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Modeling the Impact of Climate and Anthropogenic Change on Birds and Vegetation on Military Lands in California

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Contents

Introduction

Global climate change is projected to have major impacts on the environment. These changes will alter the distributions of plant and animal species and affect the environment of military installations, potentially eroding their capacity to support the military mission and creating new challenges to the management of species and ecosystems. Climate change and anthropogenic effects on areas surrounding military installations may change land uses and increase the threat of encroachment. Managing installations to ensure the long-term sustainability of the military mission and the effectiveness of natural-resource management will require an understanding of what changes the future may hold.

Despite their uncertainties, models are the most effective way to peer into the future. Sophisticated species-distribution modeling algorithms (SDMs), in conjunction with downscaled future climate projections from global climate models (GCMs), have allowed ecologists to analyze how changes in climate and vegetation over the coming decades are likely to affect the distribution and occurrence of species (e.g., Loarie et al. 2008, Stralberg et al. 2009). Such model analyses indicate not only which species may be most vulnerable to climate change, but where the shifts in distribution and greatest changes in community composition are likely to occur.

Although climate models differ in their projections of whether areas in California are likely to become wetter or drier, they agree that temperatures in many parts of the state will become much hotter (Snyder and Sloan 2005, Cayan et al. 2008). In our previous work (Stralberg et al. 2009, Wiens et al. 2009) we used two GCMs coupled with two SDMs to predict changes by 2070 in the distributions of 60 focal landbird species across California at an 800-m scale of resolution. Our analyses indicated that distributions of many bird species are likely to undergo major shifts. Because species will respond to climate change independently of one another, the distributional shifts will differ among species, leading to “re-shuffling” of current bird assemblages and creating future combinations of co-occurring species that have no contemporary analogs anywhere in California. Some parts of the state will gain in overall species richness (as represented by the number of focal species predicted to occur in an area), whereas most areas will suffer losses in species richness.

Importantly, our projections indicated that reductions in occurrences of these representative bird species are likely to be much greater on lands administered by the Department of Defense (DoD) than for any other public land-ownership entity in California (Fig. 1). DoD lands in California are also projected to have a greater proportion of future “no-analog” bird assemblages (45%) relative to the projected state average (33%; Fig. 2) and also more no-analog assemblages relative to some of the other federal land holders such as USDA Forest Service and National Park Service. Moreover, all five focal bird-species habitat groups are projected to suffer losses in species richness on DoD lands (Fig. 3).

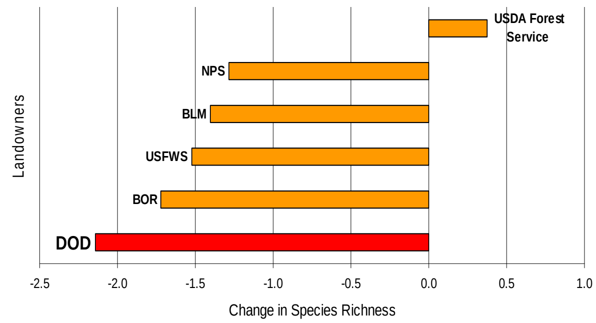

Figure 1. DoD lands show the largest predicted decrease in bird species richness among six Federal agencies in California including Bureau of Reclamation (BOR), USDA Fish and Wildlife Service (USFWS), Bureau of Land Management (BLM), National Park Service (NPS), and the US Forest Service.

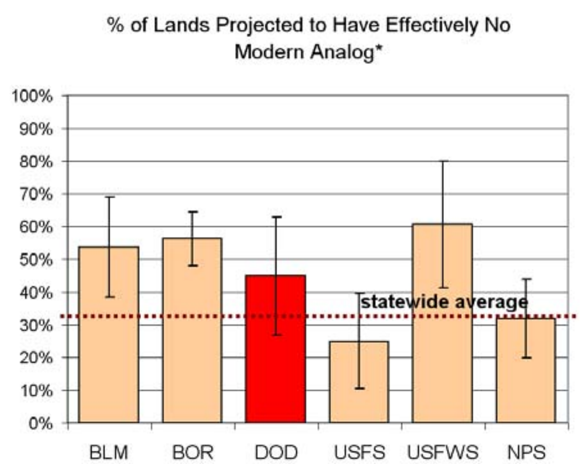

Figure 2. The proportion of areas containing “no-analog” bird assemblages in the future – combinations of species that have no contemporary counterpart in California – are projected to be greater on lands administered by several Federal agencies (including DoD) than for the state as a whole. Bars indicate ± 1 standard deviation.

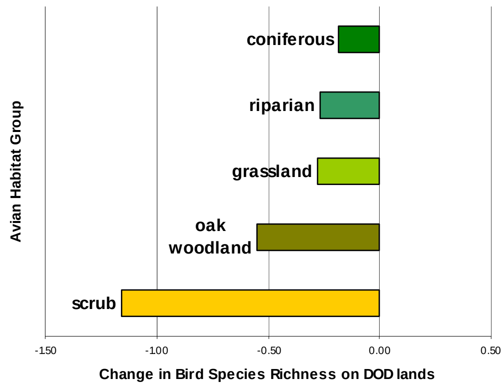

Figure 3. All major avian habitat groups are predicted to suffer losses in bird species on DoD lands in California, with the greatest reductions occurring for birds that utilize scrub-chaparral habitats.

These results suggest that, if birds are any indication, DoD lands may be especially vulnerable to the effects of climate change. Thus, the changes we document for birds are likely to be harbingers of more profound and far-reaching changes in the environments of these military lands. Accordingly, the purpose of the work summarized in this report has been to delve more deeply into how climate change, together with projected changes in land use, may affect the distributions of California bird species in relation to military lands in the state. We build on our previous work with focal bird species (Wiens et al. 2009, Stralberg et al. 2009) to include bird species that are of particular management concern: species listed under the Federal and California Endangered Species Acts and other Bird Species of Special Concern (Shuford and Gardali 2008). Our specific objectives in this project have been to extend our analysis of climate-change impacts on DoD lands in California to:

- Include a broader array of species, emphasizing threatened, endangered, and at-risk species (TER-S) and species of special concern, and summarize projected distributional changes for these species;
- Assess changes in broad vegetation types;
- Evaluate how changes vary regionally and among installations;
- Determine the effects of changes in land use (housing development) on bird distributions in areas surrounding installations;
- Test the effectiveness of assessments of species vulnerability to climate change; and
- Summarize the findings that may help to inform forward-looking environmental management on DoD installations.

Military Installations in California

We conducted analyses for 39 active military installations or lands in California (Table 1, Fig. 4)[1]. We selected all military parcels in California and then removed any military lands on islands (our predictions do not extend to islands), military lands closed due to base realignment and closure (BRAC), and all military lands less than 130 ha in size. The latter modification removed 33 isolated land parcels that primarily consisted of housing units. The resulting list of bases consisted of 39 land parcels ranging in size from NAWS China Lake (449,115 ha) to Defense Fuel Support Point San Pedro (136 ha). In a few cases we were not able to generate predictions for one small military land parcel along the Pacific coast (NB San Diego, Naval Station) because of the resolution or geographic extent of our data. For the analysis of land use surrounding military lands we combined separate land parcels if they were adjoining or within 5 km of a much larger base (i.e., MCAS Miramar). Military lands adjacent to San Diego Bay were combined because of their relatively small size and proximity to each other (Fig. 4), resulting in a total of 29 bases (Table 1).

Most of our analyses aggregated DoD installations over the entire state or in defined subsections of the state (see below). In several instances, however, we considered selected "focal installations" for more detailed, base-level analyses. These installations were selected because they represented a range of environments or ecoregions in the state and/or because we had exchanged information with base personnel during the development of this project. These focal installations were: Beale AFB; Chocolate Mountain Air Gunnery Range; NAWS China Lake; NTC and Fort Irwin; Sierra Army Depot; MTC-H Camp Roberts; ITC Camp San Luis Obispo, Fort Hunter Liggett; NCAS Miramar (combined in the analysis with NB San Diego, Mission Gorge and Murphy Canyon); MCB Camp Pendleton; NWS Seal Beach Detachment Fallbrook (attached to Camp Pendleton and analyzed together); NB Coronado, RTS Warner Springs; Travis AFB; and Vandenberg AFB.

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[1] We derived this list from the following shapefile: MILITARY_INSTALLATIONS_RANGES_TRAINING_AREAS_PT.shp, which was accessed on 1 March 2011 from the following website: http://www.data.gov/catalog/geodata/category/0/agency/0/filter/military%20installations/sort//page/1/count/10, with corrections from Tiffany Shepherd.

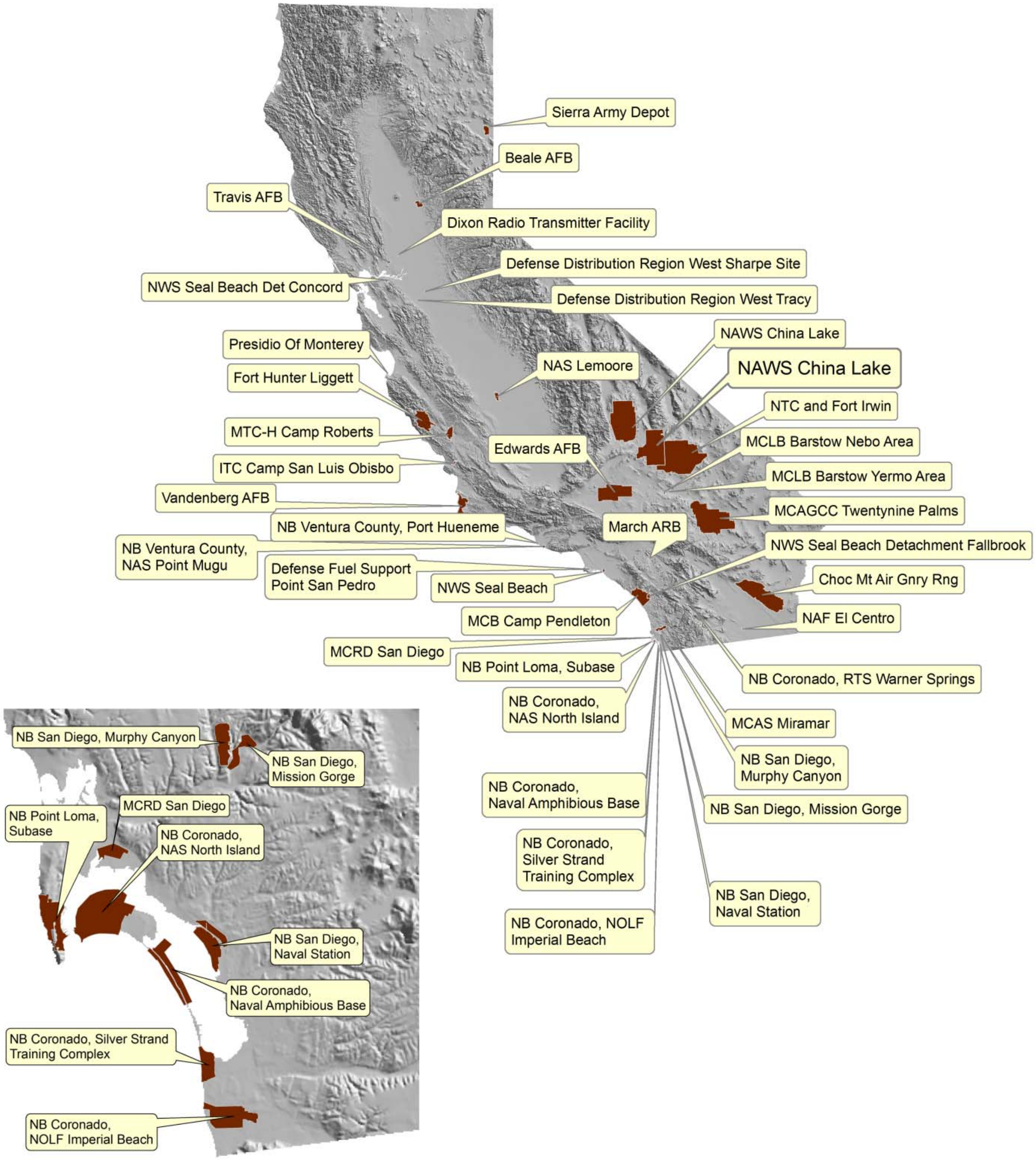


Figure 4. Locations of DoD installations in California (bases on islands and parcels <130 ha are not included). Lower inset shows bases in the San Diego region.

Table 1. California military installations used in this analysis, their area (ha) and the ecoregion in which the majority of the installation was found. Base ID was used to identify installations that were grouped together because of spatial proximity in the Changing Landuse analyses.

Military branch	Site name	Area (ha)	Base ID	Ecoregion
Army Reserve	Fort Hunter Liggett	65600	7	Central west
AF Active	Vandenberg AFB	40315	29	Central west
Army Guard	MTC-H Camp Roberts	17244	14	Central west
Army Guard	ITC Camp San Luis Obispo	2300	8	Central west
Army Active	Presidio Of Monterey	162	25	Central west
Army Active	Sierra Army Depot	12104	27	Great basin
Navy Active	NAWS China Lake	449115	20	Mojave desert
Army Active	NTC and Fort Irwin	305677	21	Mojave desert
MC Active	MCAGCC Twentynine Palms	241902	9	Mojave desert
AF Active	Edwards AFB	124761	5	Mojave desert
MC Active	MCLB Barstow Nebo Area	1498	12	Mojave desert
MC Active	MCLB Barstow Yermo Area	684	13	Mojave desert
AF Active	Beale AFB	9367	1	Sacramento valley
AF Active	Travis AFB	2053	28	Sacramento valley
Navy Active	Dixon Radio Transmitter Facility	526	19	Sacramento valley
Navy Active	NAS Lemoore	7429	16	San Joaquin valley
Navy Active	NWS Seal Beach Det Concord	2144	23	San Joaquin valley
Army Active	Defense Distribution Region West Sharpe Site	291	3	San Joaquin valley
Army Active	Defense Distribution Region West Tracy	185	4	San Joaquin valley
MC Active	Choc Mt Air Gnry Rng	186329	2	Sonoran desert
Navy Active	NAF El Centro	1083	15	Sonoran desert
MC Active	MCB Camp Pendleton	51430	11	Southwest
MC Active	MCAS Miramar	9138	10	Southwest
Navy Active	NWS Seal Beach Detachment Fallbrook	3607	11	Southwest
Navy Active	NB Coronado, RTS Warner Springs	2467	17	Southwest
Navy Active	NWS Seal Beach	1959	22	Southwest
Navy Active	Ventura County, NAS Point Mugu	1759	18	Southwest
Navy Active	NB Coronado, NAS North Island	1111	6	Southwest
AF Reserve	March ARB	872	16	Southwest
Navy Active	NB Ventura County, Port Hueneme	653	24	Southwest
Navy Active	NB Coronado, NOLF Imperial Beach	487	6	Southwest
Navy Active	NB Point Loma, Subbase	473	6	Southwest
Navy Active	NB San Diego, Naval Station	278	6	Southwest
Navy Active	NB San Diego, Murphy Canyon	275	10	Southwest
Navy Active	NB Coronado, Naval Amphibious Base	272	6	Southwest

Military branch	Site name	Area (ha)	Base ID	Ecoregion
Navy Active	NB Coronado, Silver Strand Training Complex	222	6	Southwest
Navy Active	NB San Diego, Mission Gorge	181	10	Southwest
MC Active	MCRD San Diego	172	6	Southwest
Navy Active	Defense Fuel Support Point San Pedro	136	26	Southwest

Broadening the Array of Species Modeled

In our initial modeling of climate change and species distributions, we considered 60 focal bird species recognized by Partners in Flight as representative of the major habitat types in California (Chase and Geupel 2005, Stralberg et al. 2009). Model analyses for these species were the foundation for the results shown in Figure 1. We restricted our analyses to the breeding season, when habitat associations of the species may be most clear. Therefore, we only included records of migratory species if they were encountered at more than one survey within a season for a given survey route and we excluded records of migratory species from desert areas of southern California if they are not known to breed there.

For this project, we included focal species, but we greatly expanded the array of bird species to include breeding-season species that are listed as threatened or endangered under the U.S. Endangered Species Act and the State of California Endangered Species Act or are considered to be Bird Species of Special Concern (Shuford and Gardali 2008). We used current breeding-season distributional information obtained from (1) PRBO Conservation Science (PRBO) and partners for 1993–2007 (http://www.prbo.org/cadc/); (2) USDA Forest Service Pacific Southwest Research Station Redwood Sciences Laboratory (RSL) and Klamath Bird Observatory (KBO) for 1992–2006; (3) the North American Breeding Bird Survey (BBS) for 1997–2006; and (4) Cornell Laboratory of Ornithology eBird database downloaded from the Avian Knowledge Network (http://www.avianknowledge.net) where locational accuracy was known within a 5-km radius. Breeding-season records were further filtered using breeding-season range maps to ensure that migratory records were not included in the models (Zeiner et al. 1988-1990, Shuford and Gardali 2008). In all, 202 species were included in our analysis. The list of species is included in Appendix 1. We also have added the additional species to an interactive website where maps of both current and future distribution models can be viewed as well as the projections for future climate and vegetation (http://data.prbo.org/cadc/tools/ccweb2/).

Our focus in this report is on distributional changes associated with climate change and land-use change that affect the overall species richness of bird communities and the occurrence of groups of species associated with major habitat types on military lands in California. We do not report the results of analyses of distributional changes for each of the 202 species we modeled, although these results are summarized in Appendix 1, where we report the percent change between current and future modeled mean probability of occurrence for each species across California and on DoD installations within California.

The Modeling Approach

Species-distribution modeling (SDM) involves using data on current distributions of species, coupled with information on current climate and vegetation, to develop correlative models that may then be applied to future climate and vegetation distributions to project how species will respond. For our modeling approach, we use bird-distribution data from a variety of sources (see above) collected at 23,064 locations in California, in conjunction with a distribution-modeling algorithm, maximum entropy (Maxent 3.2.1; Phillips and Dudik 2008), to project current and future bird distributions at an 800-m pixel resolution. We used the Maxent algorithm because many of our records were "presence-only" data that only recorded whether a species was present, but not whether it was absent. Maxent has excellent predictive performance for presence-only modeling (Elith et al. 2006).

Current climate data were based on 30-year (1971-2000) monthly climate normals interpolated at an 800 m grid resolution by the PRISM group (Daly et al. 1994). From the monthly temperature and precipitation grids, we produced 19 standard bioclimatic variables (Nix 1986; www.worldclim.org/bioclim.htm), but reduced these to 8 variables by removing complex variables that were derived using both temperature and precipitation, and then removing highly correlated variables ($r > 0.90$). Predictor variables selected for modeling were:

1. Annual mean temperature, calculated as the 12-month average of mean monthly temperature,
2. Mean diurnal temperature range, calculated from the 12-month average of the difference between mean maximum and mean minimum temperature for each month,
3. Isothermality, calculated as the ratio of mean diurnal temperature range to the annual temperature range (maximum temperature of the warmest month - minimum temperature of the coldest month),
4. Temperature seasonality, calculated as the 12-month standard deviation of mean monthly temperature,
5. Mean temperature of warmest quarter, calculated as the average temperature of the warmest 3-month period,
6. Annual precipitation, the 12-month total of mean monthly precipitation,
7. Precipitation seasonality, calculated as the 12-month coefficient of variation of mean monthly precipitation, and
8. Precipitation of driest quarter, calculated as the average precipitation for the driest 3 month period.

To improve the capacity of the SDMs to project changes in habitat relevant to birds, we included vegetation distribution as an input to the models. Current and future vegetation were modeled for 12 vegetation classes based on observed relations with climate, solar radiation, soil, and topography (see Vegetation Changes section).

The performance of the SDMs was tested using the area under the curve (AUC) of receiver operating characteristic (ROC) plots, which test the ability of the model to discriminate between true presence locations of a bird against all other locations that were sampled (Fielding and Bell 1997). An AUC score of 1 indicates perfect discrimination and a score of 0.5 indicates discrimination no better than random. In general, AUC scores between 0.7 and 0.8 are considered fair to good. AUC scores above 0.9 are considered excellent (Swets 1988). For each species a cross-validated mean AUC was calculated. The occurrence points were divided into 10 equal-sized groups and 10 successive models were run using 9 of the groups and predictions were made to the 1 withheld group to calculate a predictive AUC. A final cross-validated mean AUC was calculated from the AUC from all 10 models.

Future climate conditions were summarized using projections from a regional climate model (RCM), RegCM3 at a 30-km resolution (Pal et al. 2007), with emissions trajectories taken from the Intergovernmental Panel on Climate Change (IPCC) SRES A2 scenario and boundary conditions based on output from two GCMs. The GCMs used were (1) the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM3.0), an atmosphere-ocean global climate model (AOGCM) run from 1870–2099, and (2) the Geophysical Fluid Dynamics Laboratory (GFDL) GCM CM2.1, an AOGCM run from 1860–2099. The CCSM-based scenario projects temperature increases of 1–3 °C on a monthly basis and large decreases in precipitation for California, relative to a 1968–1999 base period. The GFDL-based scenario projects temperature increases of 2–5 °C on a monthly basis and small decreases in precipitation.

For the CCSM boundary conditions, the RCM was run from 2038-2069; for the GFDL boundary conditions, the run was 2038-2070. For these time periods, monthly temperature and precipitation outputs were averaged across years to obtain one set of monthly values for the current and future time windows. The 30-km resolution RCM results were then statistically downscaled to a 800-m resolution using change values relative to the 800-m PRISM grid (Stralberg et al. 2009, Wiens et al. 2009).

The modeling and analysis methods we used to examine vegetation changes, regional changes in bird communities and climate, changing land use, and assessments of species' vulnerabilities are described in the appropriate sections below.

Projected Changes in Bird Distributions

The mean percent change between current and future probability of occurrence for all species modeled was -11.98% and -13.32% for the CCSM and GFDL future climate models, respectively (Fig. 5). However, the average decrease was much greater on DoD installations, with our models projecting a -34.15% and -28.69% change (CCSM and GFDL, respectively) (Fig. 5). Individual species are projected to have varied response to climate change (Appendix 1). For example, reflecting the results for all species, the California endangered Western Yellow-Billed Cuckoo is projected to decrease by -6.2% across the state while the decrease on DoD lands is projected to be -29.35% (based on the CCSM projections). On the other hand, some species that are projected to have declining probabilities of occurrence throughout the state, such as Hermit Thrush and Ruby-crowned Kinglet, are projected to have an increased probability of occurrence on DoD lands, indicating a potential for future conservation action. In other situations, projected declines in the probability of occurrence on DoD lands may be mitigated by increases in other parts of the state. This is exemplified by the Acorn Woodpecker, which is projected to decline by -53.59% on DoD lands but to increase by 4.17% across the state (based on GFDL future climate models).

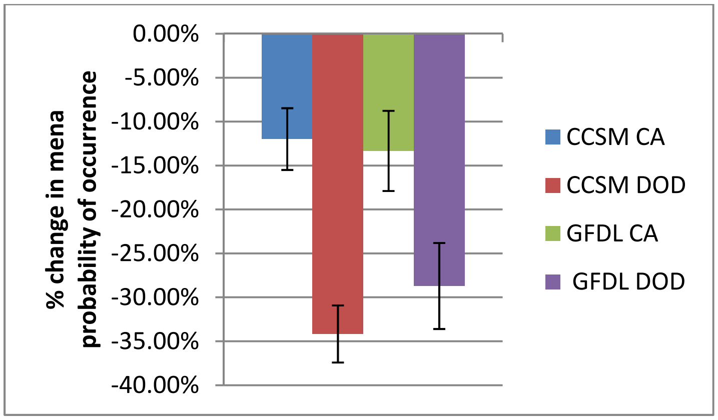


Figure 5. The percent change between the current and future mean probability of occurrence across California (CA) and across Department of Defense Installations (DOD) in California based on Maxent species distribution models for 202 species of birds using two future climate projections. Future climate projections used the National Center for Atmospheric Research Community Climate System Model 3.0 (CCSM) and the Geophysical Fluid Dynamics Laboratory Coupled Climate Model (GFDL). Error bars indicate ± 1 standard error.

For many species, future changes in projected distributions are highly sensitive to which future climate model is used. For example, the San Diego Cactus Wren is projected to increase its statewide probability of occurrence by 227.27% (99.14% on DoD lands) based on the CCSM models, whereas models based on the GFDL projections predict almost no suitable habitat for the species (-88.96% decline statewide, -94.09% decline on DoD lands). Some of the uncertainty in these model projections can be attributed to the extreme values of precipitation seasonality in southwest California projected by the GFDL model, which are beyond the range of historical values (1971-2000). The GFDL scenario also projects a warmer future than the CCSM scenario, which likely drives some of the contrasts in species projections between the two scenarios. The future projections for many of the species that occur primarily in this region (San Diego, Orange, and Los Angeles counties), such as the California Gnatcatcher, are also sensitive to which future-climate model is used.

Vegetation Changes

Vegetation Methods

To assess climate-related changes in major vegetation types, we used comparisons of current and future vegetation projections (using 2030-2070 climate to project vegetation change) modeled by Stralberg et al. (2009) based on the California Gap Analysis vegetation layer (Davis et al. 1998). These maps used 12 classes of broad vegetation groupings aggregated from the California Wildlife Habitat Relationship types (Table 2; Mayer and Laudenslayer 1988).

Table 2. General vegetation types used to project climate-related vegetation changes. Vegetation types from Mayer and Laudenslayer 1988.

Class	California Wildlife Habitat Relationships vegetation types
1	Annual Grassland (AGS), Perennial Grassland (PGS)
2	Blue Oak Woodland (BOW), Blue Oak-Foothill Pine (BOP)
3	Desert Scrub (DSC), Alkali Desert Scrub (ASC), Desert Succulent Shrub (DSS)
4	Eastside Pine (EPN), Juniper (JUN), Piñon-Juniper (PJN)
5	Mixed Chaparral (MCH), Chamise-Redshank Chaparral (CRC), Coastal Scrub (CSC)
6	Montane Hardwood-Conifer (MHC), Douglas Fir (DFR)
7	Montane Hardwood (MHW), Coastal Oak Woodland (COW)
8	Ponderosa Pine (PPN), Klamath Mixed Conifer (KMC)
9	Redwood (RWD), Closed-Cone Pine Cypress (CPC)
10	Red Fir (RFR), Lodgepole Pine (LPN), Subalpine Conifer (SCN)
11	Sagebrush (SGB), Bitterbrush (BBR), Low Sage (LSG)
12	Sierran Mixed Conifer (SMC), White Fir (WFR), Jeffrey Pine (JPN)

We excluded developed and agricultural categories from our vegetation model, as well as aquatic, wetland, riparian, and non-vegetated categories that were thought to be driven more by proximity to water sources or were not directly climate-associated. From a 10-km grid of points across the state, we removed those grid points that fell in an excluded vegetation type and used the resulting sample (n = 9,752 grid points) to develop vegetation-classification models using the Random Forest algorithm (Breiman 2001), which has consistently performed well in predicting the distributions of individual species (Lawler et al. 2006, Prasad et al. 2006). We used the randomForest package for R (R Development Core Team 2010), building 500 classification trees with three randomly sampled candidate variables evaluated at each split. Classification trees are nonparametric, hierarchical models that consist of a set of decision rules on the predictor variables, which recursively partition the data based on binary splits. The Random Forest algorithm was designed to produce accurate predictions that do not overfit the data (Breiman 2001). It develops multiple feasible models, which are then averaged to produce a more robust prediction.

As inputs to the vegetation models we used the same eight derived bioclimatic variables as for the bird distributions, as well as three soil variables, solar radiation, and two topographic variables (see Wiens et al. 2009 for additional details). The resulting set of models was used to develop model-averaged vegetation predictions for the future time periods based on the CCSM and GFDL climate scenarios. Soil and topographic variables were assumed to remain unchanged in the future period. For consistency with the current vegetation layer, predicted future vegetation was augmented with the current urban and agricultural land-cover types that were not modeled. As a proxy for riparian vegetation, models included Euclidean distance to nearest stream.

To examine projected changes in vegetation at each military installation, we used (1) the projected change in area, calculated as (Future area – Current area) and (2) the percent change in the area of a vegetation type relative to current conditions, calculated as [(Future area - Current area) / Current area]. Projections were made for each climate scenario (GFDL and CCSM).

Projected Changes in Vegetation

Based on our vegetation models for current and future conditions we calculated the area and relative percent of vegetation categories associated with military lands in California. The current vegetation on the majority (74.0%) of military bases was classified as desert scrub, followed by chaparral/coastal scrub (6.1%), grassland (4.8%), desert wash (4.4%), barren (3.6%), urban (1.8%), eastside pine/piñon pine/juniper (1.7%), and blue oak/foothill pine (1.4%). Field agriculture, valley oak woodland, montane hardwood, and valley foothill riparian each composed 0.3-0.7% of the total military lands. Orchard/vineyard, redwood/closed-cone pine, sagebrush/bitterbrush/low sage, montane riparian, lacustrine, estuarine, saline emergent wetland, and riverine each comprised <0.1% of the total military lands in California.

We examined future vegetation communities based on the CCSM and GFDL scenarios and calculated the change in area and percent change relative to current conditions. Both scenarios showed an increase in desert scrub habitat, a reduction in blue oak/foothill pine, and loss of all or almost all of eastside pine/piñon pine/juniper, redwood/closed-cone pine, and montane hardwood vegetation types on military installations in California (Fig. 6). The CCSM scenario projected a large increase in grassland habitat and a large decrease in chaparral/coastal scrub, whereas the GFDL scenario projected a small decrease in grassland and a small increase in chaparral/coastal scrub on military lands.

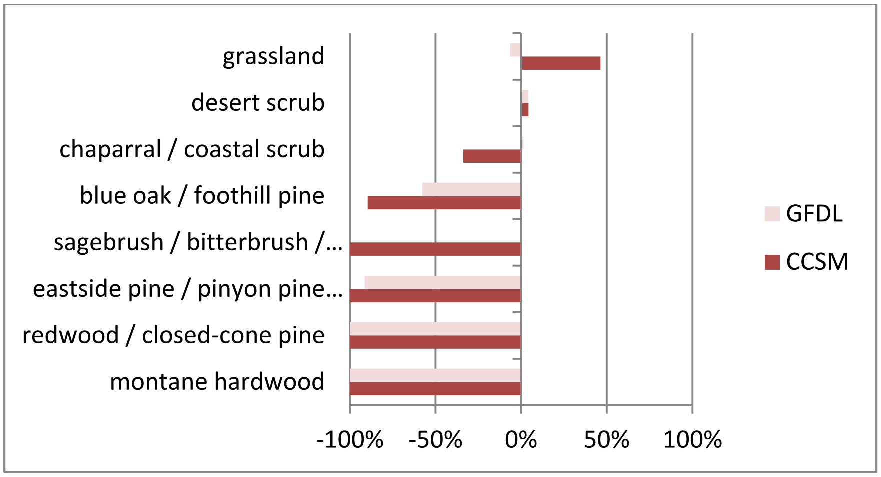


Figure 6. Projected percent change (relative to current) in area of vegetation categories on military bases in California based on two future climate scenarios (GFDL and CCSM).

We then examined which individual bases are projected to experience vegetation shifts due to climate change. Of the 41 bases we considered, only 13 are projected to experience some type of change in their vegetation composition (based on the vegetation classification system that we used) under at least one of the two future-climate scenarios we considered (Table 3). Based on at least one of the climate scenarios, eight installations are projected to experience major changes that affect over 27% of the vegetation. Five other bases are projected to experience moderate to minor changes in vegetation affecting 11.6% or less of the vegetation on that base.

Table 3. Percent change in vegetation composition due to climate change under two future climate scenarios. Bases are sorted by decreasing size.

Installation	Area (ha)	% Veg change (GFDL)	% Veg change (CCSM)
NAWS China Lake	449115	3.9%	0.0%
NTC and Fort Irwin	305677	2.3%	0.0%
MCAGCC Twentynine Palms	241902	0.0%	0.0%
Choc Mt Air Gnry Rng	186329	11.6%	11.4%
Edwards AFB	124761	0.0%	0.0%
Fort Hunter Liggett	65600	36.7%	41.8%
MCB Camp Pendleton	51430	35.7%	36.1%
Vandenberg AFB	40315	23.0%	27.1%
MTC-H Camp Roberts	17244	39.7%	39.7%
Sierra Army Depot	12104	1.7%	1.4%
Beale AFB	9367	2.2%	0.0%
MCAS Miramar	9138	2.8%	51.7%
NAS Lemoore	7429	0.0%	0.0%
NWS Seal Beach Detachment Fallbrook	3607	34.5%	37.2%
NB Coronado, RTS Warner Springs	2467	42.9%	16.2%
ITC Camp San Luis Obispo	2300	20.6%	33.3%
NWS Seal Beach Det Concord	2144	0.0%	0.0%
Travis AFB	2053	0.0%	0.0%
NWS Seal Beach	1959	0.0%	0.0%
NB Ventura County, NAS Point Mugu	1759	0.0%	0.0%
MCLB Barstow Nebo Area	1498	0.0%	0.0%
NB Coronado, NAS North Island	1111	0.0%	0.0%
NAF El Centro	1083	0.0%	0.0%
March ARB	872	0.0%	0.0%
MCLB Barstow Yermo Area	684	0.0%	0.0%
NB Ventura County, Port Hueneme	653	0.0%	0.0%
Dixon Radio Transmitter Facility	526	0.0%	0.0%
NB Coronado, NOLF Imperial Beach	487	0.0%	0.0%
NB Point Loma, Subase	473	0.0%	0.0%
Defense Distribution Region West Sharpe Site	291	0.0%	0.0%
NB San Diego, Naval Station	278	0.0%	0.0%
NB San Diego, Murphy Canyon	275	0.0%	0.0%
NB Coronado, Naval Amphibious Base	272	0.0%	0.0%
NB Coronado, Silver Strand Training Complex	222	0.0%	0.0%
Defense Distribution Region West Tracy	185	0.0%	0.0%
NB San Diego, Mission Gorge	181	0.0%	0.0%
MCRD San Diego	172	0.0%	0.0%
Presidio Of Monterey	162	0.0%	0.0%
Defense Fuel Support Point San Pedro	136	0.0%	0.0%

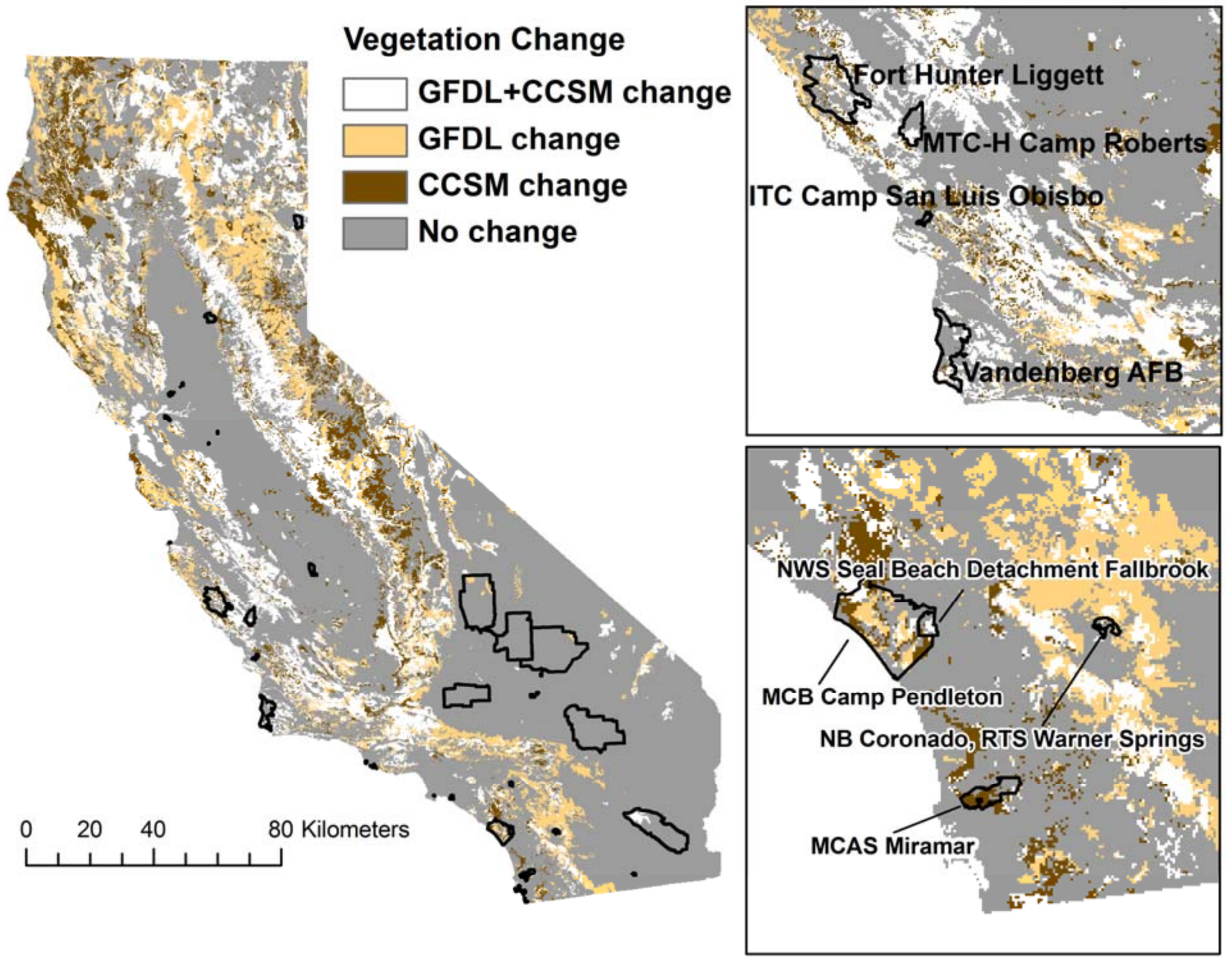


Figure 7. Locations of projected vegetation change under two future climate change projections. Eight installations are projected to have the greatest changes in vegetation. The inset on the upper right shows the Central Coast region with four bases projected to have the largest vegetation changes due to climate change in California. The inset on the lower right shows the San Diego region with the four remaining bases projected to have the largest vegetation changes due to climate change in California.

Many of the military bases in California are located in the desert, where relatively few changes in vegetation are predicted by both future climate scenarios that we considered (Fig. 7). Individual bases vary in the amount of vegetation cover that is projected to change (Table 3) and there is also variation between the two climate scenarios in terms of how individual bases will be affected. Eight military bases (NB Coronado, RTS Warner Springs; MTC=H Camp Roberts; Fort Hunter Liggett; Camp Pendleton; NWS Seal Beach Detachment Fallbrook; Vandenberg AFB';

NCAS Miramar; and ITC Camp San Luis Obispo) are projected to experience vegetation changes over 20.6-42.9% of their area under GFDL and 16.2-41.8% under CCSM. The largest disparity between future scenarios was at Miramar, which is projected to have 51.7% of vegetation change under CCSM but only 2.8% under the GFDL scenario.

For those eight bases where the greatest changes in vegetation are projected to occur, four are in the San Diego region and the other four are along the Central Coast (Fig. 7 insets). The vegetation communities that are projected to change on those eight bases include grassland, blue oak/foothill pine, chaparral, montane hardwood, and redwood/closed-cone pine (Table 4a). For the five bases for which moderate to minor vegetation changes are projected, the affected vegetation communities include grassland, desert scrub, blue oak/foothill pine, chaparral, sagebrush/bitterbrush/low sage, and eastside pine/piñon pine/juniper (Table 4b).

Table 4a. Changes in vegetation communities relative to current vegetation for eight bases showing overall vegetation shifts of at least 27% for at least one climate scenario.

Installation	Scenario	grassland	blue oak / foothill pine	chaparral / coastal scrub	montane hardwood	redwood / closed-cone pine
Camp Roberts	ccsm	74.5%	-100.0%	-100.0%	-100.0%	0.0%
	gfdl	74.5%	-100.0%	-100.0%	-100.0%	0.0%
San Luis Obispo	ccsm	55.6%	-100.0%	-100.0%	0.0%	0.0%
	gfdl	16.7%	-100.0%	-100.0%	0.0%	0.0%
Hunter Liggett	ccsm	259.1%	-87.3%	-100.0%	870.6%	0.0%
	gfdl	141.6%	-50.6%	-100.0%	1079.4%	0.0%
Miramar	ccsm	2333.3%	0.0%	-100.0%	0.0%	0.0%
	gfdl	-33.3%	0.0%	-100.0%	0.0%	0.0%
Pendleton	ccsm	76.3%	0.0%	-99.8%	957.7%	0.0%
	gfdl	-62.0%	0.0%	-100.0%	2265.4%	0.0%
Fallbrook	ccsm	-63.2%	0.0%	-100.0%	0.0%	0.0%
	gfdl	-100.0%	0.0%	-100.0%	0.0%	0.0%
RTS Warner Springs	ccsm	0.0%	0.0%	-84.8%	766.7%	0.0%
	gfdl	0.0%	0.0%	-97.0%	566.7%	0.0%
Vandenberg	ccsm	126.0%	0.0%	-100.0%	1018.2%	-100.0%
	gfdl	103.9%	0.0%	-100.0%	1145.5%	-100.0%

Table 4b. Changes in vegetation communities relative to current vegetation for five bases showing overall moderate to minor vegetation shifts of 11.6% or less for at least one climate scenario.

Installation	Scenario	grassland	blue oak / foothill pine	desert scrub	eastside pine / pinyon pine / juniper	chaparral / coastal scrub	sagebrush / bitterbrush / low sage
Choc. Mtns	ccsm	-100.00%	0%	22.38%	0%	-100.00%	0%
	gfdl	-100.00%	0%	22.38%	0%	-100.00%	0%
NAWS China Lake	ccsm	0%	0%	4.68%	-100.00%	0%	0%
	gfdl	0%	0%	4.14%	-88.37%	0%	0%
Beale AFB	ccsm	0%	0%		0%	0%	0%
	gfdl	-2.68%	>100%		0%	0%	0%
NTC and Fort Irwin	ccsm	0%	0%	2.63%	-100.00%	0%	0%
	gfdl	0%	0%	2.63%	-100.00%	0%	0%
Sierra Depot	ccsm	0%	0%	0.54%	0%	0%	-100.00%
	gfdl	0%	0%	0%	0%	0%	0%

Regional Changes

Although the species distribution modeling that is the foundation of our analyses is conducted at an 800-m scale of resolution, applying the modeling results to assess what might happen in the future in a *specific* 800-m cell is not warranted. The difficulty comes from the fact that there are uncertainties associated with all steps of the modeling process, from the spatial resolution of the climate or bird-distribution data that go into the model through the various manipulations of the data that go on during the modeling process. These uncertainties compound and magnify as the scale of resolution becomes finer and finer [Thuiller (2004), Lawler et al. (2006), and Wiens et al. (2009) discuss these uncertainties in greater detail]. For this reason, projections for individual military installations, particularly small ones (as most are; Table 1) should be considered as approximations rather than precise.

There are two potential solutions to this problem. One is to coarsen the scale of resolution of the modeling, so that projections are made at a scale of, say, tens or hundreds of km^2. This may be appropriate if one is interested in changes over very broad regions (e.g., continental United States; Lawler et al. 2009), but it entails a loss of information about what might happen at the finer scales at which environmental management is usually applied. A second approach is to group locations together, not by simply coarsening the scale to larger blocks of contiguous geographic space but by assessing the environmental or biological characteristics that places share, regardless of their locations in geographical space. Various approaches can be taken to achieve such groupings; in this project we have used biogeographical analyses (ecoregions) and statistical clustering algorithms.

Regional Analysis Methods

Because California is a large and topographically diverse state, environments and their associated biotas vary geographically. At a broad, regional scale, however, there are common, shared patterns in environments and biodiversity. Additionally, conservation planning is typically done at, or in the context of, ecologically defined regions. These regions ("ecoregions" Shuford and Gardali 2008) contain characteristic, geographically distinct assemblages of natural communities and species (Fig. 8). Ecoregions are widely used for conservation planning and management at broad, regional scales. We assigned military installations in California to ecoregions on the basis of where the majority of the area occurred (Table 1).

Figure 8. California ecoregion boundaries and names used to group bases. Bases are shown as outlines with hatch markings. See Figure 4 for individual base names. Ecoregion boundaries are based on Shuford and Gardali (2008).

We used two methods to evaluate regional changes in environment and bird communities in California. First, we used a kmeans clustering algorithm (Hartigan and Wong 1979) to classify sites into groups based on similarities in current and future environment and in current and future bird communities. This analysis placed DoD installations into clusters defined by environmental conditions and bird communities across California. In the second method we used hierarchical clustering to create clusters using only the environmental conditions or projected bird communities that coincide with DoD installations. The hierarchical clusters group DoD installations based on shared characteristics but ignore the conditions that occur outside of DoD lands.

The two clustering methods are methodologically distinct and produce complementary results. Kmeans algorithms are attractive for creating cluster maps across broad spatial scales as they are computationally efficient and produce discrete classifications of the landscape. Hierarchical clustering algorithms are much more computationally intensive and cannot be performed using all of the 800-m grid data from the state. However, hierarchical methods have the benefit of producing coarse- to fine-scale clusters so that the clusters can be assessed at different levels of similarity.

Kmeans clustering works by classifying multivariate data into a predefined number of clusters (Hartigan and Wong 1979). Points in multivariate space are assigned to the cluster based on a minimization of the distance between points and cluster centroids. Because we were interested in defining relatively broad regions of California environmental space and bird communities, we chose to create 15 clusters in all of our kmeans cluster analyses. We created maps of clusters of environmental space and clusters of California bird communities. The maps of environmental clusters were generated by applying the clustering algorithm to the same maps of the current and future environmental conditions as were used for our distributional modeling, but excluding land cover. All environmental variables were normalized to account for unit differences among variables. Maps of bird clusters were created using maps of the predicted distributions of 202 bird species for current climate and two future-climate simulations across the state of California. We then summarized the resulting cluster maps by calculating the percent area of a DoD installation that is projected to be covered by one or another of the clusters derived from the kmeans analysis. We then grouped DoD installations by the clusters that comprise the majority of the area of the installation (Tables 5 and 6).

Hierarchichal clusters are formed by initially placing each DoD installation into its own group. DoD installations are then grouped together based on a dissimilarity matrix calculated from the Euclidean distances of the environmental or bird-community data. Groups are formed based on minimization of the distances around a group centroid. Groups are hierarchically formed so that earlier groups are subsets of later groups. The process continues until all installations are joined in one group. As with the kmeans clustering, the environmental data were normalized so that all variables had the same units. The spatial mean and standard deviation of each environmental variable and each projected bird-species distribution were calculated for each DoD installation so that clusters would be based on the average conditions at an installation while also accounting for spatial variation.

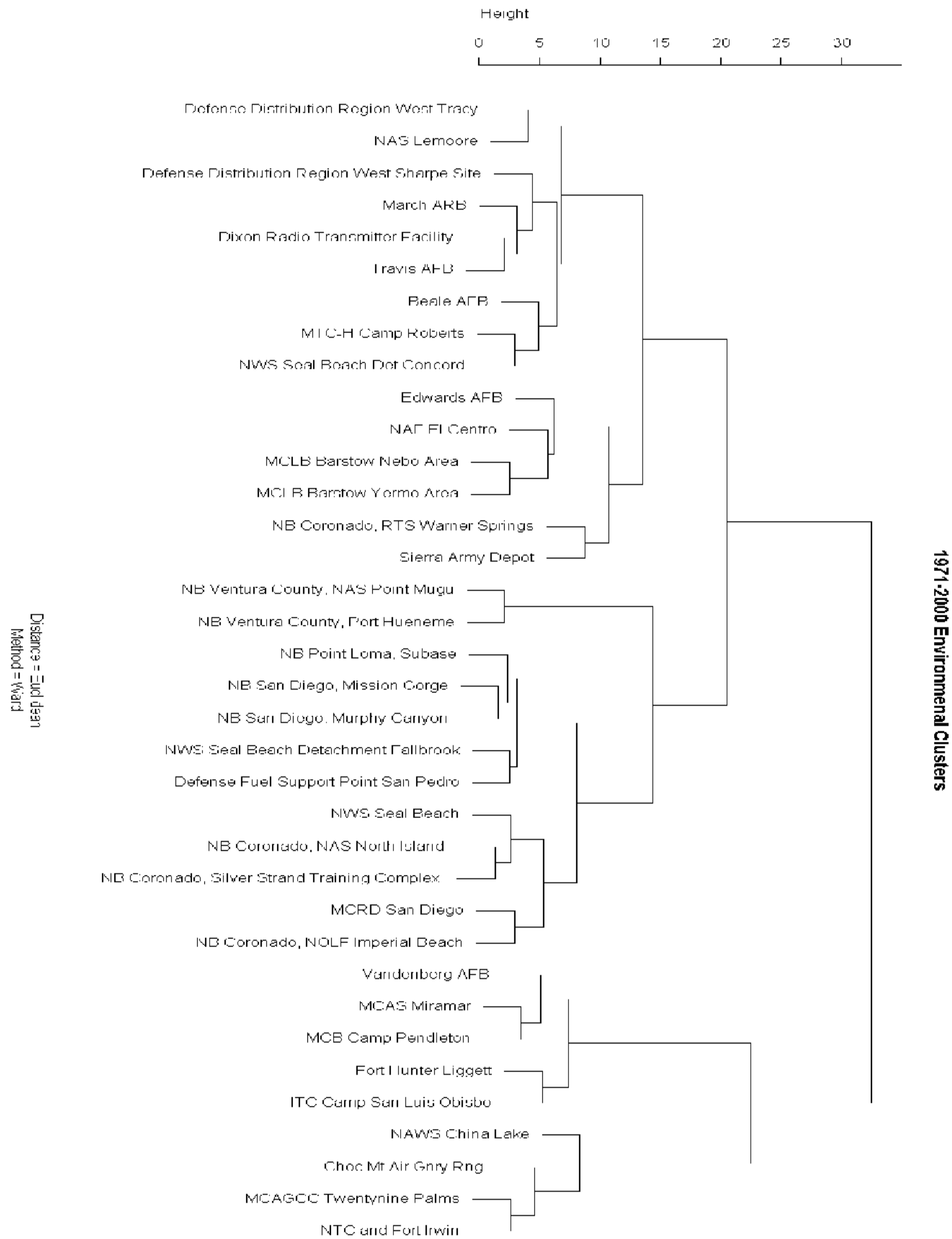
Results

Environmental Clusters

The hierarchical clustering for current environmental conditions resulted in five main clusters of installations. Installations along the south coast of California, particularly those in San Diego County, formed a distinct cluster that included NWS Seal Beach and MCRD San Diego (Fig. 9a). A second cluster was comprised of inland bases, including installations bordering the Coast Range and the Central Valley such as Travis AFB and MTC-H Camp Roberts. The hierarchical method also identified a second cluster of coastal installations, more central-coast focused, that mostly included bases north of San Diego such as Vandenberg AFB, but also included slightly inland bases like Fort Hunter Liggett. Surprisingly, two clusters containing installations located in desert areas were identified. These two desert clusters were fairly dissimilar, separating at the highest break point (Fig. 9a). One desert cluster contained bases with relatively less topographic heterogeneity and included Edwards AFB the MCLB Barstow installations. The other desert cluster contained some of the larger desert installations that contain a great deal of topographic heterogeneity, such as NAWS China Lake, Chocolate Mountain Air Gunnery Range, MCAGCC Twentynine Palms, and Fort Irwin (Fig. 9a). The hierarchical models for future environmental conditions were generally similar to the current clusters, with some installations moving into new clusters but overall patterns remaining much the same (Figs. 9b and 9c). Notable changes in future clusters included the addition of Central Valley installations such as Defense Distribution Region West Tracy and NAS Lemoore into the desert cluster that included Edwards AFB for the CSSM climate model (Fig. 9c). Similarly, NB Coronado, RTS Warner Springs moved from the central coast cluster to the same desert cluster containing Edwards AFB for the GFDL climate models (Fig. 9b).

In general, the kmeans clusters grouped the DOD installations into coarse groups reflective of the fact that the clusters were determined by conditions across the entire state. Out of the 15 clusters created across the state, only nine clusters covered the majority of DoD installations (Table 5 and Fig. 10). The largest cluster included almost all coastal bases for current and both future climate scenarios (Table 5, Fig. 10). The coastal cluster mentioned above and a cluster comprised of installations located in or near coastal mountains (March ARB, MTC-H Camp Roberts, NB Coronado, RTS Warner Springs, and Fort Hunter Liggett), were both stable across time with almost no changes in the composition of these clusters, despite the changes in climate within them (Table 5). This suggests that managers of installations that are included in the same clusters should be able to share management approaches now and into the future. Some installations are found in different clusters in each of the three climate analyses (Table 5). For example, Beale AFB is clustered with coastal and slightly inland bases based on current climate, inland/Central Valley bases for the GFDL climate models, and desert bases for the CCSM models.

a)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Defense Distribution Region West Tracy
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Defense Distribution Region West Sharpe Site
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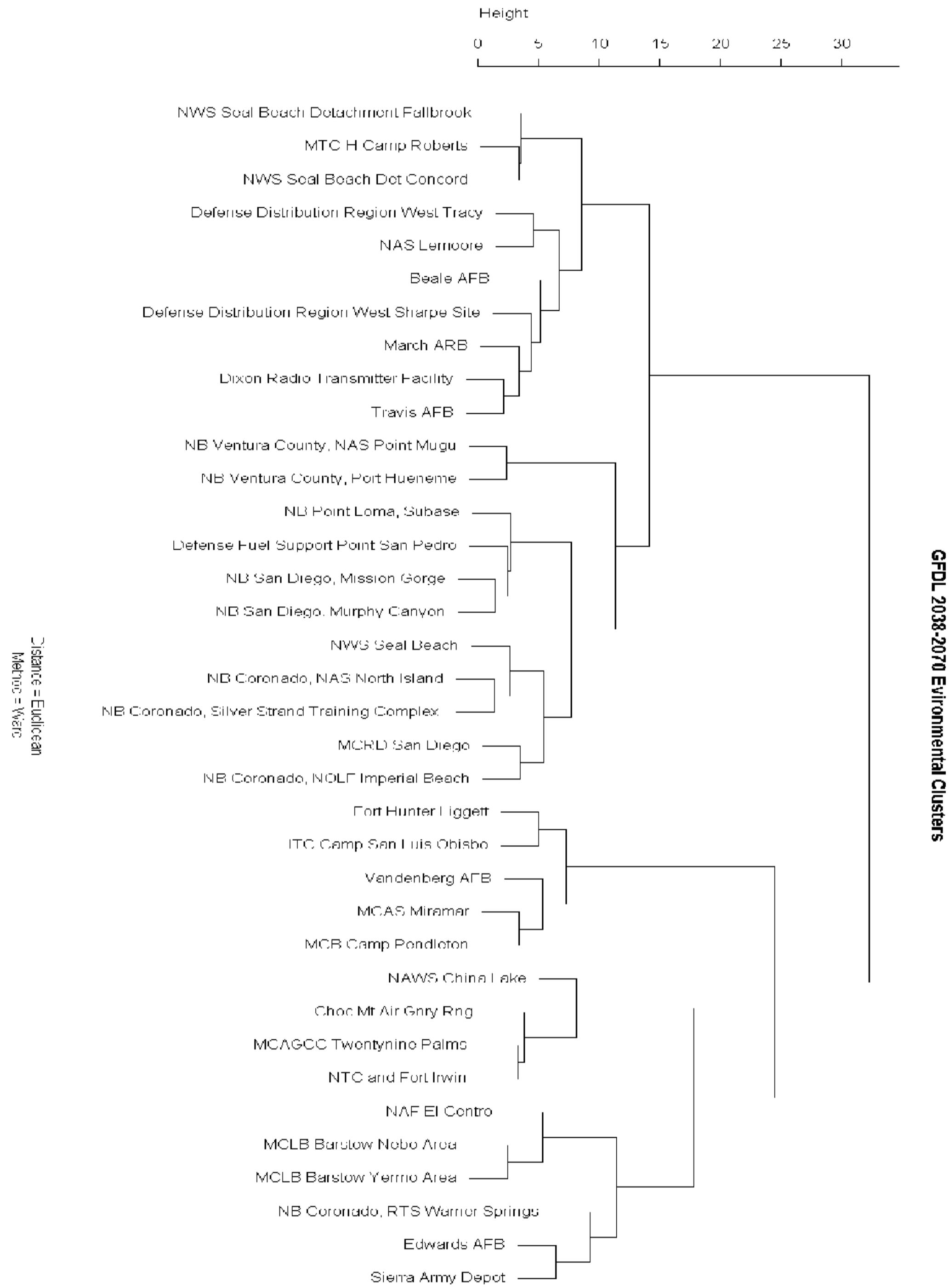
Dixon Radio Transmitter Facility
Travis AFB
Beale AFB
MTC-H Camp Roberts
NWS Seal Beach Det Concord
Edwards AFB
NAF El Centro
MCLB Barstow Nebo Area
MCLB Barstow Yermo Area
NB Coronado, RTS Warner Springs
Sierra Army Depot
NB Ventura County, NAS Point Mugu
NB Ventura County, Port Hueneme
NB Point Loma, Subase
NB San Diego, Mission Gorge
NB San Diego, Murphy Canyon
NWS Seal Beach Detachment Fallbrook
Defense Fuel Support Point San Pedro
NWS Seal Beach
NB Coronado, NAS North Island
NB Coronado, Silver Strand Training Complex
MCRD San Diego
NB Coronado, NOLF Imperial Beach
Vandenberg AFB
MCAS Miramar
MCB Camp Pendleton
Fort Hunter Liggett
ITC Camp San Luis Obisbo
NAWS China Lake
Choc Mt Air Gnry Rng
MCAGCC Twentynine Palms
NTC and Fort Irwin
Distance = Euclidean
Method = Ward
1971-2000 Environmenal Clusters

b)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NAS Lemoore
Beale AFB
Defense Distribution Region West Sharpe Site
March ARB
Dixon Radio Transmitter Facility
Travis AFB
NB Ventura County, NAS Point Mugu
NB Ventura County, Port Hueneme
NB Point Loma, Subase
Defense Fuel Support Point San Pedro
NB San Diego, Mission Gorge
NB San Diego, Murphy Canyon
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NB Coronado, Silver Strand Training Complex
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NB Coronado, NOLF Imperial Beach
Fort Hunter Liggett
ITC Camp San Luis Obispo
Vandenberg AFB
MCAS Miramar
MCB Camp Pendleton
NAWS China Lake
Choc Mt Air Gnry Rng
MCAGCC Twentynine Palms
NTC and Fort Irwin
NAF El Centro
MCLB Barstow Nebo Area
MCLB Barstow Yermo Area
NB Coronado, RTS Warner Springs
Edwards AFB
Sierra Army Depot
Distance = Euclidean
Method = Ward
GFDL 2038-2070 Evironmental Clusters

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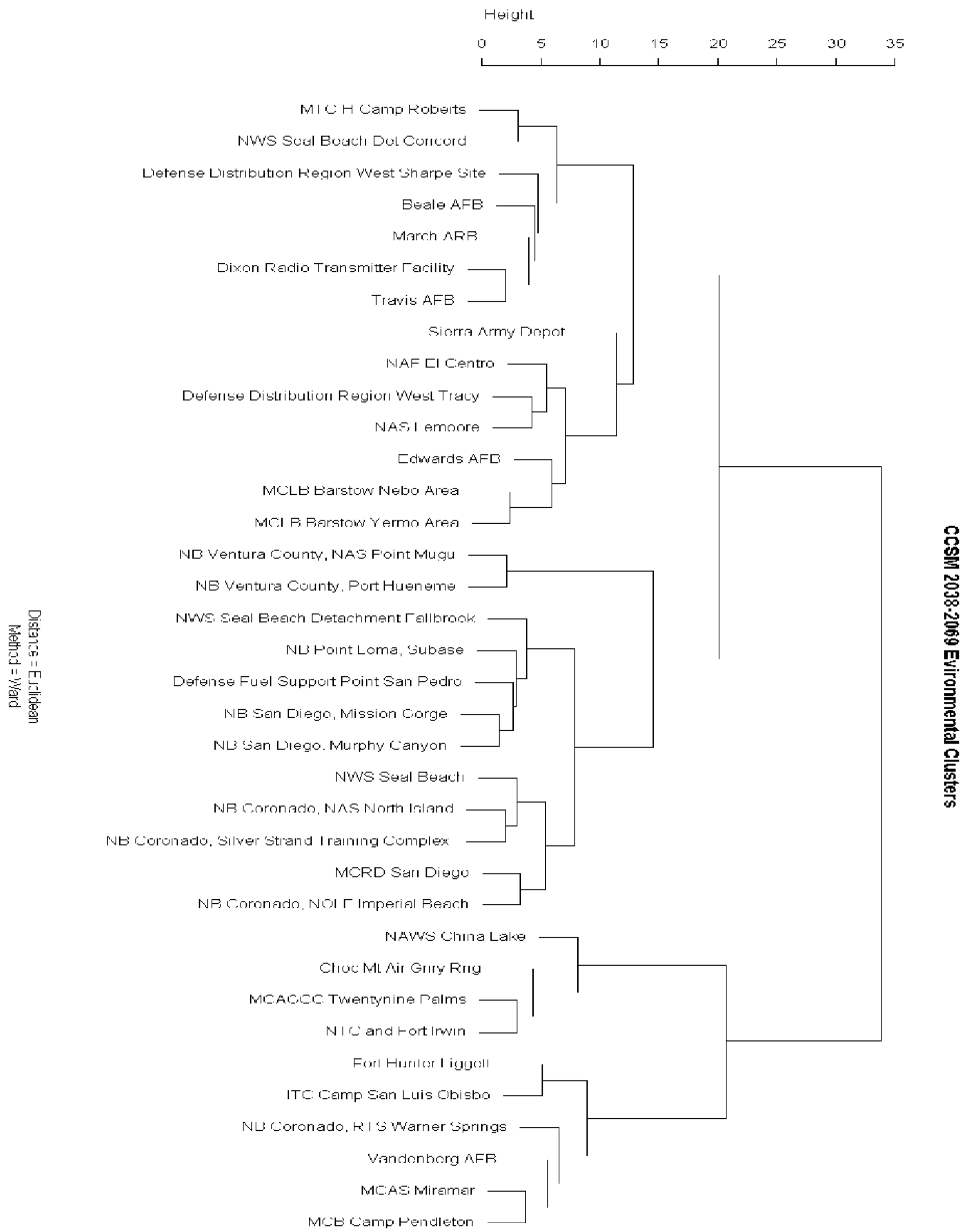


Figure 9. Dendrogram of environmental clusters based on (a) topographic and soils data and climate data from 1971-2000, (b) the GFDL model for 2038-2070, and (c) the CCSM model for 2038-2069. Each DoD installation was overlain on maps of the environmental variables and the mean and standard deviation of environmental conditions of each variable were calculated and used to determine the clusters. Clusters were formed based on a distance matrix of Euclidean distances and used the Ward method for linkage.

Table 5. The kmeans environmental clusters that covered the largest proportion of area of select DOD installations within California are given, with the proportion of the base area covered by the given cluster indicated within parentheses. The colors correspond to the clusters in Figure 10. A change in color between current and future climate conditions indicates where bases will be part of a new regional climate in the future.

DOD installation name	2010	2070 (GFDL)	2070 (CCSM)
Defense Distribution Region West Tracy	1(100%)	4(100%)	8(100%)
NAS Lemoore	1(88%)	4(91%)	8(72%)
Beale AFB	11(100)%	4(60%)	8(69%)
NB Coronado, Naval Amphibious Base	11(100)%	15(100%)	1(100%)
Dixon Radio Transmitter Facility	11(100)%	3(100%)	7(100%)
Travis AFB	11(100)%	3(100%)	7(100%)
NWS Seal Beach Det Concord	11(50%)	4(35%)	8(41%)
Sierra Army Depot	13(89%)	7(81%)	9(100%)
NAF El Centro	14(100%)	6(100%)	12(100%)
MCAGCC Twentynine Palms	14(43%)	13(60%)	13(59%)
Choc Mt Air Gnry Rng	14(48%)	6(73%)	12(55%)
NAWS China Lake	5(38%)	13(44%)	2(38%)
MCLB Barstow Yermo Area	6(100%)	13(100%)	13(100%)
NTC and Fort Irwin	6(41%)	6(55%)	2(37%)
MCLB Barstow Nebo Area	6(62%)	13(62%)	13(62%)
Defense Distribution Region West Sharpe Site	7(100%)	3(100%)	7(100%)
Edwards AFB	7(53%)	13(39%)	10(83%)
March ARB	9(100%)	10(100%)	5(100%)
MTC-H Camp Roberts	9(100%)	10(100%)	5(100%)
NB Coronado, RTS Warner Springs	9(58%)	10(75%)	5(89%)
Fort Hunter Liggett	9(77%)	10(80%)	5(81%)
MCAS Miramar	2 (66%)	15(99%)	1(73%)
MCRD San Diego	2(100%)	15(100%)	1(100%)
NB Coronado, NOLF Imperial Beach	2(100%)	15(100%)	1(100%)
NB Coronado, NAS North Island	2(100%)	15(100%)	1(100%)
NB Coronado, Silver Strand Training Complex	2(100%)	15(100%)	1(100%)
NB Ventura County, NAS Point Mugu	2(100%)	15(100%)	1(100%)
NB Point Loma, Subase	2(100%)	15(100%)	1(100%)
NB San Diego, Mission Gorge	2(100%)	15(100%)	1(100%)
NB San Diego, Murphy Canyon	2(100%)	15(100%)	1(100%)
NWS Seal Beach	2(100%)	15(100%)	1(100%)
NWS Seal Beach Detachment Fallbrook	2(100%)	15(100%)	1(100%)
NB Ventura County, Port Hueneme	2(100%)	15(100%)	1(100%)
Presidio Of Monterey	2(100%)	15(100%)	1(100%)
Defense Fuel Support Point San Pedro	2(100%)	15(100%)	1(100%)
Vandenberg AFB	2(100%)	15(100%)	1(100%)
ITC Camp San Luis Obispo	2(92%)	15(92%)	1(92%)
MCB Camp Pendleton	2(93%)	15(93%)	1(94%)

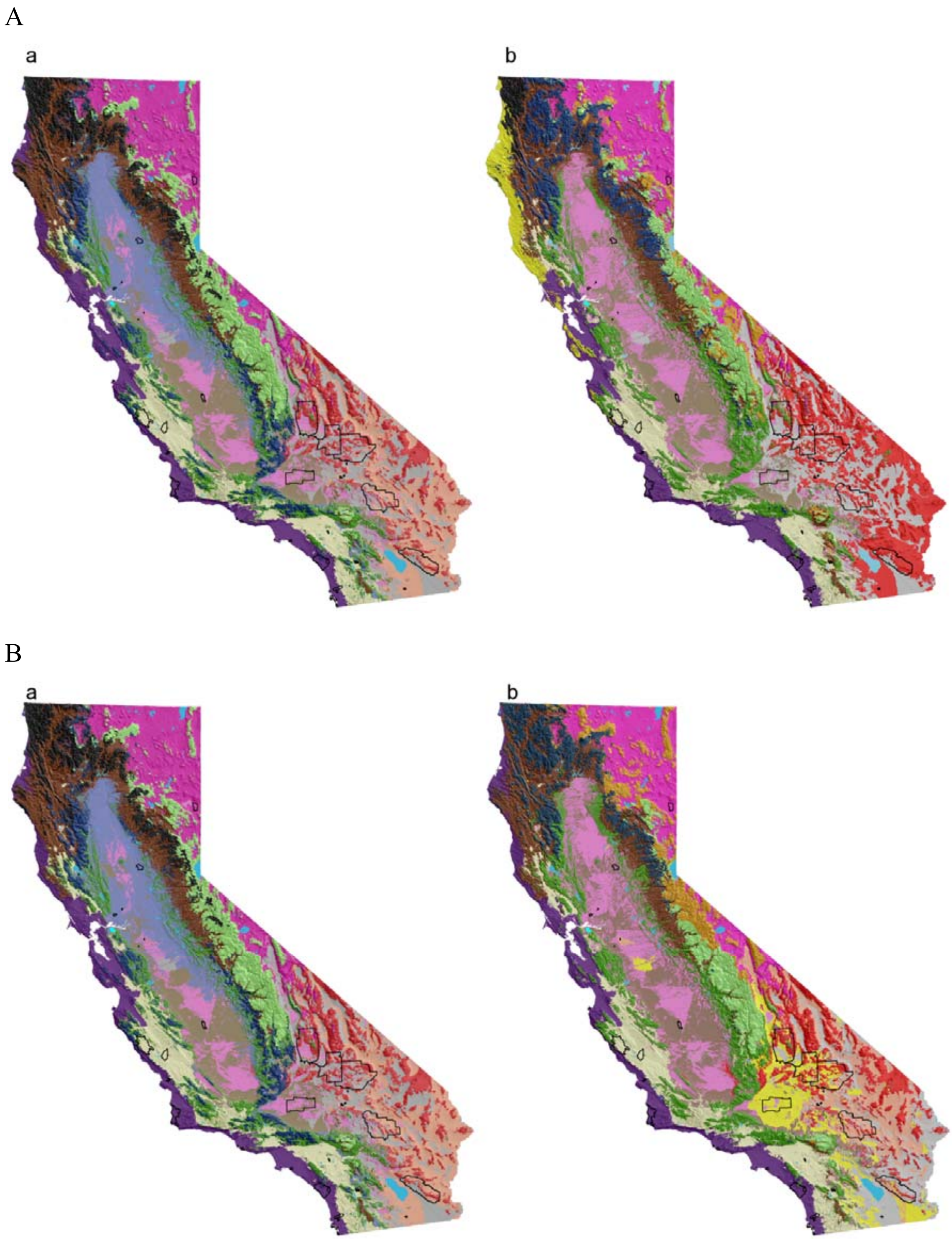


Figure 10. Kmeans clusters of environmental conditions based on (a) current (1971-2000) climate and (b) future climate (2038-2070) based on (A) the GFDL general circulation model, and (B) the CCSM general circulation model. Colors indicate regions within each map that have similar climate conditions within the given time period. Colors occurring in (a) and not (b) are clusters which disappear in the future, colors appearing in (b) and not (a) indicate novel clusters.

Bird Community Clusters

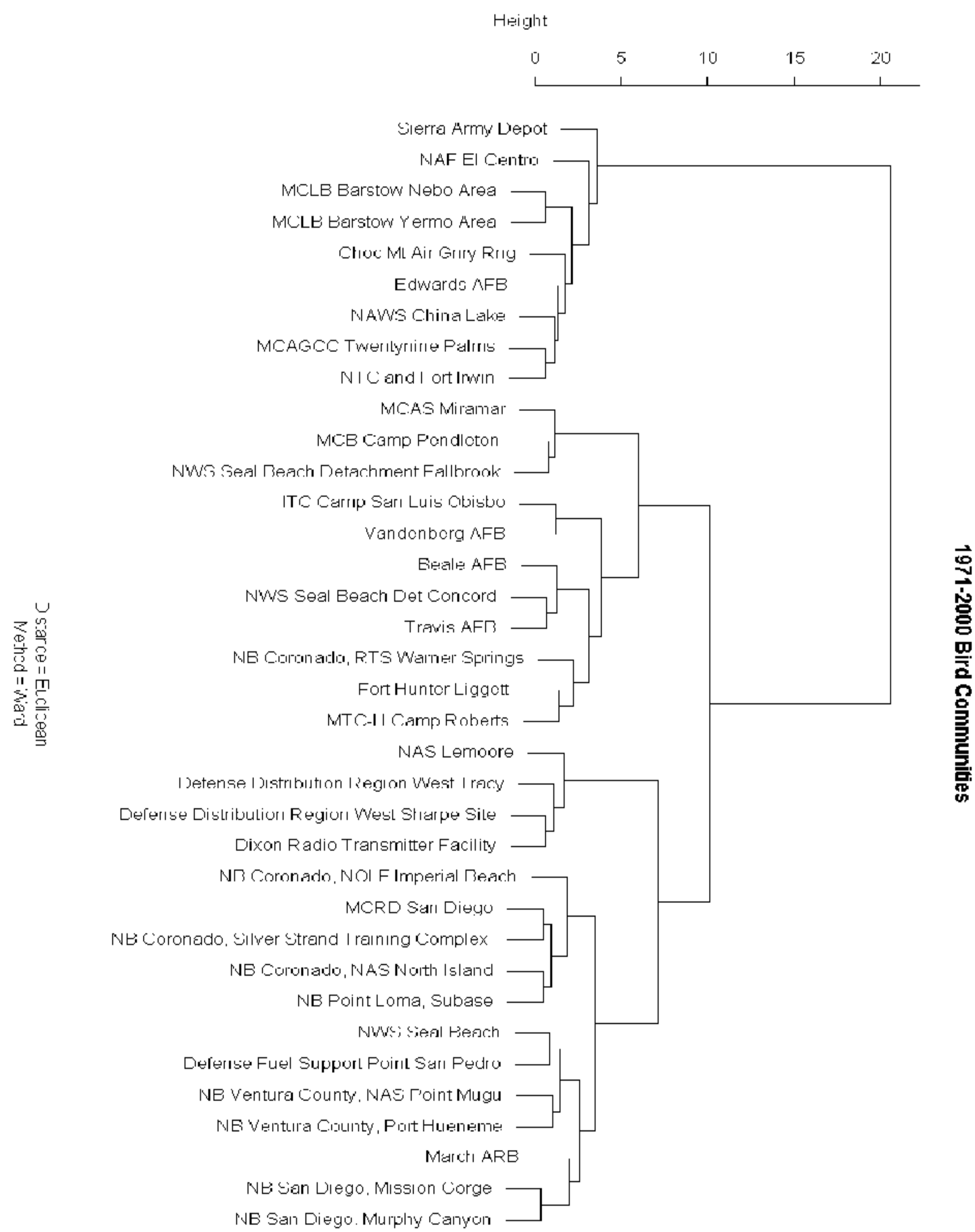
Based on the hierarchical bird-community models, DoD installations in California can be clustered into two main groups, one including desert installations (including Sierra Army Depot) and the other composed of all other bases. In general, the clustering patterns are similar to the environmental clusters, with the hierarchical bird-community analysis identifying three main clusters; the desert cluster mentioned above, a south-coast cluster (March ARB to NB Coronado, NOLF Imperial Beach, Fig. 11a), and a cluster comprised of a mix of coastal and inland coastal installations (NAS Lemoore to Fort Hunter Liggett, Fig. 11a).

The division between desert and non-desert clusters becomes less clear for models of future bird-community clusters. For the CCSM model, the desert/non-desert distinction still largely defines the clustering, although a new sub-group including NAS Lemoore to Defense Distribution Region West Tracy (Fig. 11 b) is found to be more similar to the desert cluster than to the coastal cluster it was found included within for the current bird clusters. For the GFDL model, desert and non-desert installations are mixed across clusters (Fig. 11 c). The mixing of desert installations with other clusters suggests that, in general, DoD installations across California are likely to become more desert-like in terms of bird communities; this is not surprising, given the warmer, dryer California that this model projects.

There are differences between the hierarchical models for current environmental conditions and for current bird communities. As opposed to the environmental clusters, the model for birds grouped all of the desert bases into a single cluster (El Centro to MCLB Barstow Nebo Area, Fig. 11). Many of the other differences between the environmental and bird clusters are subtle, involving single installations being placed in different clusters. For example, two central-coast installations (Vandenberg AFB and ITC Camp San Luis Obispo) are found to be more similar to each other in terms of bird communities than environmental conditions and were clustered with more inland sites such as Travis AFB in the bird-community model.

General patterns from the kmeans clusters of bird communities are similar to the kmeans clusters of environmental conditions. Again, only nine of the 15 clusters modeled included most DoD installations. Clusters including coastal installations were the most stable across current climate and future climate scenarios (Table 6). Interestingly, the bird-community cluster that includes the majority of Chocolate Mountain Air Gunnery Range is projected to dominate cluster types for desert installations based on the CCSM climate mode (Table 6). This pattern can be seen in Figure 12Ba,b where the light pink color that dominates Chocolate Mountain Air Gunnery Range in Figure 12Ba covers a large proportion of the other desert bases in projected future climate in Figure 12Bb. For the GFDL climate projections a different pattern emerges where the red cluster that dominates the MCLB Barstow installations for current bird-community distributions covers a greater extent for future projections (Fig. 12Ba).

a)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Edwards AFB
NAWS China Lake
MCAGCC Twentynine Palms
NTC and Fort Irwin
MCAS Miramar
MCB Camp Pendleton
NWS Seal Beach Detachment Fallbrook
ITC Camp San Luis Obisbo
Vandenberg AFB
Beale AFB
NWS Seal Beach Det Concord
Travis AFB
NB Coronado, RTS Warner Springs
Fort Hunter Liggott
MTC-H Camp Roberts
NAS Lemoore
Defense Distribution Region West Tracy
Defense Distribution Region West Sharpe Site
Dixon Radio Transmitter Facility
NB Coronado, NOLF Imperial Beach
MCRD San Diego
NB Coronado, Silver Strand Training Complex
NB Coronado, NAS North Island
NB Point Loma, Subase
NWS Seal Beach
Defense Fuel Support Point San Pedro
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March ARB
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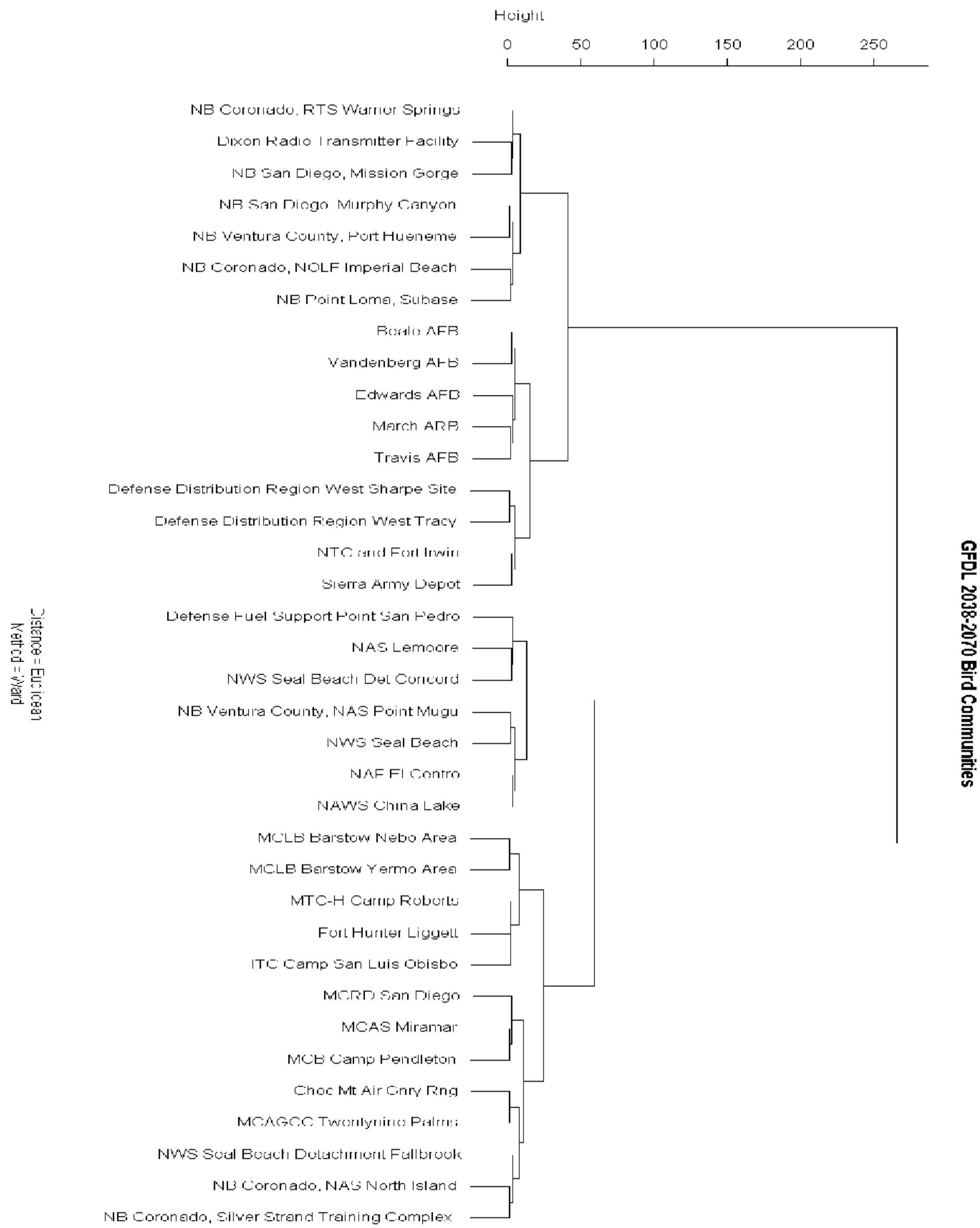
NB San Diego, Murphy Canyon
1971-2000 Bird Communities

b)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NB Point Loma, Subase
Beale AFB
Vandenberg AFB
Edwards AFB
March ARB
Travis AFB
Defense Distribution Region West Sharpe Site
Defense Distribution Region West Tracy
NTC and Fort Irwin
Sierra Army Depot
Defense Fuel Support Point San Pedro
NAS Lemoore
NWS Seal Beach Det Concord
NB Ventura County, NAS Point Mugu
NWS Seal Beach
NAF El Centro
NAWS China Lake
MCLB Barstow Nebo Area
MCLB Barstow Yermo Area
MTC-H Camp Roberts
Fort Hunter Liggett
ITC Camp San Luis Obisbo
MCRD San Diego
MCAS Miramar
MCB Camp Pendleton
Choc Mt Air Gnry Rng
MCAGCC Twentynine Palms
NWS Seal Beach Detachment Fallbrook
NB Coronado, NAS North Island
NB Coronado, Silver Strand Training Complex
Distance = Euclidean
Method = Ward
GFDL 2038-2070 Bird Communities

c)

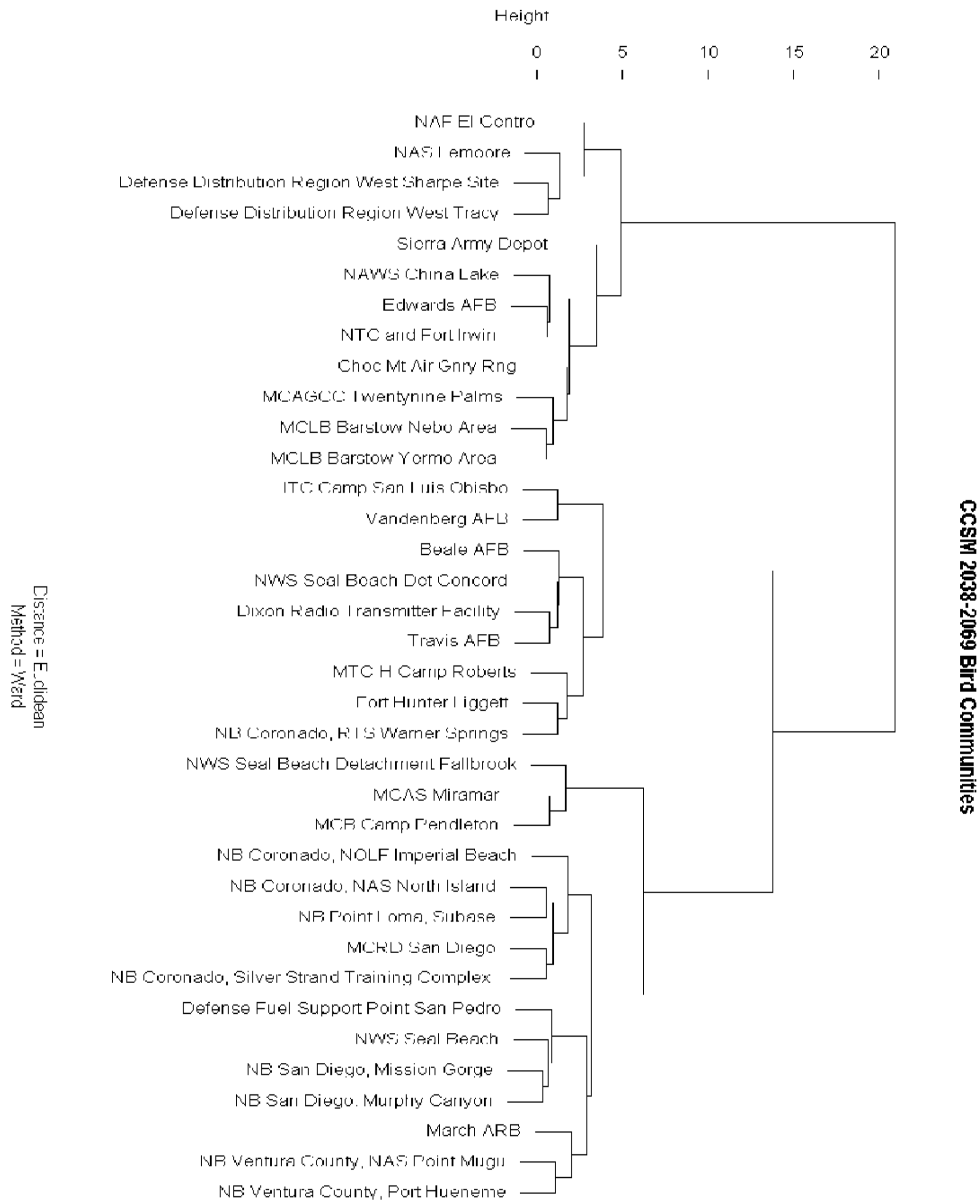


Figure 11. Dendrogram of predicted probability of occurrence for 202 California landbird species based on models using (a) climate data from 1971-2000, (b) the GFDL model for 2038-2070, and (c) the CCSM model for 2038-2069. Each DoD installation was overlain on maps of predicted bird distributions and the mean and standard deviation of the predicted probability of occurrence of each species were calculated and used to determine the clusters. Clusters were formed based on a distance matrix of Euclidean distances and used the Ward method for linkage.

Table 6. The kmeans bird community clusters that covered the largest proportion of area of select DOD installations within California are given, with the proportion of the base area covered by the given cluster indicated within parentheses. The colors correspond to the clusters in Figure 12. A change in color between current and future climate conditions indicates where bases are projected to have bird communities comprised of species which come from a different regional species pool.

DOD installation name	2010 (% area)	2050 GFDL (% area)	2050 CCSM (% area)
NAF El Centro	1(100)	8(100)	4(100)
Presidio Of Monterey	11(100)	14(100)	7(100)
Vandenberg AFB	11(100)	14(100)	7(100.00)
ITC Camp San Luis Obispo	11(88.89)	14(83.33)	7(97.22)
Beale AFB	12 (84)	12(81.33)	14(67.00)
Defense Distribution Region West Sharpe Site	12(100)	10(100)	14(100)
Dixon Radio Transmitter Facility	12(100)	10(100)	14(100)
NB Ventura County, NAS Point Mugu	12(68.00)	6(100)	7(56.00)
NWS Seal Beach Det Concord	12(88.24)	14(73.53)	7(50.00)
Travis AFB	12(96.77)	10(54.84)	14(83.87)
Choc Mt Air Gnry Rng	14(88.29)	15(83.68)	3(48.64)
Sierra Army Depot	2(100)	7(100)	6(100.00)
MCAGCC Twentynine Palms	4(67.70)	5(79.21)	3(89.34)
NTC and Fort Irwin	4(71.71)	5(97.13)	3(65.91)
NAWS China Lake	4(73.32)	5(98.25)	3(49.19)
MCLB Barstow Yermo Area	4(81.82)	5(72.73)	3(100.00)
MCLB Barstow Nebo Area	4(90.48)	5(100)	3(100.00)
Edwards AFB	4(98.31)	5(98.93)	3(73.86)
Defense Distribution Region West Tracy	7(100)	2(100)	2(100)
NAS Lemoore	7(100)	2(100)	2(100)
NB Coronado, NAS North Island	7(64.29)	6(100)	1(100)
MTC-H Camp Roberts	8(88.02)	14(50.56)	14(89.89)
Fort Hunter Liggett	8(89.01)	3(52.82)	5(42.61)
NB Coronado, RTS Warner Springs	8(97.22)	3(52.78)	5(75.00)
NB Coronado, Naval Amphibious Base	9(100)	6(100)	1(100)
March ARB	9(100)	6(100)	1(92.31)
MCAS Miramar	9(100)	6(100)	1(100)
MCRD San Diego	9(100)	6(100)	1(100)
NB Coronado, NOLF Imperial Beach	9(100)	6(100)	1(100)
NB Coronado, Silver Strand Training Complex	9(100)	6(100)	1(100)
NB San Diego, Mission Gorge	9(100)	6(100)	1(100)
NB San Diego, Murphy Canyon	9(100)	6(100)	1(100)
NWS Seal Beach	9(100)	6(100)	1(100)
NWS Seal Beach Detachment Fallbrook	9(100)	6(100)	1(100)
NB Ventura County, Port Hueneme	9(100)	6(100)	1(100)
Defense Fuel Support Point San Pedro	9(100)	6(100)	1(100)
NB Point Loma, Subase	9(50)	6(100)	1(100)
MCB Camp Pendleton	9(95.79)	6(93.85)	1(95.65)

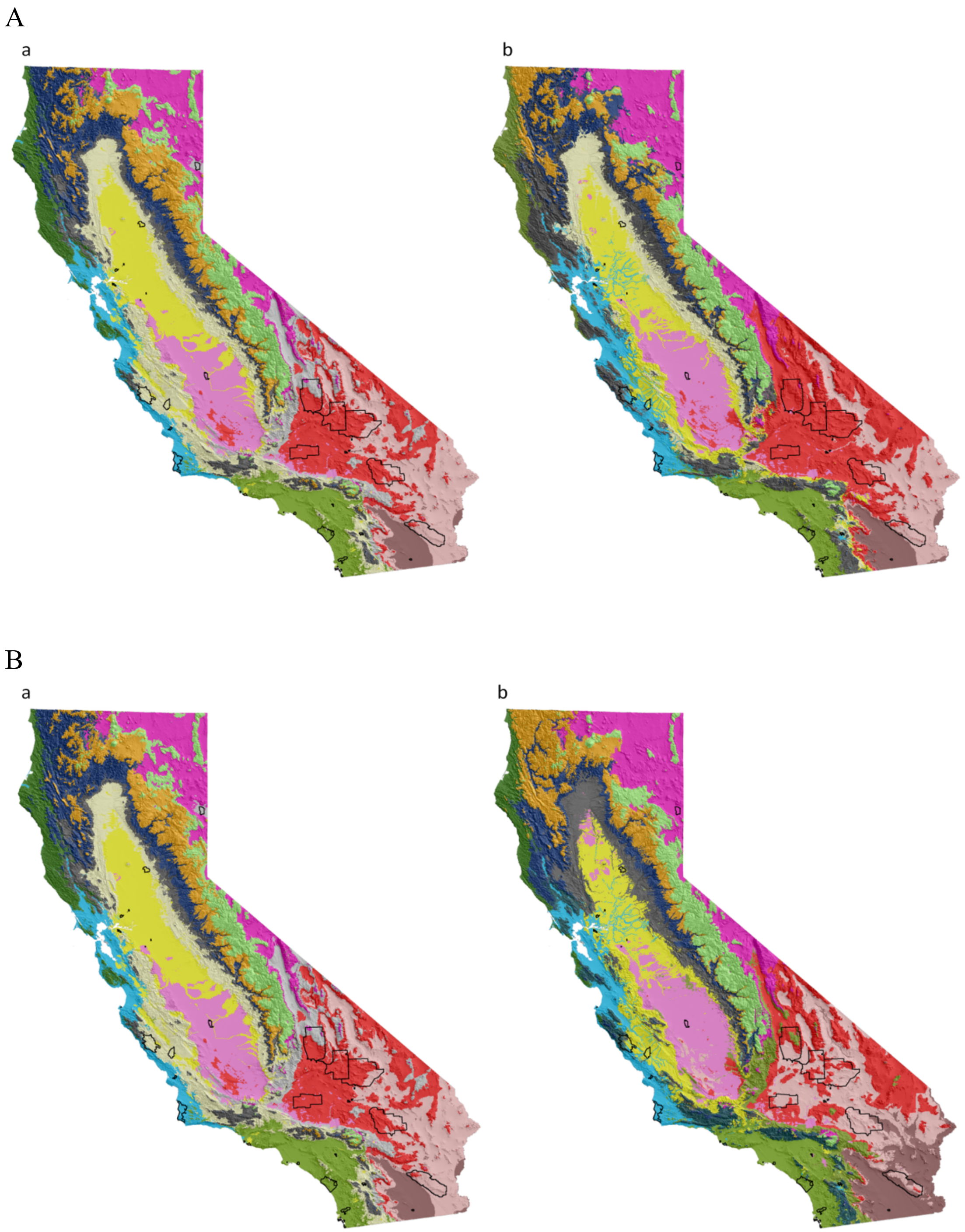


Figure 12. Kmeans clusters of bird community composition based on Maxent models of species distributions under (a) current (1971-2000) climate and (b) future climate (2038-2070) based on (A) the GFDL general circulation model, and (B) the CCSM general circulation model. Colors indicate regions within each map that have similar bird community composition within the given time period. Colors occurring in (a) and not (b) are clusters which disappear in the future, colors appearing in (b) and not (a) indicate novel clusters.

Assessing Changes in Environment and Bird Communities

Methods – Environmental Space

It is somewhat trivial to assess the change between current and projected future for any individual climate parameter. However, the overall climate of an area includes measures of temperature and precipitation as well changes in the seasonality of these variables and how the variables interact with one another. To truly understand how much the climate is projected to change in a given area it is useful to be able to condense these multivariate dimensions of climate— which we term environmental space—into a single dimension. For this analysis we included the same eight climate variables that were used to model bird-species distributions to determine the magnitude of multivariate climate that is projected to change. To estimate the magnitude of future climate change across California, we calculated the distance in environmental space between current and future climate conditions. The magnitude of climate change is calculated using the standardized Euclidean distance (SED) using the formula:

$$SED_{ij} = \sqrt{\sum_{k=1}^{n} \frac{(b_{ki} - a_{kj})^2}{s_{kj}^2}}$$

where n is the number of climate variables included in the analysis (here, $n = 8$), a is value of climate variable k from the late 20th-century California dataset at grid cell j, b is the value of climate for the future California climate projection at grid cell i, and s_{kj} is the standard deviation of climate variable k based on the inter-annual variability of late 20th-century California climate (Williams et al. 2007). The standardization is used to place all of the climate variables in the same units and to place greater weight in areas with low inter-annual variability in climate. The rationale for the temporal standardization is that in areas with low inter-annual variability, a species would be faced with future climate conditions beyond the range to which it has become adapted, based on recent climate. In areas with high inter-annual variability, however, a species may be pre-adapted to future climate conditions if future climate change is not too great.

Results – Environmental Space

Maps of the standardized Euclidean distance (SED) indicate the magnitude of future climate change relative to recent inter-annual climate variability. In general, the projections from the two future climate models produced maps with similar patterns in future climate change (Fig. 13). For example, both models project high levels of climate change in southeastern California, particularly in desert areas such as Death Valley and the Sonoran desert (Fig. 13). DoD installations in desert regions such as China Lake and Chocolate Mountain are projected to experience high magnitude of climate change. Both models project low levels of climate change along the central and southern coast (Fig. 13). There are differences between the two models; for example, the CCSM model projects moderate change along the north coast while the GFDL model projects climate to be stable in this region (Fig. 13).

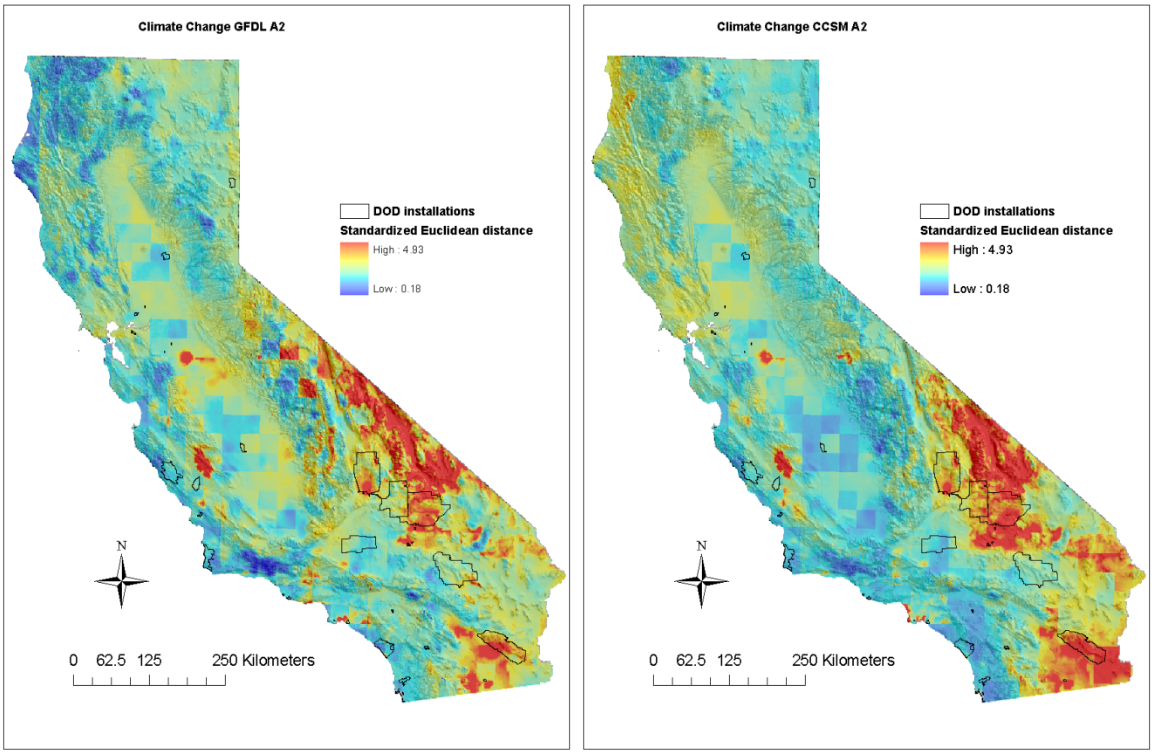


Figure 13. Maps of the magnitude of future climate change based on the GFDL and CCSM general circulation models. The magnitude of change is measured using the standardized Euclidean distance; warm colors indicate greater projected change from current climate.

Methods – Bird Community Changes

To summarize the changes in bird communities, we used maps of the predictions for 202 bird species within California under current climate and the two future climate scenarios to calculate an index of bird community turnover within each pixel between current and future climate. We used the Bray-Curtis dissimilarity index (*BC*) as a measure of community turnover based on the following equation:

$$BC_{i,h} = \frac{\sum_{j=1}^{P} |a_{ij} - a_{hj}|}{\sum_{j=1}^{P} a_{ij} + \sum_{j=1}^{P} a_{hj}}$$

where similarity is based upon the predicted suitability for species *a* at grid cell *i* for late 20th-century climate conditions and grid cell *h* for future climate predictions (Bray and Curtis 1957). The index ranges from 0 to 1, where 0 means that communities are identical across time and 1 means that bird communities are completely different. The Bray-Curtis distance provides a measure of species turnover between current and future conditions. We calculated the average

Bray-Curtis distance value for each military base in order to rank the magnitude of the projected species turnover. We also examined the relationship between turnover and the size of each military base.

Results – Bird Community Changes

Maps of community turnover indicate that locations in the foothills of the Sierra Nevada mountains though the north of the Central Valley will have the highest levels of community change (Fig. 14). Although there is agreement in the projection of high turnover in the Sierra Nevada for the two climate models used, the projected bird community differs between the two climate models in other regions. For example, high dissimilarity is projected across a larger region in the coast range of Sonoma and Mendocino counties under the CCSM model (Fig. 14). Similarly, moderate bird community dissimilarity is projected for the San Diego coast by the GFDL model whereas the same area is projected to have low dissimilarity under the CCSM model (Fig. 14). In general, the areas of highest bird community turnover occur outside of DoD lands, although some installations, such as NAWS China Lake, do have areas with moderately high projected bird community turnover for both future climate models.

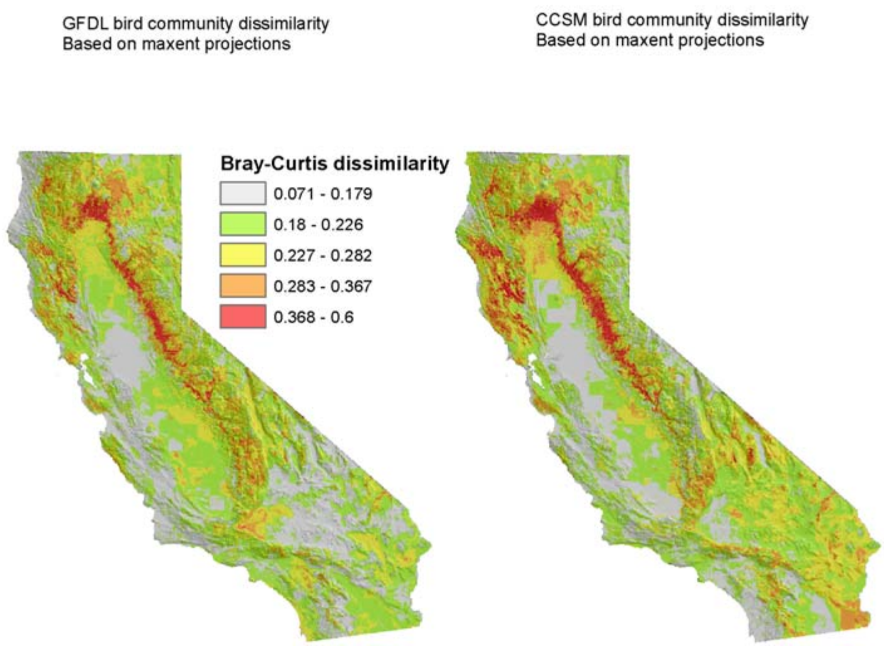


Figure 14. Maps of Bray-Curtis dissimilarity based on 202 bird species distribution models for current and future climate. High values indicate greater changes in bird community composition.

The mean turnover is related to the area of the military bases, with larger bases generally showing greater maximum turnover (Table 7, Fig. 15). This result could be due to the species-area relationship in which larger areas tend to have more species and therefore more opportunity to have greater bird community turnover with future climate change. The result may also reflect the fact that larger bases may contain greater topographic heterogeneity and as a result a greater range of climate conditions. The greater range of conditions will usually lead to a greater range of bird community types, each of which could change in different ways in the future. Therefore, larger bases, which support a greater diversity of bird community types, are more likely to need adaptation plans that incorporate the possibility of novel community types than smaller bases.

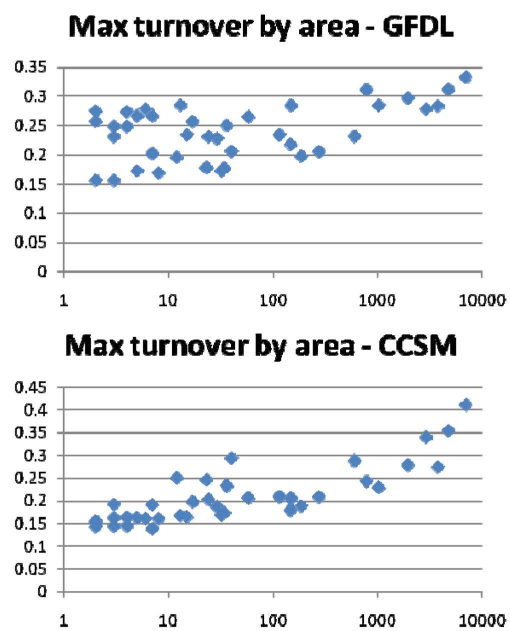


Figure 15. Maximum turnover in bird community composition (from Bray-Curtis dissimilarity index) (y-axis) versus area of military base (ha) (x-axis) for 39 bases in California.

Table 7. Mean, minimum, and maximum turnover (calculated from Bray-Curtis distance) for military bases in California based on the a) GFDL scenario and b) CCSM scenario. Bases are ranked from greatest to least amount of turnover.

(a)

Installation	GFDL turnover rank	mean	min	max
NB Coronado, NAS North Island	1	0.279	0.274	0.285
NB Coronado, Naval Amphibious Base	2	0.275	0.275	0.275
NB Point Loma, Subase	3	0.274	0.267	0.279
MCRD San Diego	4	0.270	0.268	0.274
NB Coronado, Silver Strand Training Complex	5	0.263	0.259	0.267
NB Coronado, NOLF Imperial Beach	6	0.248	0.227	0.267
NB San Diego, Murphy Canyon	7	0.246	0.242	0.249
NAF El Centro	8	0.245	0.232	0.257
NB San Diego, Mission Gorge	9	0.243	0.240	0.249
March ARB	10	0.230	0.222	0.235
Defense Fuel Support Point San Pedro	11	0.226	0.222	0.232
Edwards AFB	12	0.225	0.151	0.298
NB Ventura County, NAS Point Mugu	13	0.216	0.195	0.231
NWS Seal Beach	14	0.215	0.192	0.229
MCB Camp Pendleton	15	0.213	0.135	0.312
MCAS Miramar	16	0.210	0.177	0.285
NAS Lemoore	17	0.207	0.174	0.235
NB Ventura County, Port Hueneme	18	0.201	0.198	0.203
Choc Mt Air Gnry Rng	19	0.200	0.121	0.279
NWS Seal Beach Detachment Fallbrook	20	0.188	0.144	0.265
Beale AFB	21	0.188	0.152	0.218
ITC Camp San Luis Obispo	22	0.188	0.156	0.250
Fort Hunter Liggett	23	0.184	0.131	0.285
NAWS China Lake	24	0.184	0.121	0.333
MTC-H Camp Roberts	25	0.178	0.145	0.206
MCLB Barstow Yermo Area	26	0.174	0.159	0.196
MCAGCC Twentynine Palms	27	0.174	0.121	0.284
Defense Distribution Region West Sharpe Site	28	0.172	0.171	0.173
NTC and Fort Irwin	29	0.170	0.111	0.312
Dixon Radio Transmitter Facility	30	0.165	0.161	0.169
Travis AFB	31	0.163	0.150	0.173
NWS Seal Beach Det Concord	32	0.162	0.148	0.178
Sierra Army Depot	33	0.159	0.148	0.198
MCLB Barstow Nebo Area	34	0.158	0.147	0.178
Defense Distribution Region West Tracy	35	0.157	0.157	0.157
Presidio Of Monterey	36	0.152	0.149	0.156
NB Coronado, RTS Warner Springs	37	0.149	0.120	0.206
Vandenberg AFB	38	0.147	0.110	0.232

(b)

Installation	CCSM turnover rank	mean	min	max
Choc Mt Air Gnry Rng	1	0.265	0.167	0.340
MCLB Barstow Yermo Area	2	0.239	0.233	0.251
NAWS China Lake	3	0.236	0.164	0.411
NTC and Fort Irwin	4	0.236	0.170	0.354
MCLB Barstow Nebo Area	5	0.230	0.215	0.246
NB Coronado, RTS Warner Springs	6	0.210	0.179	0.294
MCAGCC Twentynine Palms	7	0.208	0.149	0.274
NB Ventura County, NAS Point Mugu	8	0.193	0.186	0.203
NAS Lemoore	9	0.191	0.165	0.210
Defense Fuel Support Point San Pedro	10	0.189	0.186	0.193
NB Ventura County, Port Hueneme	11	0.188	0.186	0.192
ITC Camp San Luis Obispo	12	0.182	0.145	0.233
NAF El Centro	13	0.178	0.161	0.198
Vandenberg AFB	14	0.177	0.131	0.288
NWS Seal Beach	15	0.177	0.162	0.188
Edwards AFB	16	0.177	0.126	0.278
Fort Hunter Liggett	17	0.176	0.129	0.230
MCB Camp Pendleton	18	0.170	0.117	0.244
MTC-H Camp Roberts	19	0.169	0.128	0.209
NWS Seal Beach Detachment Fallbrook	20	0.165	0.139	0.207
MCAS Miramar	21	0.164	0.141	0.206
Travis AFB	22	0.163	0.152	0.170
MCRD San Diego	23	0.163	0.162	0.165
Defense Distribution Region West Sharpe Site	24	0.163	0.161	0.163
NB Coronado, NAS North Island	25	0.163	0.158	0.168
March ARB	26	0.162	0.158	0.166
Presidio Of Monterey	27	0.159	0.152	0.163
Beale AFB	28	0.157	0.128	0.180
Dixon Radio Transmitter Facility	29	0.156	0.149	0.161
NB Coronado, Naval Amphibious Base	30	0.155	0.154	0.157
NWS Seal Beach Det Concord	31	0.154	0.144	0.174
NB Point Loma, Subase	32	0.154	0.149	0.162
Defense Distribution Region West Tracy	33	0.152	0.152	0.152
NB Coronado, Silver Strand Training Complex	34	0.150	0.139	0.163
Sierra Army Depot	35	0.147	0.136	0.189
NB San Diego, Murphy Canyon	36	0.143	0.141	0.145
NB San Diego, Mission Gorge	37	0.141	0.140	0.145
NB Coronado, NOLF Imperial Beach	38	0.129	0.112	0.139

Community Change and Climate Change

Methods

To assess how locations might change in the future in terms of the combination of climate change and changes in bird-community composition, we plotted the values for each pixel from the projected bird-community change (Bray-Curtis distance) and the projected magnitude of climate change (standardized Euclidean distance) within each DoD installation. This provided a way to rank the exposure and sensitivity of bird communities to climate change on DoD lands.

Results

Figure 16 shows how the combined climate/bird community changes within several installations relate to the combined changes for all of California. Bases that have many pixels in the top right corner of the plots are projected to have a high magnitude of climate change and high degree of bird community turnover (e.g., China Lake, Fig. 16 a-b.). These bases are those projected to be exposed to high levels of climate change and whose bird communities will be sensitive to this change. Natural-resource management on installations such as China Lake will require flexibility as both the future climate conditions and projected bird communities will likely change as compared to contemporary conditions. On the other hand, some bases (e.g., MLCB Barstow Nebo Area) are projected to experience low levels of bird-community change even though they are exposed to high magnitudes of climate change (Fig. 16 c-d); these bird communities may be resilient to climate change. Yet other installations, such as Camp Pendleton, are projected to experience a low magnitude of climate change but high levels of community turnover, particularly for the GFDL climate model (Fig. 16 e-f). The composition of these bird communities is projected to be highly sensitive to climate change and thus small changes in management could have a disproportionate effect on the resulting bird communities.

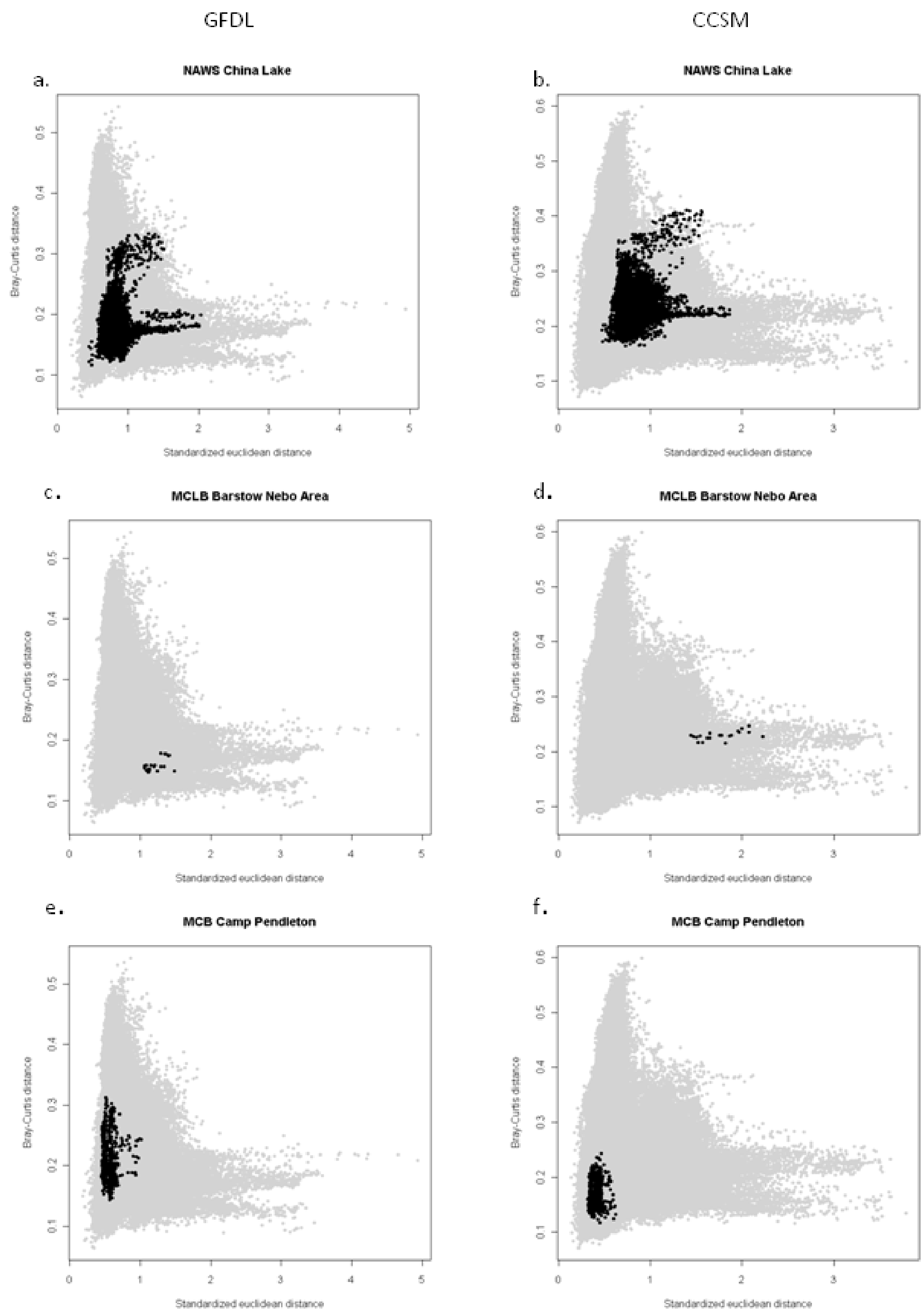


Figure 16. The change in composition of bird communities (Bray-Curtis dissimilarity) based on Maxent models of 202 species in California are plotted against the corresponding projected magnitude of climate change (Standardized Euclidean Distance). Black dots indicate the values of pixels within the corresponding DoD installation: NAWS China Lake (a,b), MCLB Barstow Nebo Area (c,d), and MCB Camp Pendleton (e,f). The grey points show the values of all points within California.

Changing Land Use

Climate change is only one of several environmental changes that will threaten species and biological communities in the future. Rapid changes in land use, particularly urban, suburban, and exburban housing development, has and may in the future pose a more immediate threat to conservation and environmental management than climate change (Czech et al. 1997, Davies et al. 2006, Jetz et al. 2007). Species responses to development have been shown to vary across the urban gradient, with native species predominating in relatively undisturbed areas and invasive or exotic species predominating in more urban areas (Blair 1996, Hansen et al. 2005). These changes are of particular concern for management on military bases, where encroachment of development from "outside the fence" may compromise activities that are essential to meeting the military mission.

Methods

Following an approach developed in our other work (Jongsomjit et al., in review), we examined the potential combined impacts of climate change and future housing development at both the individual base level and at the ecoregional level. We restricted our analysis to California breeding landbird special-status species (i.e., listed as either a species of special concern (Shuford and Gardali 2008) or threatened or endangered at the federal or state level) for which there were sufficient records (>20) to model. At the level of individual installations, we looked at three buffer zones surrounding the base (2 km, 5 km, and 10 km) including the area within the base (e.g., Fig. 17). These buffers allowed us to look at potential development impacts immediately surrounding the base as well as development pressure at broader scales. To examine impacts at a regional scale, we grouped together bases that occurred within the same ecoregion (Table 1), using the same buffer zones as before. Buffer zones were created within ArcGIS 9.3.1 (ESRI 2009) using projected shape files that were converted to 800-m grids to match the spatial resolution of the climate-grid surfaces.

To estimate the impact of climate change on species distributions, for each base and its respective buffer zones we calculated the mean difference in probability of occurrence across all pixels between current and future SDMs for each species. To constrain our climate-impact calculations to suitable habitat, areas currently classified as urban or commercial were excluded from SDM outputs for climate-change impact calculations. We estimated development impacts on species distributions for each base and its respective buffer zones by calculating the mean difference in probability of occurrence across all pixels between future species distributions with *current* developed areas removed and future species distributions with *future* developed areas removed. This was done for each of three housing-density classes: >12.4 units/ha (high/urban), 2.47 – 12.4 units/ha (low/suburban), and 0.247 – 2.47 units/ha (very low/exurban), following Beardsley et al. (2009). Current commercial areas were excluded for development-impact

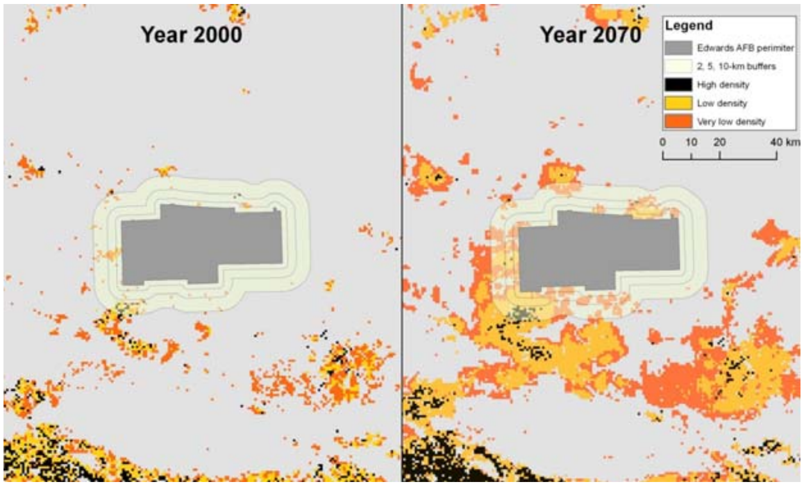


Figure 17. Detail of Edwards Air Force Base showing base area and perimeter in gray with three buffer zones used for analysis in light green (2, 5, and 10-km). Housing density classes are also shown for the current period (year 2000) and projected future (year 2070).

calculations. For each housing-density class examined, areas classified as higher density housing were also excluded from development-impact calculations. Although our SDMs provided explicit information on probabilities of species occurrence, our analysis of development only provides information on how much of a species' range may be impacted by each development density.

Spatial calculations were conducted in R (R Development Core Team 2010), as follows: Let A = probability of current species distribution, B = probability of future species distribution, C = area of current residential development, and D = area of future residential development. Then:

Δ_C = Change Due to Climate = $(B \setminus C) - (A \setminus C)$

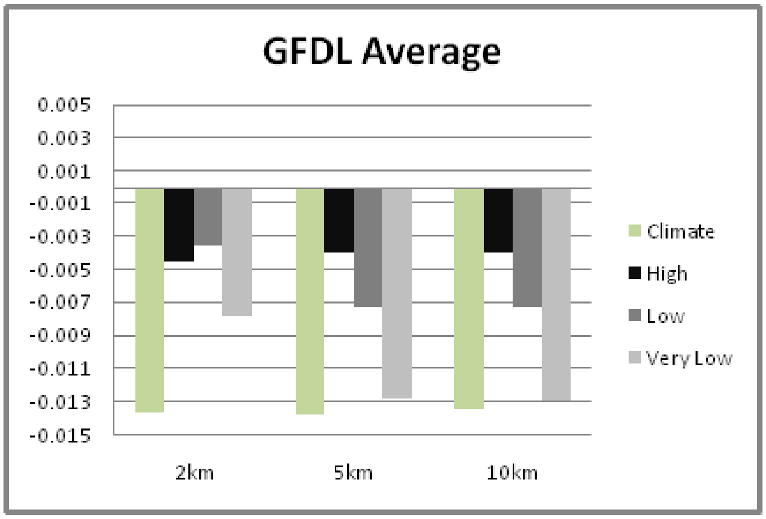
Δ_L = Change Due to Development = $(B \setminus D) - (B \setminus C)$

Δ_O = Overall Change = $\Delta_C + \Delta_L = (B \setminus D) - (B \setminus C) + (B \setminus C) - (A \setminus C) = (B \setminus D) - (A \setminus C)$

Installation Results

When averaged across all installations, both climate scenarios show potentially larger impacts from housing development than from climate change across all three buffer distances examined. The GFDL scenario (Fig. 18A), the warmer of the two scenarios, projected average climate-induced decreases in species probabilities of occurrence that varied little among buffer distances. For this scenario the overall impacts of housing were greater than climate impacts, with high-density impacts varying little between buffers and suburban and exurban densities becoming more prominent at the 5-km and 10-km levels. The CCSM scenario (Fig. 18B) projected average increases in species probabilities of occurrence due to climate change. This increase was overshadowed, however, by larger impacts due to housing. High-density impacts remained fairly stable among buffer distances while low- and very-low-density impacts became more prominent at 5 km and 10 km. Under both scenarios, these patterns indicate that low- and very-low-density impacts become proportionately most important between 2 km and 10 km from base perimeters.

A



B

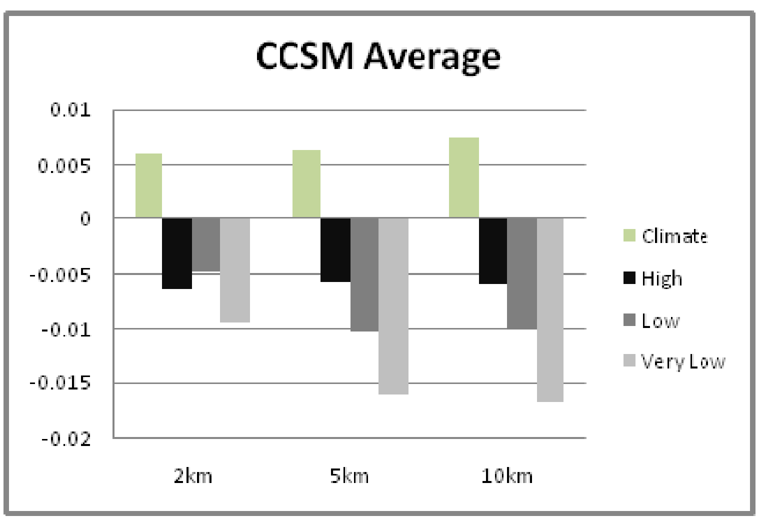
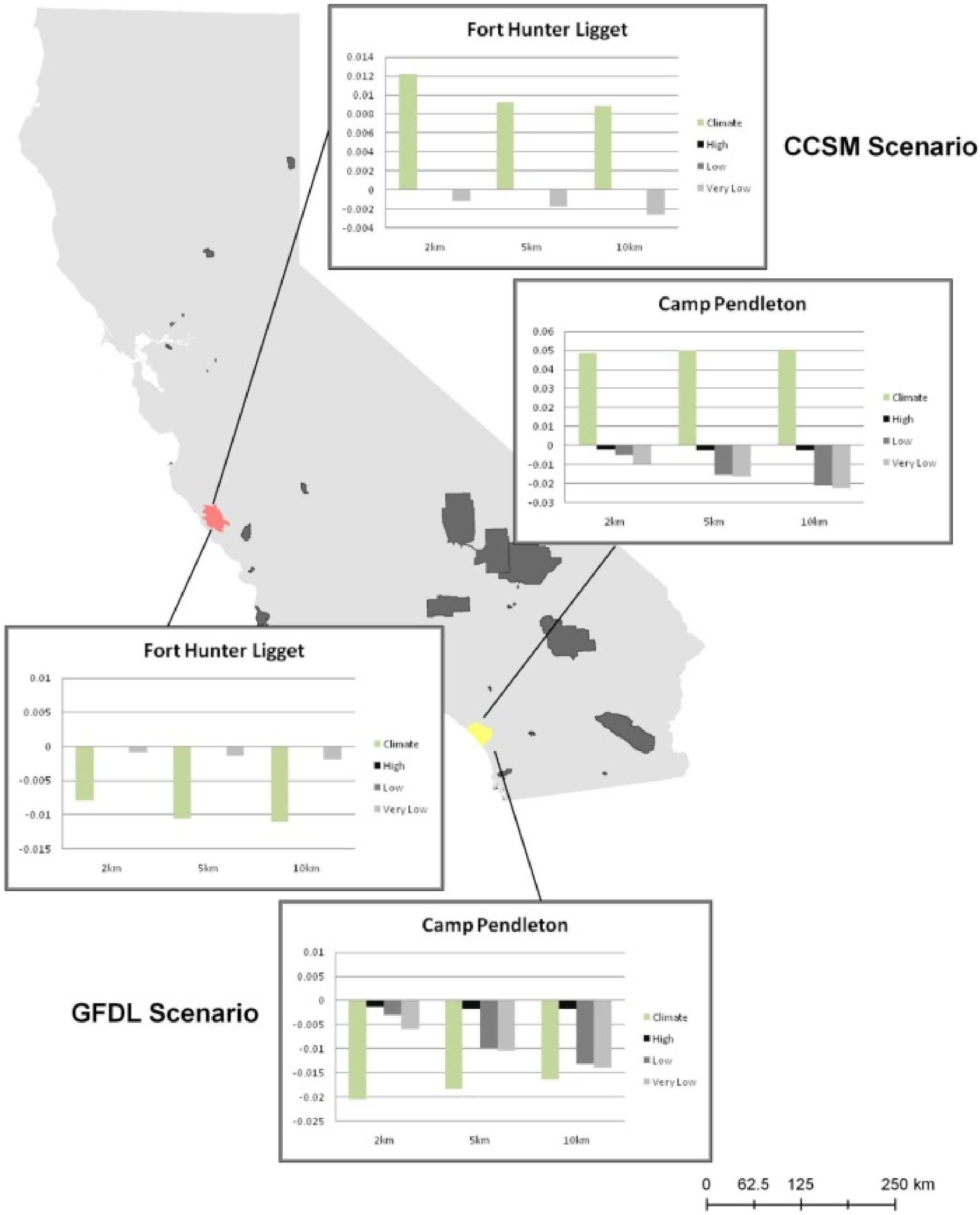


Figure 18. The effect of climate and high-, low-, and very-low-density housing on the projected distribution of special-status bird species on and within 2-km, 5-km, and 10-km buffer zones averaged across DoD installations for two climate scenarios: A) GFDL, and B) CCSM. The Y axis is the mean change in the probability of occurrence between current and future climate given the climate or land-use scenario. Note the different scales in each graph.

Of the 29 bases examined under the GFDL scenario, 23 had climate-induced reductions in species occurrences, 10 of which had even larger reductions due to housing change (Appendix 2, 3, and 4). For this same scenario, 6 bases had climate-related increases in species probabilities of occurrence, 5 of which had housing-related reductions that were as great as or greater than the impacts of climate. Under the CCSM scenario, 16 bases had climate-induced decreases, 8 of which had larger reductions due to housing change. For this scenario, 13 bases had climate-related increases, 7 of which had housing related reductions that were as great as or greater than the impacts of climate.

At the installation level, climate impacts varied considerably, both between climate scenarios and among bases, reflecting the uncertainty associated with future climate and the geographic variation across California, respectively. For example, Fort Hunter Liggett and Camp Pendleton showed reductions in species probabilities of occurrence due to climate change under the GFDL scenario while showing increases in probability of occurrence under the CCSM scenario (Fig. 19). Here, impacts of housing density were slightly smaller under the GFDL scenario. But not all bases had such large swings in climate impact between scenarios. For example, Travis Air Force Base, Fort Irwin, and China Lake each showed decreases in species' probabilities of occurrence under both climate scenarios (Fig. 19). In general, the impacts of housing tended to vary much less than those of climate. Although some bases had comparatively low to no impacts from development (e.g., Fort Irwin, Sierra Army Depot), most had large impacts that often were larger than climate (e.g. Chocolate Mountain Air Gunnery Range, NB Coronado, Naval Amphibious Base).


Fort Hunter Ligget
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
2km
5km
10km
Climate
High
Low
Very Low
CCSM Scenario
Camp Pendleton
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
2km
5km
10km
Climate
High
Low
Very Low
Fort Hunter Ligget
0.01
0.005
0
-0.005
-0.01
-0.015
2km
5km
10km
Climate
High
Low
Very Low
Camp Pendleton
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
2km
5km
10km
Climate
High
Low
Very Low
GFDL Scenario
0
62.5
125
250 km

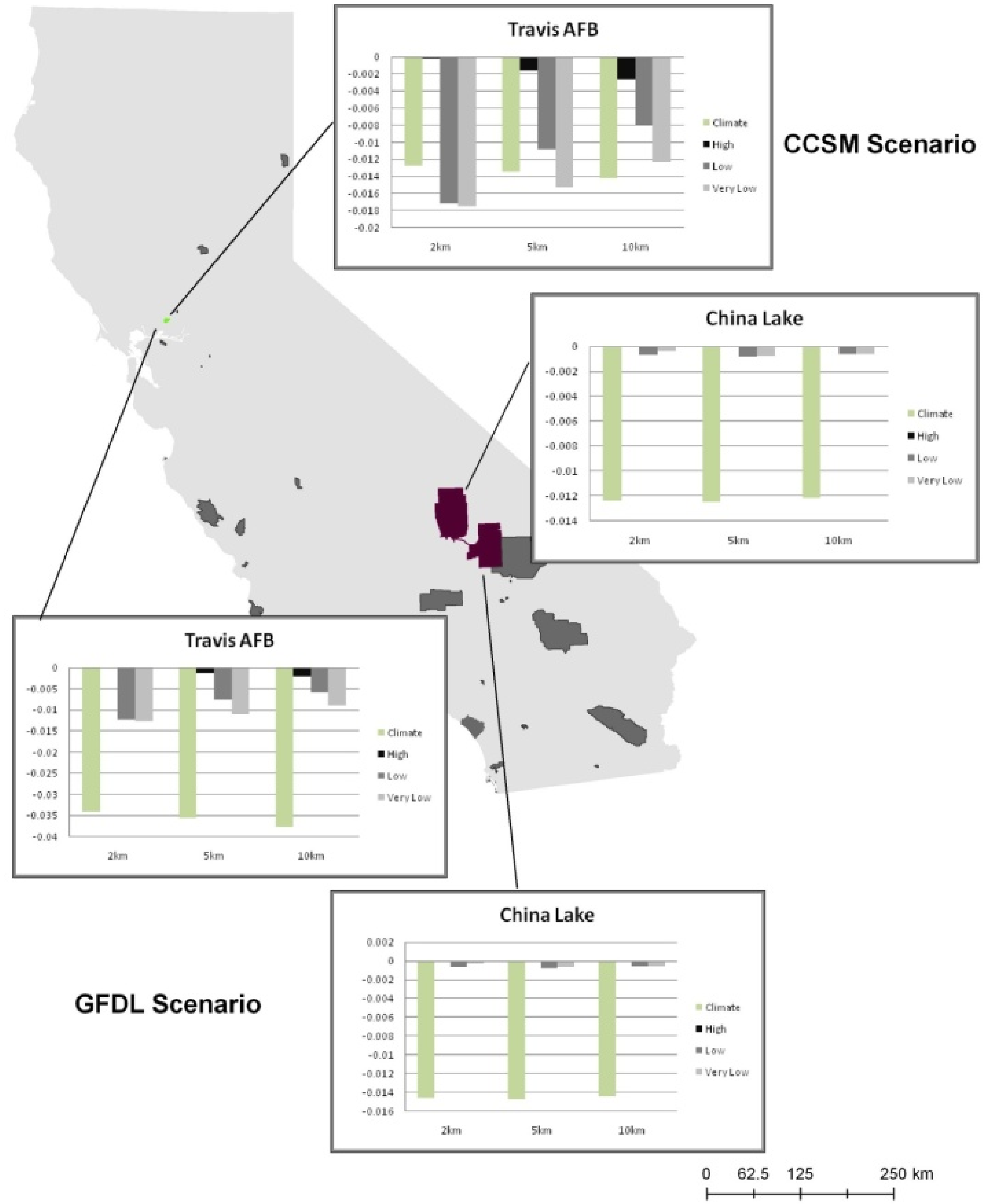


Figure 19. Installation-level summaries of climate and housing-density changes in distributions of special-status bird species for three buffer distances for selected bases under two climate scenarios (CCSM and GFDL). Note the different scales in each graph.

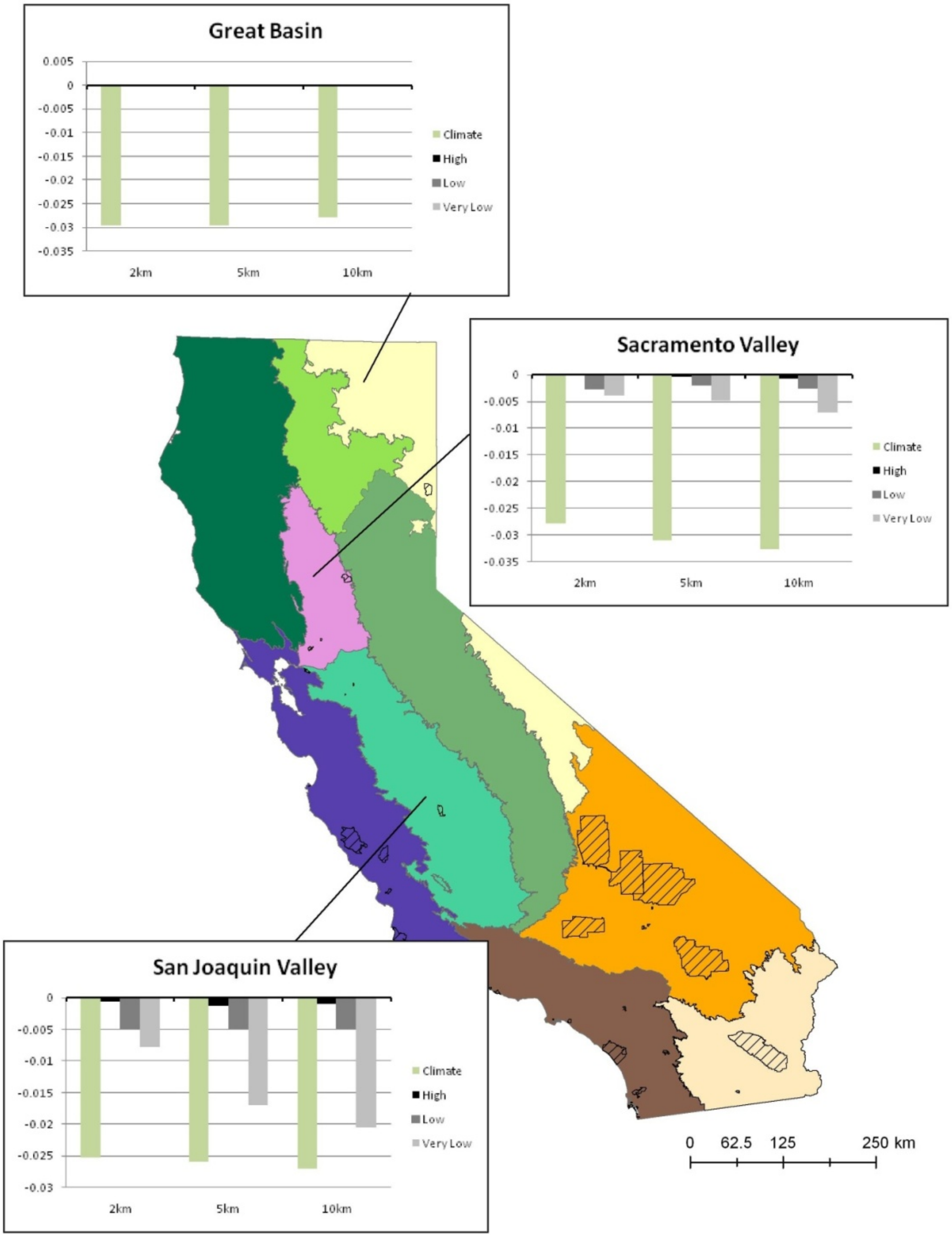
Ecoregional Results

Under the GFDL scenario, the top three ecoregions with the greatest climate-induced declines in species probability of occurrence were the Sacramento Valley, Great Basin, and San Joaquin Valley (Fig. 20a). Under this scenario, the San Joaquin Valley also had one of the greatest potential impacts from housing, nearly matching the negative impact from climate at the 5-km and 10-km buffers. The Southwestern ecoregion had the greatest overall impacts from housing, potentially eclipsing the reductions due to climate across all buffers. All ecoregions except the Sonoran Desert had negative climate impacts under this scenario.

Under the CCSM scenario, the ecoregions with the greatest climate-induced declines were the Great Basin and the San Joaquin Valley followed by the Sacramento Valley and Mojave Desert with nearly identical climate impacts (Fig. 20b). Under this scenario, the San Joaquin Valley also had high impacts from housing density, eclipsing the climate impacts across all buffers. Housing impacts were also nearly as large as or larger than climate impacts for the Sacramento Valley and Sonoran Desert ecoregions. The Southwestern ecoregion had increases due to climate under this scenario, but it again had the greatest decreases from housing compared to all other ecoregions. The Central Coast was the only other region with projected increases due to climate under this scenario.

Overall, the entire Central Valley region is vulnerable to both future climate and housing-density change. Not surprisingly, the Southwestern ecoregion of the state, encompassing the Los Angeles and San Diego areas, had the greatest potential impacts from housing-density change. Although we only examined one base in the Great Basin region, it had the greatest decreases due to climate compared to all other regions.

A


Great Basin
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
2km
5km
10km
Climate
High
Low
Very Low
Sacramento Valley
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
2km
5km
10km
Climate
High
Low
Very Low
San Joaquin Valley
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
2km
5km
10km
Climate
High
Low
Very Low
0 62.5 125 250 km

B

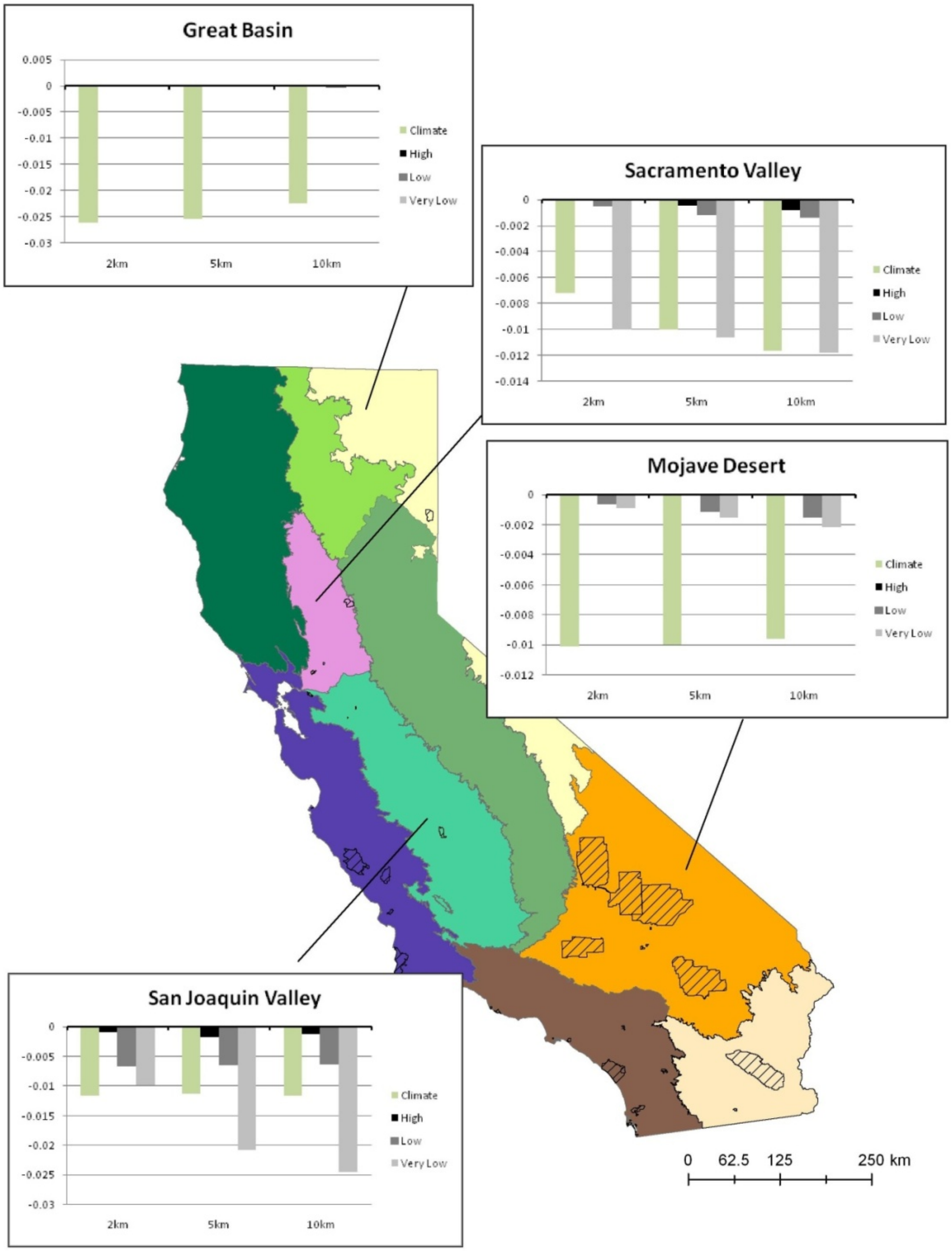


Figure 20. Ecoregional summaries for the regions with the largest declines in species probabilities of occurrence due to climate under the A) GFDL, and B) CCSM scenarios. The San Joaquin Valley had potential impacts from housing that were larger than the climate impacts for the GFDL scenario, and it and the Sacramento Valley had large impacts from housing density in the CCSM scenario. Note the different scales in each graph.

Assessing Species Vulnerability Rating Systems

Methods

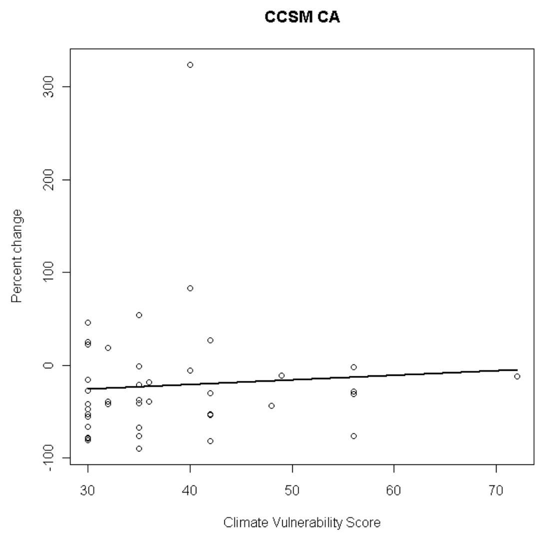
Although several rating systems have been proposed or developed to assess the potential vulnerability of birds to climate change (Williams et al. 2008, Thomas et al., 2010, Rowland et al. 2011) most of these systems are general and are intended for broad-scale application. In order to tailor our analysis to the species and region (California) considered in this project, we used a vulnerability-rating framework currently being developed at PRBO Conservation Science (Gardali et al. 2012). This framework uses information on the sensitivity of a species to climate change (physiological tolerances, dispersal ability, migratory behavior, and habitat specialization) and its potential exposure to climate change (habitat, food availability, and extreme weather events) to generate a single vulnerability score for each species. To assess whether these vulnerability scores matched the magnitudes of distributional change for species projected by the two climate-model scenarios (CCSM and GFDL), we conducted regression analyses using the vulnerability scores from Gardali et al. and the percent distributional change values from Appendix 2 for all 42 species that we modeled and for which Gardali et al. calculated vulnerability scores.

Results

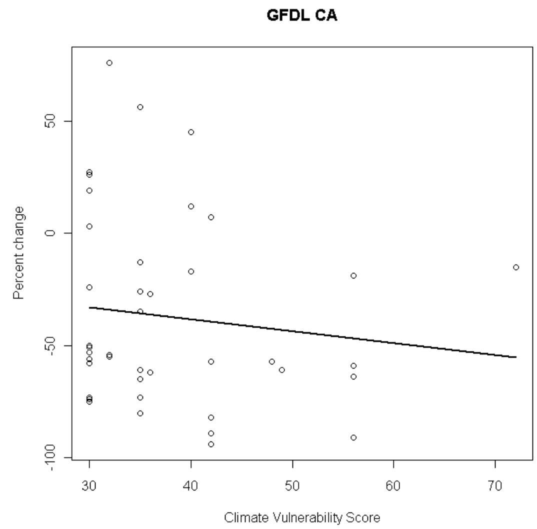
Even though the species-vulnerability score incorporates several key factors that should indicate the ability of a species to cope with the effects of climate change, the regression analyses indicated no significant relationships between the vulnerability scores and our model-based projections of distributional change (Fig. 21). This was the case whether the CCSM or GFDL scenario was used or whether the projected distributional change was calculated over the state as a whole or just for DoD installations. At this scale of analysis using these models, the vulnerability scores do not match (i.e., predict) the magnitudes of distributional change for these bird species.

This does not mean that the search for a predictive index of species vulnerability to climate change is in vain and should be abandoned, just that it is not as simple and straightforward as we might have hoped. There are many reasons why the vulnerability scores may not have matched the distributional-model projections. Most importantly, the vulnerability scores incorporate important aspects of a species' vulnerability that distribution models do not account for. For example, we project that California will have increases in suitable habitat for the Light-footed Clapper Rail for both future climate scenarios, despite the species being ranked as somewhat vulnerable to climate change (vulnerability index = 40). Our distribution models do not account for the fact that this species may not be able to disperse to areas that are not currently suitable but are projected to become suitable in the future, whereas Gardali et al.'s study does explicitly account for dispersal limitations. Also, the factors that affect a species' vulnerability at a broad, range-wide scale may not be the same as the factors determining occupancy of 800-m grid cells.

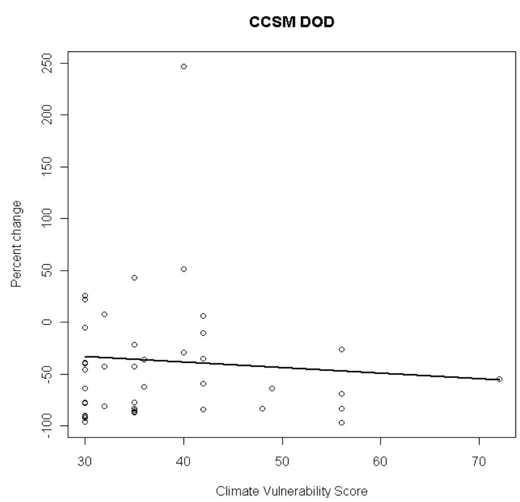
A



B



C



D

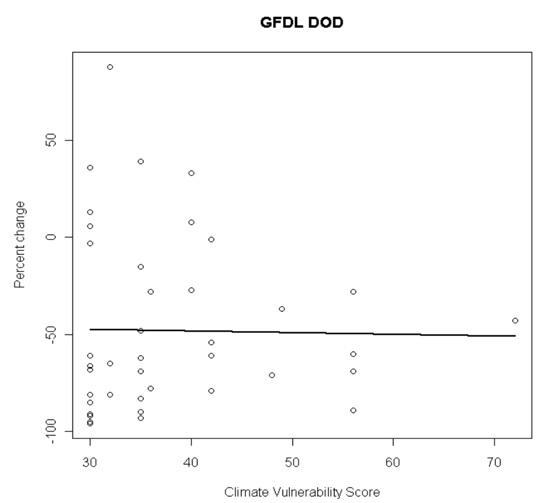


Figure 21. Regressions of the percent change in bird-species probabilities of occurrence over the state of California (A, B) and only DoD lands (C, D) versus the climate-vulnerability score for each species for two climate-change scenarios (CCSM: A, C; GFDL: B, D).

Implications for Environmental Management on DoD Installations

Climate change will require that resource managers utilize information at various spatial scales in order to effectively manage natural resources during a period of rapid environmental change. Our results provide a broad synthesis of how climate, vegetation, and bird distributions are projected to change across California and, in particular, on Department of Defense lands during this century. We have conducted our analysis at various spatial scales to provide resource managers with multiple frames of reference for unpredictable future management issues that are likely to arise.

Our distribution models formed the basis of subsequent analyses but can also be used in their own right to inform management decisions. Our projections can give managers an idea of whether or not they should continue to manage for the same sets of species that they currently manage. The models also give an indication of whether species that do not currently occur at a particular base are likely to occur in the future. Similarly, we have identified some species, such as Hermit Thrush and Ruby-crowned Kinglet, that are likely to experience declining environmental suitability across the state in the future but an increase in suitability on DoD lands, indicating potential future conservation priorities.

As with the bird-distribution models, our models of vegetation change may help managers begin to plan for future shifts in the dominant communities that make up DoD installations. Our models project that many of the bases along the central and southern California coast will experience moderate to large changes in vegetation cover for both future climate scenarios. Shifts of vegetation types on DoD lands will not only change the habitat available for animal species but will also require managers to adapt to changing conditions, for example by modifying restoration techniques. In some cases we project that certain vegetation types will no longer persist under future climate conditions, such as redwood/closed cone pine at Vandenberg AFB. Our projections can serve as a guide for where monitoring will likely provide an early warning of vegetation transitions that require adaptive planning.

Although the changes in vegetation and bird distributions that we project suggest that climate change will have significant impacts, it is also useful to have direct measures of the magnitude of future climate change. Single measures of climate such as annual precipitation may not be projected to change much in the future, as is the case with the GFDL model we use. Small decreases in precipitation combined with increasing temperature, however, can radically change the availability of water for vegetation. In some areas of California, future climate will have no current analog (Wiens et al. 2011) and in those case there are likely to be ecological surprises that will require novel approaches for resource management. Our maps of the magnitude of climate change indicate areas at the grid-cell level where future climate is projected to be quite different from current conditions or where current climate conditions may persist into the future. Combining our projections of climate and bird-community turnover further allows mangers to assess the exposure and sensitivity of their systems to climate change— important factors for guiding climate-change adaptation and assessing species vulnerabilities (Dawson et al. 2011).

The dendrograms produced by the cluster analyses can be used by resource managers on DoD installations to identify other bases that may have similar management issues with regard to the environment and bird communities. Bases with similar environments and/or similar bird communities could use this information to coordinate actions to most efficiently protect natural resources. This could be achieved by developing regional plans that are coordinated within the clusters we have identified. The climate-change projections illustrate how the regional similarities that we currently observe may or may not persist into the future. Thus, any regional plans developed for current conditions will need to be flexible enough to adapt as climate changes in the future.

As opposed to the direct effects of climate change, which are uncertain for many species even given our empirical efforts, the effects of changes in land use on species are often well understood and much simpler to predict. Urbanization can result in the loss of habitat and corresponding reductions in range sizes and populations. Our models indicate that bases within the Central Valley and southwestern parts of the state are most susceptible to this threat. Individual species responses to land-use change will vary across the urban-density gradient. For many species, even low-density housing can have significant impacts. This may be particularly true for the special status species we examined, several of which have become listed or are threatened due in part to loss and degradation of suitable habitat via urbanization (e.g., Coastal California Gnatcatcher, Grasshopper Sparrow, San Diego Cactus Wren). For others better adapted to living with people, low- or even high-density housing may represent opportunities. By combining projections of species response to climate and projections of land use we demonstrate that species distributions along the periphery of DoD installations are sensitive to both the changes in climate and land use. This is relevant for DoD land managers in several ways. For example, increases in urbanization near DoD installations could result in species seeking refuge on DoD lands, potentially compromising DoD activities. Disturbance caused by habitat degradation can lead to the establishment of non-native or invasive species, which may further degrade habitat suitability or threaten the population viability of native species within installations. Moreover, loss of habitat around DoD lands could serve to isolate populations, restricting their ability to migrate into or out of installations and making them more susceptible to rapidly changing climate. Model projections show that low- and very low-density urbanization will be particularly prevalent around most bases, much more so than high-density urbanization. This pattern suggests opportunities to protect habitat around installations through reductions in urban sprawl. Regardless, managers should be aware that land-use change can have larger impacts than climate on species and their habitats.

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Appendix 1A. Percentage changes in distribution of 202 breeding landbird species from the present to 2070 in response to climate changes projected by the CCSM and GFDL climate-change models. Changes are evaluated separately for all of California and for only areas within DoD installations in the state. Special-status species are highlighted (see key at end of table).

Common Name	**Scientific Name**	**% Change CCSM CA**	**% Change GFDL CA**	**% Change CCSM DOD**
Acorn Woodpecker	*Melanerpes formicivorus*	-2.06%	4.17%	-51.66%
Allen's Hummingbird	*Selasphorus sasin*	-54.01%	-21.86%	-81.81%
American Crow	*Corvus brachyrhynchos*	-12.85%	-17.16%	-28.73%
American Dipper	*Cinclus mexicanus*	-36.32%	-27.32%	-68.91%
American Goldfinch	*Carduelis tristis*	-12.71%	-23.03%	-12.84%
American Kestrel	*Falco sparverius*	20.67%	-8.36%	30.44%
American Robin	*Turdus migratorius*	-20.73%	-24.95%	-51.98%
Anna's Hummingbird	*Calypte anna*	-1.71%	11.49%	-49.02%
Ash-throated Flycatcher	*Myiarchus cinerascens*	3.20%	33.45%	-32.82%
Bald Eagle	*Haliaeetus leucocephalus*	-45.23%	-50.52%	-75.75%
Barn Owl	*Tyto alba*	13.62%	-17.18%	5.46%
Bank Swallow	*Riparia riparia*	-39.18%	-53.87%	-81.23%
Barn Swallow	*Hirundo rustica*	-31.75%	-58.49%	-61.98%
Black-billed Magpie	*Pica hudsonia*	0.53%	-30.14%	-57.90%
Black-backed Woodpecker	*Picoides arcticus*	-21.33%	-26.31%	-42.62%
Black-capped Chickadee	*Poecile atricapillus*	-80.60%	-57.94%	-78.49%
Black-chinned Hummingbird	*Archilochus alexandri*	2.13%	34.34%	-39.30%
Black-chinned Sparrow	*Spizella atrogularis*	-20.61%	38.06%	-23.38%
Belted Kingfisher	*Ceryle alcyon*	-38.70%	-61.91%	-62.42%
Bendire's Thrasher	*Toxostoma bendirei*	-54.47%	-57.48%	-84.35%
Bell's Vireo	*Vireo bellii*	50.89%	72.51%	-0.60%
Bewick's Wren	*Thryomanes bewickii*	0.58%	7.92%	-43.21%
Blue-gray Gnatcatcher	*Polioptila caerulea*	7.40%	30.34%	-47.32%
Brown-headed Cowbird	*Molothrus ater*	-1.67%	-11.06%	-13.57%
Black-headed Grosbeak	*Pheucticus melanocephalus*	-15.87%	-4.43%	-41.34%
Blue Grosbeak	*Guiraca caerulea*	5.15%	-13.14%	-20.45%
Black Phoebe	*Sayornis nigricans*	10.81%	-1.72%	-9.13%
Blue Grouse	*Dendragapus obscurus*	-33.98%	-38.53%	-76.06%
Brewer's Blackbird	*Euphagus cyanocephalus*	-3.75%	-13.67%	-44.58%
Brown Creeper	*Certhia americana*	-43.95%	-39.05%	-92.31%
Brewer's Sparrow	*Spizella breweri*	22.28%	3.38%	-4.70%
Band-tailed Pigeon	*Columba fasciata*	-52.01%	-34.42%	-83.56%
Black-throated Sparrow	*Amphispiza bilineata*	-25.34%	-31.65%	-58.80%
Black-throated Gray Warbler	*Setophaga nigrescens*	-30.23%	-3.17%	-69.89%
Bullock's Oriole	*Icterus bullockii*	14.93%	28.33%	-3.57%
Burrowing Owl	*Athene cunicularia*	45.34%	-3.52%	31.18%

Bushtit	*Psaltriparus minimus*	-11.26%	-12.98%	-40.04%
Cactus Wren	*Campylorhynchus brunneicapillus*	-18.03%	-27.15%	-36.20%
Cassin's Finch	*Carpodacus cassinii*	-43.41%	-54.02%	-79.29%
Coastal California Gnatcatcher	*Polioptila californica californica*	4.51%	-23.04%	-21.05%
California Gnatcatcher	*Polioptila californica*	269.93%	-59.25%	150.36%
Calliope Hummingbird	*Stellula calliope*	-34.61%	-46.22%	-73.57%
Cassin's Kingbird	*Tyrannus vociferans*	52.00%	4.72%	50.70%
Inyo California Towhee	*Pipilo crissalis eremophilus*	-29.91%	-37.66%	-54.18%
California Towhee	*Melozone crissalis*	-1.91%	16.44%	-34.34%
Canyon Wren	*Catherpes mexicanus*	14.78%	53.19%	-57.85%
California Quail	*Callipepla californica*	-2.37%	3.03%	-54.07%
California Thrasher	*Toxostoma redivivum*	-0.49%	41.02%	-21.35%
Cassin's Vireo	*Vireo cassinii*	-38.74%	-37.49%	-93.54%
San Diego Cactus Wren	*Campylorhynchus brunneicapillus sandiegensis*	227.27%	-88.96%	98.70%
Chestnut-backed Chickadee	*Poecile rufescens*	-48.13%	-39.97%	-69.39%
Cedar Waxwing	*Bombycilla cedrorum*	-82.31%	-57.89%	-2.06%
Chipping Sparrow	*Spizella passerina*	-24.21%	-15.72%	-57.53%
Clark's Nutcracker	*Nucifraga columbiana*	-40.53%	-55.04%	-63.08%
Cliff Swallow	*Petrochelidon pyrrhonota*	1.68%	-10.65%	-18.85%
Common Ground-Dove	*Columbina passerina*	236.80%	121.67%	430.67%
Cooper's Hawk	*Accipiter cooperii*	10.74%	27.28%	-16.11%
Costa's Hummingbird	*Calypte costae*	-13.17%	31.92%	-45.95%
Common Nighthawk	*Chordeiles minor*	-15.61%	-24.42%	-63.63%
Common Poorwill	*Phalaenoptilus nuttallii*	24.90%	25.65%	26.42%
Common Raven	*Corvus corax*	3.04%	15.67%	-14.72%
Common Yellowthroat	*Geothlypis trichas*	11.12%	-15.99%	1.49%
San Francisco Common Yellowthroat	*Geothlypis trichas sinuosa*	-30.12%	-89.28%	-10.40%
Crissal Thrasher	*Toxostoma crissale*	-26.76%	18.71%	-38.76%
Dark-eyed Junco	*Junco hyemalis*	-45.82%	-42.35%	-84.27%
Downy Woodpecker	*Picoides pubescens*	-2.25%	-1.51%	-26.49%
Dusky Flycatcher	*Empidonax oberholseri*	-34.77%	-41.09%	-64.97%
Evening Grosbeak	*Coccothraustes vespertinus*	-65.21%	-74.90%	-94.85%
Flammulated Owl	*Otus flammeolus*	-8.24%	68.18%	-54.76%
Fox Sparrow	*Passerella iliaca*	-47.13%	-58.42%	-91.98%
Gambel's Quail	*Callipepla gambelii*	-39.66%	-27.06%	-50.74%
Golden-crowned Kinglet	*Regulus satrapa*	-56.82%	-53.78%	-92.59%
Great Horned Owl	*Bubo virginianus*	20.64%	18.28%	11.42%
Gila Woodpecker	*Melanerpes uropygialis*	17.98%	201.00%	-3.95%
Golden Eagle	*Aquila chrysaetos*	-8.52%	-29.00%	-42.81%
Gray Jay	*Perisoreus canadensis*	-78.51%	-75.34%	-96.19%
Gray Flycatcher	*Empidonax wrightii*	10.22%	-13.54%	-53.34%

Greater Roadrunner	*Geococcyx californianus*	54.03%	55.91%	43.01%
Greater Sage-Grouse	*Centrocercus urophasianus*	-11.99%	-15.08%	-54.56%
Grasshopper Sparrow	*Ammodramus savannarum*	-17.80%	-41.20%	-27.97%
Great-tailed Grackle	*Quiscalus mexicanus*	5.44%	208.42%	22.01%
Green-tailed Towhee	*Pipilo chlorurus*	-30.48%	-33.38%	-89.47%
Hammond's Flycatcher	*Empidonax hammondii*	-43.37%	-56.55%	-73.36%
Hairy Woodpecker	*Picoides villosus*	-40.56%	-37.40%	-88.90%
Hermit Thrush	*Catharus guttatus*	-50.14%	-55.08%	366.01%
Hermit Warbler	*Setophaga occidentalis*	-49.00%	-47.07%	-92.91%
House Finch	*Carpodacus mexicanus*	8.84%	12.80%	-12.06%
Horned Lark	*Eremophila alpestris*	20.77%	-7.05%	7.92%
Hooded Oriole	*Icterus cucullatus*	16.93%	0.93%	5.17%
House Wren	*Troglodytes aedon*	-4.28%	-2.18%	-32.23%
Hutton's Vireo	*Vireo huttoni*	-23.84%	7.71%	-67.33%
Lawrence's Goldfinch	*Spinus lawrencei*	24.57%	67.26%	34.72%
Lark Sparrow	*Chondestes grammacus*	-4.30%	-3.48%	-43.62%
Lazuli Bunting	*Passerina amoena*	-12.74%	-3.56%	-42.23%
Least Bell's Vireo	*Vireo bellii pusillus*	82.56%	12.10%	51.28%
Ladder-backed Woodpecker	*Picoides scalaris*	-8.20%	-3.61%	-23.20%
Le Conte's Thrasher	*Toxostoma lecontei*	-0.65%	-13.17%	-22.10%
Lesser Goldfinch	*Spinus psaltria*	-4.53%	8.63%	-36.93%
Lesser Nighthawk	*Chordeiles acutipennis*	45.51%	26.75%	21.76%
Long-eared Owl	*Asio otus*	37.67%	25.86%	22.62%
Lewis's Woodpecker	*Melanerpes lewis*	-21.91%	-21.13%	-77.89%
Lincoln's Sparrow	*Melospiza lincolnii*	-40.64%	-60.59%	-76.80%
Loggerhead Shrike	*Lanius ludovicianus*	22.95%	5.64%	-7.14%
Lucy's Warbler	*Oreothlypis luciae*	-63.26%	141.55%	-79.68%
Marsh Wren	*Cistothorus palustris*	309.77%	5.14%	169.11%
MacGillivray's Warbler	*Geothlypis tolmiei*	-44.09%	-47.62%	-76.04%
Mountain Bluebird	*Sialia currucoides*	-28.85%	-40.38%	-75.09%
Mountain Chickadee	*Poecile gambeli*	-37.15%	-42.07%	-87.08%
Mourning Dove	*Zenaida macroura*	5.91%	7.12%	-16.85%
Mountain Quail	*Oreortyx pictus*	-30.24%	-18.58%	-80.37%
Nashville Warbler	*Oreothlypis ruficapilla*	-33.17%	-28.06%	-88.52%
Northern Flicker	*Colaptes auratus*	-19.22%	-18.12%	-44.41%
Northern Goshawk	*Accipiter gentilis*	-32.05%	-22.66%	-78.31%
Northern Harrier	*Circus cyaneus*	-23.01%	-71.69%	-50.31%
Northern Mockingbird	*Mimus polyglottos*	11.08%	3.10%	-9.35%
Northern Pygmy-Owl	*Glaucidium gnoma*	-33.05%	2.46%	-67.32%
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	3.97%	2.00%	-10.11%
Northern Saw-whet Owl	*Aegolius acadicus*	-42.08%	-54.97%	-42.71%
Nuttall's Woodpecker	*Picoides nuttallii*	-2.42%	-4.31%	-33.47%
Oak Titmouse	*Baeolophus inornatus*	-3.39%	23.21%	-52.85%

Orange-crowned Warbler	*Oreothlypis celata*	-29.26%	-9.18%	-41.91%
Olive-sided Flycatcher	*Contopus cooperi*	-39.52%	-25.91%	-77.56%
Osprey	*Pandion haliaetus*	-36.52%	-34.55%	-86.07%
Pacific Wren	*Troglodytes pacificus*	-49.61%	-33.97%	-90.11%
Peregrine Falcon	*Falco peregrinus*	-37.88%	-28.72%	-70.51%
Phainopepla	*Phainopepla nitens*	-6.73%	46.81%	-51.95%
Pine Grosbeak	*Pinicola enucleator*	-65.92%	-56.36%	-91.18%
Pinyon Jay	*Gymnorhinus cyanocephalus*	-0.06%	-7.16%	-50.23%
Pine Siskin	*Spinus pinus*	-46.12%	-48.92%	-88.42%
Pileated Woodpecker	*Dryocopus pileatus*	-55.14%	-53.19%	-95.83%
Prairie Falcon	*Falco mexicanus*	18.49%	-4.71%	-1.51%
Pacific-slope Flycatcher	*Empidonax difficilis*	-33.66%	-14.41%	-36.51%
Purple Finch	*Carpodacus purpureus*	-39.21%	-15.75%	-89.35%
Purple Martin	*Progne subis*	-38.52%	-29.34%	-69.57%
Pygmy Nuthatch	*Sitta pygmaea*	-45.53%	-52.92%	-94.80%
Red-breasted Nuthatch	*Sitta canadensis*	-40.95%	-38.84%	-96.99%
Red-breasted Sapsucker	*Sphyrapicus ruber*	-44.83%	-52.41%	-90.06%
Ruby-crowned Kinglet	*Regulus calendula*	-10.44%	-21.42%	10.47%
Rufous-crowned Sparrow	*Aimophila ruficeps*	10.57%	62.93%	-21.88%
Red Crossbill	*Loxia curvirostra*	-53.29%	-50.01%	-90.43%
Rock Dove	*Columba livia*	5.97%	-11.33%	-21.54%
Rock Wren	*Salpinctes obsoletus*	-17.20%	8.31%	-61.22%
Red-shouldered Hawk	*Buteo lineatus*	-8.06%	-7.99%	-22.05%
Red-tailed Hawk	*Buteo jamaicensis*	3.15%	-1.11%	-11.78%
Ruffed Grouse	*Bonasa umbellus*	-75.86%	-65.48%	-84.62%
Rufous Hummingbird	*Selasphorus rufus*	-77.75%	-73.78%	-77.28%
Red-winged Blackbird	*Agelaius phoeniceus*	5.13%	-6.88%	-14.97%
Sage Sparrow	*Amphispiza belli*	8.01%	-6.98%	-49.17%
Say's Phoebe	*Sayornis saya*	38.97%	20.59%	19.30%
Sage Thrasher	*Oreoscoptes montanus*	-19.89%	-55.63%	-55.33%
Bryant's Savannah Sparrow	*Passerculus sandwichensis alaudinus*	-56.78%	-75.75%	-6.64%
Savannah Sparrow	*Passerculus sandwichensis*	-17.40%	-30.57%	-16.23%
Scott's Oriole	*Icterus parisorum*	-43.90%	-57.22%	-82.68%
Alameda Song Sparrow	*Melospiza melodia pusillula*	-31.20%	-63.50%	-82.63%
Modesto Song Sparrow	*Melospiza melodia mailliardi*	-82.19%	-94.12%	-59.43%
Song Sparrow	*Melospiza melodia*	-11.36%	-27.76%	-11.81%
Samuels song sparrow	*Melospiza melodia samuelis*	-76.18%	-90.64%	-96.53%
Suisun song sparrow	*Melospiza melodia maxillaris*	-2.45%	-18.57%	-25.70%
Spotted Owl	*Strix occidentalis*	-35.14%	44.48%	-54.04%
Spotted Towhee	*Pipilo maculatus*	-14.94%	-7.31%	-44.56%
Sharp-shinned Hawk	*Accipiter striatus*	-40.11%	-28.77%	-43.04%
Steller's Jay	*Cyanocitta stelleri*	-42.97%	-41.82%	-86.14%
Swainson's Hawk	*Buteo swainsoni*	-53.02%	-81.69%	-34.97%

Swainson's Thrush	*Catharus ustulatus*	-53.47%	-50.74%	-39.99%
Townsend's Solitaire	*Myadestes townsendi*	-33.87%	-34.88%	-79.77%
Tricolored Blackbird	*Agelaius tricolor*	3.48%	-32.02%	-20.56%
Tree Swallow	*Tachycineta bicolor*	-25.07%	-48.74%	-42.80%
Turkey Vulture	*Cathartes aura*	4.91%	9.66%	-13.92%
Vaux's Swift	*Chaetura vauxi*	-66.54%	-73.35%	-86.59%
Varied Thrush	*Ixoreus naevius*	-90.38%	-80.10%	-82.99%
Verdin	*Auriparus flaviceps*	-12.06%	-7.68%	-24.25%
Vesper Sparrow	*Pooecetes gramineus*	2.83%	-27.11%	50.88%
Violet-green Swallow	*Tachycineta thalassina*	-2.77%	14.88%	-61.28%
Warbling Vireo	*Vireo gilvus*	-26.44%	-12.87%	-47.42%
White-breasted Nuthatch	*Sitta carolinensis*	-9.49%	-2.60%	-50.68%
White-crowned Sparrow	*Zonotrichia leucophrys*	-60.87%	-73.61%	-41.41%
Western Bluebird	*Sialia mexicana*	1.80%	44.21%	-49.64%
Western Kingbird	*Tyrannus verticalis*	21.41%	9.40%	-5.76%
Western Meadowlark	*Sturnella neglecta*	7.92%	-16.67%	-4.28%
Western Scrub-Jay	*Aphelocoma californica*	-9.50%	-3.50%	-42.89%
Western Screech-Owl	*Megascops kennicottii*	-9.49%	16.21%	-6.20%
Western Tanager	*Piranga ludoviciana*	-23.69%	-9.44%	-63.61%
Western Wood-Pewee	*Contopus sordidulus*	-20.72%	-5.86%	-61.85%
White-headed Woodpecker	*Picoides albolarvatus*	-45.32%	-52.99%	-96.48%
Willow Flycatcher	*Empidonax traillii*	41.81%	176.70%	257.31%
Southwestern willow Flycatcher	*Empidonax traillii extimus*	19.02%	76.22%	8.18%
Williamson's Sapsucker	*Sphyrapicus thyroideus*	-34.75%	-28.58%	-34.96%
Wilson's Warbler	*Cardellina pusilla*	-48.65%	-48.19%	-61.03%
Wrentit	*Chamaea fasciata*	-28.20%	-4.74%	-32.79%
White-tailed Kite	*Elanus leucurus*	-15.66%	-44.01%	-28.15%
White-throated Swift	*Aeronautes saxatalis*	27.64%	35.01%	23.61%
White-winged Dove	*Zenaida asiatica*	10.91%	53.89%	-9.25%
Yellow-breasted Chat	*Icteria virens*	-20.18%	-6.73%	-51.83%
Western yellow-billed Cuckoo	*Coccyzus americanus occidentalis*	-6.20%	-16.87%	-29.17%
Yellow-billed Magpie	*Pica nuttalli*	-42.00%	-72.95%	-45.52%
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	47.77%	20.74%	28.94%
Yellow-rumped Warbler	*Setophaga coronata*	-34.79%	-30.26%	-42.26%
Yellow Warbler	*Setophaga petechia*	-20.44%	-3.52%	-28.58%
California Black Rail	*Laterallus jamaicensis coturniculus*	-11.45%	-60.97%	-64.38%
California Clapper Rail	*Rallus longirostris obsoletus*	-28.25%	-59.42%	-69.02%
Light-footed Clapper Rail	*Rallus longirostris levipes*	324.09%	44.97%	246.63%
Western Snowy Plover	*Charadrius alexandrinus nivosus*	26.85%	6.69%	5.84%
Northern Spotted Owl	*Strix occidentalis caurina*	-32.82%	-36.18%	-97.95%

(orange)	California Threatened Species
(yellow)	California Endangered Species

(green)	Federal Threatened Species
(red)	Federal Endangered Species

Appendix 1B. Relative changes in projected distributions of California breeding landbird species between DoD lands and the state of California as a whole, as modeled in response to two climate change models (CCSM and GFDL). Negative values mean that the distributional change is greater for the state than for DoD lands.

Common Name	**Scientific Name**	**DOD - CA % change CCSM**	**DOD - CA % change GFDL**
Acorn Woodpecker	*Melanerpes formicivorus*	-49.60%	-57.82%
Allen's Hummingbird	*Selasphorus sasin*	-27.80%	-14.72%
American Crow	*Corvus brachyrhynchos*	-15.88%	-6.56%
American Dipper	*Cinclus mexicanus*	-32.59%	-31.86%
American Goldfinch	*Carduelis tristis*	-0.13%	9.96%
American Kestrel	*Falco sparverius*	9.77%	-6.17%
American Robin	*Turdus migratorius*	-31.25%	-24.58%
Anna's Hummingbird	*Calypte anna*	-47.31%	-30.24%
Ash-throated Flycatcher	*Myiarchus cinerascens*	-36.02%	-21.21%
Bald Eagle	*Haliaeetus leucocephalus*	-30.52%	-13.66%
Barn Owl	*Tyto alba*	-8.15%	-8.39%
Bank Swallow	*Riparia riparia*	-42.05%	-11.42%
Barn Swallow	*Hirundo rustica*	-30.23%	-15.91%
Black-billed Magpie	*Pica hudsonia*	-58.43%	-39.56%
Black-backed Woodpecker	*Picoides arcticus*	-21.30%	-42.45%
Black-capped Chickadee	*Poecile atricapillus*	2.11%	-22.98%
Black-chinned Hummingbird	*Archilochus alexandri*	-41.43%	-21.60%
Black-chinned Sparrow	*Spizella atrogularis*	-2.76%	1.85%
Belted Kingfisher	*Ceryle alcyon*	-23.72%	-15.82%
Bendire's Thrasher	*Toxostoma bendirei*	-29.87%	-21.29%
Bell's Vireo	*Vireo bellii*	-51.49%	32.59%
Bewick's Wren	*Thryomanes bewickii*	-43.79%	-32.18%
Blue-gray Gnatcatcher	*Polioptila caerulea*	-54.72%	-29.20%
Brown-headed Cowbird	*Molothrus ater*	-11.90%	-7.47%
Black-headed Grosbeak	*Pheucticus melanocephalus*	-25.47%	-9.79%
Blue Grosbeak	*Guiraca caerulea*	-25.60%	-17.12%
Black Phoebe	*Sayornis nigricans*	-19.94%	-34.94%
Blue Grouse	*Dendragapus obscurus*	-42.09%	-33.48%
Brewer's Blackbird	*Euphagus cyanocephalus*	-40.84%	-22.79%
Brown Creeper	*Certhia americana*	-48.37%	-51.61%
Brewer's Sparrow	*Spizella breweri*	-26.98%	-6.49%
Band-tailed Pigeon	*Columba fasciata*	-31.55%	-17.64%

Black-throated Sparrow	*Amphispiza bilineata*	-33.46%	-13.50%
Black-throated Gray Warbler	*Setophaga nigrescens*	-39.66%	-24.30%
Bullock's Oriole	*Icterus bullockii*	-18.50%	-4.34%
Burrowing Owl	*Athene cunicularia*	-14.17%	-28.41%
Bushtit	*Psaltriparus minimus*	-28.78%	-19.15%
Cactus Wren	*Campylorhynchus brunneicapillus*	-18.17%	-0.35%
Cassin's Finch	*Carpodacus cassinii*	-35.88%	-33.49%
Coastal California Gnatcatcher	*Polioptila californica californica*	-25.56%	-6.52%
California Gnatcatcher	*Polioptila californica*	-119.56%	3.25%
Calliope Hummingbird	*Stellula calliope*	-38.96%	-37.91%
Cassin's Kingbird	*Tyrannus vociferans*	-1.30%	9.67%
Inyo California Towhee	*Pipilo crissalis eremophilus*	-24.27%	-18.95%
California Towhee	*Melozone crissalis*	-32.43%	-24.07%
Canyon Wren	*Catherpes mexicanus*	-72.64%	12.70%
California Quail	*Callipepla californica*	-51.70%	-48.46%
California Thrasher	*Toxostoma redivivum*	-20.87%	-21.37%
Cassin's Vireo	*Vireo cassinii*	-54.80%	-51.65%
San Diego Cactus Wren	*Campylorhynchus brunneicapillus sandiegensis*	-128.57%	-5.13%
Chestnut-backed Chickadee	*Poecile rufescens*	-21.26%	-54.38%
Cedar Waxwing	*Bombycilla cedrorum*	80.26%	-20.62%
Chipping Sparrow	*Spizella passerina*	-33.32%	-2.67%
Clark's Nutcracker	*Nucifraga columbiana*	-22.55%	-27.95%
Cliff Swallow	*Petrochelidon pyrrhonota*	-20.53%	-12.55%
Common Ground-Dove	*Columbina passerina*	193.87%	57.98%
Cooper's Hawk	*Accipiter cooperii*	-26.86%	-0.78%
Costa's Hummingbird	*Calypte costae*	-32.77%	-9.03%
Common Nighthawk	*Chordeiles minor*	-48.02%	-41.92%
Common Poorwill	*Phalaenoptilus nuttallii*	1.52%	-19.79%
Common Raven	*Corvus corax*	-17.76%	-8.74%
Common Yellowthroat	*Geothlypis trichas*	-9.63%	-8.76%
San Francisco Common Yellowthroat	*Geothlypis trichas sinuosa*	19.72%	27.84%
Crissal Thrasher	*Toxostoma crissale*	-12.01%	17.11%
Dark-eyed Junco	*Junco hyemalis*	-38.45%	-27.62%
Downy Woodpecker	*Picoides pubescens*	-24.24%	-13.89%
Dusky Flycatcher	*Empidonax oberholseri*	-30.21%	-39.49%
Evening Grosbeak	*Coccothraustes vespertinus*	-29.65%	-17.73%
Flammulated Owl	*Otus flammeolus*	-46.52%	-51.40%
Fox Sparrow	*Passerella iliaca*	-44.85%	-32.38%
Gambel's Quail	*Callipepla gambelii*	-11.08%	0.96%
Golden-crowned Kinglet	*Regulus satrapa*	-35.77%	-39.33%
Great Horned Owl	*Bubo virginianus*	-9.21%	-8.25%

Gila Woodpecker	*Melanerpes uropygialis*	-21.93%	-6.40%
Golden Eagle	*Aquila chrysaetos*	-34.29%	-12.04%
Gray Jay	*Perisoreus canadensis*	-17.68%	-19.67%
Gray Flycatcher	*Empidonax wrightii*	-63.56%	-60.36%
Greater Roadrunner	*Geococcyx californianus*	-11.03%	-17.11%
Greater Sage-Grouse	*Centrocercus urophasianus*	-42.58%	-28.12%
Grasshopper Sparrow	*Ammodramus savannarum*	-10.17%	-19.85%
Great-tailed Grackle	*Quiscalus mexicanus*	16.58%	371.94%
Green-tailed Towhee	*Pipilo chlorurus*	-58.99%	-55.42%
Hammond's Flycatcher	*Empidonax hammondii*	-29.99%	-25.07%
Hairy Woodpecker	*Picoides villosus*	-48.34%	-38.02%
Hermit Thrush	*Catharus guttatus*	416.15%	-31.58%
Hermit Warbler	*Setophaga occidentalis*	-43.91%	-45.61%
House Finch	*Carpodacus mexicanus*	-20.90%	-7.61%
Horned Lark	*Eremophila alpestris*	-12.86%	-4.72%
Hooded Oriole	*Icterus cucullatus*	-11.76%	-5.60%
House Wren	*Troglodytes aedon*	-27.95%	-13.06%
Hutton's Vireo	*Vireo huttoni*	-43.49%	-33.48%
Lawrence's Goldfinch	*Spinus lawrencei*	10.15%	-43.12%
Lark Sparrow	*Chondestes grammacus*	-39.31%	-42.65%
Lazuli Bunting	*Passerina amoena*	-29.49%	-30.28%
Least Bell's Vireo	*Vireo bellii pusillus*	-31.29%	-3.79%
Ladder-backed Woodpecker	*Picoides scalaris*	-15.00%	-0.86%
Le Conte's Thrasher	*Toxostoma lecontei*	-21.46%	-1.50%
Lesser Goldfinch	*Spinus psaltria*	-32.40%	-16.96%
Lesser Nighthawk	*Chordeiles acutipennis*	-23.74%	-14.06%
Long-eared Owl	*Asio otus*	-15.05%	-6.99%
Lewis's Woodpecker	*Melanerpes lewis*	-55.97%	-54.28%
Lincoln's Sparrow	*Melospiza lincolnii*	-36.16%	-22.85%
Loggerhead Shrike	*Lanius ludovicianus*	-30.10%	-0.89%
Lucy's Warbler	*Oreothlypis luciae*	-16.42%	46.04%
Marsh Wren	*Cistothorus palustris*	-140.66%	-22.14%
MacGillivray's Warbler	*Geothlypis tolmiei*	-31.95%	-38.38%
Mountain Bluebird	*Sialia currucoides*	-46.24%	-37.65%
Mountain Chickadee	*Poecile gambeli*	-49.94%	-46.47%
Mourning Dove	*Zenaida macroura*	-22.76%	-7.17%
Mountain Quail	*Oreortyx pictus*	-50.13%	-34.64%
Nashville Warbler	*Oreothlypis ruficapilla*	-55.35%	-54.50%
Northern Flicker	*Colaptes auratus*	-25.19%	-13.63%
Northern Goshawk	*Accipiter gentilis*	-46.27%	-52.39%
Northern Harrier	*Circus cyaneus*	-27.30%	-12.86%
Northern Mockingbird	*Mimus polyglottos*	-20.43%	-9.75%
Northern Pygmy-Owl	*Glaucidium gnoma*	-34.28%	-1.15%

Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	-14.08%	-17.34%
Northern Saw-whet Owl	*Aegolius acadicus*	-0.62%	-26.02%
Nuttall's Woodpecker	*Picoides nuttallii*	-31.05%	-20.42%
Oak Titmouse	*Baeolophus inornatus*	-49.46%	-25.45%
Orange-crowned Warbler	*Oreothlypis celata*	-12.65%	-7.41%
Olive-sided Flycatcher	*Contopus cooperi*	-38.03%	-38.17%
Osprey	*Pandion haliaetus*	-49.55%	-12.98%
Pacific Wren	*Troglodytes pacificus*	-40.50%	-53.81%
Peregrine Falcon	*Falco peregrinus*	-32.63%	-16.04%
Phainopepla	*Phainopepla nitens*	-45.22%	-8.41%
Pine Grosbeak	*Pinicola enucleator*	-25.26%	-35.36%
Pinyon Jay	*Gymnorhinus cyanocephalus*	-50.18%	-40.67%
Pine Siskin	*Spinus pinus*	-42.29%	-42.61%
Pileated Woodpecker	*Dryocopus pileatus*	-40.68%	-42.37%
Prairie Falcon	*Falco mexicanus*	-20.00%	-3.50%
Pacific-slope Flycatcher	*Empidonax difficilis*	-2.85%	-7.10%
Purple Finch	*Carpodacus purpureus*	-50.14%	-39.47%
Purple Martin	*Progne subis*	-31.05%	-30.08%
Pygmy Nuthatch	*Sitta pygmaea*	-49.27%	-37.08%
Red-breasted Nuthatch	*Sitta canadensis*	-56.03%	-54.70%
Red-breasted Sapsucker	*Sphyrapicus ruber*	-45.23%	-30.32%
Ruby-crowned Kinglet	*Regulus calendula*	20.90%	-38.30%
Rufous-crowned Sparrow	*Aimophila ruficeps*	-32.45%	-24.24%
Red Crossbill	*Loxia curvirostra*	-37.15%	-34.69%
Rock Dove	*Columba livia*	-27.51%	-31.79%
Rock Wren	*Salpinctes obsoletus*	-44.03%	-11.90%
Red-shouldered Hawk	*Buteo lineatus*	-13.99%	-15.90%
Red-tailed Hawk	*Buteo jamaicensis*	-14.93%	-3.97%
Ruffed Grouse	*Bonasa umbellus*	-8.75%	3.42%
Rufous Hummingbird	*Selasphorus rufus*	0.47%	-11.05%
Red-winged Blackbird	*Agelaius phoeniceus*	-20.10%	-9.96%
Sage Sparrow	*Amphispiza belli*	-57.19%	-25.43%
Say's Phoebe	*Sayornis saya*	-19.67%	-17.15%
Sage Thrasher	*Oreoscoptes montanus*	-35.44%	-17.05%
Bryant's Savannah Sparrow	*Passerculus sandwichensis alaudinus*	50.14%	8.28%
Savannah Sparrow	*Passerculus sandwichensis*	1.17%	-4.22%
Scott's Oriole	*Icterus parisorum*	-38.78%	-13.72%
Alameda Song Sparrow	*Melospiza melodia pusillula*	-51.43%	-5.80%
Modesto Song Sparrow	*Melospiza melodia mailliardi*	22.77%	39.85%
Song Sparrow	*Melospiza melodia*	-0.45%	-10.94%
Samuels song sparrow	*Melospiza melodia samuelis*	-20.35%	1.57%
Suisun song sparrow	*Melospiza melodia maxillaris*	-23.25%	-9.40%
Spotted Owl	*Strix occidentalis*	-18.89%	69.02%

Spotted Towhee	*Pipilo maculatus*	-29.62%	-23.79%
Sharp-shinned Hawk	*Accipiter striatus*	-2.94%	-2.21%
Steller's Jay	*Cyanocitta stelleri*	-43.17%	-46.67%
Swainson's Hawk	*Buteo swainsoni*	18.05%	3.13%
Swainson's Thrush	*Catharus ustulatus*	13.49%	-10.30%
Townsend's Solitaire	*Myadestes townsendi*	-45.90%	-48.29%
Tricolored Blackbird	*Agelaius tricolor*	-24.04%	-10.55%
Tree Swallow	*Tachycineta bicolor*	-17.74%	-10.22%
Turkey Vulture	*Cathartes aura*	-18.83%	0.95%
Vaux's Swift	*Chaetura vauxi*	-20.05%	-19.50%
Varied Thrush	*Ixoreus naevius*	7.39%	-9.48%
Verdin	*Auriparus flaviceps*	-12.19%	-0.05%
Vesper Sparrow	*Pooecetes gramineus*	48.04%	10.53%
Violet-green Swallow	*Tachycineta thalassina*	-58.50%	-22.31%
Warbling Vireo	*Vireo gilvus*	-20.98%	-25.63%
White-breasted Nuthatch	*Sitta carolinensis*	-41.19%	-19.92%
White-crowned Sparrow	*Zonotrichia leucophrys*	19.46%	-7.93%
Western Bluebird	*Sialia mexicana*	-51.44%	-44.21%
Western Kingbird	*Tyrannus verticalis*	-27.17%	-22.82%
Western Meadowlark	*Sturnella neglecta*	-12.21%	-21.43%
Western Scrub-Jay	*Aphelocoma californica*	-33.39%	-20.76%
Western Screech-Owl	*Megascops kennicottii*	3.29%	-2.63%
Western Tanager	*Piranga ludoviciana*	-39.92%	-49.19%
Western Wood-Pewee	*Contopus sordidulus*	-41.12%	-31.70%
White-headed Woodpecker	*Picoides albolarvatus*	-51.17%	-39.43%
Willow Flycatcher	*Empidonax traillii*	215.50%	51.75%
Southwestern willow Flycatcher	*Empidonax traillii extimus*	-10.83%	12.00%
Williamson's Sapsucker	*Sphyrapicus thyroideus*	-0.21%	-18.72%
Wilson's Warbler	*Cardellina pusilla*	-12.38%	-27.17%
Wrentit	*Chamaea fasciata*	-4.59%	2.83%
White-tailed Kite	*Elanus leucurus*	-12.49%	-2.13%
White-throated Swift	*Aeronautes saxatalis*	-4.03%	-0.93%
White-winged Dove	*Zenaida asiatica*	-20.16%	35.99%
Yellow-breasted Chat	*Icteria virens*	-31.65%	-31.88%
Western yellow-billed Cuckoo	*Coccyzus americanus occidentalis*	-22.96%	-10.45%
Yellow-billed Magpie	*Pica nuttalli*	-3.52%	5.14%
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	-18.82%	-24.45%
Yellow-rumped Warbler	*Setophaga coronata*	-7.47%	34.87%
Yellow Warbler	*Setophaga petechia*	-8.13%	-1.25%
California Black Rail	*Laterallus jamaicensis coturniculus*	-52.93%	24.37%
California Clapper Rail	*Rallus longirostris obsoletus*	-40.77%	-0.77%
Light-footed Clapper Rail	*Rallus longirostris levipes*	-77.46%	-11.72%
Western Snowy Plover	*Charadrius alexandrinus nivosus*	-21.02%	-8.14%

Northern Spotted Owl	*Strix occidentalis caurina*	-65.13%	-58.36%

	California Threatened Species
	California Endangered Species
	Federal Threatened Species
	Federal Endangered Species

Appendix 2. Impacts of climate change (Climate) and housing density change for three housing density classes (High, Low, Very Low), housing density impacts combined across all classes (Total Housing), and the net change considering both climate and housing density (Net Change) . Results shown for all 29 base groupings for two climate scenarios (GFDL and CCSM) using a 2-km buffer around the bases.

Installation Group 2km	**Scenario**	**Climate**	**High**	**Low**	**Very Low**	**Total Housing**	**Net Change**
Beale AFB	GFDL	-0.0232	0.0000	0.0000	-0.0023	-0.0023	-0.0255
	CCSM	-0.0025	0.0000	0.0000	-0.0035	-0.0035	-0.0060
Choc Mt Air Gnry Rng	GFDL	0.0048	0.0000	-0.0003	-0.0009	-0.0012	0.0036
	CCSM	-0.0030	0.0000	-0.0003	-0.0009	-0.0013	-0.0042
Defense Distribution Region West Sharpe Site	GFDL	-0.0311	-0.0019	-0.0259	-0.0238	-0.0517	-0.0828
	CCSM	-0.0154	-0.0023	-0.0313	-0.0286	-0.0622	-0.0776
Defense Distribution Region West Tracy	GFDL	-0.0242	-0.0020	-0.0081	-0.0297	-0.0398	-0.0640
	CCSM	-0.0128	-0.0024	-0.0091	-0.0346	-0.0461	-0.0589
Edwards AFB	GFDL	-0.0259	0.0000	-0.0014	-0.0029	-0.0043	-0.0302
	CCSM	-0.0129	0.0000	-0.0018	-0.0038	-0.0056	-0.0185
NB Coronado, NAS North Island	GFDL	-0.0257	-0.0162	0.0000	-0.0038	-0.0200	-0.0457
	CCSM	0.0181	-0.0249	0.0000	-0.0054	-0.0302	-0.0122
Fort Hunter Liggett	GFDL	-0.0079	0.0000	0.0000	-0.0008	-0.0008	-0.0087
	CCSM	0.0122	0.0000	0.0000	-0.0011	-0.0011	0.0111
ITC Camp San Luis Obisbo	GFDL	-0.0160	0.0000	-0.0010	-0.0049	-0.0059	-0.0219
	CCSM	0.0240	0.0000	-0.0016	-0.0076	-0.0092	0.0148
MCAGCC Twentynine Palms	GFDL	-0.0075	0.0000	-0.0003	-0.0007	-0.0010	-0.0085
	CCSM	-0.0044	0.0000	-0.0003	-0.0008	-0.0011	-0.0055
MCAS Miramar	GFDL	-0.0289	-0.0086	-0.0070	-0.0050	-0.0207	-0.0496
	CCSM	0.0320	-0.0133	-0.0111	-0.0079	-0.0323	-0.0003
MCB Camp Pendleton	GFDL	-0.0205	-0.0013	-0.0030	-0.0060	-0.0103	-0.0308

	CCSM	0.0488	-0.0019	-0.0048	-0.0097	-0.0164	0.0324
MCLB Barstow Nebo Area	GFDL	-0.0169	0.0000	-0.0077	-0.0018	-0.0096	-0.0265
	CCSM	-0.0249	0.0000	-0.0068	-0.0017	-0.0085	-0.0333
MCLB Barstow Yermo Area	GFDL	-0.0098	-0.0011	-0.0032	-0.0262	-0.0304	-0.0402
	CCSM	-0.0176	-0.0010	-0.0028	-0.0241	-0.0279	-0.0455
MTC-H Camp Roberts	GFDL	0.0016	0.0000	0.0000	-0.0073	-0.0073	-0.0056
	CCSM	0.0188	0.0000	0.0000	-0.0089	-0.0089	0.0099
NAF El Centro	GFDL	-0.0061	-0.0016	0.0000	-0.0387	-0.0403	-0.0464
	CCSM	-0.0118	-0.0015	0.0000	-0.0371	-0.0386	-0.0504
NAS Lemoore	GFDL	-0.0223	-0.0010	-0.0031	-0.0072	-0.0113	-0.0336
	CCSM	-0.0108	-0.0011	-0.0040	-0.0085	-0.0136	-0.0244
NB Coronado, RTS Warner Springs	GFDL	-0.0164	0.0000	0.0000	-0.0041	-0.0041	-0.0205
	CCSM	-0.0075	0.0000	0.0000	-0.0048	-0.0048	-0.0123
NB Ventura County, NAS Point Mugu	GFDL	0.0271	0.0000	0.0000	-0.0315	-0.0315	-0.0043
	CCSM	0.0515	0.0000	0.0000	-0.0390	-0.0390	0.0125
Dixon Radio Transmitter Facility	GFDL	-0.0392	0.0000	0.0000	0.0000	0.0000	-0.0392
	CCSM	-0.0208	0.0000	0.0000	0.0000	0.0000	-0.0208
NAWS China Lake	GFDL	-0.0146	0.0000	-0.0006	-0.0003	-0.0009	-0.0156
	CCSM	-0.0124	0.0000	-0.0007	-0.0004	-0.0010	-0.0134
NTC and Fort Irwin	GFDL	-0.0115	0.0000	0.0000	-0.0001	-0.0001	-0.0116
	CCSM	-0.0100	0.0000	0.0000	-0.0001	-0.0001	-0.0101
NWS Seal Beach	GFDL	0.0013	-0.0374	-0.0036	0.0000	-0.0410	-0.0397
	CCSM	0.0412	-0.0528	-0.0050	0.0000	-0.0578	-0.0166
NWS Seal Beach Det Concord	GFDL	-0.0213	-0.0012	-0.0088	-0.0144	-0.0244	-0.0457
	CCSM	0.0068	-0.0019	-0.0130	-0.0213	-0.0361	-0.0293
NB Ventura County, Port	GFDL	0.0181	-0.0243	0.0019	0.0000	-0.0224	-0.0043

Hueneme							
	CCSM	0.0428	-0.0325	0.0000	0.0000	-0.0325	0.0103
Presidio Of Monterey	GFDL	-0.0199	-0.0094	-0.0203	0.0000	-0.0297	-0.0496
	CCSM	0.0012	-0.0143	-0.0267	0.0000	-0.0410	-0.0398
Defense Fuel Support Point San Pedro	GFDL	0.0135	-0.0240	0.0000	0.0000	-0.0240	-0.0105
	CCSM	0.0486	-0.0362	0.0000	0.0000	-0.0362	0.0124
Sierra Army Depot	GFDL	-0.0296	0.0000	0.0000	0.0000	0.0000	-0.0296
	CCSM	-0.0262	0.0000	0.0000	0.0000	0.0000	-0.0262
Travis AFB	GFDL	-0.0342	-0.0002	-0.0123	-0.0127	-0.0251	-0.0593
	CCSM	-0.0127	-0.0002	-0.0172	-0.0175	-0.0350	-0.0477
Vandenberg AFB	GFDL	-0.0084	-0.0002	-0.0006	-0.0032	-0.0039	-0.0123
	CCSM	0.0350	-0.0003	-0.0008	-0.0046	-0.0057	0.0293

Appendix 3. Impacts of climate change (Climate) and housing density change for three housing density classes (High, Low, Very Low), housing density impacts combined across all classes (Total Housing), and the net change considering both climate and housing density (Net Change) . Results shown for all 29 base groupings for two climate scenarios (GFDL and CCSM) using a 5-km buffer around the bases.

Installation Group 5km	**Scenario**	**Climate**	**High**	**Low**	**Very Low**	**Total Housing**	**Net Change**
Beale AFB	GFDL	-0.0255	0.0000	0.0000	-0.0026	-0.0026	-0.0281
	CCSM	-0.0045	0.0000	0.0000	-0.0038	-0.0038	-0.0083
Choc Mt Air Gnry Rng	GFDL	0.0038	0.0000	-0.0008	-0.0011	-0.0019	0.0019
	CCSM	-0.0034	0.0000	-0.0009	-0.0012	-0.0020	-0.0055
Defense Distribution Region West Sharpe Site	GFDL	-0.0292	-0.0014	-0.0171	-0.0566	-0.0751	-0.1043
	CCSM	-0.0140	-0.0016	-0.0206	-0.0670	-0.0892	-0.1032
Defense Distribution Region West Tracy	GFDL	-0.0265	-0.0043	-0.0074	-0.0305	-0.0422	-0.0687
	CCSM	-0.0135	-0.0052	-0.0084	-0.0356	-0.0491	-0.0627
Edwards AFB	GFDL	-0.0251	0.0000	-0.0031	-0.0047	-0.0078	-0.0328
	CCSM	-0.0125	0.0000	-0.0040	-0.0059	-0.0099	-0.0224
NB Coronado, NAS North Island	GFDL	-0.0260	-0.0160	-0.0044	-0.0044	-0.0248	-0.0507
	CCSM	0.0194	-0.0250	-0.0064	-0.0064	-0.0379	-0.0184
Fort Hunter Liggett	GFDL	-0.0106	0.0000	0.0000	-0.0013	-0.0013	-0.0119
	CCSM	0.0092	0.0000	0.0000	-0.0018	-0.0018	0.0074
ITC Camp San Luis Obisbo	GFDL	-0.0173	-0.0008	-0.0005	-0.0106	-0.0119	-0.0291
	CCSM	0.0233	-0.0013	-0.0007	-0.0166	-0.0187	0.0047
MCAGCC Twentynine Palms	GFDL	-0.0065	0.0000	-0.0008	-0.0016	-0.0024	-0.0090
	CCSM	-0.0041	0.0000	-0.0009	-0.0018	-0.0027	-0.0068
MCAS Miramar	GFDL	-0.0259	-0.0101	-0.0172	-0.0061	-0.0334	-0.0594
	CCSM	0.0303	-0.0157	-0.0271	-0.0096	-0.0523	-0.0220
MCB Camp Pendleton	GFDL	-0.0183	-0.0017	-0.0098	-0.0104	-0.0219	-0.0402

	CCSM	0.0499	-0.0026	-0.0154	-0.0165	-0.0346	0.0153
MCLB Barstow Nebo Area	GFDL	-0.0168	-0.0008	-0.0079	-0.0047	-0.0133	-0.0301
	CCSM	-0.0228	-0.0007	-0.0069	-0.0043	-0.0119	-0.0347
MCLB Barstow Yermo Area	GFDL	-0.0124	-0.0003	-0.0025	-0.0119	-0.0147	-0.0271
	CCSM	-0.0182	-0.0003	-0.0021	-0.0111	-0.0135	-0.0316
MTC-H Camp Roberts	GFDL	0.0021	-0.0001	0.0000	-0.0094	-0.0095	-0.0074
	CCSM	0.0204	-0.0001	0.0000	-0.0116	-0.0117	0.0087
NAF El Centro	GFDL	-0.0069	-0.0005	-0.0067	-0.0443	-0.0515	-0.0584
	CCSM	-0.0107	-0.0005	-0.0066	-0.0432	-0.0503	-0.0610
NAS Lemoore	GFDL	-0.0217	-0.0005	-0.0057	-0.0097	-0.0159	-0.0375
	CCSM	-0.0079	-0.0007	-0.0077	-0.0117	-0.0201	-0.0279
NB Coronado, RTS Warner Springs	GFDL	-0.0168	0.0000	0.0000	-0.0115	-0.0115	-0.0283
	CCSM	-0.0062	0.0000	0.0000	-0.0135	-0.0135	-0.0196
NB Ventura County, NAS Point Mugu	GFDL	0.0252	-0.0011	-0.0028	-0.0270	-0.0309	-0.0057
	CCSM	0.0500	-0.0014	-0.0035	-0.0335	-0.0384	0.0116
Dixon Radio Transmitter Facility	GFDL	-0.0400	0.0000	0.0000	-0.0039	-0.0039	-0.0439
	CCSM	-0.0209	0.0000	0.0000	-0.0052	-0.0052	-0.0261
NAWS China Lake	GFDL	-0.0147	0.0000	-0.0007	-0.0006	-0.0014	-0.0160
	CCSM	-0.0124	0.0000	-0.0008	-0.0007	-0.0015	-0.0140
NTC and Fort Irwin	GFDL	-0.0107	0.0000	0.0000	-0.0001	-0.0001	-0.0108
	CCSM	-0.0101	0.0000	0.0000	-0.0001	-0.0001	-0.0101
NWS Seal Beach	GFDL	0.0009	-0.0367	-0.0033	0.0000	-0.0400	-0.0391
	CCSM	0.0376	-0.0523	-0.0042	0.0000	-0.0565	-0.0189
NWS Seal Beach Det Concord	GFDL	-0.0234	-0.0019	-0.0069	-0.0188	-0.0277	-0.0510
	CCSM	0.0056	-0.0030	-0.0102	-0.0285	-0.0417	-0.0361
NB Ventura County, Port	GFDL	0.0208	-0.0148	-0.0501	-0.0716	-0.1365	-0.1158

Hueneme							
	CCSM	0.0498	-0.0199	-0.0697	-0.0935	-0.1831	-0.1332
Presidio Of Monterey	GFDL	-0.0181	-0.0050	-0.0342	-0.0129	-0.0521	-0.0702
	CCSM	0.0099	-0.0076	-0.0500	-0.0184	-0.0760	-0.0661
Defense Fuel Support Point San Pedro	GFDL	0.0117	-0.0179	-0.0225	0.0000	-0.0404	-0.0286
	CCSM	0.0434	-0.0270	-0.0373	0.0000	-0.0642	-0.0209
Sierra Army Depot	GFDL	-0.0296	0.0000	0.0000	0.0000	0.0000	-0.0296
	CCSM	-0.0254	0.0000	0.0000	0.0000	0.0000	-0.0254
Travis AFB	GFDL	-0.0356	-0.0012	-0.0077	-0.0109	-0.0199	-0.0554
	CCSM	-0.0134	-0.0016	-0.0109	-0.0153	-0.0277	-0.0411
Vandenberg AFB	GFDL	-0.0060	-0.0003	-0.0009	-0.0051	-0.0063	-0.0123
	CCSM	0.0378	-0.0005	-0.0014	-0.0075	-0.0093	0.0285

Appendix 4. Impacts of climate change (Climate) and housing density change for three housing density classes (High, Low, Very Low), housing density impacts combined across all classes (Total Housing), and the net change considering both climate and housing density (Net Change) . Results shown for all 29 base groupings for two climate scenarios (GFDL and CCSM) using a 10-km buffer around the bases.

Installation Group 10km	**Scenario**	**Climate**	**High**	**Low**	**Very Low**	**Total Housing**	**Net Change**
Beale AFB	GFDL	-0.0266	0.0000	-0.0003	-0.0056	-0.0058	-0.0325
	CCSM	-0.0065	0.0000	-0.0003	-0.0081	-0.0084	-0.0149
Choc Mt Air Gnry Rng	GFDL	0.0020	0.0000	-0.0006	-0.0011	-0.0018	0.0003
	CCSM	-0.0041	0.0000	-0.0007	-0.0012	-0.0019	-0.0061
Defense Distribution Region West Sharpe Site	GFDL	-0.0289	-0.0010	-0.0117	-0.0418	-0.0545	-0.0835
	CCSM	-0.0125	-0.0013	-0.0142	-0.0500	-0.0655	-0.0780
Defense Distribution Region West Tracy	GFDL	-0.0284	-0.0017	-0.0064	-0.0278	-0.0359	-0.0643
	CCSM	-0.0126	-0.0020	-0.0078	-0.0332	-0.0430	-0.0556
Edwards AFB	GFDL	-0.0236	-0.0003	-0.0037	-0.0065	-0.0105	-0.0341
	CCSM	-0.0117	-0.0004	-0.0047	-0.0081	-0.0132	-0.0249
NB Coronado, NAS North Island	GFDL	-0.0246	-0.0153	-0.0114	-0.0188	-0.0455	-0.0701
	CCSM	0.0226	-0.0239	-0.0176	-0.0283	-0.0698	-0.0472
Fort Hunter Liggett	GFDL	-0.0110	0.0000	0.0000	-0.0019	-0.0019	-0.0130
	CCSM	0.0088	0.0000	0.0000	-0.0026	-0.0026	0.0062
ITC Camp San Luis Obisbo	GFDL	-0.0164	-0.0006	-0.0001	-0.0098	-0.0105	-0.0269
	CCSM	0.0227	-0.0009	-0.0001	-0.0151	-0.0162	0.0065
MCAGCC Twentynine Palms	GFDL	-0.0060	0.0000	-0.0019	-0.0027	-0.0046	-0.0106
	CCSM	-0.0041	0.0000	-0.0021	-0.0030	-0.0050	-0.0091
MCAS Miramar	GFDL	-0.0229	-0.0092	-0.0155	-0.0144	-0.0392	-0.0620
	CCSM	0.0315	-0.0144	-0.0245	-0.0229	-0.0618	-0.0302

MCB Camp Pendleton	GFDL	-0.0164	-0.0017	-0.0131	-0.0139	-0.0287	-0.0451
	CCSM	0.0504	-0.0026	-0.0209	-0.0224	-0.0458	0.0045
MCLB Barstow Nebo Area	GFDL	-0.0159	-0.0006	-0.0068	-0.0054	-0.0127	-0.0287
	CCSM	-0.0201	-0.0005	-0.0061	-0.0051	-0.0117	-0.0318
MCLB Barstow Yermo Area	GFDL	-0.0142	-0.0001	-0.0026	-0.0070	-0.0097	-0.0239
	CCSM	-0.0183	-0.0001	-0.0022	-0.0065	-0.0089	-0.0271
MTC-H Camp Roberts	GFDL	0.0020	0.0000	0.0000	-0.0078	-0.0078	-0.0059
	CCSM	0.0212	0.0000	0.0000	-0.0099	-0.0099	0.0113
NAF El Centro	GFDL	-0.0049	-0.0008	-0.0089	-0.0288	-0.0386	-0.0434
	CCSM	-0.0065	-0.0008	-0.0087	-0.0283	-0.0378	-0.0443
NAS Lemoore	GFDL	-0.0228	-0.0006	-0.0087	-0.0180	-0.0273	-0.0501
	CCSM	-0.0044	-0.0008	-0.0125	-0.0228	-0.0361	-0.0405
NB Coronado, RTS Warner Springs	GFDL	-0.0168	0.0000	0.0000	-0.0073	-0.0073	-0.0241
	CCSM	-0.0040	0.0000	0.0000	-0.0088	-0.0088	-0.0128
NB Ventura County, NAS Point Mugu	GFDL	0.0231	-0.0027	-0.0126	-0.0395	-0.0549	-0.0318
	CCSM	0.0476	-0.0036	-0.0156	-0.0492	-0.0684	-0.0208
Dixon Radio Transmitter Facility	GFDL	-0.0397	-0.0001	-0.0024	-0.0095	-0.0120	-0.0517
	CCSM	-0.0201	-0.0002	-0.0031	-0.0124	-0.0157	-0.0358
NAWS China Lake	GFDL	-0.0145	0.0000	-0.0005	-0.0005	-0.0011	-0.0155
	CCSM	-0.0122	0.0000	-0.0006	-0.0006	-0.0012	-0.0134
NTC and Fort Irwin	GFDL	-0.0093	0.0000	0.0000	-0.0001	-0.0001	-0.0094
	CCSM	-0.0097	0.0000	0.0000	-0.0001	-0.0001	-0.0098
NWS Seal Beach	GFDL	0.0012	-0.0416	-0.0157	0.0000	-0.0573	-0.0561
	CCSM	0.0355	-0.0598	-0.0224	0.0000	-0.0822	-0.0467
NWS Seal Beach Det Concord	GFDL	-0.0247	-0.0018	-0.0062	-0.0141	-0.0221	-0.0468
	CCSM	0.0037	-0.0027	-0.0092	-0.0211	-0.0331	-0.0294

NB Ventura County, Port Hueneme	GFDL	0.0262	-0.0068	-0.0319	-0.0648	-0.1035	-0.0773
	CCSM	0.0544	-0.0090	-0.0426	-0.0818	-0.1334	-0.0790
Presidio Of Monterey	GFDL	-0.0198	-0.0023	-0.0221	-0.0115	-0.0360	-0.0557
	CCSM	0.0158	-0.0035	-0.0333	-0.0173	-0.0540	-0.0382
Defense Fuel Support Point San Pedro	GFDL	0.0111	-0.0271	-0.0214	0.0000	-0.0485	-0.0375
	CCSM	0.0451	-0.0404	-0.0329	0.0000	-0.0733	-0.0282
Sierra Army Depot	GFDL	-0.0278	0.0000	-0.0001	0.0000	-0.0001	-0.0279
	CCSM	-0.0224	0.0000	-0.0001	0.0000	-0.0001	-0.0225
Travis AFB	GFDL	-0.0377	-0.0021	-0.0059	-0.0089	-0.0169	-0.0546
	CCSM	-0.0142	-0.0026	-0.0081	-0.0123	-0.0231	-0.0372
Vandenberg AFB	GFDL	-0.0036	-0.0004	-0.0011	-0.0083	-0.0098	-0.0134
	CCSM	0.0415	-0.0005	-0.0017	-0.0124	-0.0146	0.0269