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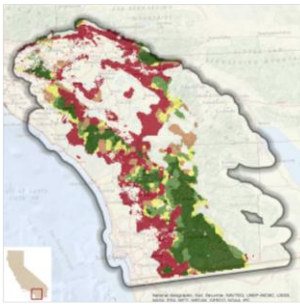

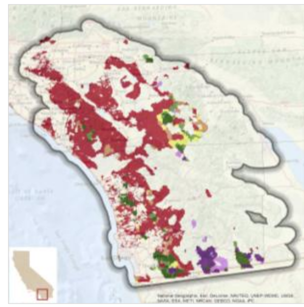

50-Year Climate Scenarios and Plant Species Distribution Forecasts for Setting Conservation Priorities in Southwestern California

October 2013

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Recommended Citation: Principe, Z., J.B. MacKenzie, B. Cohen, J.M. Randall, W. Tippets, T. Smith and S.A. Morrison. 2013. *50-Year Climate Scenarios and Plant Species Distribution Forecasts for Setting Conservation Priorities in Southwestern California* v.1. The Nature Conservancy of California, San Francisco, CA. 36 pages + Appendices

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Executive Summary

Global greenhouse gas levels and annual emissions already exceed the projections of many climate policy scenarios, suggesting nature and humans will have to adapt to rapid changes in climate in the decades ahead. Projecting where suitable conditions for native species will prevail under projected mid-century climate conditions and how species distributions are likely to shift in response can help conservation practitioners identify the most important places to work and provide insights on the conservation strategies and the management and monitoring activities needed today and in the near future.

To help address these concerns, we developed species distribution models (SDMs) for 106 native plant species under projected climatic conditions of the mid-21st-century (2045 – 2065) for southwestern California. We used the results of these models to examine the protection likely to be provided for this broadly representative sample of plants within the conservation reserve network implemented or approved under the Natural Conservation Communities Planning/Habitat Conservation Plan program (NCCP/HCP) at mid-century. The study area encompasses over 22,770 km^2 (over 5.6 million acres) covering most of San Diego and Orange Counties, plus western Riverside, southeastern Los Angeles, southwestern San Bernardino, and extreme western Imperial counties.

Our SDMs were based on climate scenarios generated with the International Panel on Climate Change's (IPCC) global climate models (GCMs; also referred to as general circulation models). The 106 plant species we analyzed included a wide variety of taxa including ferns, grasses, herbs, vines, shrubs, broad-leaf trees, conifers, cacti, and other succulents. All of these plants are relatively common in the state or region, and none are listed as rare, threatened or endangered by the state or federal government. Six of the species we modeled are among those designated as covered species by at least one of the Habitat Conservation Plans and Natural Community Conservation Plans within the study area.

We obtained presence-absence data for these plants from four large datasets, originally collected by other organizations to address different objectives (e.g., vegetation mapping, wildlife habitat monitoring). Our SDMs considered a combination of climate and soil-water-storage attributes, including extremes and seasonality of temperature and rainfall, as explanatory variables. We compared each species' current distribution with its forecast distribution and then calculated and mapped the area that would remain as suitable habitat ("refugia"), the area that would become unsuitable ("stress areas") and the area not suitable currently but projected to be suitable by mid-century ("expansion areas").

We next conducted a gap analysis to quantify the area of land forecast to be suitable for each species under mid-century conditions within five land-use categories: 1) protected conservation lands (all lands classified GAP 1, 2 & 3); 2) lands in approved NCCP/HCP conservation reserve designs but not yet protected; 3) military lands; 4) other unprotected, undeveloped lands; and, 5) developed lands. We also tallied the numbers of species forecast to have refugia, stress areas and expansion areas in each of the SDM's 30,789 860m x 860m cells to identify sites that may be especially important to protect, manage or monitor.

In common with most climate projections, ours predicted that mean annual temperatures will increase by mid-century, in our case by 2.24°C. Projections for precipitation, however, were equivocal, increasing in some scenarios, decreasing in others. Our SDMs produced species distribution forecasts that varied widely among species. Percentages of a species current range projected to remain as suitable habitat (= climate refugia) ranged from 0% to 100%. Overall, our forecasts indicated that for most species analyzed over half of their current distributions will remain suitable (i.e. will serve as refugia) at mid-century. On the other hand, two of the most widespread oak trees in the region were projected to fare poorly. Coast live oak (*Quercus agrifolia*) and Engelmann oak (*Quercus engelmannii*) were projected to have only 28% and 46% of their current distributions in refugia, respectively.

Most shrub species that are currently widespread were projected to fare well. Two that are common in and important for structuring Coastal Sage Scrub communities, however, were predicted to fare poorly. California buckwheat (*Eriogonum fasciculatum var. fasciculatum*) and California sagebrush (*Artemisia californica*) were predicted to have only 13% and 22% of their current distributions in refugia by mid-century, respectively. This suggests that monitoring and management plans may have to be revised to manage for the persistence of these two important species.

Our results also indicated that existing protected areas contain 50% or more of projected climate refugia for roughly half the species we assessed. Further, full implementation of the approved NCCP/HCP reserve designs in our study area would likely yield a reserve network capable of supporting most of the species modeled at mid-century. Implementation of reserve design features aimed at maintaining landscape scale connectivity across important gradients, and the maintenance of currently available habitat on military lands would further enhance most species ability to persist.

This assessment is a first pass. We hope it catalyzes and contributes to a vigorous, productive conversation among conservation planners and managers regarding the implications of climate change in the region and actions that can be taken to address them. We underscore that these and other ecological forecasts are merely hypotheses, which can and should be tested and refined with experiments, observations and models. We list caveats and limitations associated with this study in the Methods section. We recommend that our results be just one of several tools used to assess future climate change influences on distributions of species and natural communities in the region.

Introduction

Global greenhouse gas emissions today already exceed the projections of many future climate policy scenarios (IPCC 2007), suggesting the climate in our study area, and around the world, will undergo substantial changes in coming decades and that nature and humans will have to adapt to these changes (Parmesan and Yohe 2003). As the climate changes, many plants and animals will need to move across the landscape to new areas to find suitable habitat if they are to survive. Large blocks of intact and connected habitat are essential for this to happen. While millions of acres of California's natural habitats have been converted to urban areas, crops and roads, almost half of the state remains relatively intact and connected.

Climate impacts are already visible in marine (Hoegh-Guldberg and Bruno 2010), terrestrial (Thomas et al. 2004) and freshwater (aquatic) protected areas (Seavy et al. 2009) and published species forecasts suggest a future of large-scale range shifts, regional extirpations and formation of novel (no-analog) community types (Stralberg et al. 2009). Consequently, many conservation practitioners are eager to identify solutions that promote adaptation to climate change and enhance the resilience of ecological systems (Heller and Zavaleta 2009, Hansen and Hoffman 2011). How species adapt to changes has profound implications for where to prioritize conservation efforts and what management strategies to employ (Hannah et al. 2007, Wiens and Bachelet 2010). Ecological forecasts can be designed to explore a variety of climate change scenarios, their effects on distributions and abundance of species, and possible effects of different conservation interventions (Araujo and New 2007, Carrol et al. 2010; Shaw et al. 2012; Millar et al. 2007) Conservation planners and land managers can use this information to help set short- and long-term priorities and identify the management actions and monitoring programs needed to accomplish their conservation goals.

In California, climate projections (Cayan et al. 2008) indicate significant risks loom ahead for conservation (Ackerly et al. 2010). Observations in the field already confirm that many plant (Kelly and Goulden 2008) and animal species (Moritz et al. 2008) are on the move to compensate for rising temperatures and physiological limitations.

Southwestern California is highly biodiverse and has been the focus of much public and private conservation investment, including efforts to design and implement regional-scale networks of conservation lands. We undertook the analysis herein to assess the durability of those past conservation investments, and to inform future investments so they are more likely to make the overall conservation estate more robust in a warming world. We had two major goals:

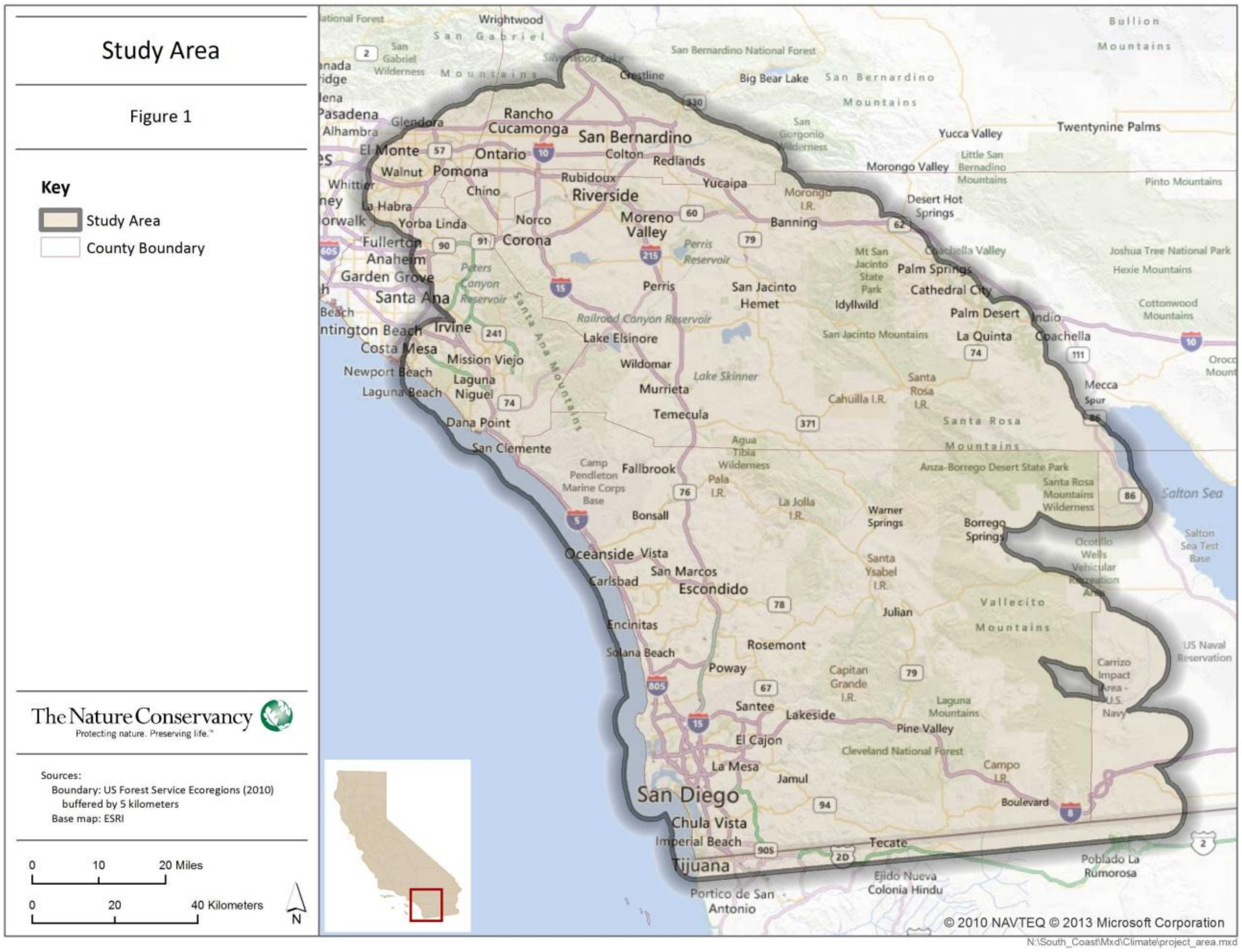
1. Forecast how a wide variety of plant species characteristic of southwestern California may respond to future climate scenarios, and;
2. Generate hypotheses about the degree to which populations of these species may be accommodated in the future by the existing conservation lands and by the approved but not-yet-implemented conservation reserve network designs.

We collaborated with public and private partners to compile data from a decade of presence-absence surveys in the region which we used to generate distribution forecasts for 106 plant species. The original datasets remain the intellectual property of the institutions and individuals that gathered or paid for them. The full set of species distribution forecasts produced for this assessment is available via an online webmap (species distribution forecast maps). This collaborative approach allows the implications of climate change to be assessed across ownership types (e.g., public versus private lands) and jurisdictional boundaries (city, county, state, and federal). It is our hope that this report and accompanying supplemental information will stimulate and contribute to a vigorous and productive conversation among conservation planners and managers regarding the implications of climate change, and results in collaborative efforts to develop conservation, management, and monitoring strategies to address these changes and promote adaptation.

Study Area

Our study area includes over 5.5 million acres of coastal and interior southwestern California including most of San Diego and Orange Counties, plus western Riverside, southeastern Los Angeles, southwestern San Bernardino, and western Imperial counties (Figure 1). The complex terrain of coastal southern California provides steep environmental gradients that delineate well-described ecological zones, from coastal plains and foothills to mountains of the peninsular range to desert slopes (Figure 2; Grinnell 1917a). Most of the study area falls within the California South Coast Ecoregion, one of the most biodiverse ecoregions in North America (Olson and Dinerstein 2002) and a global biodiversity hotspot representing a Mediterranean biome (Underwood et al. 2009). The remainder of the study area falls within the western Sonoran Desert Ecoregion, which is strikingly diverse in its own right, and which contains a biota that is almost entirely distinct from that of the South Coast Ecoregion. The study area is also home to a large human population that continues to grow rapidly (Mackun and Wilson 2011). The convergence of the high biodiversity and habitat loss as a result of intense human use and ongoing development also has created a hotspot here for threatened and endangered species (Stein et al. 2000, Dobson et al. 2007).

Figure 1: Study Area

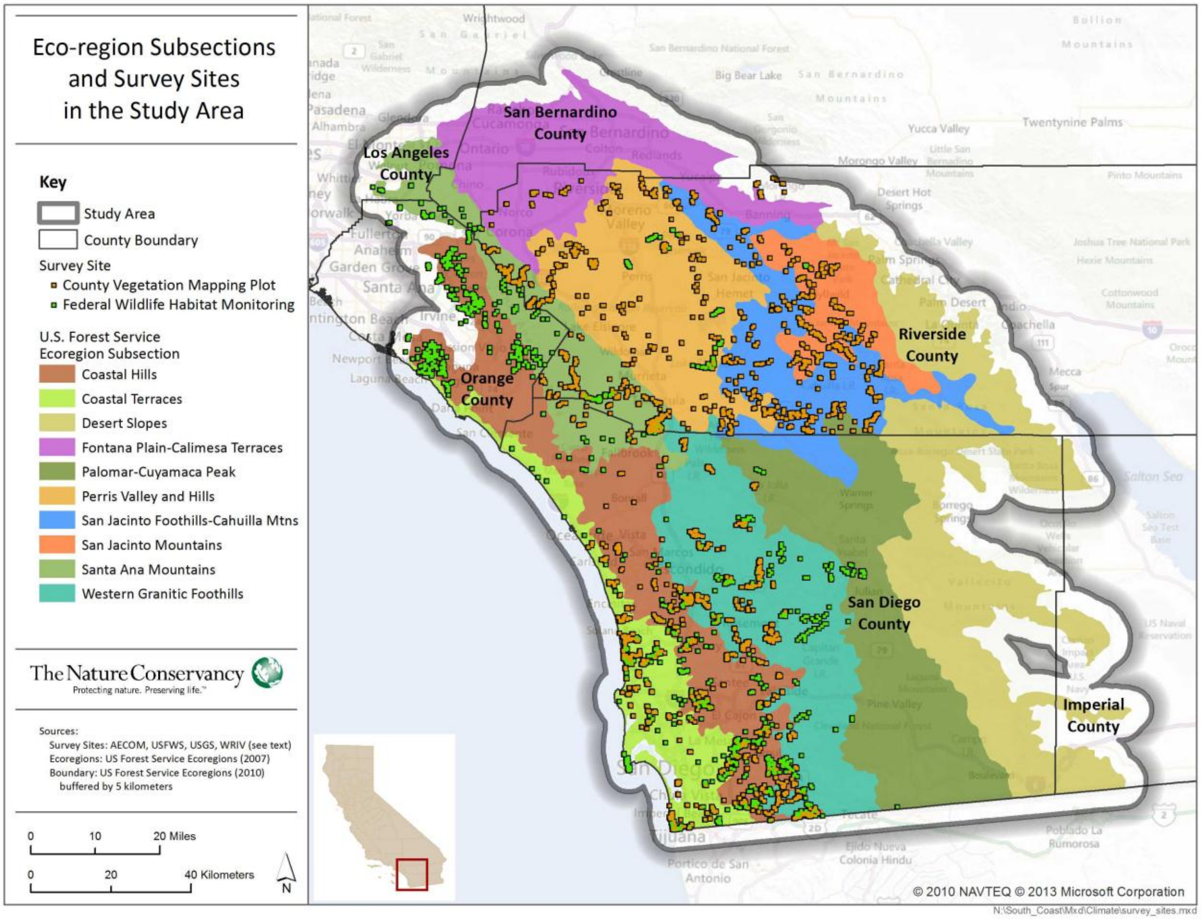


Conservation Context**.** Our study area has been the focus of much regional conservation planning under the state of California's Natural Communities Conservation Planning (NCCP) and the federal government's Habitat Conservation Plan programs which are overseen by the California Department of Fish & Wildlife (DFW) and the US Fish & Wildlife Service (USFWS) (Figure 3). Under these programs, local jurisdictions with approved plans are granted permitting authority for development, in exchange for commitments to secure specified conservation goals. Conserved lands within the NCCP/HCP areas may fall under many different types of ownerships (e.g., local, state, federal, tribal, and private) and a mosaic of existing management plans.

In San Diego County, there are four key land management plans which are at varying stages of planning, approval or implementation (Figure 3). The Multiple Species Conservation Program (MSCP) in southwestern San Diego County includes the cities of San Diego, Chula Vista, Poway, plus San Diego County. Each of these jurisdictions has its own permit, but lands from all of them contribute to the MSCP reserve network. The Multiple Habitat Conservation Program (MHCP) is comprised of several cities in north San Diego County. The MSCP North is a County-of-San Diego-only plan; and the County of

San Diego also eventually intends to develop an east county plan, the Multiple Species Conservation and Open Space Program (MSCOSP).

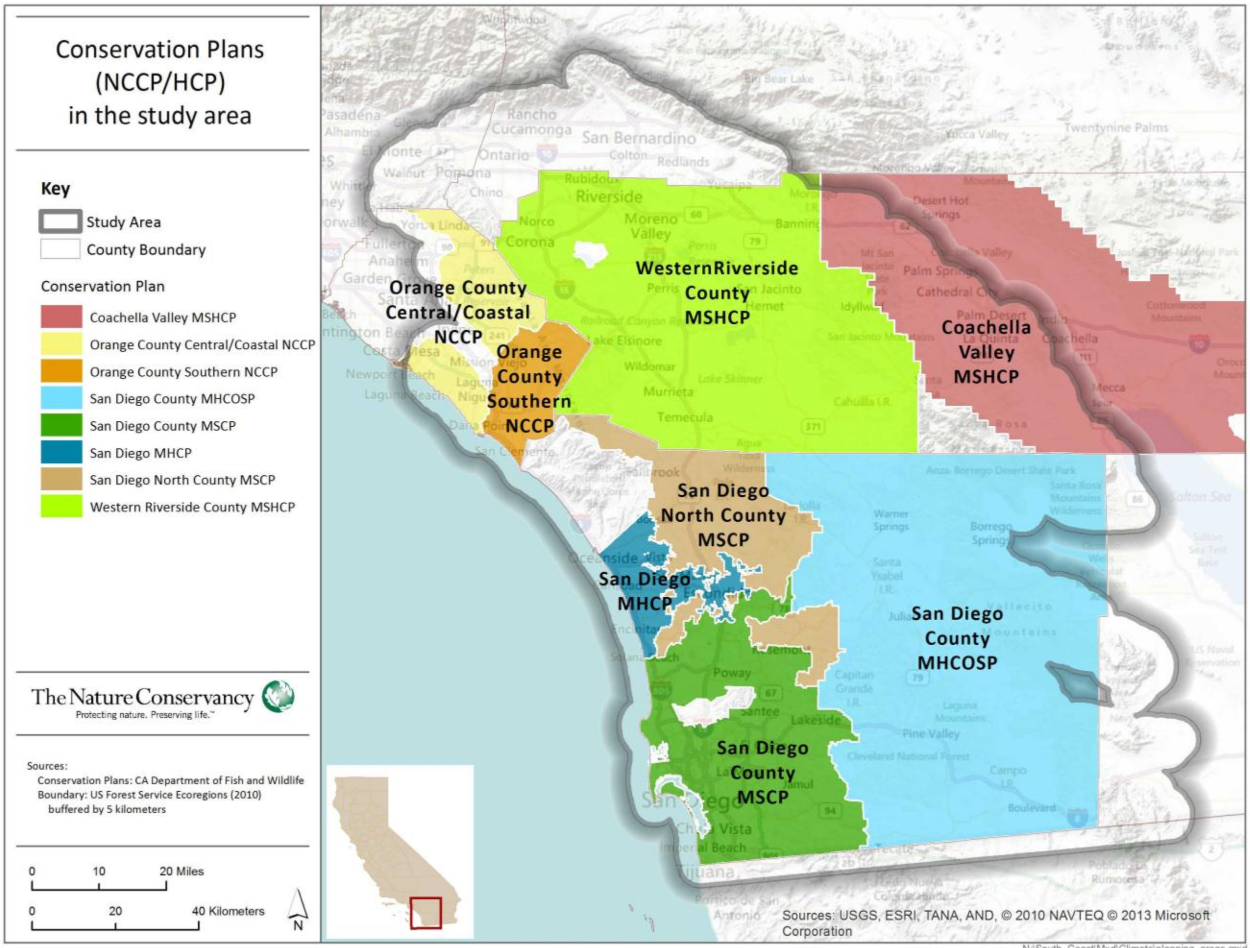
Figure 2: U.S. Forest Service ecoregion sub-sections and locations of species presence-absence survey sites for datasets used in this study



The San Diego Association of Governments (SANDAG) helps to fund management and monitoring efforts, and coordinates data sharing from all active NCCP/HCPs in San Diego County. The San Diego Management and Monitoring Program (SDMMP) is currently developing a Management Strategic Plan (MSP) to identify region-wide management and monitoring priorities and approaches. Concurrently, San Diego State University's (SDSU) Institute for Ecological Monitoring and Management (IEMM) is developing a framework management plan template for the region's preserve managers.

The Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP) (Figure 3) is administered by Riverside County's Regional Conservation Agency (RCA). It is responsible for coordinating reserve budgets and overall management and developing the annual monitoring approach for the reserve lands. Lands in western Riverside County owned by other agencies and non-profit conservation organizations are generally managed independently of the RCA, but collaboration occurs at many levels on management and monitoring. The Western Riverside MSHCP Biological Monitoring Program monitors the 146 covered species throughout the plan area on MSHCP reserve lands and other lands that are formally recognized as protected under the MSHCP. The approved conservation reserve design in the Western Riverside MSHCP is comprised of extant conserved lands plus a grid overlay on currently un-conserved lands, with conservation criteria defined for each grid cell. Land development in a cell would be permitted only to the extent it is consistent with meeting the conservation criteria for that cell.

Figure 3: Natural Community Conservation Plans and Habitat Conservation Plans in the study area



The Nature Reserve of Orange County (NROC) is the non-profit entity that has been established to implement the 38,000 acre Coastal-Central Orange County NCCP (Figure 3). NROC is responsible for designing and implementing reserve-wide programs for monitoring and managing target and covered species under the NCCP, and facilitates coordinated management actions amongst a dozen participating land owner/managers.

Methods

Mid-21st Century climate scenarios

For future climate projections, we prepared 11 downscaled mid-21st century A2 scenarios based upon the International Panel on Climate Change's (IPCC) global climate models (GCMs; also referred to as general circulation models). Methods for downscaling GCM projections, and the specific IPCC climate models considered are described in detail in Klausmeyer et al (2011). Here we downscaled by generating climate projections for a grid of 30,789 cells, each measuring 860m x 860m, that together covered the entire study area. We used the A2 scenarios because they more closely track current emission trajectories (IPCC, 2007). We focused on mid-century (50 year) forecasts, as opposed to end-of-century (~100 year) climate projections, because these are more applicable to typical management planning cycles (i.e., 3-5 years). This assessment uses consensus-based approaches, i.e., ensembles, to summarize multiple future scenarios by treating all potential futures as equally likely. The advantage of consensus-based ensemble forecasts is that they are expected to provide more robust projections (Araujo et al. 2005; Marmion et al. 2009; Grenouillet et al. 2010; Heikkinen et al. 2011).

Species distribution models (SDM)

Background

Species Distribution Models (SDMs) use statistical methods (algorithms) to describe how species relate to their environment. In other words, SDMs use site-specific climate and environmental variables as well as species location data to identify a species climate envelope (~ecological niche). Incidentally, the theory underlying these models was developed from field observations made nearly a century ago of the California thrasher (*Toxostoma redivivum*), a bird common to coastal southern CA, (Grinnell 1917b). SDMs can be inferred from a wide variety of statistical algorithms, but all methods rely upon inputs of species observations (e.g., presence-absence or presence-only data) plus associated environmental attributes (e.g., climate, soil, terrain, hydrology). Once the relationship between a species and its environment is defined (i.e., the "niche model"), suitable areas can be projected across space or in time, assuming the appropriate GIS layers are available. Assumptions built into SDMs that may not be met and therefore limit the applications of SDMs, include 1) species are in equilibrium with their environments (i.e., all suitable areas are occupied), 2) no biotic interactions limit species distributions (such as competition, predation, and disease), 3) there is no dispersal limitation.

Species Occurrence Data

We used four large presence-absence datasets with presence-absence information on a total of 106 plant species across the study area (see Figure 2 for survey plot locations). These datasets were originally collected for a variety of different objectives (e.g., vegetation mapping, wildlife habitat monitoring). Two were collected for federal agency wildlife-habitat monitoring projects, one a set of herpetofauna transects by the United States Geological Survey (USGS) (Robert Fisher, *pers. comm*.), and the second for California gnatcatcher [*Polioptila californica*] surveys by the USFWS (Clark Winchell, *pers. comm*.). The other two datasets were collected for county-led fine-scale vegetation mapping projects which involved federal, state and county agency, university, non-profit conservation organization, and consulting firm partners. One was led by the San Diego County MSCP and a second was led by the Western Riverside County MSHCP. Together, these four datasets constitute the most comprehensive plant species presence-absence data available for the region. Contributors of presence-absence data included the US Geological Survey (USGS; Robert Fisher and Carlton Rochester), the US Fish & Wildlife Service (USFWS; Clark Winchell), the San Diego Management & Monitoring Program (SD MMP; Yvonne Moore), AECOM (Tom Oberbauer and Jonathan Dunn) and the Western Riverside County Multi Species Habitat Conservation Plan (WRIV MSHCP; Anne Klein, DFW).

In total, we included field observations from over 4500 locations (i.e., plots, transects, stands; Figure 2). Species codes and coordinate systems used in the different datasets had to be standardized to enable direct comparison and integration and so were all converted to USDA codes. To map points and review species coverage, all point coordinates were standardized to NAD83 CA Teale Albers. As noted above, our climate model was based on a grid of 860m x 860m cells, and was thus of coarser resolution than our species occurrence data. Therefore, when there were multiple observations for a single species within one grid cell we combined them, creating a single presence-absence list for each grid cell in the study area.

We used these data for a purpose not foreseen when they were originally gathered, to generate species distribution models under the climate projected for the study area at mid-21st century. All of these species presence-absence data remain the intellectual property of the individual partner agencies and organizations that gathered and/or paid for their compilation, but may be available upon request to the owners.

Selection of species

A total of 106 plant species from a variety of plant taxa were selected for distributional modeling (Appendix 1), including a spikemoss and a fern, grasses, herbs, vines, shrubs, broadleaf/dicot trees, conifers, cacti and other succulents. Species were selected for modeling if they were identified as present in at least two of the presence/absence datasets, and represented by a minimum of 30 unique presences. Note that all of these plants are relatively common in the state and/or region, and none are listed as rare, threatened or endangered by the state or federal government. Six of the species we modeled are among the designated covered species for the Habitat Conservation Plans and Natural Community Conservation Plans within the study area, including tecate cypress, Nuttall's scrub oak, California scrub oak, Engelmann oak (Fig. 9), San Diego barrel cactus, and San Diego povertyweed (Appendix 1).

Selection of explanatory variables

Our SDMs consider a combination of climate and soil-water-storage attributes as explanatory variables for species distributions. To summarize extremes and seasonality of temperature and rainfall patterns, TNC derived bioclimatic variables from 800m Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate data (Daly et al. 2008). The PRISM data are derived largely as a function of topography; therefore we chose not to include additional terrain variables as predictors (e.g., slope, aspect, elevation, rugosity). From the full suite of available climate variables (n=19), only 7 climate layers that exhibit low levels of co-linearity (e.g., correlations < 0.8) were considered as model predictors, in order to simplify interpretation and to avoid problems associated with over-fitting (data not shown). The specific climate layers considered are: annual mean temperature (bio_1); isothermality (= mean diurnal temperature range / annual temperature range) (bio_2); temperature seasonality (= standard deviation * 100) (bio_4); maximum temperature of the warmest month (bio_5); annual precipitation (bio_12); precipitation of the driest month (bio_14); and, precipitation seasonality (= coefficient of variation) (bio_15). In addition, available water storage of soil at 150cm was downloaded and extracted from the Natural Resources Conservation Service's (NRCS) State Soil Geographic (STATSGO) database. Availability of more fine-scale layers from the Soil Survey Geographic (SSURGO) database were investigated, but unfortunately gaps in coverage across the study area prevented their use.

MaxEnt

All our SDMs were derived in R (Team 2011). Construction and evaluation of SDMs based upon the maximum entropy algorithm (Phillips et al. 2006)(version 3.3.k) were made possible using the package dismo (Hijmans et al. 2012) in R. MaxEnt has been shown to perform well at predicting species distributions for a wide range of taxa and biomes (Elith et al. 2006, Heikkinen et al. 2011). Dismo allows users to both build SDMs and test model performance. For each species, we performed 10-fold cross-validation runs, by creating 10 random partitions of presence and absence data to train models (i.e., to define species niches) and then test predictive skill (i.e., evaluate ability to recover *both* true presences and true absences) following the logic of Hijmans (2012). Current climate suitability was approximated by the mean of all 10 runs, in order to control for stochastic variation in surface predictions associated with random selection of presence absence data for testing or training purposes. Total numbers of presences and absences for each species are shown in the Supplemental Materials, as is the relative significance of explanatory variables for each species model (Supplemental Materials). Continuous logistic outputs (i.e., gridded suitability scores ranging from 0-1) for each species were converted to binary 0/1 scores (suitable versus unsuitable) using species-specific thresholds that maximized the recovery of both true positives and true negatives in testing data (Liu et al. 2005). All manipulation and analyses of grids (e.g., projections across space and time, construction of ensemble forecasts, gap analyses) were done using the Raster package (Hijmans and van Etten 2012). Models were evaluated using cross-validation and scores are reported as area under the receiver-operator curve (AUC) values. Results are presented for species with AUC values ≥ 0.7 except for three widespread species: chamise 0.682, coast live oak 0.680 and California buckwheat 0.582. Although lower than the standard 0.7, recent research has demonstrated AUC values are dependent on the type of data used and the distribution of the species. AUC values for models trained with survey based absence data, as was used in this study, have been shown to be lower than those trained by the more commonly used random or pseudo-absence data (Hijmans 2012). AUC values have been shown to be lower for widespread species than species with narrow ranges (Hijmans 2012).

Species distribution forecasts

Our species distributions forecasts are available as online map services for 106 plant species native to coastal southern California (species distribution forecast maps). For each species, we modeled the suitability of coastal southern California climates today, as well as response of each species to a total of 11 mid-21st century climate change scenarios. Our ensemble forecasts distinguished three potential future outcomes: climate refugia; climate stress; and climate expansion (depicted on our distribution forecast maps in green, red and purple, respectively). They also distinguished two levels of model consensus across the 11 future scenarios (high ≥80%, and moderate ≥60%), represented by color saturation (dark and light, respectively). Species forecasts in areas with low consensus (<60%) were mapped as uncertain (U; tan).

Note that we did not explicitly assess changes at the level of a vegetation community (e.g., "coastal sage scrub"). In addition, although we forecast species distributions for some coastal wetland and other near-shore dwelling species we did *not* project the effects of mid-21st century sea-level rise on loss of available habitat in the study area.

Maps of these forecasts (Figures 5-8; species distribution forecast maps) were specifically designed to help identify locations in which various species appear most resilient (i.e., climate refugia) or most at-risk to climate change (i.e., climate stress), as well as "new" sites that have potential to support the species in the future (through migration or translocation). We identified potential climate refugia as those areas where climate appears suitable *both* today and in the future. We identified areas as climate stress where species appear suitable today, but not suitable in the future. We identified expansion areas as those that appear to be unsuitable under current climate conditions, but suitable under future climate change scenarios. As far as we are aware, this is the first analysis that attempts to identify local climate change refugia (Barrows and Murphy-Mariscal 2012), climate stress areas, and expansion areas for southwestern California. Our ensembles intentionally treated all future scenarios as equally likely because we had no reason to believe any future IPCC climate scenario is more or less likely than the others for California (P. Duffy, Climate Central, *pers. comm*.). Individual scenarios used to create ensembles are available upon request.

Important Caveats and Limitations of our Species Distribution Projections

Due to data limitations, our assessment does not include information from species distributions that extend southward into Baja California (Mexico) or north of Orange County. Because the ranges of many of the species we assessed extend beyond the study area, we likely underestimated the environmental ranges and physiological tolerances of some species, and consequently may have underestimated their adaptive capacity to respond to the hotter and otherwise changed conditions projected by mid-century. We recognize the limitations inherent in climate change modeling, the use of selected data sets, and in projecting responses by species based solely on this information.

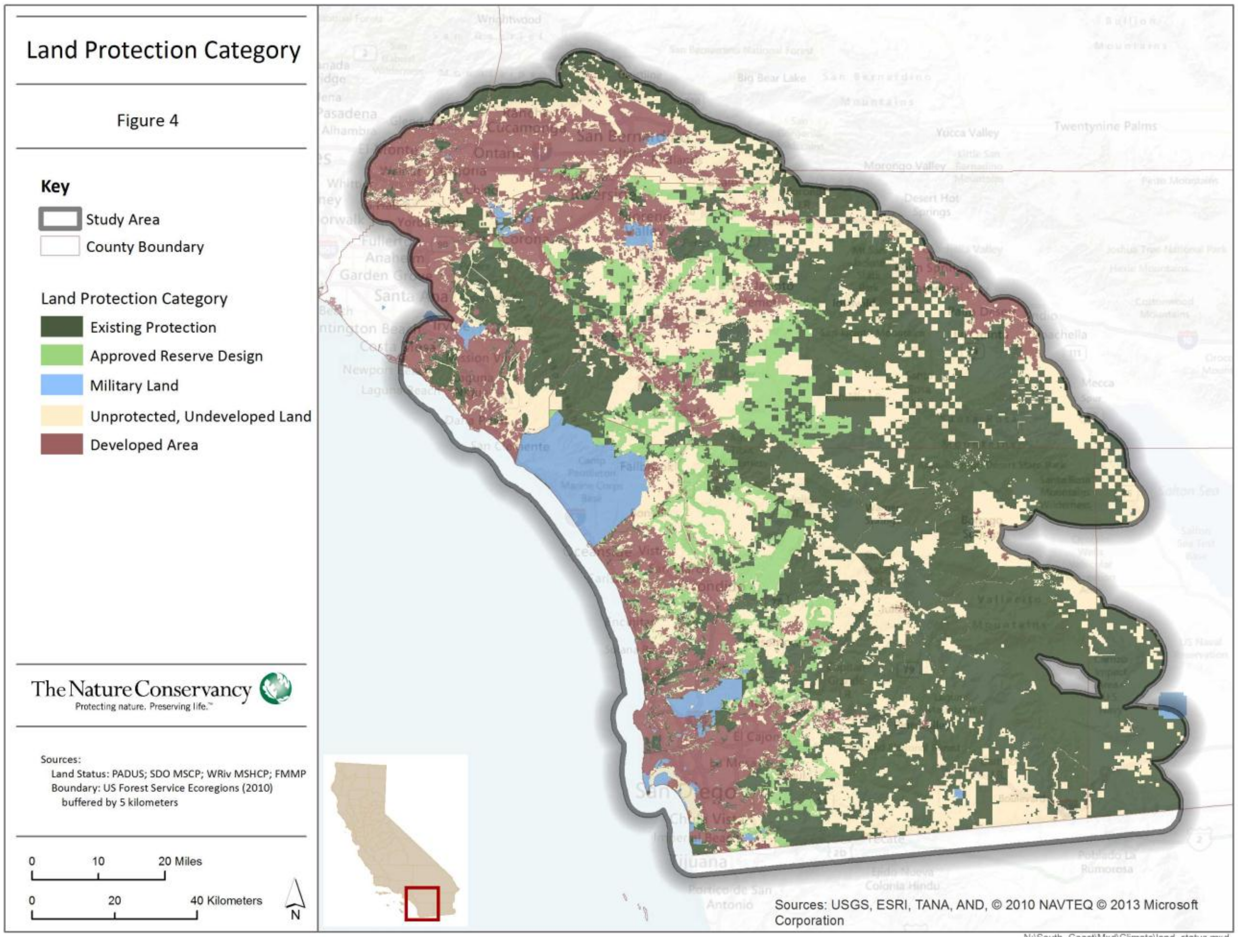
Gap Analysis

We used a gap analysis (Scott et al. 1993) to assess how well existing conservation areas, plus approved conservation reserve designs and habitat currently available on military lands within the study area may support the 106 plant species whose distributions we had forecast under mid-21st century conditions. For each species we quantified the area of its current habitat forecast to remain suitable under mid-21st century conditions (i.e. to serve as its climate refugia) on the following land use categories (Figure 4):

1. protected conservation lands (all lands classified GAP 1, 2 & 3);
2. lands in approved conservation reserve designs but not yet protected;
3. military lands;
4. other unprotected, undeveloped lands; and
5. developed lands.

We quantified the area of each species' current range that was projected to serve as climate refugia but which has already been developed and summarize this information in the results section, below. We otherwise excluded these developed areas from our other gap analysis calculations, however, since these areas already are, and will remain, unavailable as habitat. It is also important to note that our gap analysis does not address whether individual reserves are likely to meet specific requirements under species conservation permits.

Figure 4: Five categories of land use in the study area



We categorized protected lands using the Protected Areas Database of the United States (PAD-US) plus private lands protected by The Nature Conservancy using our U.S. Conservation Priority Area website. We classified all lands of GAP status 1, 2 & 3 as protected. Due to the format and the timing of release of available data we over-estimated existing protected lands in western Riverside County and underestimated the amount in Orange County. For western Riverside County we used the County's 'Habitat Conservation Summary' map (version April 2010) as an additional source of information on existing protected lands. MSHCP criteria cells containing >~30% existing protected lands were classified as completely protected. Note that this approach over-estimated the amount of existing protected lands in Riverside by roughly 5%. On the other hand, we underestimated the area of existed protected lands in Orange County by roughly 10% because we did not have access to the southern Orange County reserve design.

Developed areas were delineated using data from the state of California's Department of Conservation Farmland Monitoring and Mapping Program. Reserve designs for San Diego County were based upon the state's NCCP , whereas reserve designs for western Riverside County's MSHCP were based upon all criteria cells which were neither 'existing protected lands' nor 'developed areas '. The need for the different approach in the two counties is that San Diego planners excluded developed lands when defining future reserve design while in Riverside they did not exclude developed lands. In Orange County reserve design is defined and in the other counties in the analysis there are no future reserve designs defined. Military lands were defined by PAD-US. Unprotected lands represent all other areas within the project boundary that did not fall into categories 1-4 above.

Climate Impact Focus Areas

We tallied the number of species in each 860m x 860m grid cell of the study area for each potential future outcome category (climate refugia, stress area and expansion area). We then mapped the cells and clusters of cells projected to afford climate refugia, stress areas, or expansion areas, and considered those with relatively high numbers of species as perhaps warranting special attention for protection, management or monitoring. For example, portions of approved but not yet protected conservation reserve designs with cells or clusters of cells projected to afford climate refugia to relatively high numbers of species might be given high priority for protection. Likewise, areas that are already protected and which are projected to afford climate refugia or expansion areas to many species might be given greater attention for monitoring and active management.

Results

Climate Projections

Our climate projections agreed with those of most other climate models in projecting significantly increased temperatures by mid-century. This included increasing annual mean temperatures, maximum temperatures of the warmest month and greater inter-annual seasonal contrasts in temperature. Our projections for precipitation, however, were inconsistent and equivocal; some scenarios are wetter and others are drier than current conditions. Descriptive statistics for observed versus projected future values of all explanatory climate variables are available upon request. Fortunately, landscapes in our project area include significant spatial heterogeneity in environmental attributes, as well as steep environmental gradients, which are both expected to facilitate many species' adaptation to future changes in climate (Dobrowski 2010, Beier et al. 2011, Klausmeyer et al. 2011). For example, annual mean temperature now varies by nearly 20°C across the project area (2.97°C – 22.82°C), however the average projected increase in annual mean temperature, across all future scenarios and all grid cells is 2.24°C. Thus spatial variation in annual mean temperature today is nearly an order of magnitude more than projected temperature mid-21st century increases. Similarly, spatial variation in annual precipitation across the project area is nearly two orders of magnitude higher (74–1427mm) than the difference between observed (370mm) versus projected mean annual precipitation (317–414mm).

Species Distribution Forecasts

The percentage of the current range of each species that is projected to remain as suitable habitat under mid-century conditions (= climate refugia), when already developed (= urbanized) areas were excluded from the analysis, varied from a low of 0% (salty susan; *Jaumea carnosa*) to highs of 100%. Species predicted to have 99% or more of their current distribution in climate refugia (i.e., all of the their current ranges will remain suitable under mid-century climate conditions) come from a wide variety of taxonomic groups and growth forms including a fern (*Pentagramma triangularis*), annual dicot herb (e.g. *Daucus pusillus*) shrub *(e.g. Ceanothus oliganthus var. oliganthus*), tree (e.g. *Salix gooddingii*; Figure 5), and a long-lived woody vine (*Vitis girdiana;* Figure 6).
Overall our forecasts indicated that for most of the 106 plant species we assessed, a majority of their current distributions will serve as refugia under mid-century climate conditions (Figure 7). Roughly 38% were projected to have 90% or more of their current distributions in refugia, 55% with 75% or more in

refugia, and over 80% with 50% or more in refugia. Nearly 95% of species were predicted to have at least 33% of their current distributions in refugia.

In general, riparian and freshwater wetland species were predicted to fare relatively well under projected mid-century climate conditions. The species with the lowest percentage of its current distribution projected to remain suitable among this group was broom baccharis (*Baccharis sarothroides*), at 64%. Yerba mansa (*Anemopsis californica*) is predicted to have 92% of its current distribution in refugia. Black willow (*Salix gooddingii*), desert wild grape (*Vitis girdiana*), and broad-leaved cattail (*Typha latifolia*) were predicted to fare particularly well with 99% of their current distributions in refugia.

On the other hand, two of the most widespread oak trees in the region were projected to fare poorly, with only 28% of the current distribution of coast live oak (*Quercus agrifolia;* Figure 8) projected to be in refugia and 46% of the current distribution of Engelmann oak (*Quercus engelmannii;* Figure 9) in refugia. Shrubs commonly associated with oak woodlands were projected to have a wide range of their current distributions in refugia with values of 35%, 63%, 79% and 99% for poison oak (*Toxicodendron diversilobum*), hollyleaf cherry (*Prunus ilicifolia*), hollyleaf redberry (*Rhamnus ilicifolia*) and chaparral currant (*Ribes malvaceum*), respectively.

Coastal sage scrub (CSS) shrub species were projected to have widely varying percentages of their current ranges in refugia under projected mid-century climate conditions and only a few were expected to fare well. The majority were projected to have less than 50% of their current climate envelope in refugia. Two species commonly associated with CSS were predicted to fare particularly poorly. California buckwheat (*Eriogonum fasciculatum* var*. fasciculatum*; Figure 10) and coastal sagebrush (*Artemisia californica*; Figure 11) were predicted to have only 13% and 22% of their current distributions in refugia, respectively. Four species, California encelia (*Encelia californica*), yellow bush penstemon (*Keckiella antirrhinoides*), bush monkey flower (*Mimulus aurantiacus*), and laurel sumac (*Malosma laurina*), were predicted to have between 40% and 50% of their current distributions in refugia. Four more were predicted to have 60% to 82% of their current distributions in refugia, black sage (*S. mellifera*), brittlebush (*Encelia farinosa*), Menzies' goldenbush (*Isocoma menziesii*) and sawtooth goldenbush (*Hazardia squarrosa*). None of the species commonly associated with CSS were predicted to have greater than 82% of their current range in refugia.

In contrast, shrubs associated with chaparral were generally projected to have large areas of their current distribution within refugia. One major exception to this pattern was for the species generally regarded as the most widespread and abundant shrub species in the region, chamise (*Adenostoma fasciculatum*), which was projected to only have 18% of its current distribution in refugia. A majority of other shrubs commonly associated with chaparral were projected to have 50% or more of their current distribution in refugia and over half of these species were projected to have over 75% of their distribution in refugia. The many species of ceanothus (*Ceanothus* spp.) and manzanita (*Arctostaphylos* spp.) found in the region were projected to have between 50% and 100% of their distributions in refugia. Scrub oak (*Quercus berberidifolia*) was projected to have 75% of its current distribution in refugia.

Explanatory variables for species distribution models

The most important explanatory (bioclimatic) variable influencing species distributions was temperature seasonality which accounted for an average of 35% of the explained variability across the species modeled. Temperature seasonality is a measure of seasonal variation in temperature based on mean monthly temperatures. All future scenarios predict an increase in temperature seasonality indicating greater differences between monthly average temperatures for the coolest months and the warmest months in the future. Interestingly the other three temperature variables explained relatively little of the variability for most of the modeled species. On the other hand, all precipitation measures included in the models were marginally important in determining species forecasts for most species, including measures of annual totals, precipitation of the driest month, and precipitation seasonality. Soil available water storage (at 150 cm) was also important in determining species forecasts.

Impacts of development on potential refugia

We excluded areas that are already developed from our calculations of area of the refugia, stress areas and expansion areas for each species. However, to assess whether and how urbanization has limited options for these plants, we calculated the area that could serve as suitable habitat under mid-century climate that has already been urbanized. We classified 18% of the study area as already developed. Urban development is already extensive along the coast, particularly in and around the City of San Diego and in Orange County west of the Santa Ana Mountains, but it is currently less extensive in inland areas. As a result, species with maritime and coastal distributions have lost greater proportions of their potential habitats, and greater proportions of the areas we project could have otherwise provide suitable habitat (i.e. served as refugia) for them under mid-century climate conditions. Species of this type include salty susan (*Jaumea carnosa*), alkali-heath (*Frankenia salina*), alkali weed (*Cressa truxillensis*), spineshrub (*Adolphia californica*), California encelia (*Encelia californica*) and Nuttall's scrub oak (*Quercus dumosa*) with loses of 100%, 59%, 57%, 55%, 52%, and 40%, of their projected refugia to existing development, respectively. On the other hand, inland species such as cup-leaf ceanothus (*Ceanothus greggii* var. *perplexans*; Figure 12), buckbrush (*Ceanothus cuneatus* var. *cuneatus*), interior live oak (*Quercus wislizenii*), beavertail cactus (*Opuntia basilaris* var. *basilaris*), red shank (*Adenostoma sparsifolium*) and point-leaf manzanita (*Arctostaphylos pungens*) have lost only 2% or less of their projected climate refugia to development so far. Similar losses of projected refugia to urban development amount to less than 2% for Engelmann oak (*Quercus engelmannii*), big-berry manzanita (*Arctostaphylos glauca*), thick-leaf ceanothus (*Ceanothus crassifolius*), and scrub oak (*Quercus berberidifolia*). Nonetheless, because urbanization has spread inland in some areas, other species distributed more widely throughout the study area have also lost large percentages of the land that we projected could have otherwise served as climate refugia. These include bladderpod (*Isomeris arborea,* synonym *Peritoma arborea*), coast prickly-pear (*Opuntia littoralis*; Figure 13), salt grass (*Distichlis spicata*), and broom baccharis (*Baccharis sarothroides*) with 49%, 45%, 44% and 44% loss of climate refugia to urban development, respectively. Impacts from existing development on the climate refugia of other widespread species vary greatly with ladies' fingers (*Dudleya edulis*), coastal sagebrush (*Artemisia californica*), black sage (*Salvia mellifera*), brittlebush (*Encelia farinosa*), and rigid fiddleneck (*Amsinckia menziesii*) experiencing 36%, 30%, 21%, 13%, and 9% loss, respectively.

Gap Analysis

Protection of refugia in existing conservation lands

In order to examine what the future may hold, we calculated the percentage of projected climate refugia for each species which is on lands already protected for conservation in the study area. We found that the existing network of protected areas (as of 2012) contained 50% or more of the projected climate refugia for 43% of the species we assessed (Table 1; Figures 14 and 15). However, this included some species whose refugia are just of small fraction of their current distribution. Indeed, we found that just 35% of the species we assessed have both 50% or more of their current distribution in refugia *and* 50% or more of their refugia in protected areas, meaning that at least 25% of their current distribution is already protected *and* projected to remain as suitable habitat for them (Table 2). Likewise, only 28% of the species we assessed have 75% or more of their current distribution in refugia and 50% or more of their refugia protected. Just 16% have 90% or more of their current range in refugia and 50% or more of their refugia protected (Table 2). Note that our use of the 50%, 75% and 90% values is arbitrary and does not to imply that these are ecologically meaningful thresholds or that surpassing them would or would not ensure a species long-term persistence.

Protection of refugia in existing conservation lands + approved conservation reserve designs

When we added all lands included in approved conservation reserve designs (i.e., priority areas for future protection) to the existing protected areas, the percentage of species with ≥50% of their refugia protected increased to 93% (Table 1). Note that most of the reserve designs call for the protection of specific portions of the land within the reserve design, not 100% of it. Therefore, adding <u>all</u> lands included within the approved conservation reserve designs as we did for this analysis likely overestimates the actual areas within the reserve designs that will ultimately be protected.

Protection of refugia in existing conservation lands + approved conservation reserve designs + military lands

Military lands also contain large areas that are undisturbed or lightly disturbed, currently serve as habitat for native species, and were projected to be refugia for many of the species we assessed. If these areas remain undeveloped and undisturbed the outlook for many species would further improve. Existing protected areas, approved reserve designs, and military lands contain ≥50% of refugia for 99% of the species we assessed (105 of 106 species; Table 1; Figures 14 and 15).

These results indicate that protecting all lands within the approved conservation reserve designs in the study area might allow most of the species we assessed to adapt to projected mid-century climate conditions, particularly if landscape-scale connectivity across important gradients is built in and the reserve is appropriately managed. If in addition to that, a majority of military lands now available as habitat remains suitable through mid-century, the outlook for native plant species will be further improved. Under this scenario, 83% of species would have both 50% or more of their current distribution in refugia and 50% or more of their refugia on these lands (Tables 1 and 2, Figures 14 and 15). This would mean that 87 species would have at least 25% of their projected suitable habitat available at mid-century, 50 more than if only existing protected lands were available at that time. Fifty four percent of species would have 75% or more of their distribution in refugia and 50% or more of their refugia on these lands. Thirty eight percent of species would have 90% or more of their distribution in refugia with 50% or more of the refugia on these lands. For this 38% of the species, this would result in an average increase of 54% in suitable habitat available at mid-century relative to the situation if only lands protected as of 2013 were available.

In fact, continued protection of existing conservation lands plus protection of all lands in the the approved reserve designs in San Diego and Western Riverside Counties or the continued protection of habitat currently present on military lands would ensure that 50% or more of the area of projected climate refugia under mid-century conditions would be available for a large majority of the 106 plant species that we assessed (Table 1).

Unfortunately, as noted above, our results over-estimate the size of the future reserves. Due to the uncertainty in the configuration of the final reserve designs we assumed that 100% of the Western Riverside MSHCP's criteria cells and San Diego North County MSCP Pre Approved Mitigation Areas (PAMAs) would be protected. However, actual goals for protection range from 5-95% within individual MSHCP criteria cells. The goal for protection within the MSCP PAMA is roughly 60%. Similarly, it is unlikely that all military lands in the study area currently serving as native species habitat will remain undeveloped and free of major disturbance by mid-century. Therefore, careful consideration must be given to the spatial design of the future reserves and to land use changes on military lands that could limit amounts of habitat available for many native species or sever linkages between available habitats that would otherwise allow those species to move to areas with appropriate conditions as the climate changes.

Table 1: Percentages of species assessed with >50% of their projected climate refugia available on different combinations of land use types.

Land Protection Category	Percent
Protected	43
Protected + Military	91
Protected + Approved Plans	93
Protected + Approved Plans + Military	99

Table 2: Percentages of the 106 species with ≥50% of their current range in refugia and 50%, 75% and 90% of their projected refugia on different combinations of land-use types. This equates to least 25%, 37.5% and 45% of their current distribution occurring on lands that are projected to remain suitable habitat and to be protected under three different scenarios.

	Percentage of a species current range projected to be climate refugia at mid-21st century		
Land Protection Category	**≥50%**	**≥75%**	**≥90%**
Protected	35%	28%	16%
Protected + Military	77%	50%	34%
Protected + Approved Plans	78%	54%	38%
Protected+ Approved Plans + Military	83%	54%	38%

Climate Impact Focus Areas

Our tallies of species afforded climate refugia in given grid cells of our study area were generally higher than tallies for climate stress areas or expansion areas. The highest number of species that were projected to be afforded refugia in a single grid cell was 82. Meanwhile, the highest number projected to find expansion areas in a single grid cell was 33 and the highest number projected to find climate stress areas in a single grid cell was just 14.

We mapped those cells containing refugia for 53 or more of the 106 species assessed (≥50%) and found that some were isolated, single cells while others formed a large, nearly continuous band from Highway 91 in the vicinity of Prado Dam where Orange, Riverside and San Bernardino Counties meet in the north and south to the US-Mexico border where it stretches west-east from the San Ysidro Mountains in the west to east of Tecate (Figure 16). Across the entire study area these sites were concentrated in foothill and coastal zones. In the northern portion of the study area, they were generally found west of Interstate 15 in the Santa Ana Mountains and on to the northern two-thirds of Marine Corps Base Camp Pendleton, including its' coastal lands. In San Diego County these areas were generally found west of a line running from Campo in the south, through Alpine, Eagle Peak, Mount Gower, Lake Sutherland, Rodriguez Mountain, Pauma Valley and the Agua Tibia Wilderness in the north. The northern reaches of the San Diego County climate refugia were linked to the Santa Ana Mountains by a band of cells that run east-west along the San Diego-Riverside County (i.e. the Santa Ana Range to Palomar Mountains linkage).

Clusters of grid cells projected to provide climate refugia for at least two thirds of the species assessed (>66%; >70 species) were most common in San Diego County where they were present on portions of the San Ysidro Mountains and Tecate Mountains near the international border, the Jamul Mountains and San Miguel Mountain east of the Sweetwater Reservoir, Iron Mountain and Mount Woodson east of Poway, Black Mountain north of Los Penasquitos Canyon, the lands around Lake Hodges, the hills north of the San Pasqual Valley, Escondido Creek near Harmony Grove, Double Peak of San Marcos, the Merriam Mountains near Gopher Canyon, the Pala Creek-Heriot Mountain area north of the Pala Indian Reservation, the Sandia Creek/Santa Margarita River confluence northwest of Fallbrook, and San Onofre Mountain on Marine Base Camp Pendleton. The Los Alamos Creek-San Mateo Canyon area of the Santa Ana Mountain west of Wildomar was the only large concentration of cells in Riverside County. In Orange County there is a small concentration of cells in the Santa Ana Mountains in the vicinity of San Juan Canyon (State Route 74) and the San Juan campground.

The mean elevation of sites projected to afford climate refugia to at least half of the species assessed was 344m (1,130 feet). The mean distance to the Pacific Ocean for these sites was 7.1 km (4.4 miles). The Pacific has a widely reported and recognized moderating effect on temperatures and soil moisture of coastal lands so distance from the coast may be an important determinant in climate stability. While there was no clear pattern of numbers of species projected to find refuge in grid cells with respect to elevation the number of species projected to find refuge in cells was inversely related to distance from the coast. On the other hand, although maximum tallies were much lower for numbers of species projected to find expansion areas in a given grid cell, we found that size of these tallies were positively related to the cell's elevation and that there was no clear pattern with respect to a cell's distance to the Pacific Ocean. We also found no clear patterns in the distribution of cells and the number of species projected to be stressed in them under mid-century conditions.

Caveats for interpreting species forecasts

- Management responses should be based on multiple lines of evidence, not solely species forecasts from a single exercise such as this assessment.
- For some species, incorporation of presence-absence data from Baja California, where populations may be adapted to hotter and drier conditions, could result in significantly reduced modeled climate risks than those suggested here
- Inclusion of fine-scale explanatory variables (~100m resolution) in future modeling studies should identify microrefugia where species may persist despite changes in climate
- Impacts associated with future land use scenarios, species interactions, and wildfires are not considered herein.
- While this study projected distributions for some coastal wetland and strand species it did *not* address sea-level change.

Figure 5: Mid-21st century species distribution forecast for Gooddings willow (*Salix gooddingii*). Over 99% of its current range in the study area was projected to remain suitable habitat (i.e. serve as climate refugia). In general, riparian species like Gooddings willow were predicted to fare relatively well under projected mid-century climate conditions. Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

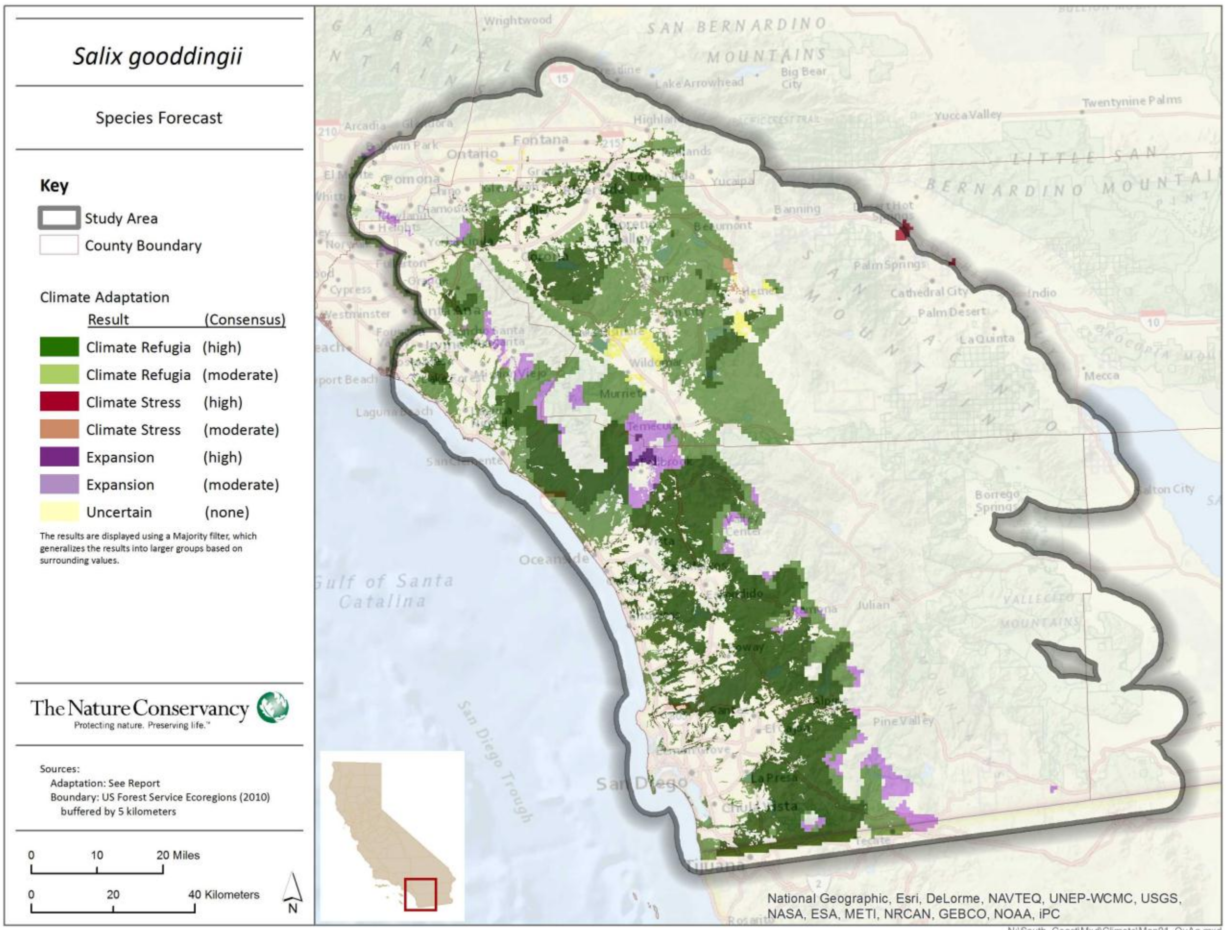


Figure 6: Mid-21st century species distribution forecast for desert wild grape (*Vitis girdiana*). Over 99% of this species current range in the study area was projected to remain suitable habitat (i.e. serve as climate refugia). Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

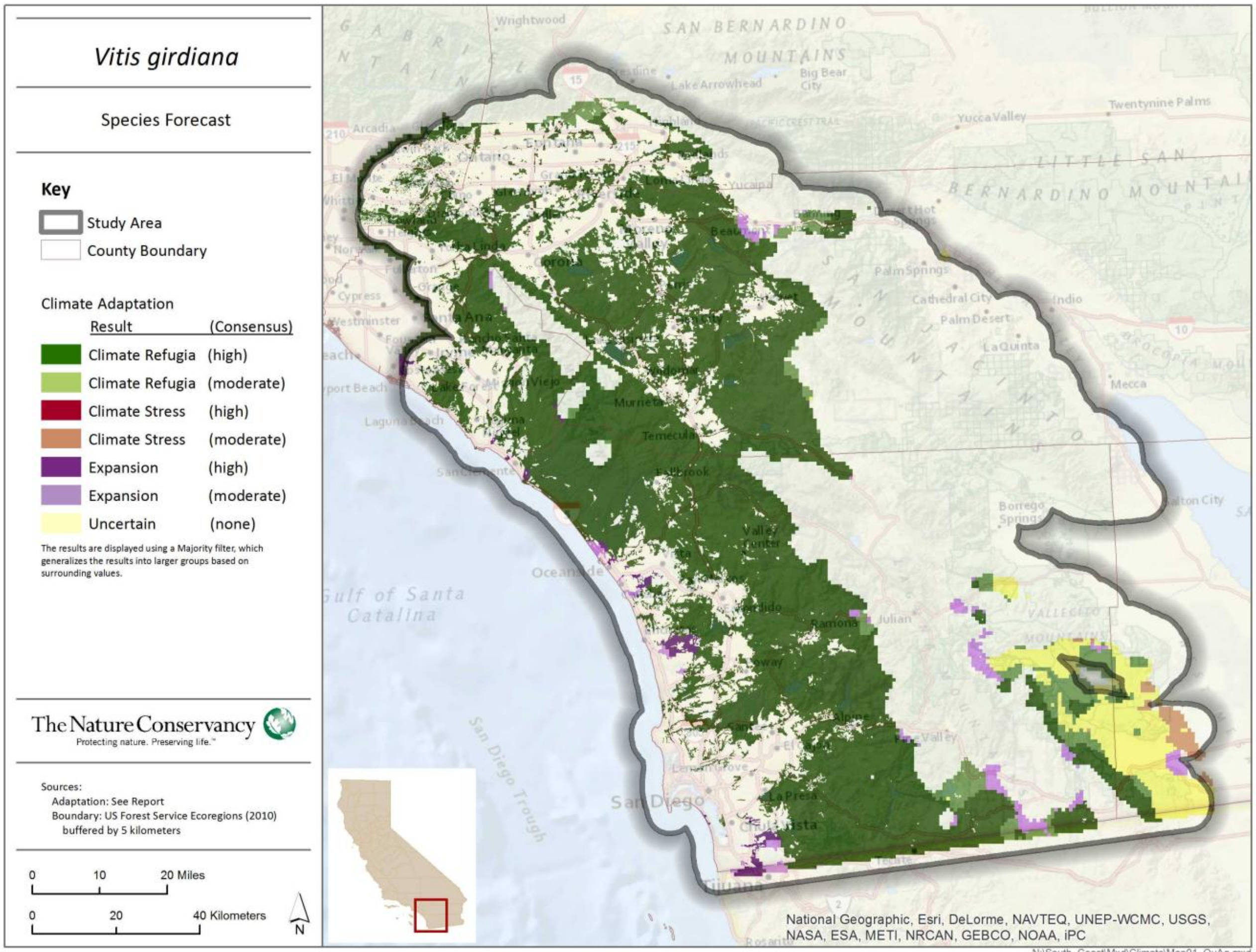


Figure 7: Percentage of the 106 species assessed vs the percentage of their current range projected to remain suitable (i.e., to serve as climate refugia) under mid-21st century climate conditions. The x-axis is the percentage of the 106 plant species modeled and the y-axis is the percentage of the current range of a species predicted to remain suitable habitat for that species under at mid-century. The graph is read on a continuum, with roughly 6% of the species having 100% of their current ranges in refugia (extreme left) and just one of the species assessed having none (0%) of its current range in refugia (extreme right).

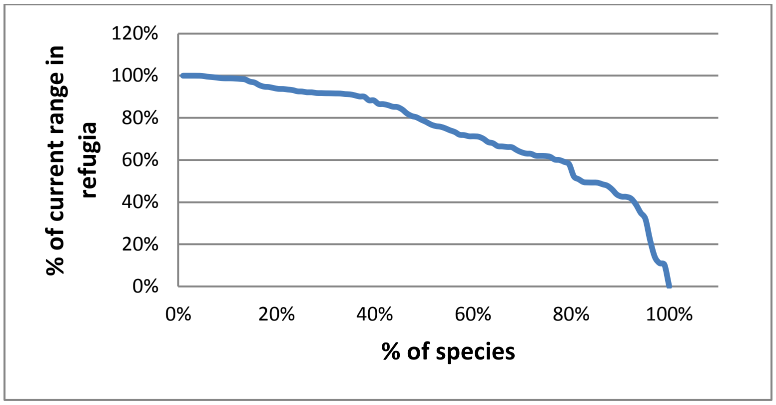


Figure 8: Mid-21st century species distribution forecast for coast live oak (*Quercus agrifolia*). Just 28% of this species current range in the study area was projected to serve as climate refugia (i.e. remain suitable habitat). Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

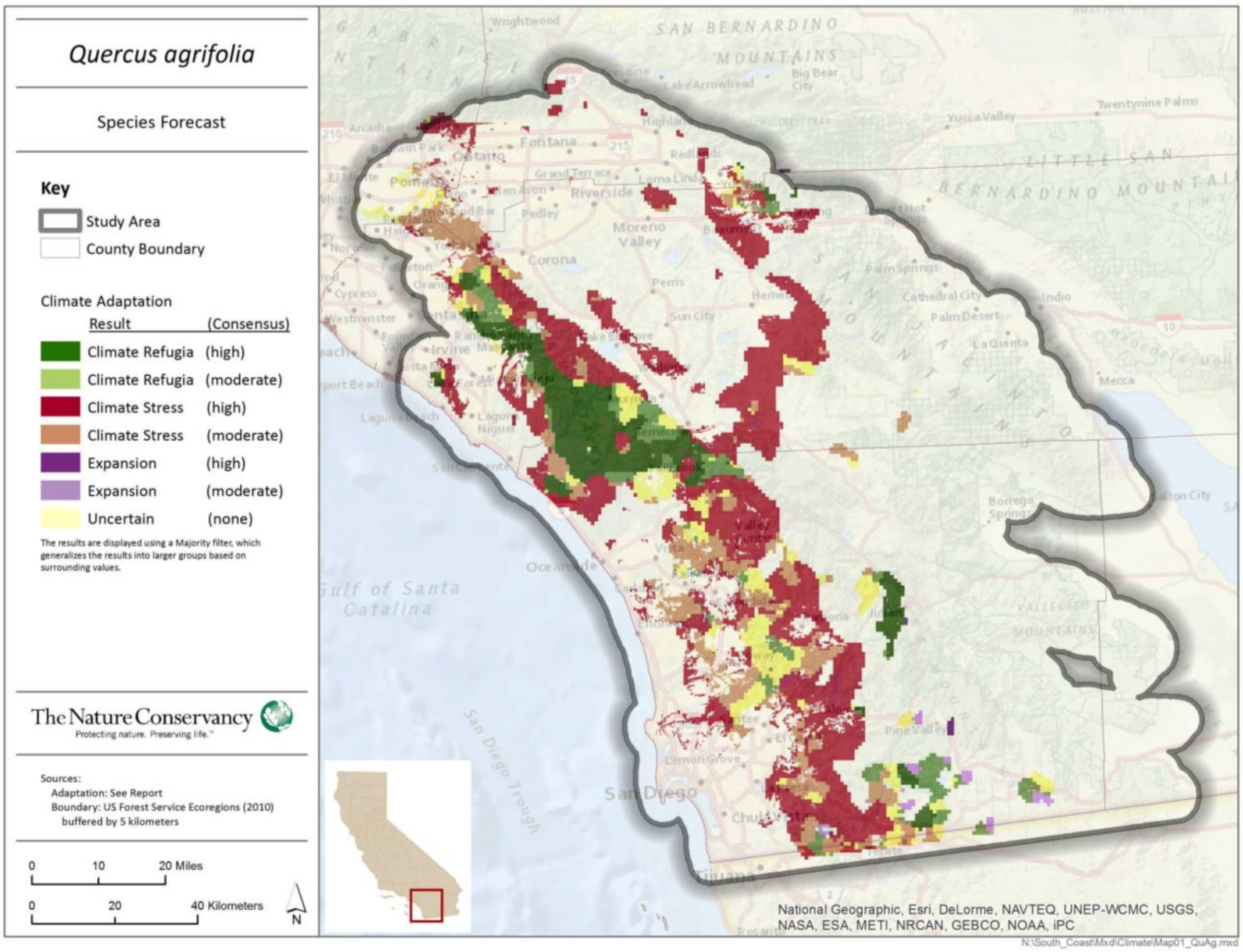


Figure 9: Mid-21st century species distribution forecast for Engelmann oak (*Quercus engelmannii*). Just 46% of this species current range in the study area was projected to serve as climate refugia (i.e. remain suitable habitat). Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

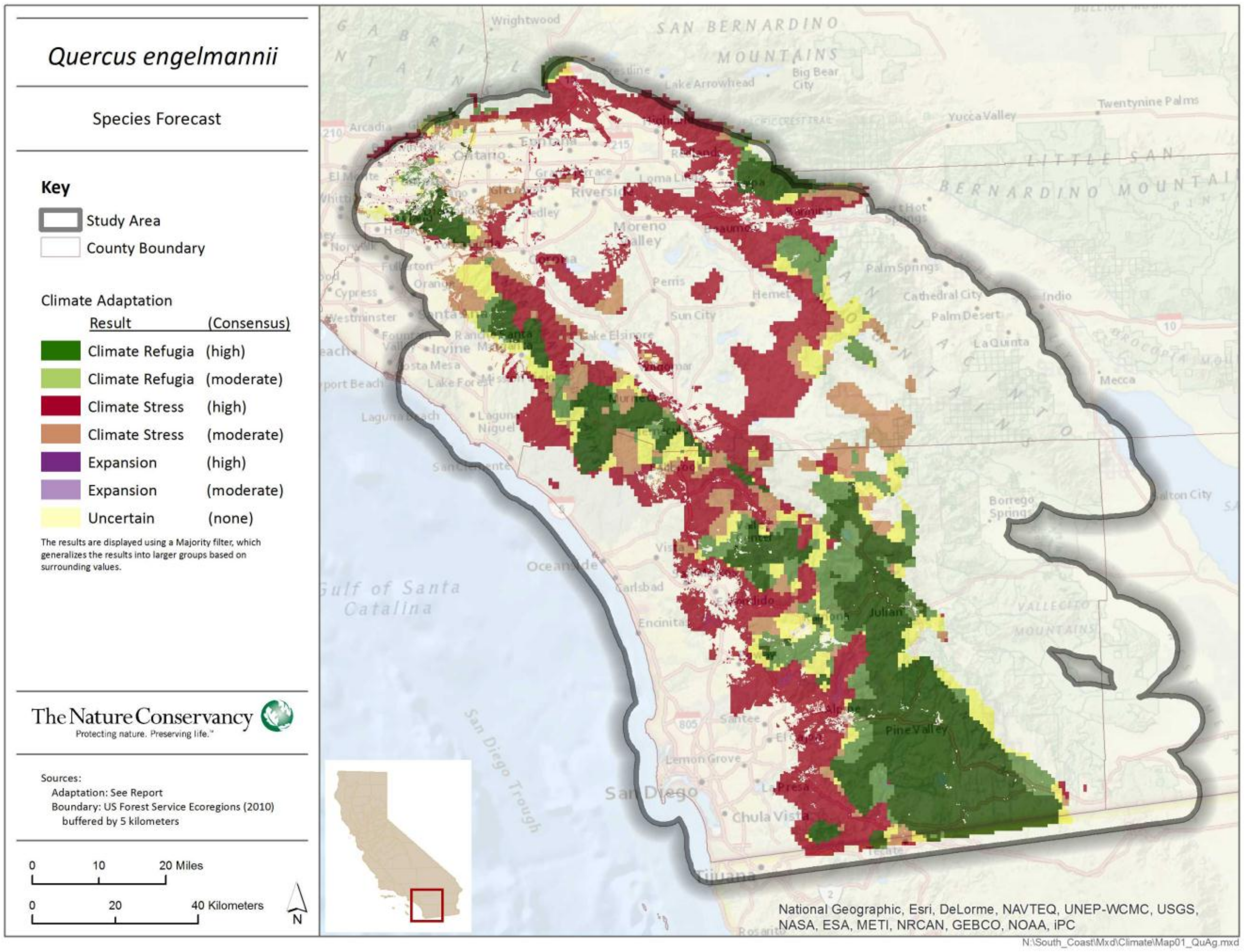


Figure10: Mid-21st century species distribution forecast for coastal California buckwheat (*Eriogonum fasciculatum* var. *fasciculatum*). This is one of the most abundant shrubs in coastal sage scrub vegetation today, but just 13% of its current range in the study area was projected to serve as climate refugia (i.e. remain suitable habitat) by mid-century. Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

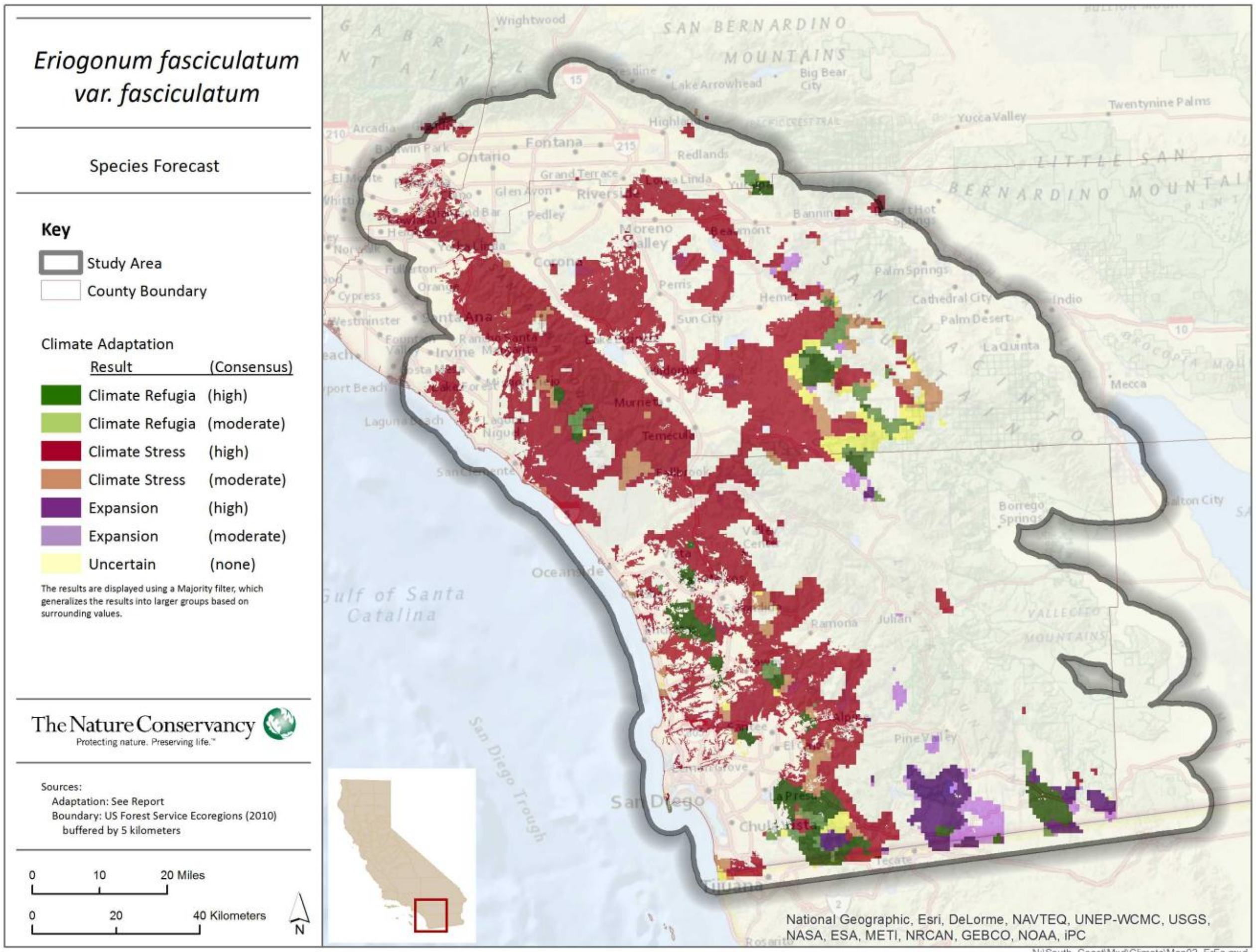


Figure 11: Mid-21st century species distribution forecast for coastal sagebrush (*Artemisia californica*). This is one of the most abundant shrubs in coastal sage scrub vegetation today, but just 22% of its current range in the study area was projected to serve as climate refugia (i.e. remain suitable habitat) by mid-century. Forecasts distinguish three projected future outcomes: climate refugia; climate stress; and expansion (green, red and purple, respectively). High (≥80%) and medium (≥60%) levels of consensus across all future scenarios are indicated by saturation (dark and light, respectively).

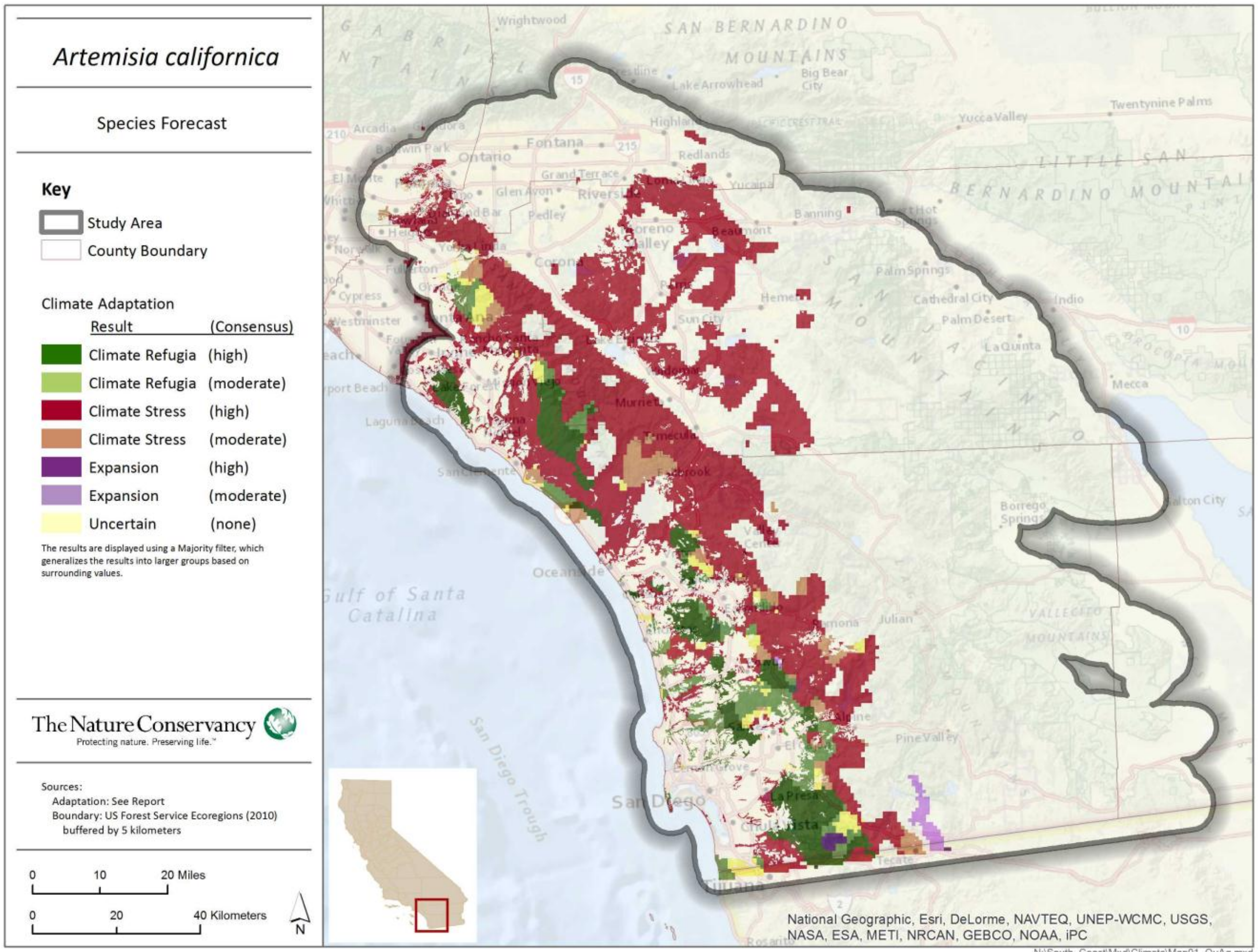


Figure 12: Mid-21st century species distribution forecast for cup-leaf ceanothus (*Ceanothus greggii*) highlighting the low percentage of its potential climate refugia (≥ 2%) that has already been lost to development. Cup-leaf ceanothus is typical of species with distributions that are restricted to inland areas to the east of most developed areas in this region.

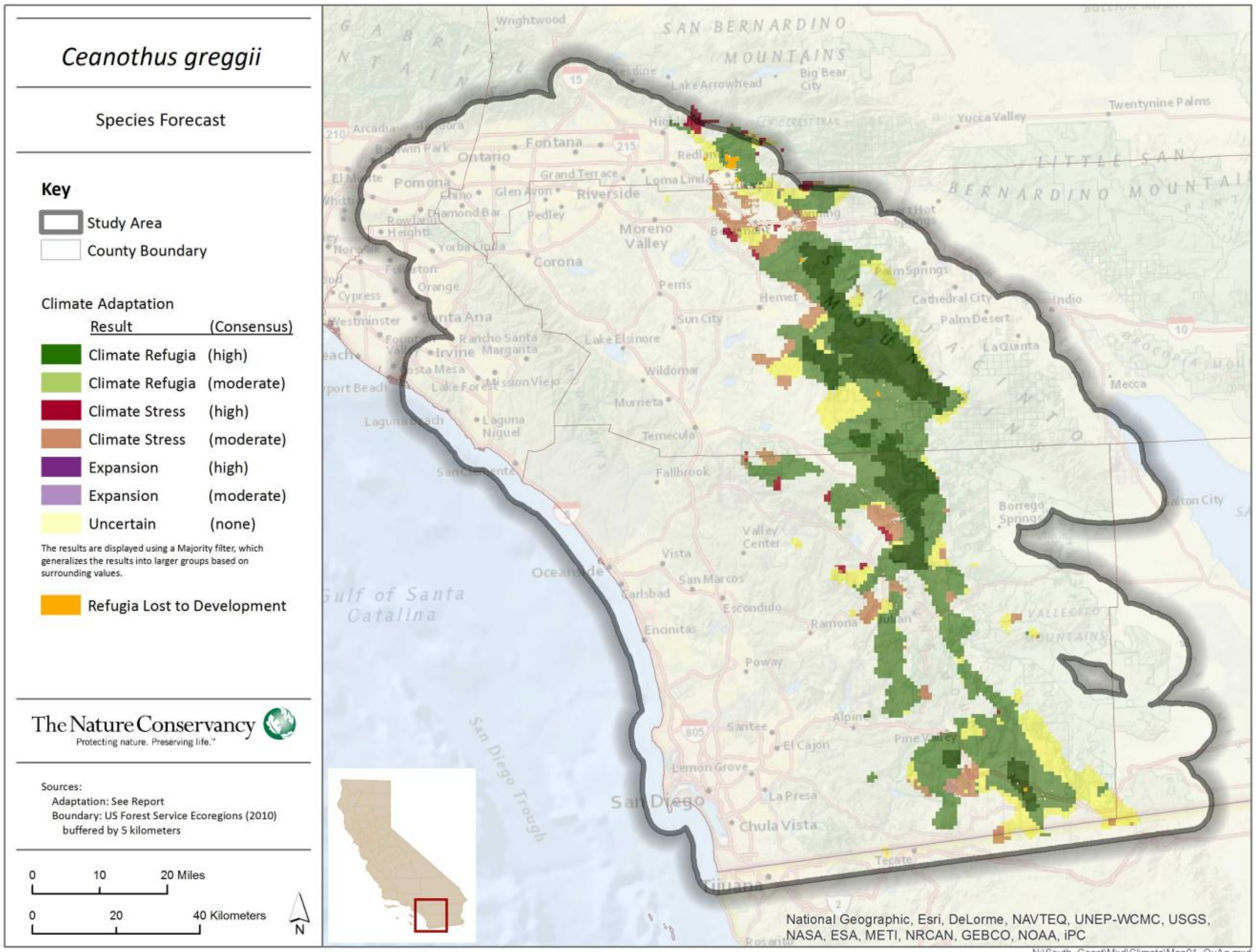


Figure 13: Mid-21st century species distribution forecast for coast prickly-pear (*Opuntia littoralis*), highlighting the percentage of its potential climate refugia already lost to development (45%). Coast prickly-pear is typical of species with near coastal distributions which coincide with the areas of greatest development in this region.

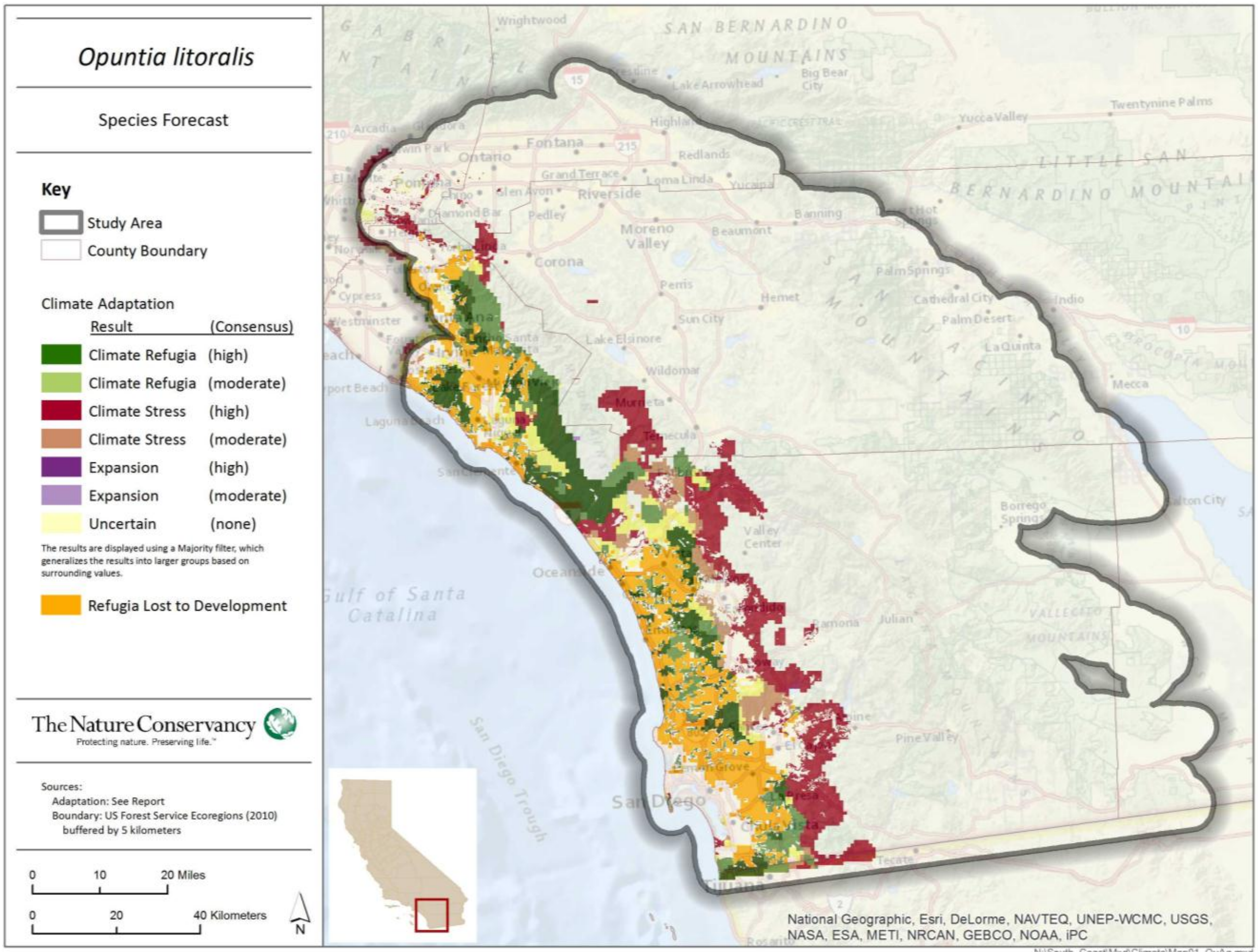


Figure 14: Percentages of each species current range projected to serve as climate refugia vs the percentage of the area of each species refugia area protected within three different combinations of land use categories. Light grey diamonds represent refugia projected to be available on existing protected lands, dark grey squares represent refugia available on existing protected lands plus approved reserve design lands, and black circles represent refugia afforded on existing protected lands, plus approved reserve design, plus military lands

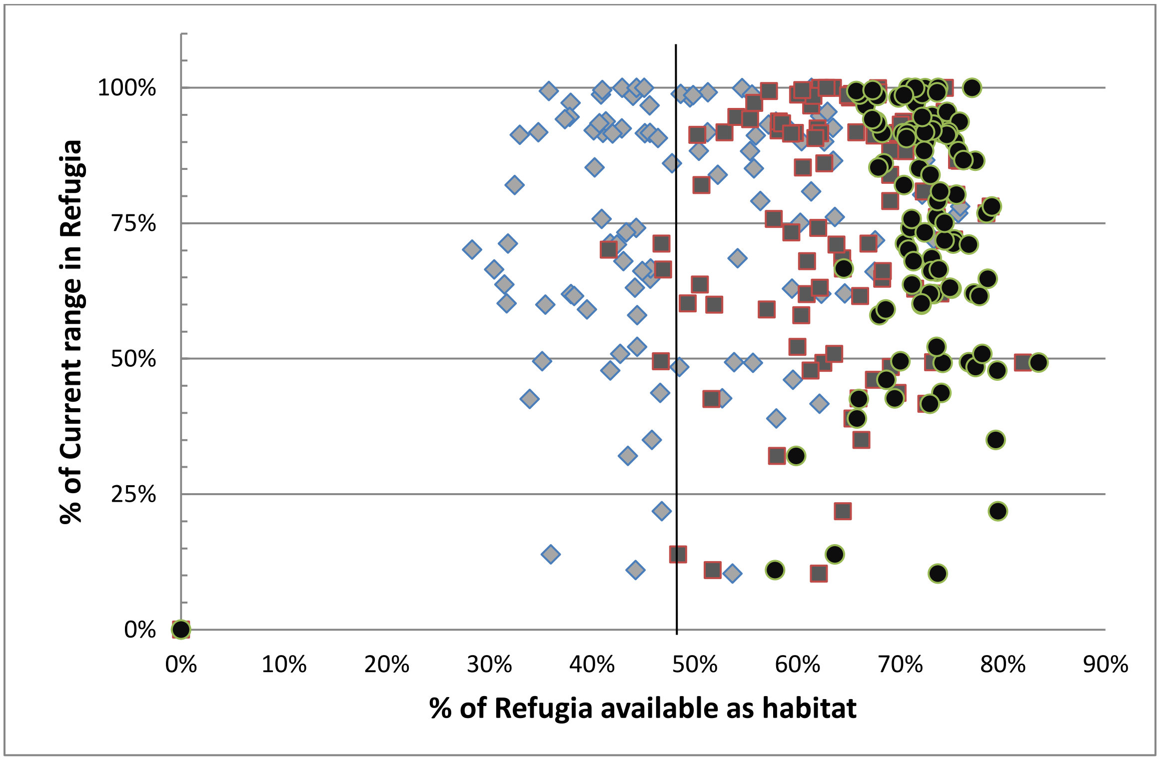


Figure 15: GAP analysis of projected plant species climate refugia

This chart shows the percentages of each species projected climate refugia which fell into four of the land use categories we used in the gap analysis:

1. Protected conservation lands, shown in green;
2. Lands in approved conservation reserve designs but not yet protected lands, shown in red;
3. Military lands, shown in yellow; and
4. Other unprotected, undeveloped lands, shown in grey.

Developed lands were not included as they are, and will not be, available as habitat in the future.

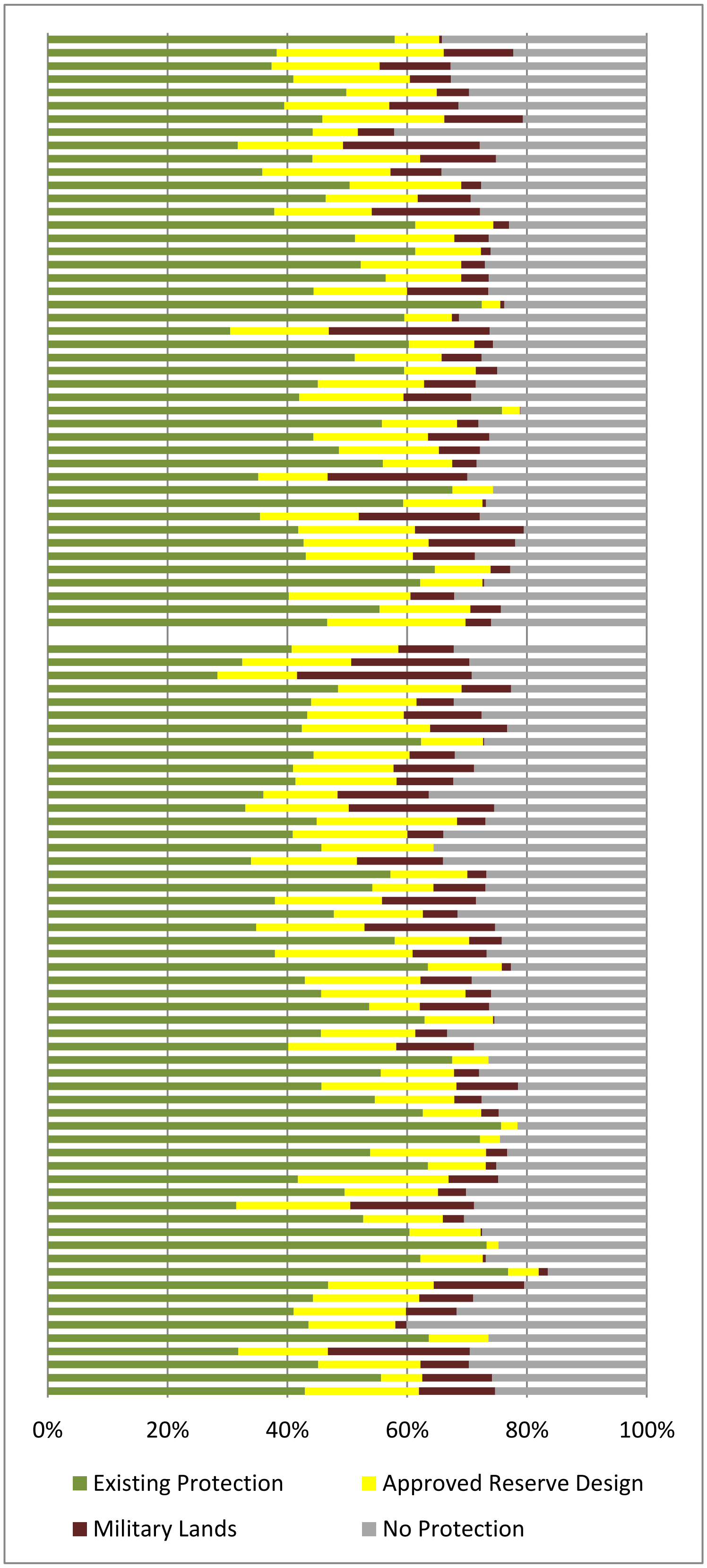
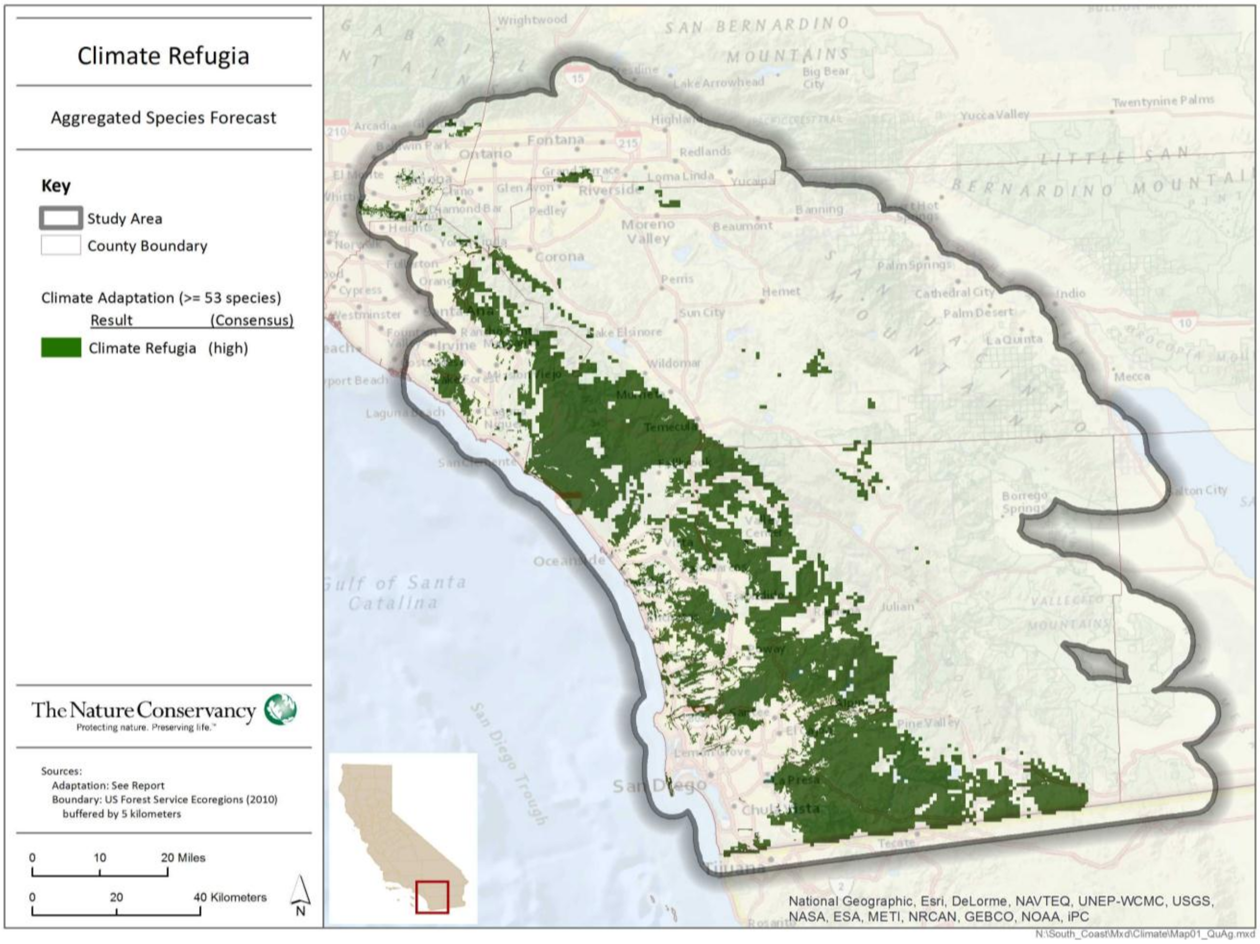


Figure 16: Sites projected to serve as climate refugia for at least half of the plant specie assessed ($\geq$ 53 species) under mid-21st century conditions.



Recommendations

The forecasts of distributions of 106 relatively common plant species under modeled mid-21st century climate scenarios for southwestern California presented in this document can be tested against observations in the field. This may refute or confirm the forecasts and the models they are based on, and/or point to the need for additional monitoring, observations and experiments needed to refine future models. We recommend that these forecasts be used as just one of many tools to predict and prepare for the effects of climate change and to guide the development of strategies and actions to facilitate adaptation by native species and systems. Additional lines of evidence worth considering include landscape-based metrics of climate vulnerability (Ackerly et al. 2010, Beier et al. 2011, Klausmeyer et al. 2011).

We hope this report helps inspire and inform dialogue among conservation planners and managers about the potential implications of climate change for biodiversity conservation that leads to the development of appropriate strategies, management plans and monitoring programs. These forecasts along with other information could be applied toward a variety of land protection and management challenges in the study area, including:

Identifying priorities for protection of core protected areas and linkages to facilitate movement between them. This could involve assessing the size and location of projected species ranges, characterizing the types of habitat or assistance species will need to move to expansion areas, identifying significant impediments to their movement between existing or planned reserves, specifying core areas and linkages that would need to be protected to enable species to move to expansion areas, and identifying species and populations that may need to be translocated to expansion areas (new sites; see below). Most or all of these efforts will require cooperation and active collaboration among groups including local, state and federal agencies, non-profit organizations, and academic researchers.

Evaluating and adaptively modifying monitoring programs to best assess whether and how well species are reacting and adapting to climate change. This may involve monitoring species now regarded as common and facing few threats if they are forecast to suffer significant range contractions or shifts (Regan et al. 2008). Sampling designs for monitoring might also be modified based on these forecasts. For example, field surveys might be stratified to include both forecast stress areas (suitable for the species now, but projected to be unsuitable in the future) and refugia. Assessments of mortality and recruitment rates for long-lived plant species, could likewise serve to both ground-truth forecast results and guide future management actions. The forecasts and preliminary monitoring data could also be used to guide the selection of threshold measures above or below which management actions would be triggered.

Developing land and water management strategies and actions to promote survival of viable populations of vulnerable native species and to facilitate their adaptation to changed conditions. Such actions might, for example, involve protecting vulnerable populations from wildfires which may become more frequent and severe as temperatures rise and soil moisture drops, or planting out species in gaps between existing populations to provide greater likelihood of re-colonization following major disturbances and greater resilience of the population overall. Identification and development of appropriate and effective management approaches needs more attention. One way to approach this would be to convene collaborative workshops and other cooperative efforts among conservation planners and managers from across Southwestern California and beyond.

Assessing whether and how translocation can be used to assure the survival of viable populations of species deemed unlikely to be able to move to appropriate sites on their own. This approach is in particular need of more conceptual and experimental development. Our forecasts could be used to help identify species most appropriate for translocation and the most appropriate sites for these moves. As just one example of the many possibilities, San Diego marsh elder (Iva hayesina) might be a candidate for translocation to disjunct currently unoccupied marshes and drainages, particularly if climate change and accompanying sea level rise (not considered in our assessment) drive it from significant portions of its current habitat. We caution that translocations should be carefully weighed by people with expertise in the physiological tolerances of the species under consideration and their interactions with other species, as well as conservation planners and managers with expertise in the ecology of the candidate donor and translocation sites.

Convening a collaborative, region-wide climate change dialogue to identify conservation protection, management and monitoring priorities using a combination of our species distribution forecasts, and other relevant climate, land use and species distribution **projections.** For example, our forecasts could be used as inputs in population viability models that are designed to evaluate best management practices (Hierl et al. 2007, Keith et al. 2008).

Working with military planners to ensure that much of the military land now available as natural habitat remains available through mid-century could contribute significantly to the core areas and important linkages that will allow native species in the region to adapt to climate change.

Fully implementing the approved HCP/NCCP reserve designs in San Diego, and western Riverside counties and securing the linkages incorporated in these designs will help native species move from areas that are currently suitable for their growth and reproduction to areas that will become suitable for them as the climate changes. Great progress has been made in protecting large areas of core habitat across southwestern California through NCCP/HCP programs but those plans have not yet been fully realized. Completing reserve designs as identified in the San Diego MSCP/MHCP and western Riverside MSHCP is imperative to ensuring the conservation of landscapes that span and link broad ecological gradients and allow natural processes to function. Indeed, completing these reserve designs represents our best hope to proactively enhance the resilience of the region's native species populations and natural communities to the effects of global climate change.

Acknowledgements

This assessment was made possible by generous contributions of time, data and insights from conservation partners throughout coastal southern California. Species forecasts contained within are dependent upon extensive field surveys of vegetation and associated wildlife by organizations overseeing a wide range of local (SDMMP, WRIV, SANDAG) and regional (DFW, USFWS) conservation objectives. This report leverages existing presence-absence data from fine-scale vegetation mapping and wildlife surveys to assess potential climate impacts for existing conserved lands. We hope hypotheses constructed from this modeling exercise begin to help 'put a face' on potential climate impacts for land managers in the region.

Robert Fisher (USGS) and Carlton Rochester (USGS) provided all presence-absence data considered for reptiles and amphibians, as well as ancillary vegetation data for three southern counties. Clark Winchell (USFWS) provided all presence-absence data for the California gnatcatcher, as well as ancillary vegetation data for three southern counties. Tom Oberbauer (AECOM) provided field insights on soil-plant distributions, county-level range limits for plant species, as well as feedback on the feasibility of managed relocation options for rare endemic gabbro and meta-volcanic plant communities. Jonathan Dunn (AECOM) provided presence-absence data for plant species in San Diego County. Yvonne Moore (SDMMP) and Elise Watson (USFWS) helped identify a wide range of relevant conservation partners and data sets in the region. Brian Anacker (UC-Davis) and Robert Hijmans (UC-Davis) provided assistance with scripting to run Maxent models, evaluations and projections using presence-absence data with the dismo package and Java GUI for R (JGR). Juan Parra (Universidad de Antioquia, Colombia) provided advice on variable selection and model evaluation with presence-absence data. Brynn Taylor (TNC) facilitated Jason MacKenzie's working overseas during the completion of this assessment. Devin Kuttiamkonath (TNC), Katie Andrews (TNC), Ben Chau (TNC) and Matt Merrifield (TNC) helped set up remote access to TNC hardware, software and data for analysis, modeling and mapping. Kirk Klausmeyer (TNC) contributed downscaled future climate scenarios, and Sophie Parker (TNC) provided advice on soil factors to consider as explanatory variables for vegetation models. Janet Franklin (Arizona State University) and Helen Regan (UC-Riverside) and Jeffrey Evans (TNC) provided very useful feedback and practical insights into SDM parameters and ensemble summaries. David Smith (NRCS), Ed Tallyn (NRCS) and Tammy Cheever (NRCS) helped identify and extract STATSGO soil variables for modeling (e.g., soil type, available water storage). Josh Madin (Macquarie University) provided computer hardware for running SDMs and Maina Joseph (Macquarie University) helped establish remote access. Kristine Preston (SDMMP) provided insightful and constructive comments on the manuscript.

Appendix I: Species whose distributions were modeled for this assessment

Scientific name	Common name	Covered Species
Achillea millefolium	Yarrow	
Acmispon strigosus	Deerweed	
Acourtia microcephala	Sacapellote	
Adenostoma fasciculatum	Chamise	
Adenostoma sparsifolium	Red shank (ribbon wood)	
Adolphia californica	Spineshrub (California adolphia)	
Amsinckia menziesii	Ridge fiddleneck	
Anemopsis californica	Yerba mansa	
Antirrhinum nuttallianum	Nuttall's snapdragon	
Arctostaphylos glandulosa ssp glandulosa	Eastwood manzanita	
Arctostaphylos glauca	Bigberry manzanita	
Arctostaphylos pungens	Mexican manzanita	
Artemisia californica	California (coastal) sagebrush	
Artemisia tridentata	Big sagebrush	
Atriplex canescens	Four-wing saltbush	
Baccharis sarothroides	Broom baccharis	
Bebbia juncea var aspera	Sweetbush	
Calystegia macrostegia	Morning glory	
Ceanothus crassifolius var crassifolius	Hoaryleaf ceanothys	
Ceanothus cuneatus var cuneatus	Buckbrush	
Ceanothus greggii	Cup-leaved ceanothus	
Ceanothus leucodermis	Chaparral whitethorn	
Ceanothus oliganthus var oliganthus	Hairy lilac	
Ceanothus tomentosus	Ramona lilac	
Cercocarpus betuloides var betuloides	Mountain mahogany	
Chaenactis artemisiifolia	White pincushion	
Claytonia parviflora	Streambank springbeauty	
Cneoridium dumosum	Bushrue	
Cressa truxillensis	Alkali weed	
Croton californicus	California croton	
Cryptantha muricata	Prickly-nut cryptantha	
Daucus pusillus	Wild carrot (rattlesnake weed)	
Dendromecon rigida	Bush poppy	
Distichlis spicata	Salt grass	
Dryopteris arguta	California wood fern	
Dudleya edulis	Ladies' fingers	
Dudleya lanceolata	Lance-leaf dudleya	
Dudleya pulverulenta	Chalky dudleya (live-forever)	
Elymus glaucus ssp glaucus	Blue wild-rye	
Emmenanthe penduliflora var penduliflora	Whispering bells	
Encelia californica	California encelia	
Encelia farinosa	Brittlebush	
Eremocarpus (Croton) setigerus	Dove weed	
Eriogonum fasciculatum var fasciculatum	California buckwheat	
Eucrypta chrysanthemifolia	Common eucrypta	
Ferocactus viridescens	San Diego barrel cactus	NoSD, SDCity
Frankenia salina	Alkali heath (Yerba reuma)	
Gutierrezia californica	California matchweed	
Gutierrezia sarothrae	Broom snakeweed	
Hazardia squarrosa	Saw-toothed goldenbush	
Helianthemum scoparium	California rush (rock) rose	
Heliotropium curassavicum var oculatum	Alkali heliotrope	
Hesperocyparis forbesii (syn. Cupressus forbesii)	Tecate cypress	SoSD, Ce&CoOC
Heteromeles arbutifolia	Toyon	
Isocoma menziesii	Coastal goldenbush	
Iva hayesiana	San Diego povertyweed	NoSD

Jaumea carnosa	Salty susan (Fleshy jaumea)	
Keckiella antirrhinoides	Yellow bush snapdragon	
Keckiella cordifolia	Heartleaf keckiella (penstemon)	
Lasthenia californica ssp californica	California goldfields	
Lonicera subspicata	Southern honeysuckle	
Malacothamnus fasciculatus var fasciculatus	Bush mallow	
Malosma laurina	Laurel sumac	
Mimulus aurantiacus	Bush monkeyflower	
Nemophila menziesii	Baby blue eyes	
Opuntia basilaris var basilaris	Beavertail cactus	
Opuntia engelmannii var engelmannii	Engelmann prickly pear	
Opuntia littoralis	Coast prickly pear	
Paeonia californica	California peony	
Pentagramma triangularis	Gold back fern	
Peritoma arborea	Bladderpod	
Phacelia distans	Common phacelia	
Pinus coulteri	Coulter pine	
Plantago erecta	California (dotseed) plantain	
Porophyllum gracile	Odora (slender poreleaf)	
Prunus ilicifolia ssp ilicifolia	Holly-leafed cherry	
Pseudognaphalium biolettii	Bicolor cudweed	
Pseudognaphalium californicum	California everlasting	
Pterostegia drymarioides	Granny's hairnet (woodland threadstem)	
Quercus agrifolia	Coast live oak	
Quercus berberidifolia	California scrub oak	Ce&CoOC
Quercus dumosa	Nuttall's scrub oak	Ce&CoOC, NoSD
Quercus engelmannii	Engelmann oak	Ce&CoOC, NoSD, WRiv
Quercus wislizeni	Interior live oak	
Rhamnus crocea	Spiny redberry	
Rhamnus ilicifolia	Holly-leaf redberry	
Rhus ovata	Sugar bush	
Rhus trilobata	Skunk bush	
Ribes indecorum	White-flowered currant	
Ribes malvaceum	Chaparral currant	
Ribes speciosum	Fuchsia-flowered gooseberry	
Rubus ursinus	California blackberry	
Salix gooddingii	Black willow	
Salvia columbariae	Chia	
Salvia mellifera	Black sage	
Simmondsia chinensis	Jojoba	
Sisyrinchium bellum	Blue-eyed grass	
Stipa coronata	Giant needlegrass	
Stipa pulchra	Purple needlegrass	
Toxicodendron diversilobum	Poison oak	
Typha domingensis	Southern cattail	
Typha latifolia	Broadleaf cattail	
Vitis girdiana	Desert wild grape	
Xanthium strumarium	Cocklebur	
Xylococcus bicolor	Mission manzanita	
Yucca schidigera	Chaparral yucca	

Abbreviations in Covered Species Column indicate species is covered by:

Ce&CoOC = Central & Coastal Subregion Orange County NCCP-HCP
http://www.naturereserveoc.org/NCCP%20Parts%20I%20&%20II%20-%20Plan.pdf

NoSD = proposed North County San Diego MSCP
http://www.sdcounty.ca.gov/pds/mscp/docs/NCMSCP/North_County_Covered_Species.pdf

SoSD = San Diego South County MSCP https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=65736&inline=1

WRiv = Western Riverside County MSHCP http://www.rctlma.org/mshcp/volume1/sec2.html#table2.2

Appendix II: Abbreviations

CA	California
CPAD	CA Protected Areas Database
CWHR	CA Wildlife Habitat Relationship
DFW	CA Department of Fish and Wildlife
GCMs	Global Climate Models or General Circulation Models
IPCC	International Panel on Climate Change
MSCP	Multiple Species Conservation Plan
MSHCP	Multiple Species Habitat Conservation Plan
NPS	National Park Service
NCCP	Natural Communities Conservation Plan
NRCS	Natural Resources Conservation Service
OC	Orange County
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SD	San Diego
SANDAG	San Diego Association of Governments
SDMMP	San Diego Management and Monitoring Program
SSURGO	Soil Survey Geographic database
SC	South Coast
SDM	Species Distribution Model
STATSGO	State Soil Geographic database
TNC	The Nature Conservancy
USFWS	United States Fish and Wildlife Service
USFS	United State Forest Service
USGS	United States Geological Survey
USPAD	United States Protected Areas Database
WAP	Wildlife Action Plans
WRIV	Western Riverside County

Appendix III: Access to Supplemental Material

A copy of this internal TNC report and a zip file with Supplemental Materials is available at scienceforconservation.org. The Supplemental Materials include summary data on the relative influence of each climate and soil moisture variable on individual species distribution models, model evaluation scores (AUC values), a table listing total presences and absences in the climate model grid cells from the field data for each of the 106 plant species whose distribution we modeled and a table with acreages of climate refugia, stress areas, and expansions areas for each of the 106 species. Ensemble distribution forecasts maps for each of the 106 species can be visualized as map services here. Raster data for individual species models x scenarios, as well as ensemble forecast summaries are available upon request. Please direct general questions about this report *to* John Randall. Please direct specific questions relating to spatial modeling and analysis to Jason MacKenzie*;* data acquisition to Brian Cohen*.*

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