/flora.html [accessed October 2018].
Carpinteria Salt Marsh Reserve	Carpinteria Salt Marsh Reserve (unknown date). Taxonomic checklist of Vascular Plants at Carpinteria Salt Marsh. (Adapted from W.R. Ferren 1985, Carpinteria Salt Marsh: Environment, History, and Botanical Resources of a Southern California Estuary). http://carpinteria.ucnrs.org/PDFs/Taxonomic%20Checklist%20of%20Vascular%20Plants.pdf [accessed September 2018].
Chickering American River Reserve	Stromberg, M. (2003) Chickering American River Reserve Plant List. (Compiled by M. Stromberg from notes provided by Allen Fish, available from B.P. Haggerty and S.J. Mazer 2010, Flora of the UC Natural Reserve System https://ucnrs.org/plant-list/ [accessed September 2018]).
Coal Oil Point Natural Reserve	Callahan, K. (Personal communication) Rare Plants of Coal Oil Point Natural Reserve [October 2018].
Dawson Los Monos Canyon Reserve	Wolf, R. (2010a) Dawson Los Monos Canyon Reserve Plant List. http://nrs.ucsd.edu/_files/dawson/dawson-flora.pdf [accessed October 2018].
Elliot Chaparral Reserve	Wolf, R. (2010b) Elliot Chaparral Reserve Plant List. http://nrs.ucsd.edu/_files/elliott/elliott-flora.pdf [accessed October 2018].
Emerson Oaks Reserve	Emerson Oaks Reserve (unknown date) Emerson Oaks Plant List [provided by K. Halama October 2018].

Reserve	Reference
Fort Ord Natural Reserve	Miller, J. Personal communication. Rare Plants of Fort Ord Natural Reserve [October 2018].
Granite Mountains	André, J.M. (2006) Vascular flora of the Granite Mountains, San Bernardino County: An annotated checklist. Crossosoma 32:38-74.
Granite Mountains	André, J.M. Personal communication [October 2018].
Hastings Natural History Reservation	Griffin, J.R. (1995) Flora of Hastings Reservation Carmel Valley, California. Regents of the University of California. http://hastingsreserve.org/natural-history-resources/plants.html [accessed November 2018].
James San Jacinto Mountains Reserve	Chester, T., D. Stith, and J. Roberts (2016) Checklist for Hall Canyon, San Jacinto Mountains. http://tchester.org/sj/flora/hall_canyon.html [accessed September 2018].
James San Jacinto Mountains Reserve	James San Jacinto Mountains Reserve (2017) James San Jacinto Mountains Reserve Vascular Plants. http://james.ucnrs.org/wp-content/uploads/2017/06/Plant_booklet_2017.pdf [accessed September 2018].
Jepson Prairie Reserve	Witham, C.W. (unknown date) Jepson Prairie Reserve Plants. https://naturalreserves.ucdavis.edu/jepson-prairie/maps-weather-and-species-lists [accessed September 2018].
Jepson Prairie Reserve	Witham, C.W. and K. Mawdsley (2012) Jepson Prairie Reserve Handbook, 3rd ed. Solano Land Trust. 80 pp.
Jepson Prairie Reserve	Witham, C.W. Personal communication [October 2018].
Kendall-Frost Mission Bay Marsh Reserve	Wolf, R. (2010c) Kendall-Frost Mission Bay Marsh Reserve Plant List. http://nrs.ucsd.edu/_files/kendall/kf-flora.pdf [accessed October 2018].
Landels-Hill Big Creek Reserve	Andonian, K. (2016) Big Creek Plant List. (Compiled by J. Smiley from C. Bickford. and P. Rich 1984, Vegetation and Flora of the Landels-Hill Big Creek Reserve, Monterey County, California, 2nd edition Environmental Field Program, University of California, Santa Cruz; E. Erik 1984, The Natural Features of the Gamboa Point Properties, Monterey County, California Volume 1 Environmental Studies Program, University of California, Santa Cruz; M. Stromberg 1993 2nd USDA proposal, Ecology and Restoration of Native Grassland Systems in California; updated by D. Neubaur 2014 and K. Andonian 2016).
McLaughlin Natural Reserve	Dean, E. (2017) Vascular Plant Species of the Greater Knoville Area. UC Davis Center For Plant Diversity. https://herbarium.ucdavis.edu/plantlistsandfloras.html [accessed September 2018].
Merced Vernal Pools and Grassland Reserve	Kolser, M. Personal communication [October 2018].
Motte Rimrock	Motte Rimrock Reserve (unknown date) University of California Natural Reserve System Motte Rimrock Reserve Flora. http://motte.ucr.edu/species_lists/Motte_Plant_List.pdf [accessed September 2018].
Kenneth S. Norrish Rancho Marino Reserve	Canestro, D. (2017) Vascular Plant Checklist of Rancho Marino Reserve. (Updated by K. Andonian August 2017).
Oasis de Los Osos Reserve	Fisher, A.E. & B. Betz (2016) Vascular plant of the Oasis de Los Osos Reserve, San Jacinto Mountains, California. Crossosoma 42(1):1-36.
Quail Ridge Reserve	Dean, E. (2016) Vascular Plants of Quail Ridge UC Reserve, Napa County. UC Davis Center For Plant Diversity. https://herbarium.ucdavis.edu/plantlistsandfloras.html [accessed September 2018].

Reserve	Reference
Sagehen Creek Field Station	iNaturalist (2018) Plants of Sagehen Creek. https://www.inaturalist.org/check_lists/65376-Plants-of-Sagehen-Creek [accessed October 2018].
San Joaquin Marsh Reserve	Bowler P.A. and M.A. Elvin (2004) Vascular Plant Checklist for the University of California Natural Reserve System's San Joaquin Freshwater Marsh Reserve. Crossosoma 29 (2):1-22. (Updated by P. Bowler and J. Rainbow 2017).
Santa Cruz Island Reserve	NPS (unknown date) Channel Islands Plant Checklist. National Park Service, U.S. Department of the Interior. https://www.nps.gov/chis/planyourvisit/upload/A-Checklist-of-Vascular-Plants-all-v1.pdf [accessed October 2018].
Santa Cruz Island Reserve	Haggery, B.P. and S.J. Mazer (2010) Flora of the UC Natural Reserve System. https://ucnrs.org/plant-list/ [accessed September 2018].
Scripps Coastal Reserve	Wolf, R. (2010d) Scripps Coastal Reserve Plant List. http://nrs.ucsd.edu/_files/scripps/scr-flora.pdf [accessed October 2018].
Sedgwick Reserve	Williams, M.P., W. Ferren, J. Hamilton, L. Ballard, et al. (2016) Checklist of the Vascular Plants of Sedgwick Reserve, Santa Barbara County, California. http://sedgwick.nrs.ucsb.edu/about/natural_resources [accessed September 2018].
SNARL	Howald, A.M. (2013) Flora of the Sierra Nevada Aquatic Research Laboratory. http://vesr.nrs.ucsb.edu/natural-resources/flora-vesr [accessed September 2018].
Stebbins Cold Canyon Reserve	Dean, E., and K. Mawdsley. (2017) Revised List of the Vascular Plant in the Cold Creek Basin. UC Davis Center For Plant Diversity. https://herbarium.ucdavis.edu/plantlistsandfloras.html [accessed September 2018].
Stunt Ranch Reserve	Haggery, B.P. and S.J. Mazer (2010) Flora of the UC Natural Reserve System. https://ucnrs.org/plant-list/ [accessed September 2018].
Valentine Camp	Orr, B.K. and A.M. Howald (2000) A Flora of Eastern Valentine Sierra Reserve. http://vesr.nrs.ucsb.edu/sites/vesr.nrs.ucsb.edu/files/vesr/vesrflorascreen.pdf [accessed September 2018].
White Mountains Research Center	Neubauer, D.M. Personal communication [September 2018].
Yosemite National Park	Calflora (2018) What Grows Here Dynamic Plant Lists for Parks in California, by County. http://www.calflora.org/entry/parks-county.html [accessed November 2018].
Yosemite National Park	Moore, P.E., A.E.L. Colwell, and C L. Coulter (2010) Special status vascular plant surveys and habitat modeling in Yosemite National Park, 2003–2004. Natural Resource Technical Report NPS/SIEN/NRTR—2010/389. National Park Service, Fort Collins, Colorado.
Yosemite National Park	Yosemite National Park (2002) Sensitive Plants of Yosemite National Park. https://www.nps.gov/yose/learn/nature/upload/veg_sensitive-sm.pdf [accessed October 2018].
Younger Lagoon Reserve	Younger Lagoon Reserve (unknown date) Younger Lagoon Reserve Plant List. https://youngerlagoonreserve.ucsc.edu/species-maps-resources/plants.html [accessed September 2018].

Appendix 2. Baseline Climate and Projected Climate Change Exposure

Appendix 2 illustrates spatial patterns of baseline (1971–2000) climate and projected future (2070–2099) climate change exposure across California and NRS reserves. Future climate scenarios are based on five different climate models assuming high radiative forcing from greenhouse gases (Table A2.1; Fig. A2.1). Exposure was calculated as the difference in 30-year climate averages (future – baseline) or, for annual precipitation, the percent difference relative to baseline. Baseline climate and projected exposure were summarized by region (Table A2.2) and NRS reserve (Tables A2.3, A2.4). Abbreviations: Tmin = minimum winter temperature (calculated December–February); Tmax = Maximum summer temperature (calculated June–August); PPT = annual precipitation; CWD = climatic water deficit.

Table A2.1. List of climate models used for future climate scenarios.

Climate Model	Institution
CCSM 4.0	National Center for Atmospheric Research, United States
CNRM CM5	Centre National de Recherches Métérologigues/Météo-France, France
FGOALS G2	LASG/Institute of Atmospheric Physics, China
IPSL CM5A-LR	Institut Pierre Simon Laplace, France
MIROC ESM	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)

Table A2.2. Regional baseline (1971–2000) climate and projected (2070–2099) climate exposure summaries. Baseline values are the mean ± standard deviation of climate pixels summarized by region. Projected values are the median (minimum–maximum) of the mean exposure across the five future climate scenarios. Regions: NW Northwestern; SN Sierra Nevada; SNE East of Sierra Nevada; GV Great Central Valley; CW Centralwestern; SW Southwestern; DMoj Mojave Desert; DSon Sonoran Desert.

Region	**Baseline Climate (1971–2000)**				**Projected Climate Exposure (2070–2099)**				
	Tmin (°C)	Tmax (°C)	PPT (mm)	CWD (mm)	Tmin (°C)	Tmax (°C)	PPT (%)	CWD (%)	CWD (mm)
State	1.0 ± 4.4	30.9 ± 5.7	621.5 ± 547	913 ± 339	4.5 (3.3–6.3)	4.9 (4.4–6.5)	0 (-28–29)	25 (16–32)	166 (100–210)
MP	-6.2 ± 1.0	26.7 ± 1.9	445 ± 151	608 ± 106	4.0 (3.7–8.1)	5.9 (5.7–7.3)	3 (-22–26)	32 (23–42)	187 (135–244)
CR	-2.8 ± 3.6	27.6 ± 3.7	1149 ± 520	529 ± 156	3.5 (3.3–7.2)	5.5 (5.4–6.7)	1 (-20–26)	44 (30–57)	167 (117–209)
SN	-2.5 ± 4.7	26.6 ± 5.5	978 ± 424	648 ± 248	3.4 (3.3–6.6)	5.2 (4.8–7.6)	-2 (-28–31)	47 (32–65)	197 (136–260)
SNE	-7.2 ± 3.3	25.8 ± 6.2	368 ± 235	725 ± 309	3.8 (3.7–7.2)	5.6 (5.1–8.7)	-8 (-28–30)	50 (38–71)	259 (199–363)
GV	3.5 ± 0.6	33.9 ± 1.3	345 ± 143	1064 ± 154	3.5 (3.1–6.0)	4.7 (4.4–7.0)	-8 (-31–25)	12 (6–19)	126 (60–202)
NW	1.0 ± 2.4	28.0 ± 3.7	1429 ± 603	567 ± 176	3.3 (3.1–6.0)	4.7 (4.5–6.2)	2 (-17–26)	26 (17–33)	127 (86–164)
CWn	3.6 ± 1.7	28.5 ± 3.8	603 ± 235	900 ± 105	3.4 (3.0–5.5)	4.1 (3.4–6.3)	-8 (-30–31)	16 (8–22)	143 (72–193)
SW	4.1 ± 3.5	29.7 ± 3.1	504 ± 180	1001 ± 135	3.2 (3.1–5.7)	4.5 (3.3–5.0)	-15 (-39–27)	19 (10–23)	178 (92–225)
DMoj	2.0 ± 1.9	36.2 ± 3.3	157 ± 57	1292 ± 134	3.5 (3.5–6.4)	4.8 (4.1–6.0)	-14 (-29–35)	12 (7–15)	152 (82–192)
DSon	5.9 ± 1.4	39.7 ± 1.8	125 ± 64	1386 ± 99	3.4 (3.3–6.1)	4.5 (3.6–6.0)	-15 (-34–33)	8 (4–12)	114 (58–161)

Table A2.3. NRS reserve baseline (1971–2000) climate summaries. Table values are the mean ± standard deviation of climate pixels within reserve boundaries. Regions: NW Northwestern; SN Sierra Nevada; SNE East of Sierra Nevada; GV Great Central Valley; CW Centralwestern; SW Southwestern; DMoj Mojave Desert; DSon Sonoran Desert.

Region	Reserve	Tmin (°C)	Tmax (°C)	PPT (mm)	CWD (mm)
NW	Angelo Coast Range Reserve	1.8 ± 0.2	25.7 ± 0.4	2211 ± 144	496 ± 47
	Jenny Pygmy Forest Reserve	3.7 ± 0.01	20.2 ± 0.1	1168 ± 3	507 ± 186
	McLaughlin Reserve	3.1 ± 0.3	32.1 ± 0.7	775 ± 29	839 ± 71
	Quail Ridge Reserve	2.5 ± 0.1	31.6 ± 0.5	717 ± 15	851 ± 31
	Stebbins Cold Canyon Reserve	3 ± 0.1	30.9 ± 0.8	779 ± 28	819 ± 24
SN	Chickering American River Reserve	-7.2 ± 0.2	21.1 ± 1.5	1702 ± 21	316 ± 60
	Sagehen Creek Field Station	-8.8 ± 0.5	22.6 ± 0.9	951 ± 87	380 ± 45
	Yosemite National Park	-7.6 ± 3.3	20.5 ± 3.4	1207 ± 182	400 ± 144
SNE	VESR - Sierra Nevada Aquatic Research Laboratory	-8.3 ± 0.1	25.6 ± 0.1	431 ± 1	640 ± 15
	VESR - Valentine Camp	-10 ± 0.1	22.6 ± 0.2	591 ± 14	462 ± 7
	White Mountains Research Center - Barcroft	-13.3 ± 0.2	11.1 ± 0.4	428 ± 2	102 ± 15
	White Mountains Research Center - Crooked Creek	-12.9 ± 0.1	17.1 ± 0.3	369 ± 3	264 ± 14
	White Mountains Research Center - Owens Valley Lab	-4.7 ± 0.03	34.6 ± 0.02	128 ± 1	1125 ± 2
	White Mountains Research Center - Summit Lab	-14.3 ± 0.3	8.9 ± 0.6	449 ± 4	22 ± 13
GV	Jepson Prairie Reserve	3.8 ± 0.04	30.8 ± 0.1	502 ± 4	962 ± 53
	Merced Vernal Pools and Grassland Reserve	3.4 ± 0.1	33.5 ± 0.1	341 ± 13	1045 ± 27
CW	Blue Oak Ranch Reserve	4.8 ± 0.4	25.9 ± 0.7	625 ± 15	750 ± 21
	Bodega Marine Reserve	4.2 ± 0.1	18.8 ± 0.04	875 ± 1	764 ± 28
	Fort Ord Natural Reserve	5.5 ± 0.1	19.7 ± 0.3	400 ± 3	835 ± 7
	Hastings Natural History Reservation	3.7 ± 0.2	27.3 ± 0.6	688 ± 36	886 ± 38
	Kenneth S. Norris Rancho Marino Reserve	5.6 ± 0.4	19.6 ± 0.2	560 ± 26	855 ± 40
	Landels-Hill Big Creek Reserve	4.8 ± 0.6	24 ± 1.6	1004 ± 246	817 ± 46
	Sedgwick Reserve	5.4 ± 1.1	30.8 ± 0.2	674 ± 56	1025 ± 52
	Younger Lagoon Reserve	4.8 ± 0.03	21 ± 0.1	762 ± 8	685 ± 64

Region	Reserve	Tmin (°C)	Tmax (°C)	PPT (mm)	CWD (mm)
SW	Box Springs Reserve	5.5 ± 0.03	32.7 ± 0.1	321 ± 5	1139 ± 20
	Carpinteria Salt Marsh Reserve	6.9 ± 0.1	23.5 ± 0.02	430 ± 2	985 ± 23
	Coal Oil Point Natural Reserve	5.8 ± 0.02	23.2 ± 0.01	444 ± 1	943 ± 52
	Dawson Los Monos Canyon Reserve	6.8 ± 0.1	26.6 ± 0.3	384 ± 9	1080 ± 20
	Elliott Chaparral Reserve	6.4 ± 0.3	29.1 ± 0.7	374 ± 9	1058 ± 6
	Emerson Oaks Reserve	5.1 ± 0.2	33.6 ± 0.2	450 ± 9	996 ± 21
	James San Jacinto Mountains Reserve	-1.8 ± 0.1	27.8 ± 0.2	684 ± 6	776 ± 0
	Kendall-Frost Mission Bay Marsh Reserve	9.4 ± 0.1	23 ± 0.04	314 ± 1	1033 ± 1
	Motte Rimrock Reserve	3.8 ± 0.1	34 ± 0.1	301 ± 4	1199 ± 9
	San Joaquin Marsh Reserve	8 ± 0.04	25.8 ± 0.1	323 ± 1	1117 ± 11
	Santa Cruz Island Reserve	5.8 ± 0.7	23.1 ± 1	496 ± 61	894 ± 33
	Scripps Coastal Reserve	8 ± 0.3	24.1 ± 0.5	302 ± 5	1026 ± 10
	Stunt Ranch Santa Monica Mountains Reserve	8.9 ± 0.1	31.2 ± 0.4	677 ± 17	993 ± 31
DMoj	Burns Piñon Ridge Reserve	1 ± 0.2	32.6 ± 0.3	262 ± 1	1153 ± 15
	Oasis de Los Osos	4.4 ± 0.2	36.6 ± 0.5	358 ± 14	1078 ± 37
	Old Woman Mountains	4.2 ± 0.1	36.1 ± 0.4	242 ± 7	1165 ± 11
	Sacramento Mountains Reserve	4.6 ± 0.1	37 ± 0.3	182 ± 1	1241 ± 8
	Sweeney Granite Mountains Desert Research Center	2.3 ± 0.3	33.2 ± 0.8	239 ± 16	1134 ± 41
DSon	Anza-Borrego Desert State Park	4.1 ± 1.6	37.1 ± 3.4	248 ± 130	1227 ± 157
	Steele/Burnand Anza-Borrego Desert Research Center	6.9 ± 0.1	40.7 ± 0.1	167 ± 9	1409 ± 8
	Boyd Deep Canyon Desert Research Center	4.5 ± 1.3	37 ± 2.8	226 ± 84	1198 ± 117

Table A2.4. NRS reserve projected (2070–2099) climate exposure summaries. Table values are the median (minimum–maximum) of the projected mean exposure across the five future climate scenarios. Regions: NW Northwestern; SN Sierra Nevada; SNE East of Sierra Nevada; GV Great Central Valley; CW Centralwestern; SW Southwestern; DMoj Mojave Desert; DSon Sonoran Desert.

Region	Reserve	Tmin (°C)	Tmax (°C)	PPT (%)	CWD (%)	CWD (mm)
NW	Angelo Coast Range Reserve	3.7 (3.0–5.7)	4.4 (3.9–5.9)	8 (-17–30)	22 (17–36)	107 (82–177)
	Jenny Pygmy Forest Reserve	3.8 (3.1–5.7)	4.7 (4.0–6.4)	6 (-16–34)	28 (20–39)	126 (92–177)
	McLaughlin Reserve	4.2 (3.2–6.0)	4.8 (4.1–6.6)	4 (-24–33)	12 (8–18)	101 (68–148)
	Quail Ridge Reserve	4.4 (3.4–6.2)	5.0 (4.2–6.9)	5 (-25–33)	12 (8–17)	99 (70–146)
	Stebbins Cold Canyon Reserve	4.4 (3.4–6.2)	5.0 (4.2–6.9)	3 (-26–31)	12 (8–17)	98 (69–143)
SN	Chickering American River Reserve	4.8 (3.6–7.4)	5.4 (5.0–7.7)	3 (-26–30)	88 (56–107)	266 (170–323)
	Sagehen Creek Field Station	4.9 (3.7–7.6)	5.9 (5.4–8.1)	5 (-26–32)	78 (54–93)	289 (202–347)
	Yosemite National Park	4.7 (3.3–6.6)	5.4 (4.9–8.4)	7 (-26–34)	75 (50–98)	241 (166–313)
SNE	VESR - Sierra Nevada Aquatic Research Laboratory	5.3 (3.7–7.2)	5.7 (5.3–9.0)	2 (-28–28)	44 (31–59)	283 (198–378)
	VESR - Valentine Camp	5.2 (3.5–7.0)	5.8 (5.4–9.0)	1 (-29–27)	69 (50–87)	319 (231–403)
	White Mountains Research Center-Barcroft	5.5 (3.9–7.7)	5.9 (5.4–9.3)	2 (-26–24)	301 (200–390)	300 (199–388)
	White Mountains Research Center-Crooked Creek	5.5 (3.9–7.6)	5.8 (5.3–9.1)	3 (-26–26)	139 (87–170)	365 (229–448)
	White Mountains Research Center-Owens Valley Lab	5.2 (3.5–7.1)	5.4 (4.9–8.7)	6 (-26–38)	20 (15–27)	221 (172–302)
	White Mountains Research Center-Summit Lab	5.7 (4.1–7.9)	6.0 (5.5–9.4)	3 (-25–25)	1306 (729–1778)	224 (126–306)
GV	Jepson Prairie Reserve	4.2 (3.1–6.0)	4.8 (3.9–6.8)	2 (-29–29)	11 (8–17)	108 (75–164)
	Merced Vernal Pools and Grassland Reserve	4.5 (3.2–6.1)	5.3 (4.5–8.0)	3 (-30–28)	11 (7–21)	120 (73–215)
CW	Blue Oak Ranch Reserve	3.7 (2.9–5.5)	4.8 (3.8–7.2)	5 (-29–29)	15 (10–23)	110 (74–173)
	Bodega Marine Reserve	3.7 (3.1–5.6)	4.3 (3.4–6.1)	11 (-19–39)	15 (11–22)	117 (82–165)
	Fort Ord Natural Reserve	3.4 (2.8–5.2)	4.0 (2.9–6.3)	4 (-30–28)	15 (7–25)	125 (56–210)
	Hastings Natural History Reservation	3.6 (3.0–5.4)	4.4 (3.3–6.7)	8 (-29–35)	15 (9–20)	129 (80–179)
	Kenneth S. Norris Rancho Marino Reserve	3.5 (3.1–5.4)	3.8 (2.9–5.9)	7 (-29–38)	17 (9–22)	146 (80–188)
	Landels-Hill Big Creek Reserve	3.3 (2.7–5.1)	4.3 (3.3–6.5)	20 (-22–52)	15 (9–21)	124 (76–171)
	Sedgwick Reserve	3.4 (2.9–5.3)	3.8 (3.1–5.0)	1 (-32–33)	17 (7–18)	171 (73–185)
	Younger Lagoon Reserve	3.5 (2.9–5.2)	4.2 (3.1–6.6)	8 (-29–35)	18 (11–29)	123 (73–199)

Region	Reserve	Tmin (°C)	Tmax (°C)	PPT (%)	CWD (%)	CWD (mm)
SW	Box Springs Reserve	4.1 (3.2–6.0)	4.2 (3.3–5.2)	-13 (-38–35)	15 (6–18)	165 (74–203)
	Carpinteria Salt Marsh Reserve	3.3 (2.8–5.3)	3.8 (3.1–4.7)	-3 (-33–34)	15 (1–24)	147 (10–241)
	Coal Oil Point Natural Reserve	3.3 (2.9–5.2)	3.7 (2.9–4.7)	-4 (-34–29)	17 (2–25)	157 (19–233)
	Dawson Los Monos Canyon Reserve	3.6 (3.0–5.6)	3.8 (2.5–4.7)	-20 (-39–23)	17 (9–20)	179 (97–213)
	Elliott Chaparral Reserve	3.8 (3.2–5.8)	4.2 (2.8–5.2)	-25 (-41–18)	18 (9–20)	189 (98–217)
	Emerson Oaks Reserve	3.9 (3.1–5.9)	4.3 (3.2–5.4)	-20 (-42–26)	20 (5–26)	200 (47–262)
	James San Jacinto Mountains Reserve	4.1 (3.2–6.0)	4.3 (3.4–5.4)	-21 (-38–29)	24 (16–36)	183 (127–279)
	Kendall-Frost Mission Bay Marsh Reserve	3.6 (3.0–5.7)	3.8 (2.5–4.9)	-26 (-41–17)	19 (4–23)	201 (40–235)
	Motte Rimrock Reserve	3.8 (3.1–5.8)	4.3 (3.3–5.2)	-16 (-41–31)	14 (7–17)	169 (82–209)
	San Joaquin Marsh Reserve	3.4 (2.9–5.4)	4.1 (3.1–4.9)	-16 (-40–28)	15 (4–20)	170 (42–223)
	Santa Cruz Island Reserve	3.4 (3.0–5.3)	3.6 (2.8–4.7)	-4 (-35–33)	17 (7–19)	152 (66–170)
	Scripps Coastal Reserve	3.6 (3.0–5.7)	4.2 (2.9–5.2)	-24 (-40–19)	19 (5–22)	193 (56–224)
	Stunt Ranch Santa Monica Mountains Reserve	3.7 (3.2–5.7)	3.9 (3.0–4.5)	-8 (-37–34)	15 (7–17)	150 (73–169)
DMoj	Burns Piñon Ridge Reserve	4.3 (3.5–6.3)	4.7 (3.7–5.8)	-24 (-43–33)	16 (9–20)	187 (100–232)
	Oasis de Los Osos	4.0 (3.1–5.9)	4.6 (3.7–5.7)	-23 (-44–25)	16 (6–21)	168 (65–224)
	Old Woman Mountains	3.9 (3.4–6.1)	4.9 (3.8–6.2)	-22 (-28–28)	13 (6–17)	148 (64–195)
	Sacramento Mountains Reserve	4.1 (3.6–6.3)	5.0 (3.8–6.3)	-18 (-27–31)	11 (5–14)	135 (56–177)
	Sweeney Granite Mountains Desert Research Center	4.0 (3.3–6.1)	5.1 (4.1–6.3)	-25 (-29–27)	15 (7–19)	175 (78–213)
DSon	Anza-Borrego Desert State Park	4.1 (3.2–6.0)	4.4 (3.4–5.6)	-28 (-41–26)	13 (6–17)	155 (75–204)
	Steele/Burnand Anza-Borrego Desert Research Center	3.5 (2.6–5.4)	4.2 (3.0–5.3)	-29 (-44–21)	9 (4–12)	128 (55–164)
	Boyd Deep Canyon Desert Research Center	4.1 (3.2–6.0)	4.6 (3.6–5.8)	-26 (-41–28)	12 (6–16)	145 (67–192)

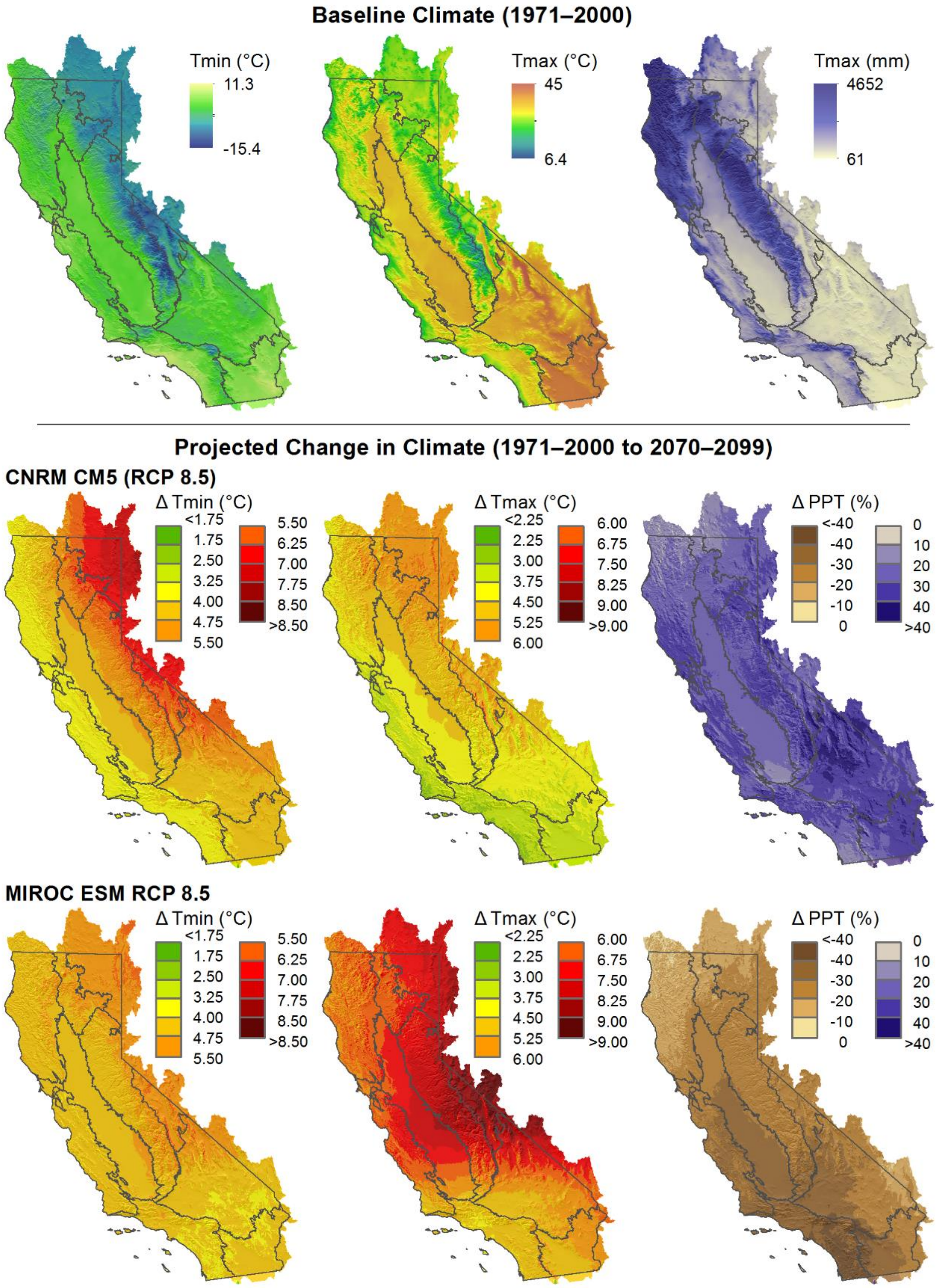


Figure A2.1. Maps of California baseline climate and projected climate change exposure.

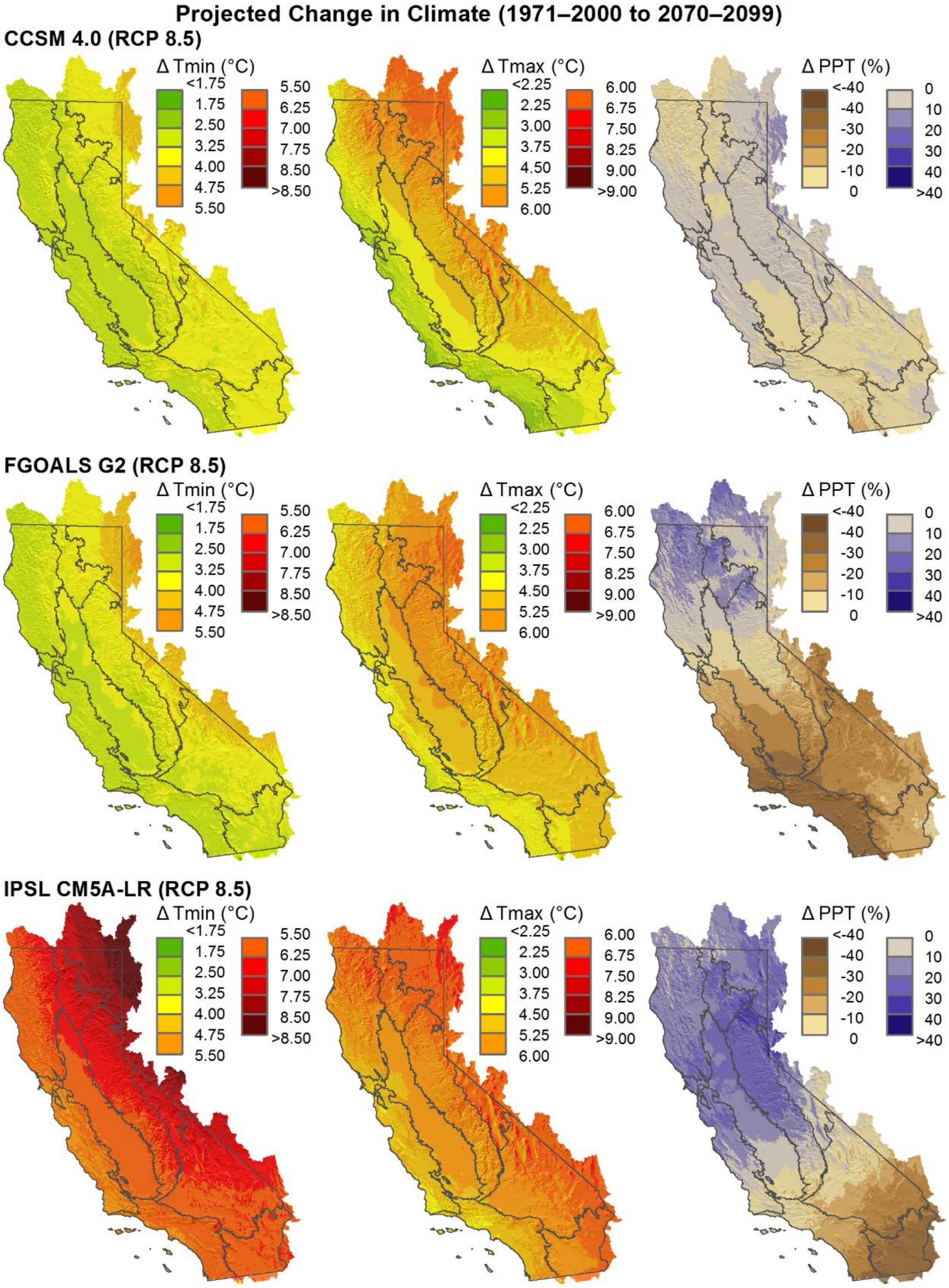


Figure A2.1 (cont.). Maps of California baseline climate and projected climate change exposure.

Appendix 3. Detailed SDM Methods

We used the modeling algorithm Maxent (Phillips et al. 2006), a maximum entropy method for modeling species distributions from presence-only occurrence data, implemented in R (R Core Team 2018) with the 'dismo' package (Hijmans et al. 2013). When modeling species distributions from presence-only data, environmental conditions at species occurrence locations are compared to a background sample of environmental conditions from the study region rather than true species absences. The quality and biases of occurrence data, method of background selection, and study area extent can all affect model predictive performance (Anderson and Raza 2010, Barve et al. 2011, Barbet-Massin et al. 2012, Kramer-Schadt et al. 2013, Syfert et al. 2013). Plant collections often contain spatial bias where easily accessible areas are over-represented. One method to account for such bias is to generate similar geographic bias in the sampling of the background data. We achieved this by using a background dataset based on the occurrences of all sensitive plant species in California. This approach, called target background, has been shown to improve model performance (Phillips et al. 2009). We further tailored the background data to each species by restricting the sample to an area within 100 km of the species known occurrences (Fig. A3.1) to ensure models captured the environmental conditions most relevant in shaping distributional patterns (Anderson and Raza 2010, Barve et al. 2011).

For each species we modeled the relationship between species presence and baseline (1971–2000) climate data and soil data using the following Maxent settings: linear quadratic, and hinge features, default beta-regularization, and logistic output. This species-environment relationship was then projected onto each of five future climate scenarios for the end of the century (2070–2099). We converted Maxent's continuous logistic output to binary maps resenting baseline and future suitable habitat using the maximum sensitivity plus specificity threshold (Jimenez-Valverde and Lobo 2007, Liu et al. 2013) (Fig. A3.1). Future suitable habitat was mapped assuming two dispersal scenarios: no dispersal and full (100 km) dispersal.

We evaluated model performance using four-fold cross validation to estimate two metrics, the area under the receiver operating characteristic curve (AUC) and the True Skill Statistic (TSS). AUC ranges from 0 to 1 and can be interpreted as the ability of the model to discriminate presence sites from background when using presence-only data (Fielding and Bell 1997, but see Lobo et al. 2008). TSS considers both commission and omission errors and is equal to the sum of the sensitivity and sensitivity minus 1. Unlike AUC, TSS is independent of prevalence (Allouche et al. 2006). TSS ranges from –1 to 1, with values below 0 indicating classification no better than random. We used the following criteria to interpret evaluation statistics: AUC: < 0.7 poor, 0.7–0.9 fair to good, > 0.9 very good to excellent; TSS: < 0.4 poor, 0.4–0.75 fair to good, >0.75 very good to excellent. We also estimated the omission (false negative) rate at the maximum sensitivity plus specificity threshold. Only species with AUC ≥ 0.7 and TSS ≥ 0.4 and an omission (false negative) rate ≤ 30% at the maximum sensitivity plus specificity threshold were retained for report analyses.

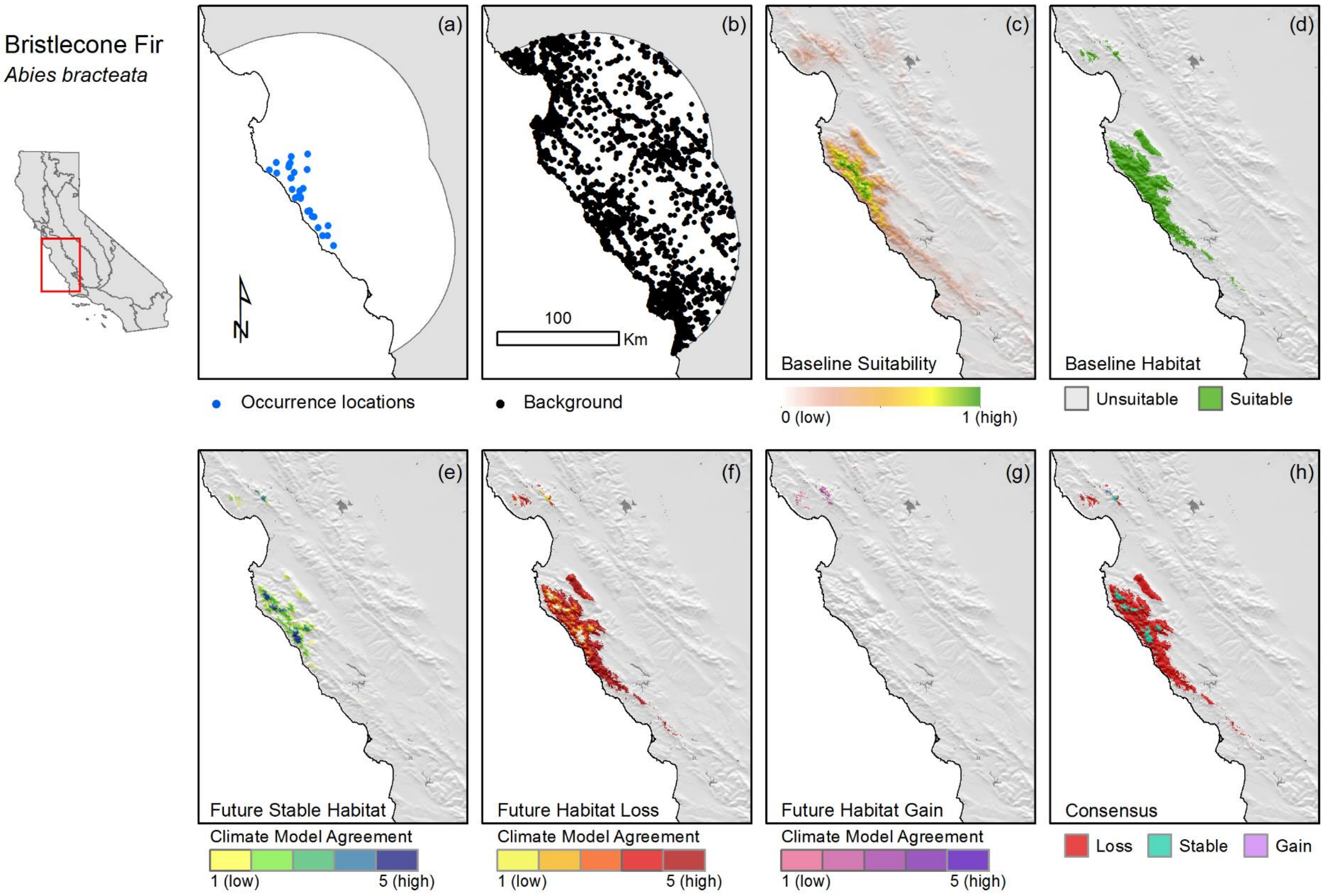


Figure A3.1. SDM habitat prediction for bristlecone fir. Top row: (a) occurrence locations; (b) targeted background locations; (c) baseline (1971–2000) habitat suitability (logistic); and (d) baseline (1971–2000) suitable habitat (thresholded). Bottom row: spatial agreement (N climate models) in predicted future (2070–2099) (e) stable habitat, (f) habitat loss, (g) habitat gain; and (h) consensus habitat change where predictions under three or more future climate scenarios agree.

Appendix 4. SDM Performance and Suitable Habitat Predictions

Appendix 4 contains detailed information on species characteristics, model performance, and predicted baseline and future suitable habitat for the 180 modeled sensitive plant species. Species characteristics include serpentine affinity (Safford et al. 2005), life form, and elevational range. California Rare Plant Rank (CRPR) status and taxonomy reflect the most recent information at the time of the report (CNPS 2018). Overall model performance is measured by the area under the receiver operating characteristic curve (AUC) and the True Skill Statistic (TSS) (see Appendix 3 for modeling details). The omission rate measures the number of occurrences incorrectly predicted as unsuitable (false negative rate) at the maximum sum of sensitivity and specificity threshold used to designate suitable/unsuitable habitat. All model evaluation metrics are reported as mean ± SD from four-fold cross validation. Predicted baseline suitable habitat is reported in km^2. The percent spatial overlap in baseline and future habitat, as well as predicted percent habitat loss, gain, and net change are calculated relative to baseline suitable habitat and are reported for the consensus and range (min–max) across the five climate scenarios. Species characteristics, model performance, and habitat predictions are available in an excel spreadsheet [Appendix4.xls].

Link to download Appendix 4 data:

Erin C. Riordan. 2019. Supplemental information (Appendix 1, Appendix 4, Appendix5) from the report: Evaluating the future role of the University of California Natural Reserve System for sensitive plant protection under climate change. Knowledge Network for Biocomplexity. doi:10.5063/F15X2773.

Appendix 5. Predicted Baseline and Future Suitable Habitat Maps

Appendix 5 contains habitat suitability maps for the 180 modeled sensitive plant species. Occurrences, baseline (1971–2000) suitable habitat, future (2070–2099) suitable habitat, and future suitable habitat change are provided for each species. Future suitable habitat shows the spatial agreement in predicted future habitat across the five future climate scenarios. Future habitat change shows the consensus where there is spatial agreement under least three climates scenarios for stable habitat, habitat loss, and habitat gain. Dotted line indicates 100 km limit for the full dispersal scenario. High resolution maps for all species are in a zipped folder. [Appendix5. zip]

Link to download Appendix 5 habitat suitability maps:
Erin C. Riordan. 2019. Supplemental information (Appendix 1, Appendix 4, Appendix5) from the report: Evaluating the future role of the University of California Natural Reserve System for sensitive plant protection under climate change. Knowledge Network for Biocomplexity. [doi:10.5063/F15X2773](https://doi.org/10.5063/F15X2773).

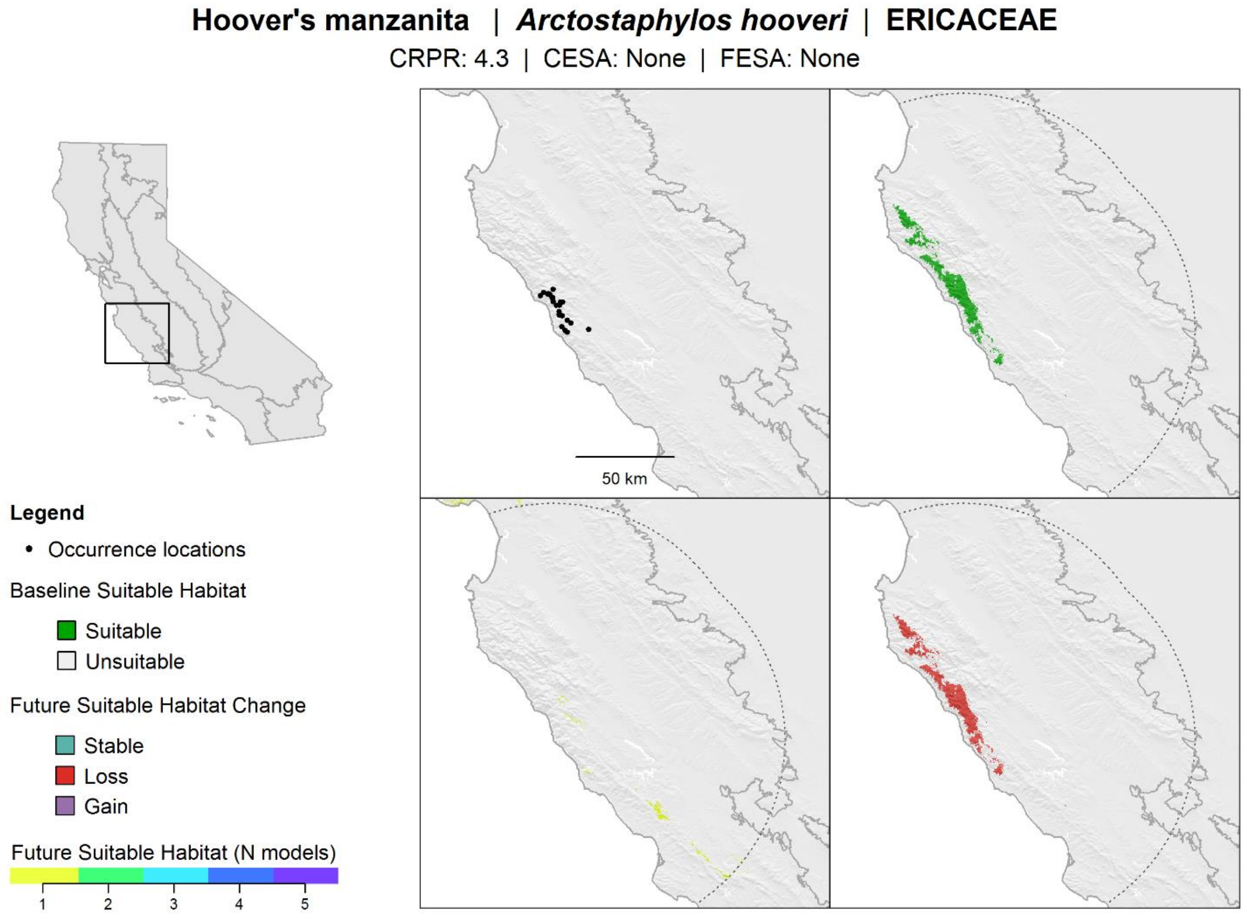


Figure A5.1. Hoover's manzanita (*Arctostaphylos hooveri*) suitable habitat map. Hoover's manzanita is an evergreen shrub that is endemic to the Santa Lucia Mountains and occurs on Landels-Hill Big Creek Reserve.

Appendix 6. Focal Reserve Sensitive Species Maps

Appendix 6 contains overlay maps for sensitive species habitat at focal reserves. Baseline and future suitable habitat maps were overlaid for all modeled plant species to identify areas of future species richness (e.g., climate refugia; Keppel et al. 2012), loss, gain, and turnover (Figs A6.1-A6.6).

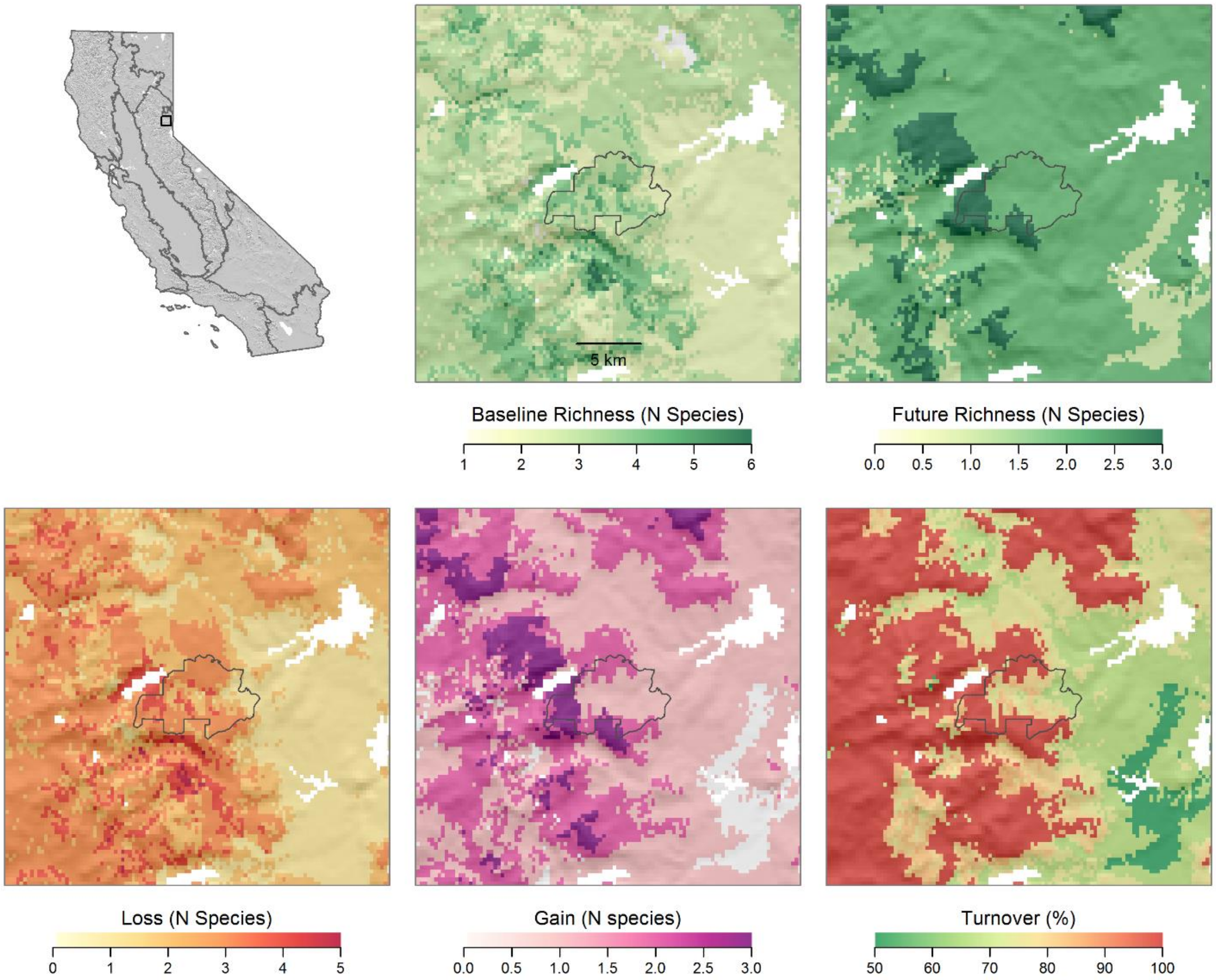


Figure A6.1. Predicted change in sensitive plant species at Sagehen Creek Field Station. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

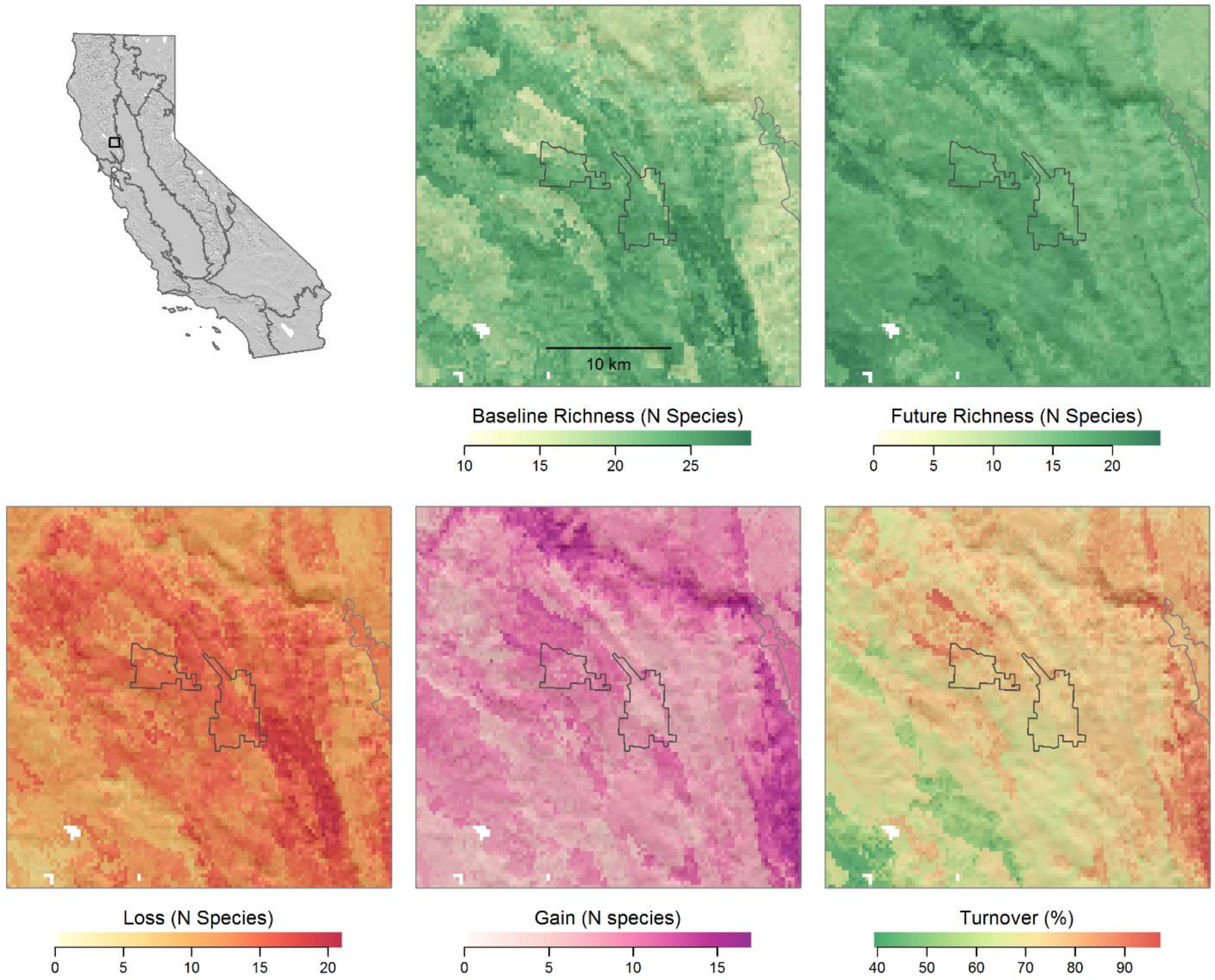


Figure A6.2. Predicted change in sensitive plant species at McLaughlin Natural Reserve. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

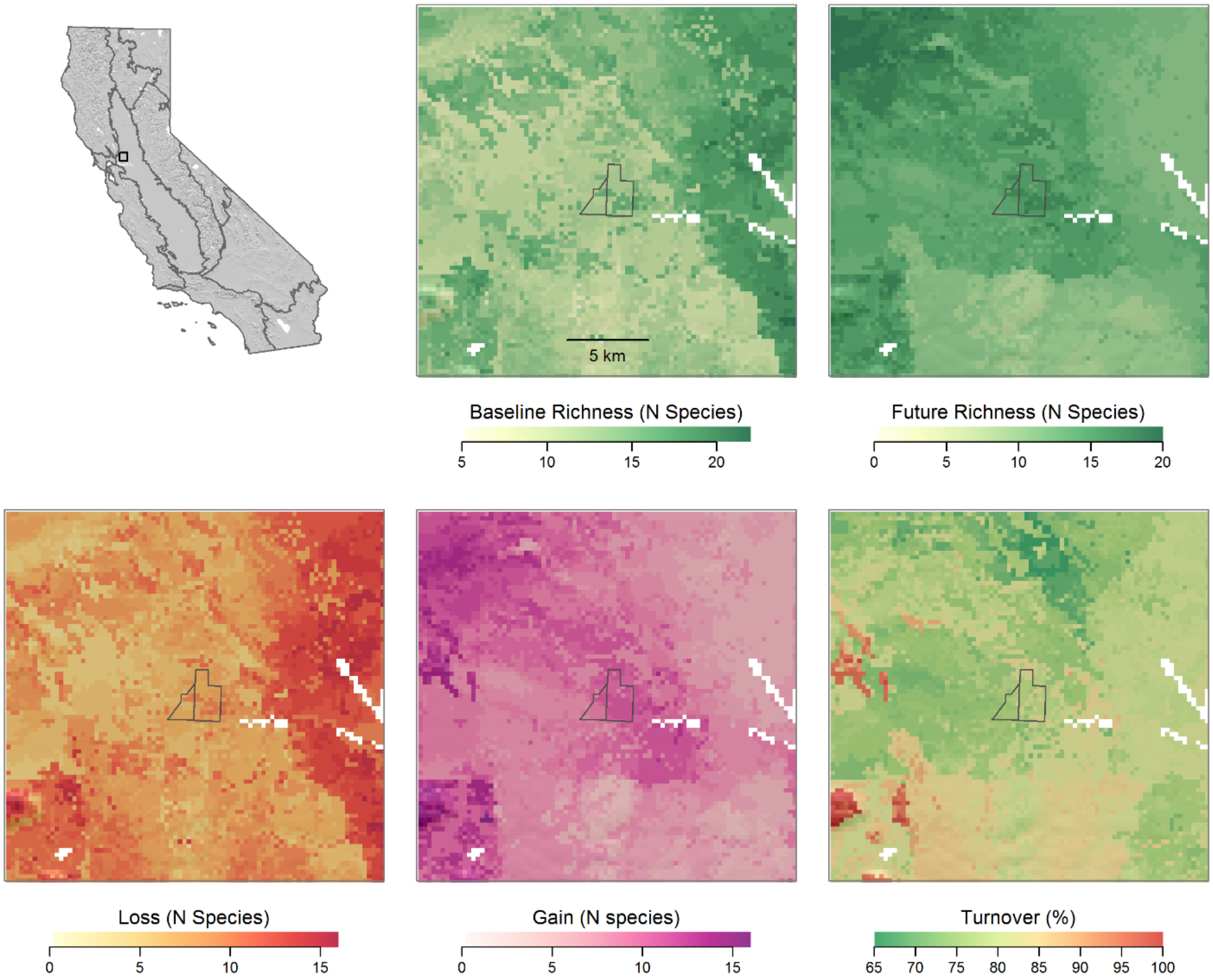


Figure A6.3. Predicted change in sensitive plant species at Jepson Prairie Reserve. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

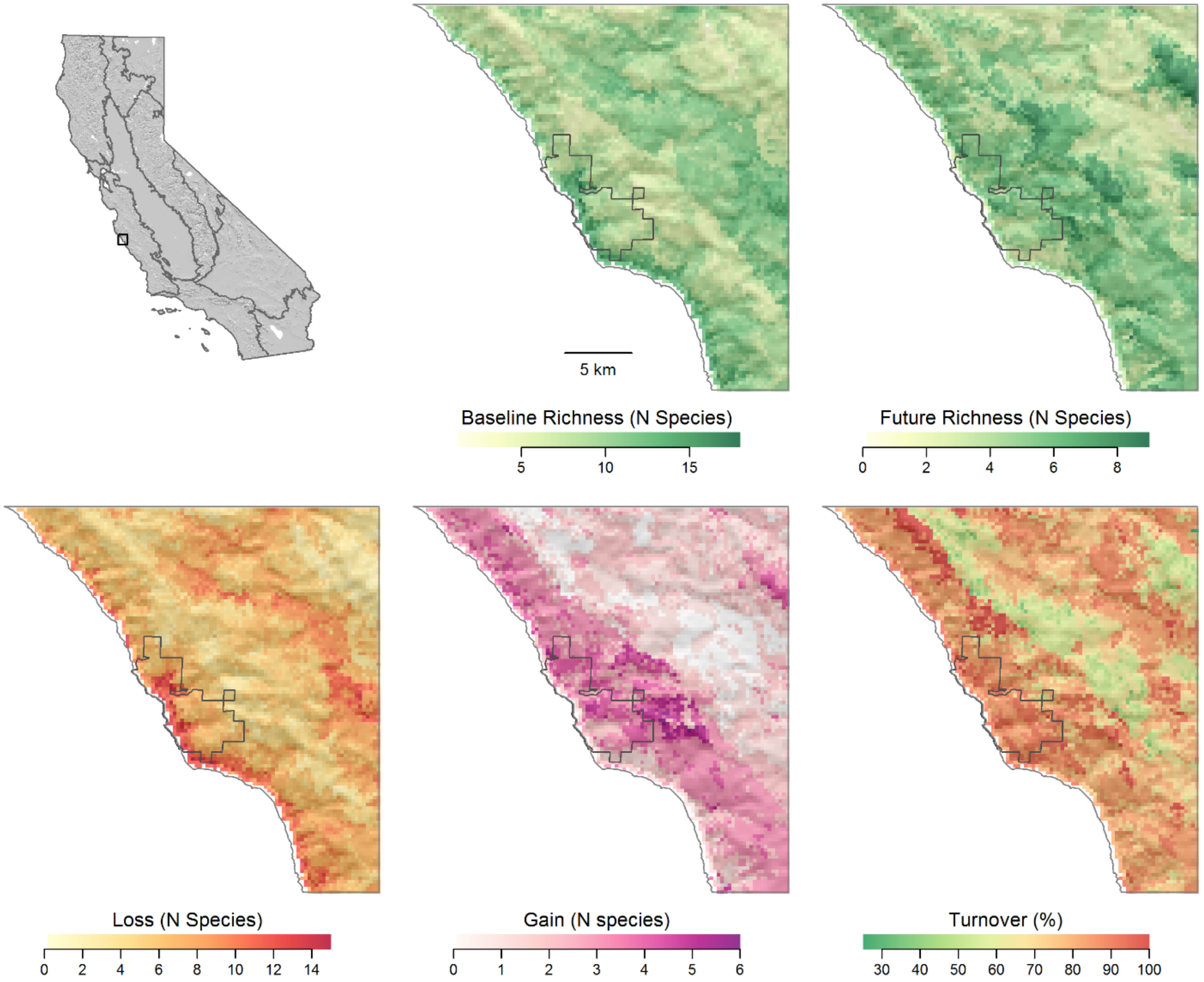


Figure A6.4. Predicted change in sensitive plant species at Landels-Hill Big Creek Reserve. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

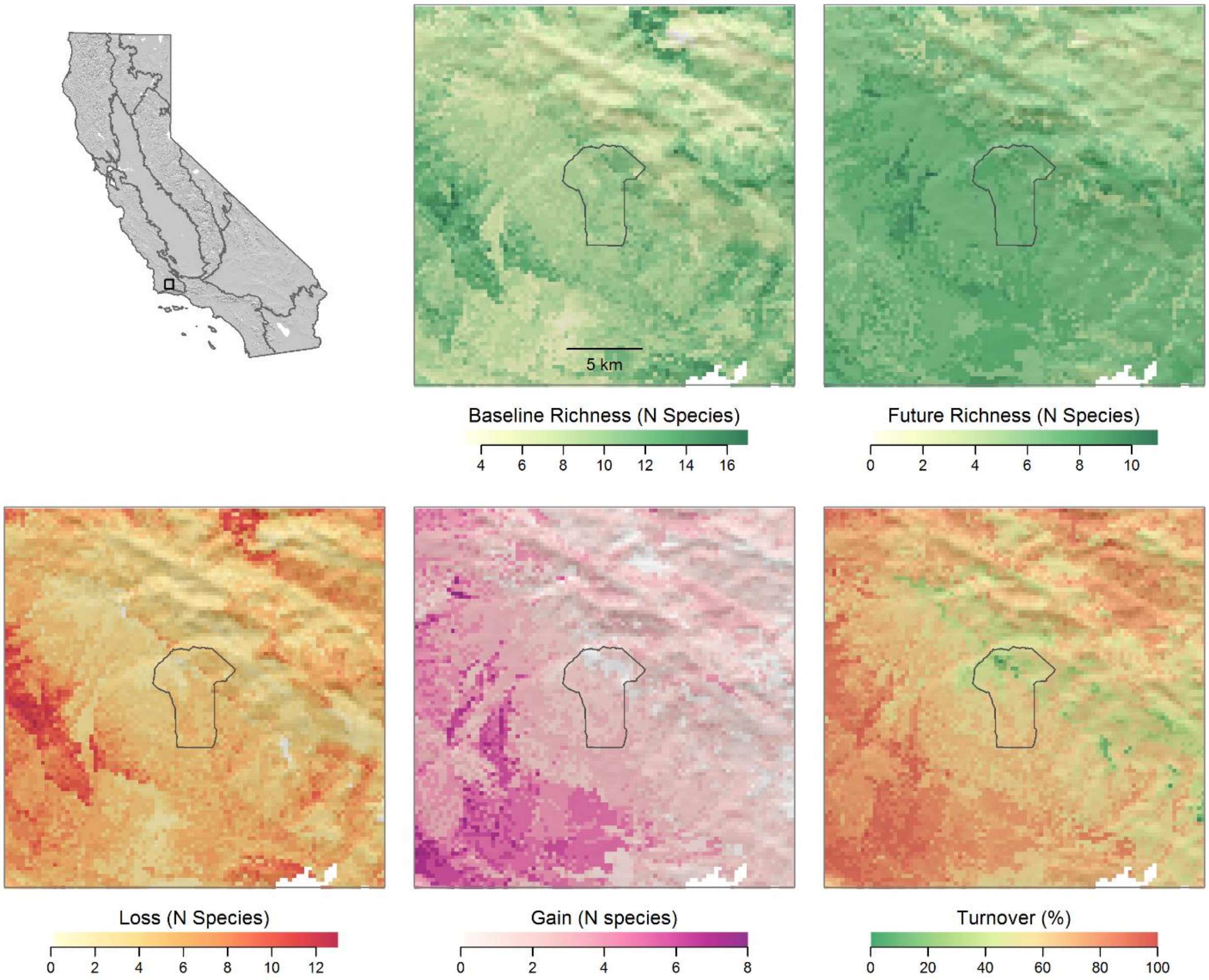


Figure A6.5. Predicted change in sensitive plant species at Sedgwick Reserve. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

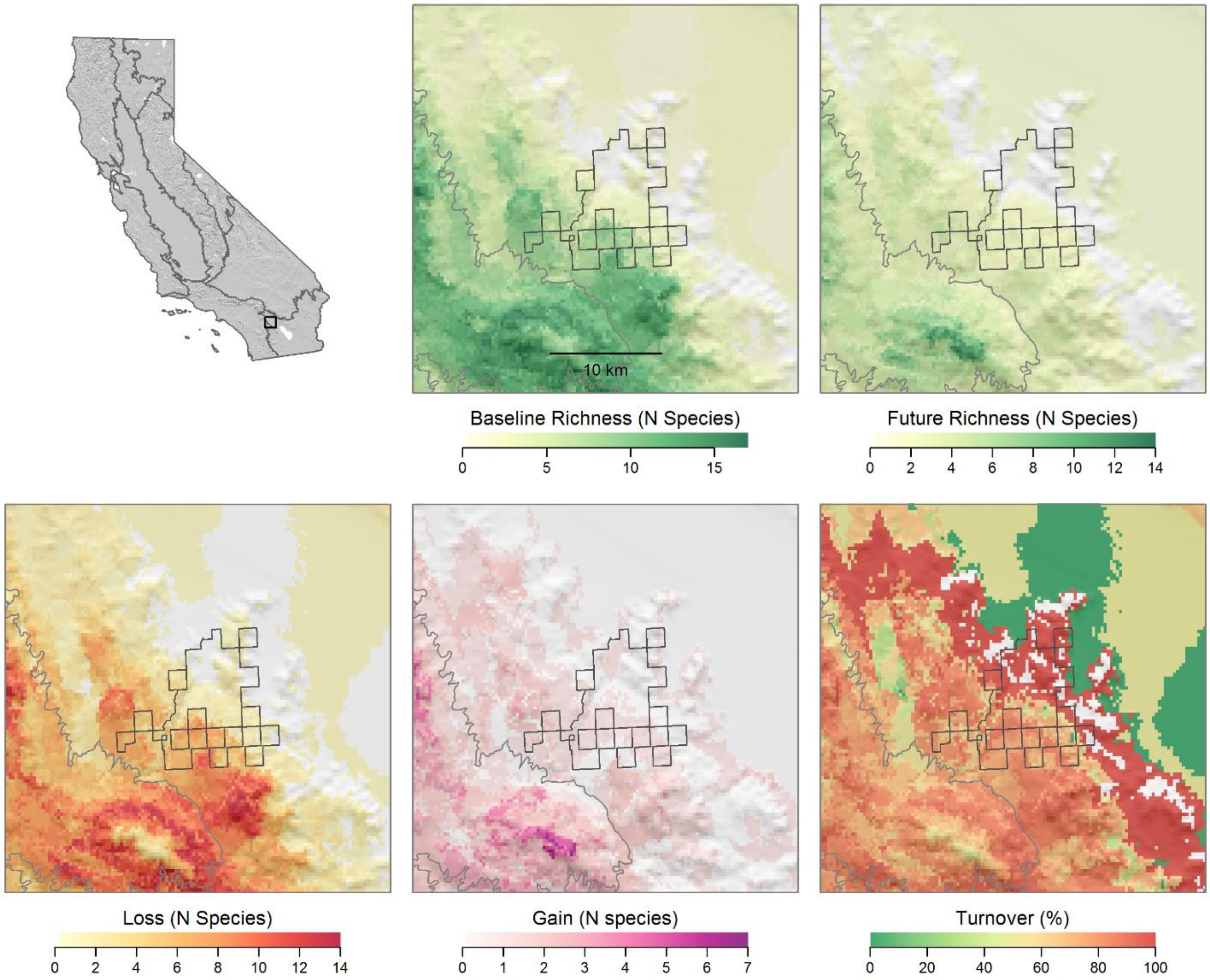


Figure A6.6. Predicted change in sensitive plant species at Boyd Deep Canyon. Clockwise from upper left: baseline (1971–2000) richness, future (2070–2099) richness, future species loss, future species gain, and future turnover. Maps show the overlap (N species) of predicted suitable habitat for modeled sensitive species within the vicinity of the focal reserve. Future maps are based on the consensus scenario where there is spatial agreement in predicted suitable habitat under three or more climate models.

References

Ackerly, D. D., S. R. Loarie, W. K. Cornwell, S. B. Weiss, H. Hamilton, R. Branciforte, and N. J. B. Kraft. 2010. The geography of climate change: implications for conservation biogeography. Diversity and Distributions **16**:476-487.

Aitken, S. N., and M. C. Whitlock. 2013. Assisted gene flow to facilitate local adaptation to climate change. Annual Review of Ecology, Evolution, and Systematics **44**:367-388.

Allouche, O., A. Tsoar, and R. Kadmon. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology **43**:1223-1232.

Anacker, B. L., M. Gogol-Prokurat, K. Leidholm, and S. Schoenig. 2013. Climate change vulnerability assessment of rare plants in California. Madrono **60**:193-210.

Anderson, R. P., and A. Raza. 2010. The effect of the extent of the study region on GIS models of species geographic distributions and estimates of niche evolution: preliminary tests with montane rodents (genus *Nephelomys*) in Venezuela. Journal of Biogeography **37**:1378-1393.

André, J. M. 2006. Vascular flora of the Granite Mountains, San Bernardino County: An annotated checklist. Crossosoma **32**:38-74.

André, J. M. 2014. Floristic diversity and discovery in the California desert. Fremontia **42**:3-8.

Araújo, M. B., D. Alagador, M. Cabeza, D. Nogues-Bravo, and W. Thuiller. 2011. Climate change threatens European conservation areas. Ecology Letters **14**:484-492.

Araújo, M. B., M. Cabeza, W. Thuiller, L. Hannah, and P. H. Williams. 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology **10**:1618-1626.

Araújo, M. B., and R. G. Pearson. 2005. Equilibrium of species' distributions with climate. Ecography **28**:693-695.

Araújo, M. B., and A. T. Peterson. 2012. Uses and misuses of bioclimatic envelope modeling. Ecology **93**:1527-1539.

Baldwin, B. G., D. H. Goldman, D. J. Keil, R. Patterson, T. J. Rosatti, and D. H. Wilken. 2012. The Jepson Manual: Vascular Plants of California. 2nd edition. University of California Press, Berkeley.

Barbet-Massin, M., F. Jiguet, C. H. Albert, and W. Thuiller. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? Methods in Ecology and Evolution **3**:327-338.

Barve, N., V. Barve, A. Jimenez-Valverde, A. Lira-Noriega, S. P. Maher, A. T. Peterson, J. Soberon, and F. Villalobos. 2011. The crucial role of the accessible area in ecological niche modeling and species distribution modeling. Ecological Modelling **222**:1810-1819.

Beauregard, F., and S. de Blois. 2014. Beyond a climate-centric view of plant distribution: edaphic variables add value to distribution models. Plos One **9**:e92642.

Belote, R. T., M. S. Dietz, C. N. Jenkins, P. S. McKinley, G. H. Irwin, T. J. Fullman, J. C. Leppi, and G. H. Aplet. 2017. Wild, connected, and diverse: building a more resilient system of protected areas. Ecological Applications **27**:1050-1056.

Beltran, B. J., J. Franklin, A. D. Syphard, H. M. Regan, L. E. Flint, and A. L. Flint. 2014. Effects of climate change and urban development on the distribution and conservation of vegetation in a Mediterranean type ecosystem. International Journal of Geographical Information Science **28**:1561-1589.

Bonebrake, T. C., C. J. Brown, J. D. Bell, J. L. Blanchard, A. Chauvenet, C. Champion, I.-C. Chen, T. D. Clark, R. K. Colwell, F. Danielsen, I. Dell Anthony, J. M. Donelson, B. Evengård, S. Ferrier, S. Frusher, R. A. Garcia, R. B. Griffis, A. J. Hobday, M. A. Jarzyna, E. Lee, J. Lenoir, H. Linnetved, V. Y. Martin, P. C. McCormack, J. McDonald, E. McDonald-Madden, N. Mitchell, T. Mustonen, J. M. Pandolfi, N. Pettorelli, H. Possingham, P. Pulsifer, M. Reynolds, B. R. Scheffers, C. J. B. Sorte, J. M. Strugnell, M.-N. Tuanmu, S. Twiname, A. Vergés, C. Villanueva, E. Wapstra, T. Wernberg, and G. T. Pecl. 2018. Managing consequences of climate-driven species redistribution requires integration of ecology, conservation and social science. Biological Reviews **93**:284-305.

Burns, C. E., K. M. Johnston, and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in U.S. national parks. Proceedings of the National Academy of Sciences **100**:11474-11477.

CalPhotos. 2013. CalPhotos. Regents of the University of California, Berkeley, Berkeley, California. https://calphotos.berkeley.edu [accessed 10 September 2013].

Carroll, C., D. R. Roberts, J. L. Michalak, J. J. Lawler, S. E. Nielsen, D. Stralberg, A. Hamann, B. H. Mcrae, and T. Wang. 2017. Scale-dependent complementarity of climatic velocity and environmental diversity for identifying priority areas for conservation under climate change. Global Change Biology **23**:4508-4520.

CCH. 2014. Consortium of California Herbaria. Regents of the University of California, Berkeley, California. http://ucjeps.berkeley.edu/consortium/ [accessed 24 April 2014].

Chen, I.-C., J. K. Hill, R. Ohlemüller, D. B. Roy, and C. D. Thomas. 2011. Rapid range shifts of species associated with high levels of climate warming. Science **333**:1024-1026.

Christmas, M. J., M. F. Breed, and A. J. Lowe. 2016. Constraints to and conservation implications for climate change adaptation in plants. Conservation Genetics **17**:305-320.

CNDDB. 2013. California Natural Diversity Database. California Department of Fish and Game, Biogeographic Data Branch, Sacramento, CA [accessed 17 December 2013].

CNPS California Native Plant Society. 2018. Inventory of rare and endangered plants (online edition, v8-03 0.39). California Native Plant Society, Sacramento, CA. http://www.rareplants.cnps.org/ [accessed 30 September 2018].

Corlett, R. T., and D. A. Westcott. 2013. Will plant movements keep up with climate change? Trends in Ecology & Evolution **28**:482-488.

Cox, R. L., and E. C. Underwood. 2011. The importance of conserving biodiversity outside of protected areas in mediterranean ecosystems. Plos One **6**:e14508.

CPAD. 2017. California Protected Areas Database (CPAD). GreenInfo Network. www.calands.org [accessed 01 August 2018].

Davis, M. B., and R. G. Shaw. 2001. Range shifts and adaptive responses to Quaternary climate change. Science **292**:673-679.

Dean, E. 2017. Vascular Plant Species of the Greater Knoville Area. UC Davis Center For Plant Diversity. https://herbarium.ucdavis.edu/plantlistsandfloras.html.

Dubuis, A., S. Giovanettina, L. Pellissier, J. Pottier, P. Vittoz, and A. Guisan. 2013. Improving the prediction of plant species distribution and community composition by adding edaphic to topo-climatic variables. Journal of Vegetation Science **24**:593-606.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudik, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. M. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberon, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography **29**:129-151.

Elith, J., and J. R. Leathwick. 2009. Species distribution models: Ecological explanation and prediction across space and time. Annual Review of Ecology Evolution and Systematics **40**:677-697.

Engler, R., A. Guisan, and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology **41**:263-274.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management **61**:603-610.

Fiedler, P. L., S. G. Rumsey, and K. M. Wong. 2013. The Environmental Legacy of the UC Natural Reserve System. University of California Press, Berkeley.

Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation **24**:38-49.

Flint, L. E., and A. L. Flint. 2012. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. Ecological Processes **1**: doi: 10.1186/2192-1709-1181-1182.

Flint, L. E., A. L. Flint, J. H. Thorne, and R. Boynton. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes **2**: doi:10.1186/2192-1709-1182-1125.

Franklin, J., J. M. Serra-Diaz, A. D. Syphard, and H. M. Regan. 2016. Global change and terrestrial plant community dynamics. Proceedings of the National Academy of Sciences **113**:3725-3734.

Füssel, H.-M., and R. J. T. Klein. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change **75**:301-329.

Gaston, K. J., K. Charman, S. F. Jackson, P. R. Armsworth, A. Bonn, R. A. Briers, C. S. Q. Callaghan, R. Catchpole, J. Hopkins, W. E. Kunin, J. Latham, P. Opdam, R. Stoneman, D. A. Stroud, and R. Tratt. 2006. The ecological effectiveness of protected areas: The United Kingdom. Biological Conservation **132**:76-87.

Glick, P., B. A. Stein, and N. A. Edelson, editors. 2011. Scanning the Conservation Horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington DC, USA.

Gogol-Prokurat, M. 2011. Predicting habitat suitability for rare plants at local spatial scales using a species distribution model. Ecological Applications **21**:33-47.

Gonzalez, P., F. Wang, M. Notaro, D. J. Vimont, and J. W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. Environmental Research Letters **13**:104001.

Graham, C. H., J. Elith, R. J. Hijmans, A. Guisan, A. T. Peterson, and B. A. Loiselle. 2008. The influence of spatial errors in species occurrence data used in distribution models. Journal of Applied Ecology **45**:239-247.

Guisan, A., O. Broennimann, R. Engler, M. Vust, N. G. Yoccoz, A. Lehmann, and N. E. Zimmermann. 2006. Using niche-based models to improve the sampling of rare species. Conservation Biology **20**:501-511.

Guisan, A., and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters **8**:993-1009.

Guisan, A., R. Tingley, B. Baumgartner John, I. Naujokaitis-Lewis, R. Sutcliffe Patricia, I. T. Tulloch Ayesha, J. Regan Tracey, L. Brotons, E. McDonald-Madden, C. Mantyka-Pringle, G. Martin Tara, R. Rhodes Jonathan, R. Maggini, A. Setterfield Samantha, J. Elith, W. Schwartz Mark, A. Wintle Brendan, O. Broennimann, M. Austin, S. Ferrier, R. Kearney Michael, P. Possingham Hugh, and M. Buckley Yvonne. 2013. Predicting species distributions for conservation decisions. Ecology Letters **16**:1424-1435.

Haggerty, B. P., and S. J. Mazer. 2010. Flora of the UC Natural Reserve System. University of California Natural Reserve System. https://ucnrs.org/plant-list/ [accessed 10 September 2013].

Hannah, L., G. Midgley, S. Andelman, M. Araújo, G. Hughes, E. Martinez-Meyer, R. Pearson, and P. Williams. 2007. Protected area needs in a changing climate. Frontiers in Ecology and the Environment **5**:131-138.

Hannah, L., M. R. Shaw, P. Roehrdanz, M. Ikegami, O. Soong, and J. Thorne. 2012. Consequences of climate change for native plants and conservation. Publication number CEC-500-2012-024. Calfiornia Energy Commission, Sacramento, CA.

Harrison, S. 2013. Plant and animal endemism in California. University of California Press, Berkeley.

Harrison, S., E. Damschen, B. Fernandez-Going, A. Eskelinen, and S. Copeland. 2015. Plant communities on infertile soils are less sensitive to climate change. Ann Bot **116**:1017-1022.

Harrison, S., J. Maron, and G. Huxel. 2000. Regional turnover and fluctuation in populations of five plants confined to serpentine seeps. Conservation Biology **14**:769-779.

Hernandez, P. A., C. H. Graham, L. L. Master, and D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography **29**:773-785.

Hijmans, R. J., S. Phillips, J. Leathwick, and J. Elith. 2013. Dismo: Species Distribution Modeling. R package version 0.9-3. http://CRAN.R-project.org/package=dismo [accessed August 2014].

Hole, D. G., S. G. Willis, D. J. Pain, L. D. Fishpool, S. H. M. Butchart, Y. C. Collingham, C. Rahbek, and B. Huntley. 2009. Projected impacts of climate change on a continent-wide protected area network. Ecology Letters **12**:420-431.

IPCC. 2013. Climate change 2013: The physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2014. Annex II: Glossary [Mach, K. J., S. Planton, and C. von Stechow (eds.)]. *In* Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

JFP Jepson Flora Project (eds.). 2018. Jepson eFlora. http://ucjeps.berkeley.edu/eflora/ [accessed 30 September 2018].

Jimenez-Valverde, A., and J. M. Lobo. 2007. Threshold criteria for conversion of probability of species presence to either-or presence-absence. Acta Oecologica-International Journal of Ecology **31**:361-369.

Keppel, G., K. P. Van Niel, G. W. Wardell-Johnson, C. J. Yates, M. Byrne, L. Mucina, A. G. T. Schut, S. D. Hopper, and S. E. Franklin. 2012. Refugia: identifying and understanding safe havens for biodiversity under climate change. Global Ecology and Biogeography **21**:393-404.

Klausmeyer, K. R., and M. R. Shaw. 2009. Climate change, habitat loss, protected areas and the climate adaptation potential of species in mediterranean ecosystems worldwide. Plos One **4**:e6392.

Kramer-Schadt, S., J. Niedballa, J. D. Pilgrim, B. Schroder, J. Lindenborn, V. Reinfelder, M. Stillfried, I. Heckmann, A. K. Scharf, D. M. Augeri, S. M. Cheyne, A. J. Hearn, J. Ross, D. W. Macdonald, J. Mathai, J. Eaton, A. J. Marshall, G. Semiadi, R. Rustam, H. Bernard, R. Alfred, H. Samejima, J. W. Duckworth, C. Breitenmoser-Wuersten, J. L. Belant, H. Hofer, and A. Wilting. 2013. The importance of correcting for sampling bias in MaxEnt species distribution models. Diversity and Distributions **19**:1366-1379.

Liu, C. R., M. White, and G. Newell. 2013. Selecting thresholds for the prediction of species occurrence with presence-only data. Journal of Biogeography **40**:778-789.

Loarie, S. R., B. E. Carter, K. Hayhoe, S. McMahon, R. Moe, C. A. Knight, and D. D. Ackerly. 2008. Climate change and the future of California's endemic flora. Plos One **3**:e2502.

Loarie, S. R., P. B. Duffy, H. Hamilton, G. P. Asner, C. B. Field, and D. D. Ackerly. 2009. The velocity of climate change. Nature **462**:1052-1055.

Lobo, J. M., A. Jimenez-Valverde, and R. Real. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography **17**:145-151.

Lomba, A., L. Pellissier, C. Randin, J. Vicente, F. Moreira, J. Honrado, and A. Guisan. 2010. Overcoming the rare species modelling paradox: a novel hierarchical framework applied to an Iberian endemic plant. Biological Conservation **143**:2647-2657.

Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. Nature **405**:243.

McCarty, J. P. 2001. Ecological consequences of recent climate change. Conservation Biology **15**:320-331.

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich. 2002. Climate change hastens population extinctions. Proceedings of the National Academy of Sciences **99**:6070-6074.

Monahan, W. B., and D. M. Theobald. 2018. Climate change adaptation benefits of potential conservation partnerships. Plos One **13**:e0191468.

Monzón, J., L. Moyer-Horner, and M. B. Palamar. 2011. Climate change and species range dynamics in protected areas. Bioscience **61**:752-761.

Moore, K. A., and J. M. André. 2014. Rare plant diversity in the California deserts: priorities for research and conservation. Fremontia **42**:9-14.

Morefield, J. D. 2016. Complete working checklist of the White Mountains flora, updated 20 July 2016. Unpublished data provided by the author 03 October 2018.

Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. B. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant, and T. J. Wilbanks. 2010. The next generation of scenarios for climate change research and assessment. Nature **463**:747-756.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403**:853-858.

Nicotra, A. B., O. K. Atkin, S. P. Bonser, A. M. Davidson, E. J. Finnegan, U. Mathesius, P. Poot, M. D. Purugganan, C. L. Richards, F. Valladares, and M. van Kleunen. 2010. Plant phenotypic plasticity in a changing climate. Trends in Plant Science **15**:684-692.

Nix, H. 1986. A biogeographic analysis of Australian elapid snakes. Pages 4-15 *in* R. Longmore, editor. Atlas of Elapid Snakes of Australia. Australian Government Publishing Service, Canberra.

Parker, S. 2012. Small reserves can successfully preserve rare plants despite management challenges. Natural Areas Journal **32**:403-411.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology Evolution and Systematics **37**:637-669.

Pearson, R. G., and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography **12**:361-371.

Pearson, R. G., C. J. Raxworthy, M. Nakamura, and A. T. Peterson. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography **34**:102-117.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling **190**:231-259.

Phillips, S. J., M. Dudik, J. Elith, C. H. Graham, A. Lehmann, J. Leathwick, and S. Ferrier. 2009. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. Ecological Applications **19**:181-197.

Pimm, S. L., G. J. Russell, J. L. Gittleman, and T. M. Brooks. 1995. The future of biodiversity. Science **269**:347-350.

R Core Team. 2018. R: A Language and Environment for Statistical Computing (version 3.5.1). R Foundation for Statistical Computing, Vienna, Austria.

Rapacciuolo, G., S. P. Maher, A. C. Schneider, T. T. Hammond, M. D. Jabis, R. E. Walsh, K. J. Iknayan, G. K. Walden, M. F. Oldfather, D. D. Ackerly, and S. R. Beissinger. 2014. Beyond a warming fingerprint: individualistic biogeographic responses to heterogeneous climate change in California. Global Change Biology **20**:2841-2855.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences **167**:1123-1150.

Ricketts, T. H., E. Dinerstein, T. Boucher, T. M. Brooks, S. H. M. Butchart, M. Hoffmann, J. F. Lamoreux, J. Morrison, M. Parr, J. D. Pilgrim, A. S. L. Rodrigues, W. Sechrest, G. E. Wallace, K. Berlin, J. Bielby, N. D. Burgess, D. R. Church, N. Cox, D. Knox, C. Loucks, G. W. Luck, L. L. Master, R. Moore, R. Naidoo, R. Ridgely, G. E. Schatz, G. Shire, H. Strand, W. Wettengel, and E. Wikramanayake. 2005. Pinpointing and preventing imminent extinctions. Proceedings of the National Academy of Sciences **102**:18497-18501.

Safford, H. D., J. H. Viers, and S. P. Harrison. 2005. Serpentine endemism in the California flora: a database of serpentine affinity. Madrono **52**:222-257.

Schwartz, M. W. 2012. Using niche models with climate projections to inform conservation management decisions. Biological Conservation **155**:149-156.

Schwartz, M. W., J. H. Thorne, and J. H. Viers. 2006. Biotic homogenization of the California flora in urban and urbanizing regions. Biological Conservation **127**:282-291.

Selwood, K. E., M. A. McGeoch, and R. Nally. 2015. The effects of climate change and land-use change on demographic rates and population viability. Biological Reviews **90**:837-853.

Stephenson, N. L. 1990. Climatic control of vegetation distribution: the role of water balance. American Naturalist **135**:649-670.

Stephenson, N. L. 1998. Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales. Journal of Biogeography **25**:855-870.

Svenning, J. C., and B. Sandel. 2013. Disequilibrium vegetation dynamics under future climate change. American Journal of Botany **100**:1266-1286.

Syfert, M. M., M. J. Smith, and D. A. Coomes. 2013. The effects of sampling bias and model complexity on the predictive performance of MaxEnt species distribution models. Plos One **8**.

Thomas, C. D. 2010. Climate, climate change and range boundaries. Diversity and Distributions **16**:488-495.

Thomas, C. D., and P. K. Gillingham. 2015. The performance of protected areas for biodiversity under climate change. Biological Journal of the Linnean Society **115**:718-730.

Thomas, C. D., P. K. Gillingham, R. B. Bradbury, D. B. Roy, B. J. Anderson, J. M. Baxter, N. A. D. Bourn, H. Q. P. Crick, R. A. Findon, R. Fox, J. A. Hodgson, A. R. Holt, M. D. Morecroft, N. J. O'Hanlon, T. H. Oliver, J. W. Pearce-Higgins, D. A. Procter, J. A. Thomas, K. J. Walker, C. A. Walmsley, R. J. Wilson, and J. K. Hill. 2012. Protected areas facilitate species' range expansions. Proceedings of the National Academy of Sciences **109**:14063-14068.

Thorne, J. H., R.M. Boynton, A. J. Holguin, J. A. E. Stewart, and J. Bjorkman. 2016. A climate change vulnerability assessment of California’s terrestrial vegetation. California Department of Fish and Wildlife, Sacramento, CA.

Thuiller, W., S. Lavorel, M. B. Araújo, M. T. Sykes, and I. C. Prentice. 2005. Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences **102**:8245-8250.

Underwood, E. C., J. H. Viers, K. R. Klausmeyer, R. L. Cox, and M. R. Shaw. 2009. Threats and biodiversity in the mediterranean biome. Diversity and Distributions **15**:188-197.

Urban, M. C. 2015. Accelerating extinction risk from climate change. Science **348**:571-573.

Walther, G.-R., S. Beißner, and C. A. Burga. 2005. Trends in the upward shift of alpine plants. Journal of Vegetation Science **16**:541-548.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature **416**:389.

Wiens, J. A., D. Stralberg, D. Jongsomjit, C. A. Howell, and M. A. Snyder. 2009. Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National Academy of Sciences **106**:19729-19736.

Wiens, J. J., and C. H. Graham. 2005. Niche conservatism: integrating evolution, ecology, and conservation biology. Annual Review of Ecology Evolution and Systematics **36**:519-539.

Williams, J. W., and S. T. Jackson. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment **5**:475-482.