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A Climate Change Vulnerability Assessment for Twenty California Mammal Taxa

By

Joseph A.E. Stewart, James H. Thorne, Melanie Gogol-Prokurat, Scott D. Osborn

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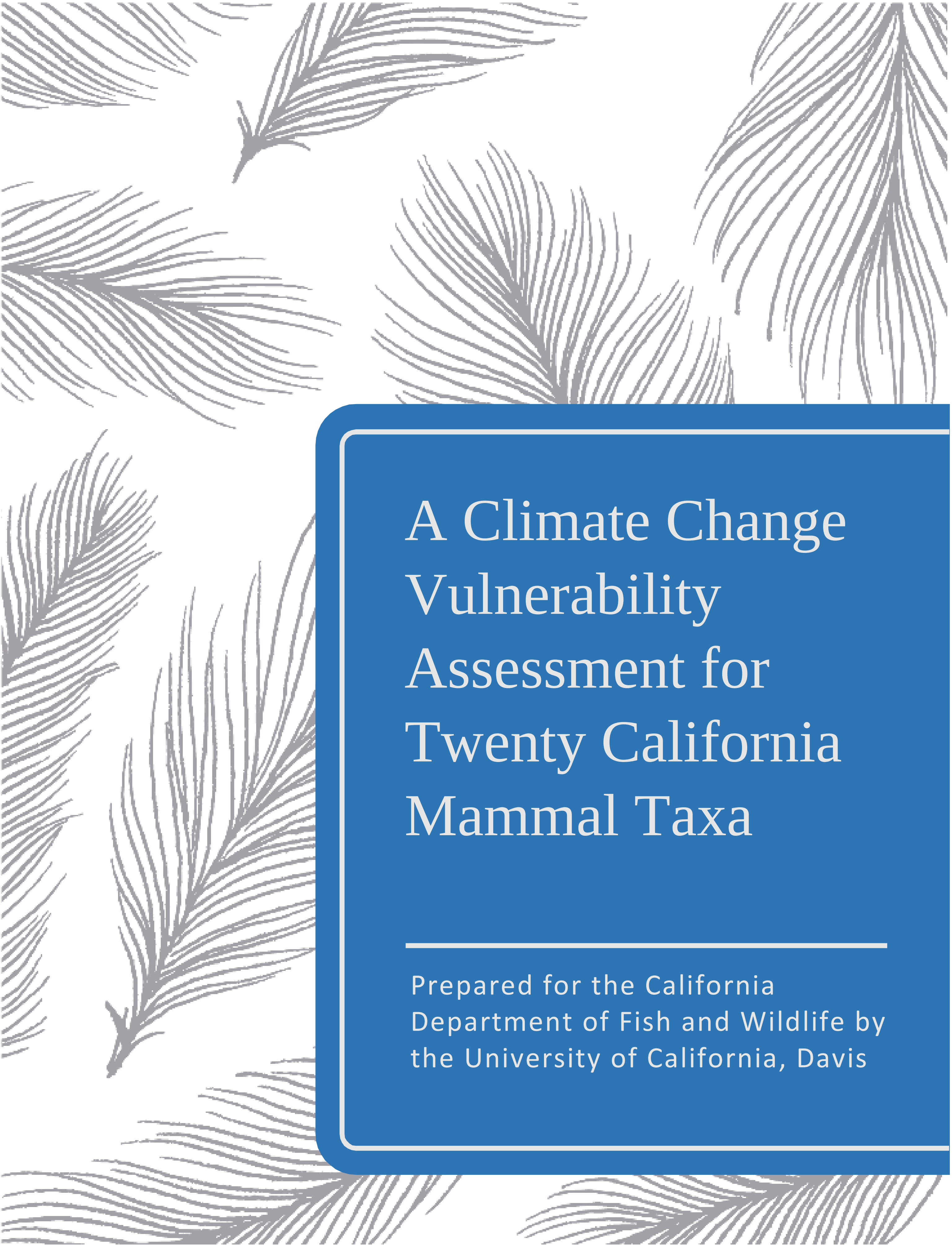

A Climate Change Vulnerability Assessment for Twenty California Mammal Taxa

Prepared for the California
Department of Fish and Wildlife by
the University of California, Davis

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ACRONYMS

AET	Actual Evapotranspiration
BCM	Basin Characterization Model
CCVS	Climate Change Vulnerability Score
CDFW	California Department of Fish and Wildlife
CMIP5	Coupled Model Intercomparison Project Phase 5
CNRM-CM5	The “Warm and Wet” GCM Used in This Report
CWD	Climatic Water Deficit
GCM	Global Circulation Model (or Global Climate Model)
MIROC-ESM	The “Hot and Dry” GCM Used in This Report
PCK	Snowpack
PET	Potential Evapotranspiration
PPT	Precipitation
RCP	Representative Concentration Pathway or Greenhouse Gas Emission Scenario
RCP4.5	The Lower Emission Scenario Used in This Report
RCP8.5	The Higher Emission Scenario Used in This Report
RUN	Runoff
SDM	Species Distribution Model
SWAP	State Wildlife Action Plan
TMN	Minimum Daily Temperature
TMX	Maximum Daily Temperature

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EXECUTIVE SUMMARY

This report contains results on the assessment of climate change vulnerability for 20 native California mammal taxa and documents standardized methods that can be used in assessing the climate change vulnerability of all 587 native California mammal taxa. We combine three distinct approaches for assessing vulnerability to climate change: modelled geographic response, consideration of the ratio of climatic exposure to climatic niche breadth, and consideration of expert-assessed qualitative vulnerability categories. Projected geographic response is composed of the projected impact of climate change and sea level rise on species distribution (i.e. range contraction and expansion). The species distribution models used to assess geographic response benefit from recent advances in explicit consideration of individual-species ability to disperse to habitats that are projected to become newly suitable in response to climate change and from recent mechanistic advances in statewide characterization of the hydroclimate of California. Vulnerability of taxa to sea level rise was assessed using high-resolution coastal LiDAR surfaces (5 m horizontal resolution, 1 mm vertical resolution). The ratio of climatic exposure to climatic niche breadth ("exposure/niche breadth") is calculated as the ratio of the projected amount of climate change the taxa will experience to the breadth of thermal and hydroclimatic conditions the species currently experiences throughout its range. The logic of this metric is two simple principles; first, that increased exposure to climate change results in increased vulnerability to climate change, and second, that species that currently tolerate a greater breadth of climate conditions tend to have higher capacity to cope with climatic extremes. Finally, expert-assessed qualitative vulnerability categories are composed of average scores from 19 species traits. For each category, we combed the literature for information on the species environment and natural history to score the effect of each trait on vulnerability into one of seven categories ranging from "greatly decreases vulnerability to climate change" to "greatly increases vulnerability to climate change".

These three approaches were combined to calculate an overall climate change vulnerability score (CCVS). The CCVS was based on NatureServe's Climate Change Vulnerability Index (CCVI), but uses a slightly modified set of inputs and calculations that incorporate the best available climate and species trait data for our study area. We explicitly document the formulas used to calculate the CCVS, whereas the equations used in the CCVI tool have not been published. We document all methods and formulas in this report and make the Excel® spreadsheet we developed for these calculations publically available for download with the report. Transparency in how metrics of climate change vulnerability are calculated is crucial for the scientific process to advance. The CCVS can be represented as a continuous vulnerability value or as one of five vulnerability categories, ranging from "May Benefit" to "Extremely Vulnerable."

The 20 taxa included in this report were prioritized for climate change vulnerability assessment by the California Department of Fish and Wildlife (CDFW). Two of the taxa are listed as Threatened under the federal and/or California Endangered Species Act and seven are designated as Species of Special Concern by CDFW. The constraint that limited this report to include CCVS scores for only 20 taxa, of the 587 native terrestrial California mammal taxa (species and subspecies), was inclusion of expert-assessed qualitative vulnerability categories in calculation of the score. This qualitative component of the CCVS score requires time-intensive processing of peer reviewed literature. Incorporation of these details of species natural history information and measurements of species traits, such as is obtained in this type of literature review process, can be important for developing more detailed models that explicitly incorporate more of the mechanism that determine how individual taxa, or clades of taxa, respond to climate. Projected geographic response scores and exposure/niche breadth scores have been calculated for all 587 native California mammal taxa, but are not presented in this report.

We evaluated the vulnerability of each taxon to four climate change scenarios for the period 2070-2099, comprised of low and high greenhouse gas emission trajectories and ranging from relatively hot and dry to relatively warm and wet climate scenarios. The resulting overall climate change vulnerability scores (CCVS) were strongly dependent on the climate change scenario considered. Under the two low-emission scenarios we considered, four of 20 species were ranked as extremely vulnerable. Under the two high-emission scenarios, between 8 and 10 of the taxa were ranked as extremely vulnerable. One taxon had insufficient data on occurrence locations to be assessed. Under the scenarios we considered, taxa experienced an average 45% decline in climatically suitable habitat area due to changes to upland climate. Six of the 20 taxa assessed were projected to suffer some loss of habitat due to sea level rise. Amongst the 6 taxa projected to suffer loss of habitat to sea level rise, the average loss of habitat was estimated to be 13%.

Six taxa were projected to suffer complete loss of climatically suitable habitat within their plausible area of dispersal under at least one climate scenario considered: Southern California salt marsh shrew (*Sorex ornatus salicornicus*), salt marsh wandering shrew (*Sorex vagrans halicoetes*), American pika (*Ochotona princeps*), Point Reyes mountain beaver (*Aplodontia rufa phaea*), San Bernardino golden-mantled ground squirrel (*Callospermophilus lateralis bernardinus*), and Mount Pinos lodgepole chipmunk (*Tamias speciosus callipeplus*). Assisted migration to areas of the state where the taxa cannot disperse on their own could be necessary if we wish to conserve wild populations of these taxa. The taxa with the highest vulnerability to sea level rise, the salt marsh wandering shrew (*Sorex vagrans halicoetes*), was projected to lose 30% of its habitat to 1 m of sea level rise. Five taxa were ranked as Extremely Vulnerable under three or more of the four climate scenarios considered: Southern California salt marsh shrew (*Sorex ornatus salicornicus*), salt marsh wandering shrew (*Sorex vagrans halicoetes*), American pika (*Ochotona princeps*), Point Reyes mountain beaver (*Aplodontia rufa phaea*), and San Bernardino golden-mantled ground squirrel (*Callospermophilus lateralis bernardinus*). Though three taxa were ranked as Less Vulnerable under one or more scenario, no species were ranked Less Vulnerable under all scenarios. The species with the lowest vulnerability ranking overall, San Joaquin kit fox (*Vulpes macrotis mutica*), ranked Less Vulnerable under both low emission scenarios, and Moderately Vulnerable under both high emission scenarios.

OVERVIEW

The purpose of this report is to present results on the assessment of climate change vulnerability for 20 native California mammal taxa and to document standardized methods for use in assessing the climate change vulnerability of all 587 native California terrestrial (non-marine) mammal taxa. Results of this assessment can contribute to the development of climate adaptation strategies that complement and provide context for conservation strategies for California's mammal taxa. California is ranked as a global biodiversity hotspot. As stewards of the state's diverse fish, wildlife, and plant species, and the habitats they depend on, the California Department of Fish and Wildlife (CDFW) has taken a lead role in climate adaptation planning for biodiversity conservation, and must understand and plan for these environmental changes.

This report presents the results of a climate vulnerability assessment for 20 mammal taxa of California. The assessment is based on two global climate models (GCMs) and two emission scenarios that were selected from among 12 considered to represent a range of future conditions for California by the end of the 21st century. The GCMs, CNRM CM5 and MIROC ESM, and emission scenarios used, RCP4.5 and RCP 8.5, represent a range of warming statewide from 1.99 to 4.56°C and between a 24.8% decrease in precipitation and a 22.9% increase, respectively (Table 1). They are the same four climate projections used in the CDFW's report on the climate vulnerability of terrestrial vegetation for the state[1], meaning that the results from this study and from that assessment may be cross-compared.

Table 1. Simplified names and technical specifications for the four future climate change scenarios used in this report. Future climate change scenarios are projections for the 2070-2099 period, sometimes abbreviated to "2080s".

Climate Change Scenario Simplified Name	Representative Concentration Pathway (Emissions Track)	Global Circulation Model
Low Emission, Warm & Wet	RCP 4.5	CNRM CM5
High Emission, Warm & Wet	RCP 8.5	CNRM CM5
Low Emission, Hot & Dry	RCP 4.5	MIROC ESM
High Emission, Hot & Dry	RCP 8.5	MIROC ESM

The 20 taxa included in this report were prioritized for climate change vulnerability assessment by the California Department of Fish and Wildlife. Two of the taxa are listed as threatened (San Joaquin kit fox, Sierra Nevada red fox) and seven are listed as species of special concern (Humboldt marten, Mount Lyell shrew, Salt Marsh wandering shrew, Southern California salt marsh shrew, Point Reyes mountain beaver, California red tree vole, San Pablo vole) by the state of California. The 20 taxa represent a sampling of California mammal diversity, ranging from small (e.g. shrews) to large (e.g. bighorn sheep), herbivorous (e.g. mountain beaver) to carnivorous (e.g. marten), and occupying a diversity of habitats types from coastal salt marsh (e.g. Salt marsh wandering shrew) to high elevation mountaintops (e.g. alpine chipmunk).

The methods we present in this report are intended for use in the assessment and ranking of climate change vulnerability for all 587 native California mammal taxa (species and subspecies) and to be generally adaptable to all types of worldwide species. We combined 27 metrics of climate change vulnerability including metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a cross-comparable overall climate change vulnerability score (CCVS) score for each taxon. We explicitly document all the equations used to combine multiple metrics of climate change vulnerability into a single composite score. The aim is to present explicit methods that can be easily understood, critiqued, and improved upon in the

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[1] Thorne, J.H., RM Boynton, AJ Holguin, JAE Stewart, & J Bjorkman. (2016) A climate change vulnerability assessment for California's vegetation: a macro-habitat scale for aggregated terrestrial vegetation types. California Department of Wildlife and Fisheries, Sacramento, CA.

spirit of open source science. We took measures to account for mechanisms, improve predictive ability, and reduce overfitting in species distribution models used in the analysis. Four steps taken this regard include:

> We explicitly incorporated each species' unique capacity to disperse to track their suitable climate niche.
>
> We used phylogenetic regressions to estimate species trait values (i.e. body mass, diet) for species with missing trait data.
>
> We include mechanistic hydroclimatic candidate predictor variables relevant to mammal ecology and natural history, such as surface runoff, snow depth, and actual evapotranspiration.
>
> We implemented several measures intended to increase the predictive performance and temporal transferability of our Maxent species distribution models, including AICc variable selection, correction for bias detection through the use of background occurrence data, and reduction of overfitting via disabling Maxent hinge and threshold features.

Overall Vulnerability

Overall climate change vulnerability scores (CCVS) were derived from a weighted mean of each taxon's modeled geographic response, exposure/niche breadth, and qualitative vulnerability scores. Each metric has a potential maximum value of 100, with higher values indicating greater vulnerability to climate change and zero indicating no vulnerability to climate change (Figure 1). Among these three metrics of climate change vulnerability, projected geographic response contributed the most to the interspecific variance in the overall vulnerability scores. Projected geographic response can be interpreted as the percent of climatically suitable potential habitat projected to be lost to climate change, with negative values representing potential increase in climatically suitable habitat from climate change. Exposure/niche breadth is the ratio of projected change in temperature and hydroclimate for each taxon relative to the range of conditions that taxon currently experiences throughout its documented occurrence locations, scaled such that a value of 100 indicates exposure is greater than or equal to niche breadth. Qualitative vulnerability is the mean score among of 19 categorical vulnerability categories adapted from Young *et al.* (2011)[2] methods, and scaled such that a score of 100 indicated the highest possible level of vulnerability and -100 indicates the highest potential to benefit from climate change.

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[2] Young, B, Byers, E, Gravuer, K., Hall, K., Hammerson, G., & Redder, A. (2011). Guidelines for using the NatureServe climate change vulnerability index. *NatureServe, Arlington, VA.*

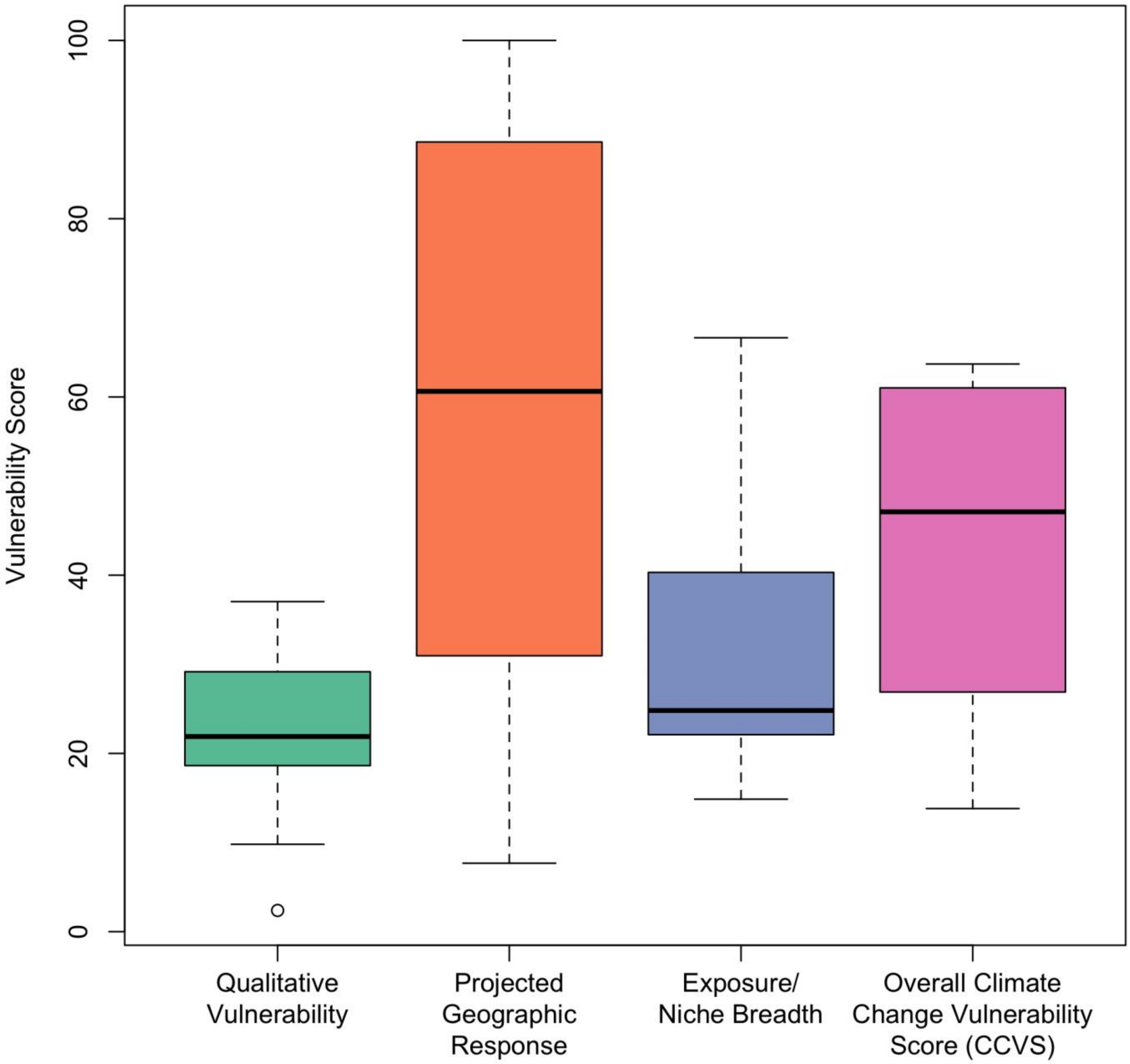

Figure 1. Range of scores for qualitative vulnerability, projected geographic response, exposure/niche breadth, and overall climate change vulnerability for the 20 taxa assessed in this report. All 20 taxa received qualitative vulnerability scores. For one taxon there was insufficient information to score projected geographic response, exposure/niche breadth, and overall climate change vulnerability. Thick line shows median value. Boxes show the interquartile range. Whiskers show minimum and maximum values.

The resulting overall climate change vulnerability scores (CCVS) were strongly dependent on the climate change scenario considered (Figure 2). Overall vulnerability to climate change across taxa was lowest for the low emission, warm and wet scenario and highest for the high emission, hot and dry scenario. One taxon had insufficient information to be evaluated. Under the low emission, warm and wet scenario four taxa were classified as extremely vulnerable, six as highly vulnerable, six as moderately vulnerable, and three as less vulnerable. Under the high emission, warm and wet scenario eight taxa were classified as extremely vulnerable, six as highly vulnerable, and five as moderately vulnerable. Under the low emission, hot and dry scenario four taxa were classified as extremely vulnerable, nine as highly vulnerable, five as moderately vulnerable, and one as less vulnerable. And, under the high emission, hot and dry scenario ten taxa were classified as extremely vulnerable, seven as highly vulnerable, and two as moderately vulnerable (Table 2).

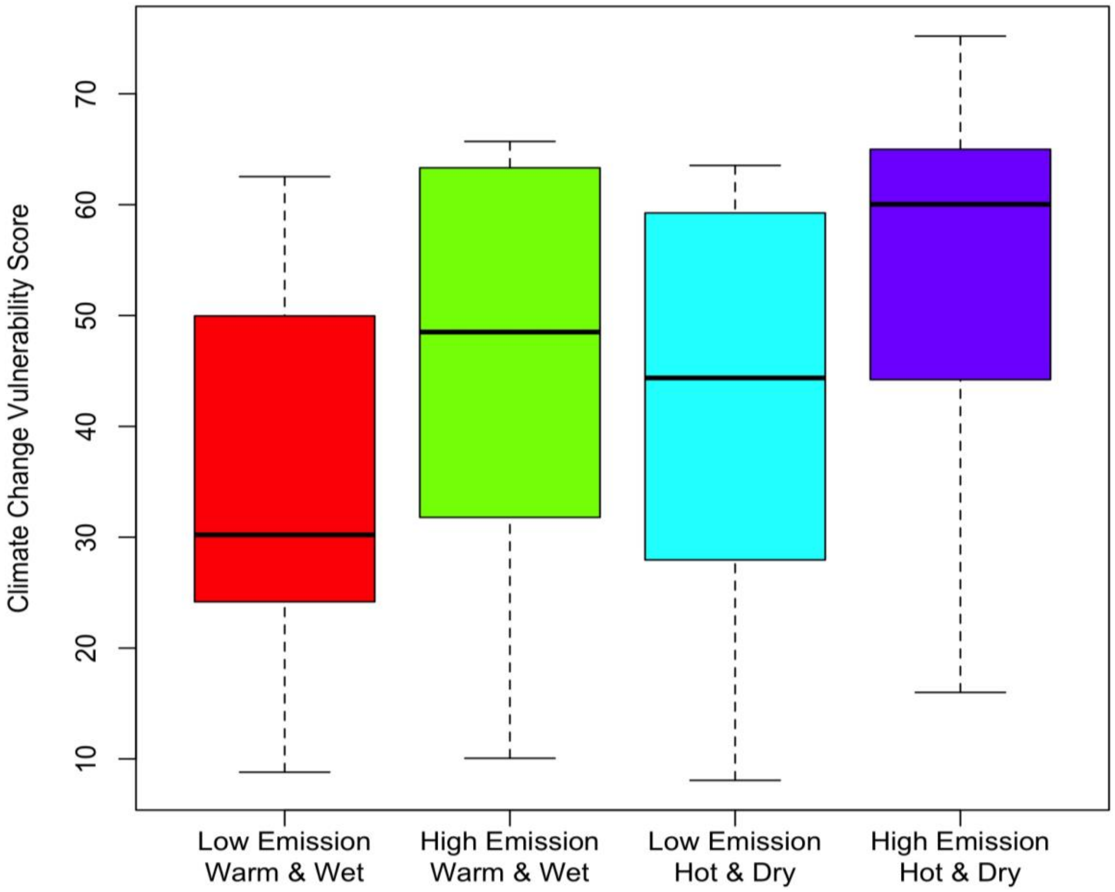

Figure 2. Overall climate change vulnerability scores for California mammal taxa evaluated in this report under four climate change scenarios used in this assessment. Climate change vulnerability scores (CCVS) have potential range between -80 and 100, with higher positive values representing higher vulnerability to climate change and negative values representing potential for taxa to benefit from climate change. This plot represents scores for 19 taxa. One priority taxon had insufficient information to be scored. Boxes show the median and interquartile ranges. Whiskers show minimum and maximum values.

Table 2. Overall climate change vulnerability scores for 20 taxa included in this report under four future climate change scenarios for the 2080s.

Taxa	**Overall Climate Change Vulnerability Index Score by Climate Change Scenario**			
	Low Emission Warm & Wet	High Emission Warm & Wet	Low Emission Hot & Dry	High Emission Hot & Dry
Mount Lyell shrew (*Sorex lyelli*)	Highly Vulnerable	Extremely Vulnerable	Highly Vulnerable	Extremely Vulnerable
Southern California salt marsh shrew (*Sorex ornatus salicornicus*)	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable
Salt marsh wandering shrew (*Sorex vagrans halicoetes*)	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable
American pika (*Ochotona princeps*)	Highly Vulnerable	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable
Point Reyes mountain beaver (*Aplodontia rufa phaea*)	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable	Extremely Vulnerable
Belding's ground squirrel (*Urocitellus beldingi*)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
San Bernardino golden-mantled ground squirrel (*Callospermophilus lateralis bernardinus*)	Extremely Vulnerable	Extremely Vulnerable	Highly Vulnerable	Extremely Vulnerable
Alpine chipmunk (*Tamias alpinus*)	Moderately Vulnerable	Highly Vulnerable	Highly Vulnerable	Extremely Vulnerable
Mount Pinos lodgepole chipmunk (*Tamias speciosus callipeplus*)	Highly Vulnerable	Extremely Vulnerable	Highly Vulnerable	Extremely Vulnerable
Western jumping mouse (*Zapus princeps*)	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable	Extremely Vulnerable
California red tree vole (*Arborimus pomo*)	Moderately Vulnerable	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
Monterey vole (*Microtus californicus halophilus*)	Highly Vulnerable	Extremely Vulnerable	Highly Vulnerable	Extremely Vulnerable
Marsh vole (*Microtus californicus paludicola*)	Insufficient Information	Insufficient Information	Insufficient Information	Insufficient Information
San Pablo vole (*Microtus californicus sanpabloensis*)	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
Montane vole (*Microtus montanus*)	Moderately Vulnerable	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
San Joaquin kit fox (*Vulpes macrotis mutica*)	Less Vulnerable	Moderately Vulnerable	Less Vulnerable	Moderately Vulnerable
Sierra Nevada red fox (*Vulpes vulpes necator*)	Less Vulnerable	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
Humboldt marten (*Martes caurina humboldtensis*)	Less Vulnerable	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
Sierra Nevada marten (*Martes caurina sierra*)	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable	Highly Vulnerable
Desert bighorn sheep (*Ovis canadensis nelson*)	Moderately Vulnerable	Highly Vulnerable	Moderately Vulnerable	Moderately Vulnerable

Species Distribution Models

For each taxon we used occurrence locations and seven climatic and hydrological variables to parameterize species distribution models (SDMs). The resulting models we used to project future change in climatic suitability for each taxon at occurrence locations and within species-specific plausible dispersal boundaries. Across all taxa included in this report the mean percent of occurrence locations projected to be no longer suitable was 68.0%. The average projected percent loss of occurrence locations across taxa was 51.0% for the low emission warm and wet scenario, 69.1% for the high emission warm and wet scenario, 66.9% for the low emission hot and dry scenario, and 84.8% for the high emission hot and dry scenario (Table 3).

Table 3. Projected loss of habitat to climate change under four climate change scenarios for the 2080s for the 20 taxa included in this report as assessed through species distribution models. One taxon, *Microtus californicus paludicola*, had too few occurrence locations to model.

	Projected Percent of Occurrence Locations Lost to Climate Change			
Taxa	**Low Emission Warm & Wet**	**High Emission Warm & Wet**	**Low Emission Hot & Dry**	**High Emission Hot & Dry**
Mount Lyell shrew (*Sorex lyelli*)	52.6%	89.5%	68.4%	89.5%
Southern California salt marsh shrew (*Sorex ornatus salicornicus*)	100%	100%	100%	100%
Salt marsh wandering shrew (*Sorex vagrans halicoetes*)	100%	100%	100%	100%
American pika (*Ochotona princeps*)	57.8%	92%	90.4%	100%
Point Reyes mountain beaver (*Aplodontia rufa phaea*)	100%	100%	100%	100%
Belding's ground squirrel (*Urocitellus beldingi*)	32.8%	51.7%	43.1%	63.8%
San Bernardino golden-mantled ground squirrel (*Callospermophilus lateralis bernardinus*)	100%	100%	100%	100%
Alpine chipmunk (*Tamias alpinus*)	8%	50.7%	72%	97.3%
Mount Pinos lodgepole chipmunk (*Tamias speciosus callipeplus*)	33.3%	100%	100%	100%
Western jumping mouse (*Zapus princeps*)	34.5%	75%	81%	100%
California red tree vole (*Arborimus pomo*)	69.2%	80%	76.8%	89.2%
Monterey vole (*Microtus californicus halophilus*)	100%	100%	100%	100%
Marsh vole (*Microtus californicus paludicola*)	*	*	*	*
San Pablo vole (*Microtus californicus sanpabloensis*)	100%	100%	100%	100%
Montane vole (*Microtus montanus*)	45%	70.6%	48.6%	78.9%
San Joaquin kit fox (*Vulpes macrotis mutica*)	0.9%	24.3%	7.9%	74%
Sierra Nevada red fox (*Vulpes vulpes necator*)	4.7%	14.2%	16.6%	46.7%
Humboldt marten (*Martes caurina humboldtensis*)	0.9%	1.8%	15.6%	77.1%
Sierra Nevada marten (*Martes caurina sierra*)	2.2%	10.9%	45.7%	84.8%
Desert bighorn sheep (*Ovis canadensis nelson*)	26.3%	52.6%	5.3%	10.5%

Sea Level Rise

We assessed each taxon's vulnerability to sea level rise as the percent of occurrence locations that may become no longer suitable under a scenario of one meter of sea level rise. Six of the 20 taxa assessed are found in coastal areas, and were projected to lose habitat to sea level rise: *Sorex ornatus salicornicus*, *Sorex vagrans halicoetes*, *Aplodontia rufa phaea*, *Arborimus pomo*, *Microtus californicus halophilus*, and *Microtus californicus sanpabloensis*. Among these six taxa, the mean percent of occurrence locations projected to become no longer suitable due to sea level rise was 12.6% (Table 4).

Table 4. Projected loss of habitat to 1-m sea level rise for six species in this report projected to suffer loss of habitat to sea level rise.

Taxa	**Percent of Locations Lost to 1-m Sea Level Rise**
Southern California salt marsh shrew (*Sorex ornatus salicornicus*)	10.0%
Salt marsh wandering shrew (*Sorex vagrans halicoetes*)	30.4%
Point Reyes mountain beaver (*Aplodontia rufa phaea*)	7.1%
California red tree vole (*Arborimus pomo*)	1.1%
Monterey vole (*Microtus californicus halophilus*)	10.0%
San Pablo vole (*Microtus californicus sanpabloensis*)	16.7%

Limitations and Caveats

The science of assessing vulnerability of taxa to climate change is relatively new and is still subject to considerable uncertainty. Results presented in this report should be interpreted as a first-pass rapid assessment of each taxon's vulnerability to climate change. Our methods were designed to create a cross-comparable, rapid-assessment of climate change vulnerability for all of the 587 terrestrial mammal taxa in California. While our methods are generally concordant with methods used in similar assessments of climate change vulnerability[3,4,5], we note that there have been relatively few studies evaluating the performance of climate change vulnerability metrics in predicting species response to climate change. Studies have shown that correlative SDMs can be powerful tools for predicting climate change vulnerability for some taxa[6,7,8], but more work is needed to understand the environmental and taxon-specific conditions that influence the predictive performance of these models. The qualitative and exposure/niche breadth metrics used in this report, adapted from Young *et al.* (2011)[9], are appealing for their simplicity and straightforwardness, but have not yet been tested for their ability to predict species response to climate change. Much additional research will be needed to reduce uncertainty in assessments of species vulnerability to climate change.

The ability of correlative species distribution models (SDMs) to predict species response to climate change is premised on the assumption that limits on species current and historical distribution are set by climate variables included in the models. While our standardized methods include techniques to maximize model performance and transferability, the degree to which this assumption is true may vary across the taxa we assess in this report. For instance, a growing body of literature supports climate variables as a primary limiting factor in the distribution of many high elevation taxa included in this

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[3] Gardali T, Seavy NE, DiGaudio RT, Comrack LA (2012) A climate change vulnerability assessment of California's at-risk birds. PloS one, 7, e29507.

[4] Anacker BL, Gogol-Prokurat M, Leidholm K, Schoenig S (2013) Climate Change Vulnerability Assessment of Rare Plants in California. Madrono, 60, 193–210.

[5] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

[6] Hijmans RJ, Graham C (2006) The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology, 12, 2272–2281.

[7] Pearman PB, Randin CF, Broennimann O et al. (2008) Prediction of plant species distributions across six millennia. Ecology Letters, 11, 357–369.

[8] Dobrowski SZ, Thorne JH, Greenberg JA, Safford HD, Mynsberge AR, Crimmins SM, Swanson AK (2011) Modeling plant ranges over 75 years of climate change in California, USA: Temporal transferability and species traits. Ecological Monographs, 81, 241–257.

[9] Young, B., Byers, E., Gravuer, K., Hall, K., Hammerson, G., & Redder, A. (2011). Guidelines for using the NatureServe climate change vulnerability index. NatureServe, Arlington, VA.

report (e.g. *Ochotona princeps*, *Tamias alpinus*)[10,11,12]. Our SDMs should have relatively strong predictive ability for these taxa. In contrast, the distribution of the salt-marsh-inhabiting taxa included in this report (e.g. *Sorex ornatus salicornicus*, *Sorex vagrans halicoetes*) appears to be most limited by vegetation type and tidal-saline-edaphic factors governing vegetation type. Our SDMs for these taxa are likely to pick up on spurious correlations with climate variables and have poorer predictive ability.

Next Steps

By far the greatest source of uncertainty in the conservation status and overall vulnerability of species to climate change is a dearth of data. Additional data on where species occur and where people have looked for them but not found them would greatly improve our ability to detect changes in species distribution and abundance in response to climate change and other factors. Projects such as CDFW's Ecoregional Biodiversity Monitoring Program and citizen science data aggregators like iNaturalist.org represent invaluable contributions toward improving data coverage, but large data gaps remain. Much additional work is needed to fill these taxonomic and geographic data gaps. Additionally, many mammal taxa in California, including taxa evaluated in this report, have a high proportion of historical record locations where the taxon has not been documented to persist for many decades. Resurveys of these locations constitute opportunities for gaining greater understanding of how these species are responding to modern pressures, including climate change. The locations of some species' historical records have been revisited, but including more species in such resurveys would allow for empirical evaluation of the ability of various climate change vulnerability metrics to predict changes that have actually occurred over the past century.

Additional research on the mechanisms that control the distribution of species and groups of species will be necessary to produce more accurate forecasts of species response to climate change. Multiple complementary research approaches can serve to help clarify these mechanisms. Collaborations between species experts and researchers with modeling expertise may represent one of the most efficient pathways for producing more accurate models for individual species. Significant improvements in model performance may result from integrating existing information on species traits, such as their thermal-physiology, diet preference, and dispersal ability. Where trait data are lacking, phylogenetic imputation can often provide a reasonable estimate of species-specific traits. Model assumptions and predictions should be validated against empirical data whenever possible. In many cases experimental manipulations, such as environmental manipulations and translocations could be effective for measuring thresholds of species persistence and reproduction. Studies tracking demography and change in species abundance over time can be an effective way to assess response to inter-annual climate variation and to gain inference into species capacity to cope with anticipated climate change. While species distribution modeling represents an efficient approach for developing hypotheses to further our understanding of the factors that most influence species vulnerability to climate change, there is no apparent shortcut around sustained research and monitoring to evaluate these predictions. An early investment of resources would be prudent if we wish to produce robust forecasts, sufficient for effective response to stem the anticipated tide of climate-mediated extinction in California over the 21st century.

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[10] Moritz C, Patton JL, Conroy CJ, Parra JL, White GC, Beissinger SR (2008) Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science (New York, N.Y.), 322, 261–264.

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[12] Stewart JAE, Perrine JD, Nichols LB, Millar CI, Thorne JH, Goehring KE, Massing CP, Wright DH. (2015) Revisiting the past to foretell the future: summer temperature and habitat area predict pika extirpations in California. Journal of Biogeography, 42, 880–890.

METHODS

This report assesses the climatic vulnerability of 20 California mammal taxa. Each taxon's overall score is a combination of estimates of its vulnerability as assessed through species distribution models, loss of habitat to sea level rise, exposure/niche breadth, and expert-assessed qualitative vulnerability rankings. This section of the report provides the methods used, starting with the input data including the climate models, emission scenarios, hydroclimatic models, species occurrence data and approach to modeling; and including comments on the use of dispersal, sea level rise and the climate change vulnerability scoring approach used.

Climate Model Selection

This report uses projections of future climate using two global climate models (GCMs) that respectively are hotter and drier (MIROC-ESM), and warmer and wetter (CNRM CM) than current conditions. For each of the GCMs we used two emission scenarios that represent lower (RCP 4.5) and higher (RCP 8.5) levels of greenhouse gas concentration. All analyses were conducted on projections for the end century (2070-2099), which allow the furthest assessment of future trends. The GCMs and emission scenarios we selected are the same as those used in the CDFW's climate vulnerability assessment of terrestrial vegetation[13]. The models selected represent a bracketing of future conditions, as can be seen when the future conditions they predict are visualized along with 10 other GCMs, for the lower emissions track (RCP 4.5) and the higher, current emissions track (RCP 8.5) (Figures 3 and 4).

We statistically downscaled the GCMs at a 270 m grid scale. At this level, 410,000 km^2 California contains about 5.6 million grid cells, which can be analyzed for change in climate. We reviewed the various climate projections and found they do not represent uniform trends for precipitation and temperature across all of California. To select the futures to be used in this report, we selected two that are relatively drier or wetter than most of the models, in order to both capture a range of future conditions, and also to minimize the areas within the state that seem to be trending in opposite directions from the overall direction of a given model. The two GCMs selected are MIROC ESM and CNRM CM. The California mean change in annual precipitation (PPT) and annual minimum (TMN) and maximum temperatures (TMX) for these two GCMs and the RCP 4.5 and 8.5 are shown in Table 5. The emission levels were selected to represent a more hopeful level of climate change (the lower emissions RCP 4.5) and emissions levels that are closer to the current trend in emissions (the RCP8.5).

Table 5. The mean change in annual minimum and maximum temperature, and in precipitation from a current 30-year average, derived from maps representing all of California in 1981-2010, and 2070-2099.

GCM	RCP	Scenario Appellation	Change in Annual Minimum Temperature °C	Change in Annual Maximum Temperature °C	Percent Change in Precipitation
CNRM CM5	rcp4.5	Low Emissions, Warm and Wet	1.994	2.671	23.0%
CNRM CM5	rcp8.5	High Emissions, Warm and Wet	3.890	4.284	38.1%
MIROC ESM	rcp4.5	Low Emissions, Hot and Dry	2.534	3.667	-18.9%
MIROC ESM	rcp8.5	High Emissions, Hot and Dry	4.557	5.863	-24.9%

The downscaled CNRM CM5 and the MIROC ESM models for the RCP 4.5 and 8.5 emissions were run through the hydroclimatic model, the Basin Characterization Model[14] (BCM; Figure 5) to obtain a series of landscape hydrology

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[13] Thorne, J.H., R.M. Boynton, A.J. Holguin, J.A.E. Stewart, & J. Bjorkman. (2016) A climate change vulnerability assessment for California's vegetation: a macro-habitat scale for aggregated terrestrial vegetation types. California Department of Wildlife and Fisheries, Sacramento, CA.

[14] Flint, L.E., A.L. Flint, J.H. Thorne, R.M. Boynton. 2013. Fine-scale hydrological modeling for regional landscape applications: Model development and performance. *Ecological Processes*. 2:25. http://www.ecologicalprocesses.com/content/2/1/25;

values that represent the availability of water in the landscape, including potential evapotranspiration (PET), actual evapotranspiration (AET), climatic water deficit (CWD), snowpack (PCK), runoff (RUN) and recharge. In sum, 13 climate and hydrological variables were developed for every grid cell. Seven of these variables were used for modeling mammal distributions.

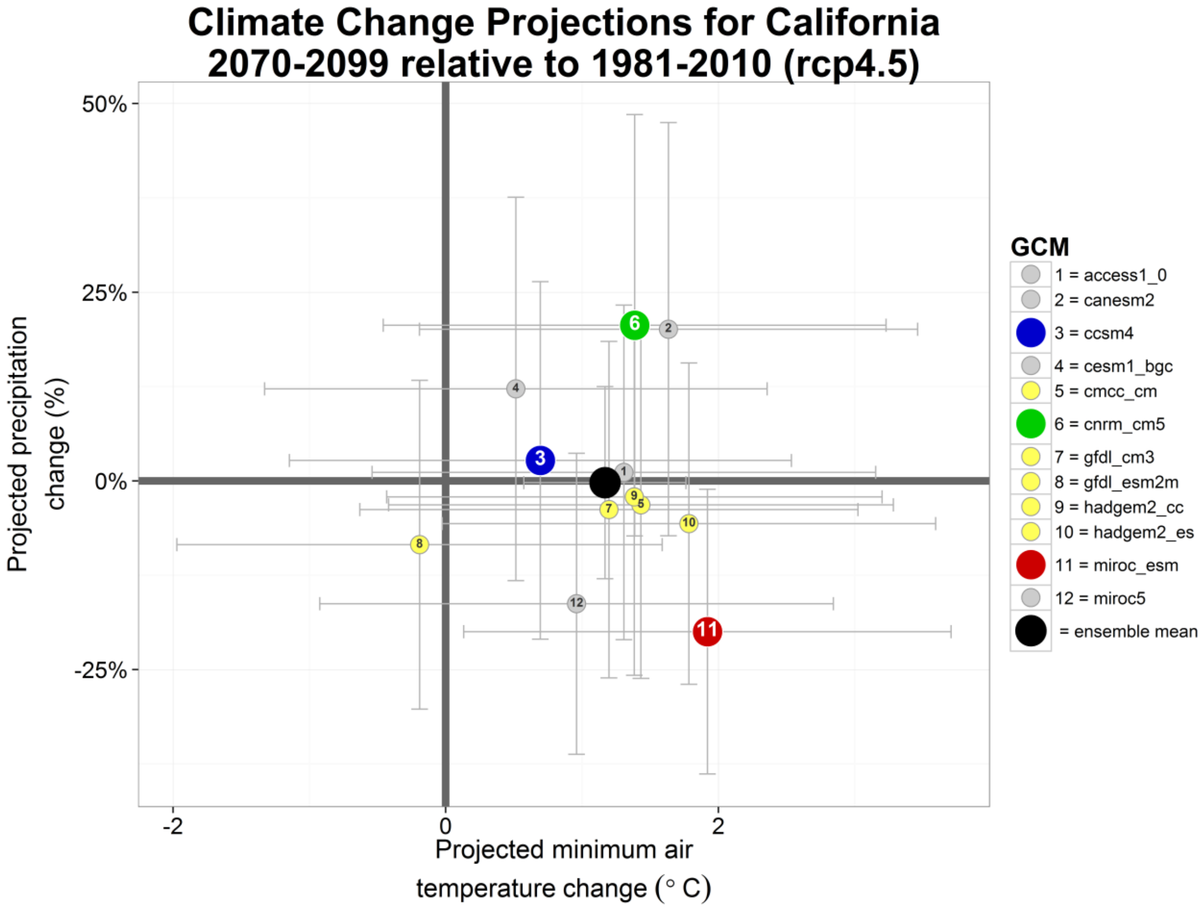

Figure 3. The difference between the 1981-2010 mean annual minimum temperatures and precipitation for California, and the 2070-2099 projections for 12 CMIP5 GCM projections and the RCP 4.5 emission scenario. The origin of the axes represents mean California conditions for the 1981-2010 time frame, used as the baseline. The x axis refers to changes in temperature, and the y axis to changes from the % of current precipitation.

Thorne, J.H., R.M. Boynton, L.E. Flint, A.L. Flint. 2015. Comparing historic and future climate and hydrology for California's watersheds using the Basin Characterization Model. *Ecosphere* 6(2). Online http://www.esajournals.org/doi/pdf/10.1890/ES14-00300.1; Flint, L. E., and A. L. Flint. 2012a. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. Ecological Processes 1:1.

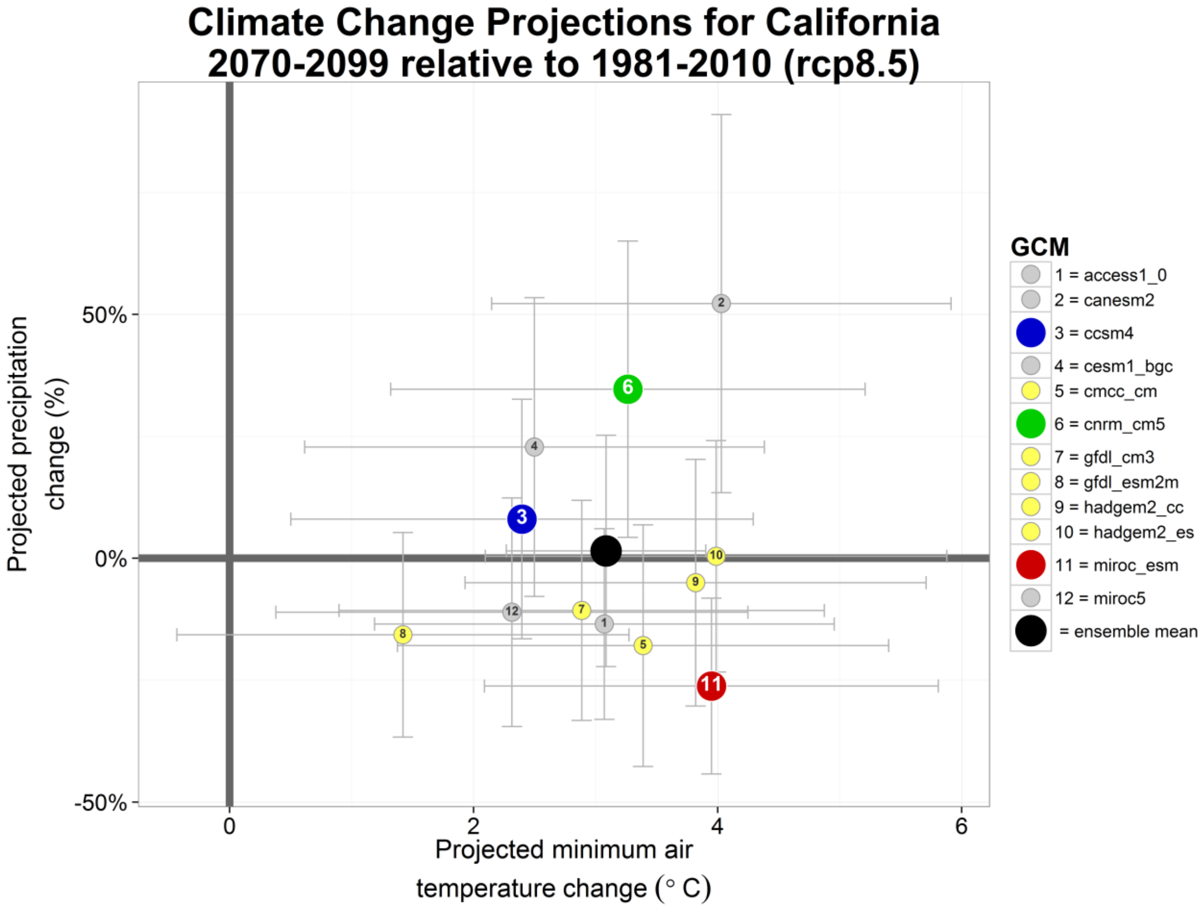

Figure 4. The difference between the 1981-2010 mean annual minimum temperatures and precipitation for California, and the 2070-2099 projections for 12 CMIP5 GCM projections and the RCP 8.5 emission scenario. The origin of the axes represents mean California conditions for the 1981-2010 time frame, used as the baseline. The x axis refers to changes in temperature, and the y axis to changes from the % of current precipitation.

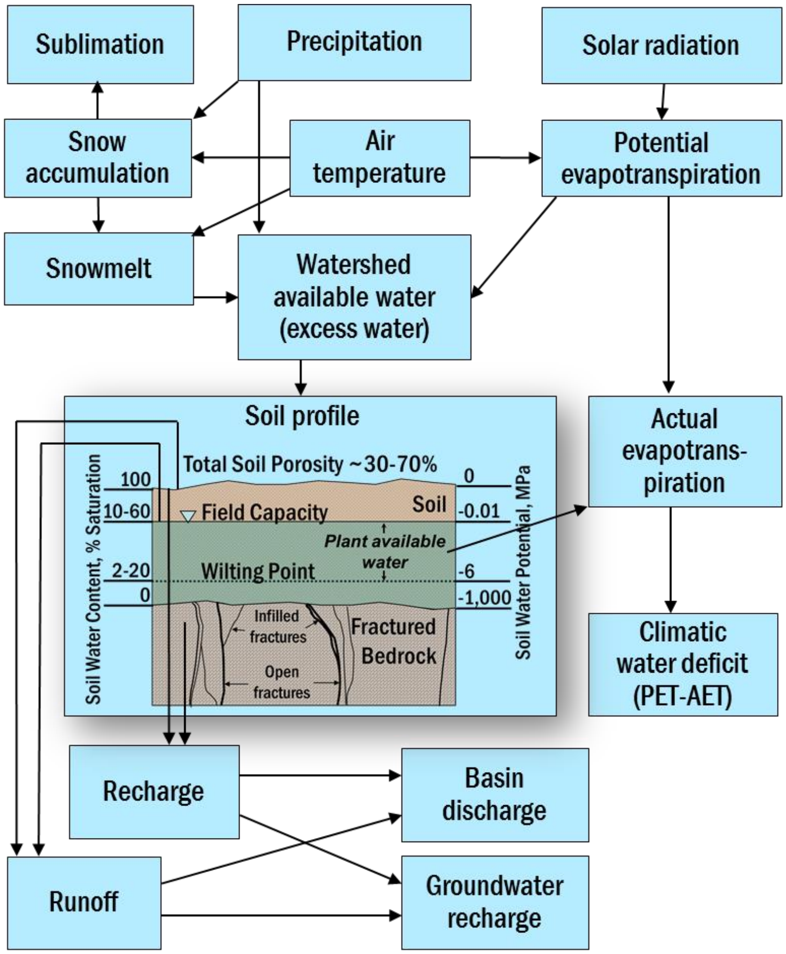

Figure 5. The variables calculated by the Basin Characterization Model (BCM). The model runs on a grid cell basis.

Taxonomic Occurrence Data

Occurrence data for 167 mammal species and 420 mammal subspecies native to California were obtained from biodiversity informatics aggregators and communication with species experts. Occurrence data were bulk downloaded from VertNet in April of 2016 and from the California Natural Diversity Database (CNDDB) in January of 2016. Additional occurrence records were obtained from species experts in 2015 and 2016. Data were quality controlled by culling records with spatial uncertainty greater than 1.6 km (1 mi), records with inconsistent county location, and records without a specified geodetic datum. The veracity of records occurring outside of species-specific CDFW range-map boundaries were scrutinized individually.

For the purposes of modeling species distributions, occurrence records were reduced to one unique record per 270 × 270 m grid cell. The mean number of unique occurrence record locations per species for the 167 native California mammal species was 172. Seventy-two percent of species (120/167) had at least 30 unique occurrence locations. Ninety-two percent (153/167) of species had at least 5 unique occurrence locations. Fourteen species were not modeled due to a paucity of (< 5) unique occurrence record locations. Five native Californian species had no occurrence data in California. The mean number of unique occurrence locations for the 420 mammal subspecies native to California was 41. Ninety percent (377/420) of subspecies had at least one occurrence record location. Forty-three native Californian subspecies had no occurrence location data within California.

Dispersal Ability

Each non-volant species' dispersal capacity for the 2080s "future" period was calculated as its potential maximum rate of dispersal multiplied by the 75-year interval between "current" and "future" periods (2010 to 2085). The potential rate of dispersal was calculated as the species' median natal dispersal distance divided by its age at first reproduction (i.e. minimum generation length). Median natal dispersal distance was estimated as a power-function of adult body mass and diet (i.e. carnivore vs. herbivore/omnivore), using equations from Schloss *et al.* 2012[15]. Data on adult body mass (n = 159), age at first reproduction (n = 91), and diet (n = 125) for California mammalian species (n = 167) were obtained from the PanTheria, a global mammal trait database[16]. Missing trait data were imputed using phylogenetic, allometric, and correlative relationships for global mammalian species (n = 5,416) and data for 12 additional traits. Trait imputations were performed using [R] version 3.3.0 and the Rphylopars[17] package version 0.2.1. A compiled phylogenetic tree, with branch lengths, for 5020 global mammalian species was obtained from onezoom.org[18]. Two native Californian species (*Sorex sonomae*, *Sorex lyelli*) were added to the tree, following the latest taxonomy[19,20], to achieve complete coverage of native Californian mammal phylogenetic relationships for all 167 species. Dispersal ability estimates were calculated for 142 terrestrial and non-volant native California mammal species (Figure 6). Trait data for the 20 taxa covered in this report were used in the vulnerability analysis.

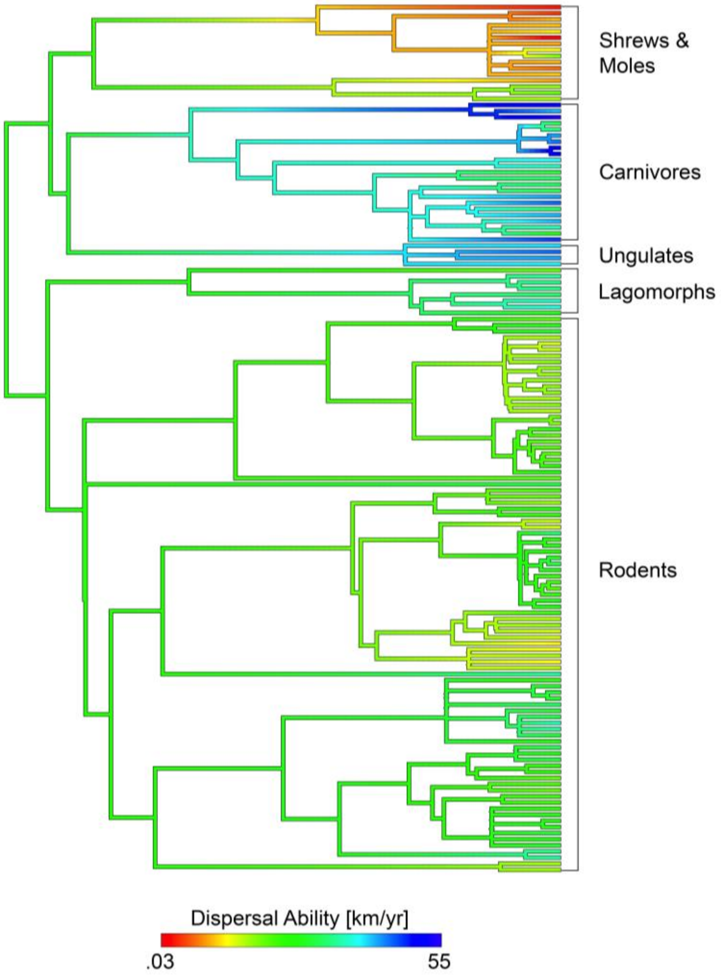

Figure 6. Estimated dispersal ability and phylogenetic relationships for native terrestrial (non-volant) mammal species of California (n = 142).

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[15] Schloss C.A., Nuñez T.A., & Lawler J.J. (2012) Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. Proceedings of the National Academy of Sciences of the United States of America, 109, 8606–11.

[16] Jones K.E., Bielby J., Cardillo M., *et al*. 2009. PanTHERIA: a species-level database of life history, ecology, and geography of extant and recently extinct mammals. *Ecology*, 90, 2648.

[17] Bruggeman J., Heringa J., & Brandt B.W. (2009) PhyloPars: estimation of missing parameter values using phylogeny. *Nucleic Acids Research* 37: W179-W184.

[18] Rosindell J, Harmon LJ (2012) OneZoom: A Fractal Explorer for the Tree of Life. PLoS Biology, 10, 1–5.

[19] Esteva M, Cervantes FA, Brant S V, Cook JA (2010) Zootaxa, Molecular phylogeny of long-tailed shrews (genus Sorex) from México and Guatemala. Zootaxa, 2615, 47–65.

[20] Demboski JR, Cook JA (2003) Phylogenetic Diversification Within the *Sorex cinereus* group (Soricidae). Journal of Mammalogy, 84, 144–158.

Species Distribution Models

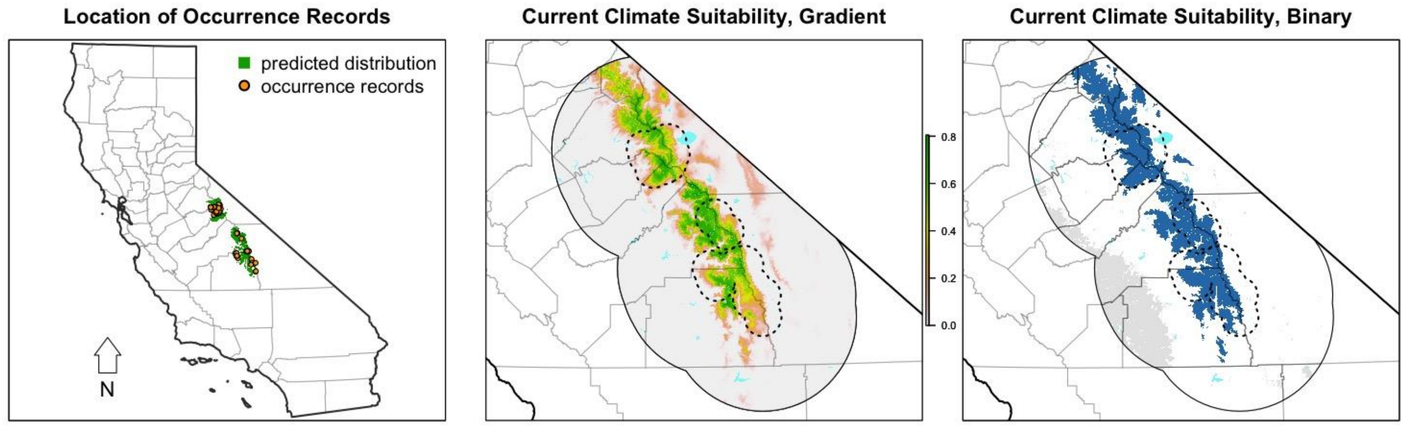

Figure 7. Occurrence locations (left), current predicted gradient climatic suitability (middle), and current thresholded climatic suitability (right) for a species (*Tamias alpinus*). The dashed boundary represents a maximum dispersal buffer around occurrence records. The solid boundary represents a 100-km buffer around occurrence records. Areas of agriculture and urban development are shown in gray. Inland bodies of water are shown in light blue. State boundaries are black. County boundaries are grey.

The SDMs were implemented in the R programming language, and used the Dismo[21] package and Maxent version 3.3.3k (Elith et al., 2011[22]) for model parameterization. The following measures were implemented to maximize model performance and temporal transferability and to reduce spurious relationships and model complexity. We used seven hydro-climatic predictor variables that we hypothesized to be important to mammal distribution: mean annual actual evapotranspiration (AET), mean annual snowpack (PCK), mean annual runoff (RUN), mean annual minimum temperature (TMN), mean annual maximum temperature (TMX), mean annual precipitation (PPT), and climate water deficit (CWD). For each species we used AIC_c model selection[23] to evaluate models produced from 33 possible predictor variable combinations with Pearson's correlation coefficients less than 0.64 and up to four predictor variables per model (Table 6). Maxent threshold and hinge features were turned off. Continuous climate suitability surfaces for each species (Figure 7, middle panel) were converted into binary surfaces representing the potential distribution of each species (Figure 7, right panel) using the threshold that maximized the sum of sensitivity and specificity. Background points (pseudo-absences), representing sampling intensity, were comprised of all quality-controlled VertNet mammal occurrence locations within 100 km of occurrence points for the target species. Occurrence and background records were reduced to one unique record per 270 m × 270 m climate grid cell. We used the best performing (lowest AICc) Maxent model parameterization to spatially project the current (1981-2010) and modeled the future (2070-2099) climatically suitable range for each species.

For each taxon (species or subspecies) we evaluated the projected change in climatically suitable habitat at and around occurrence locations for that taxon. We calculated the percent of occurrence locations projected to remain climatically suitable under future conditions (i.e. no dispersal scenario) and the percent change in climatically suitable habitat area within a plausible maximum dispersal threshold; we buffered occurrence locations by distances appropriate to capture the dispersal abilities for that species. We present graphical summaries of projected change in climatically suitable range area over time, including area remaining suitable, area no longer suitable, and area newly suitable (Figure 8).

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[21] Robert J. Hijmans, Steven Phillips, John Leathwick and Jane Elith (2015).
dismo: Species Distribution Modeling. R package version 1.0-12. http://CRAN.R-project.org/package=dismo

[22] Elith J., Phillips S., Hastie T., Dudík M., Chee Y., & Yates C. (2011) A statistical explanation of MaxEnt for ecologists. Diversity and Distributions, 17, 4357.

[23] Warren D. & Seifert S. (2011) Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications, 21, 335–42.

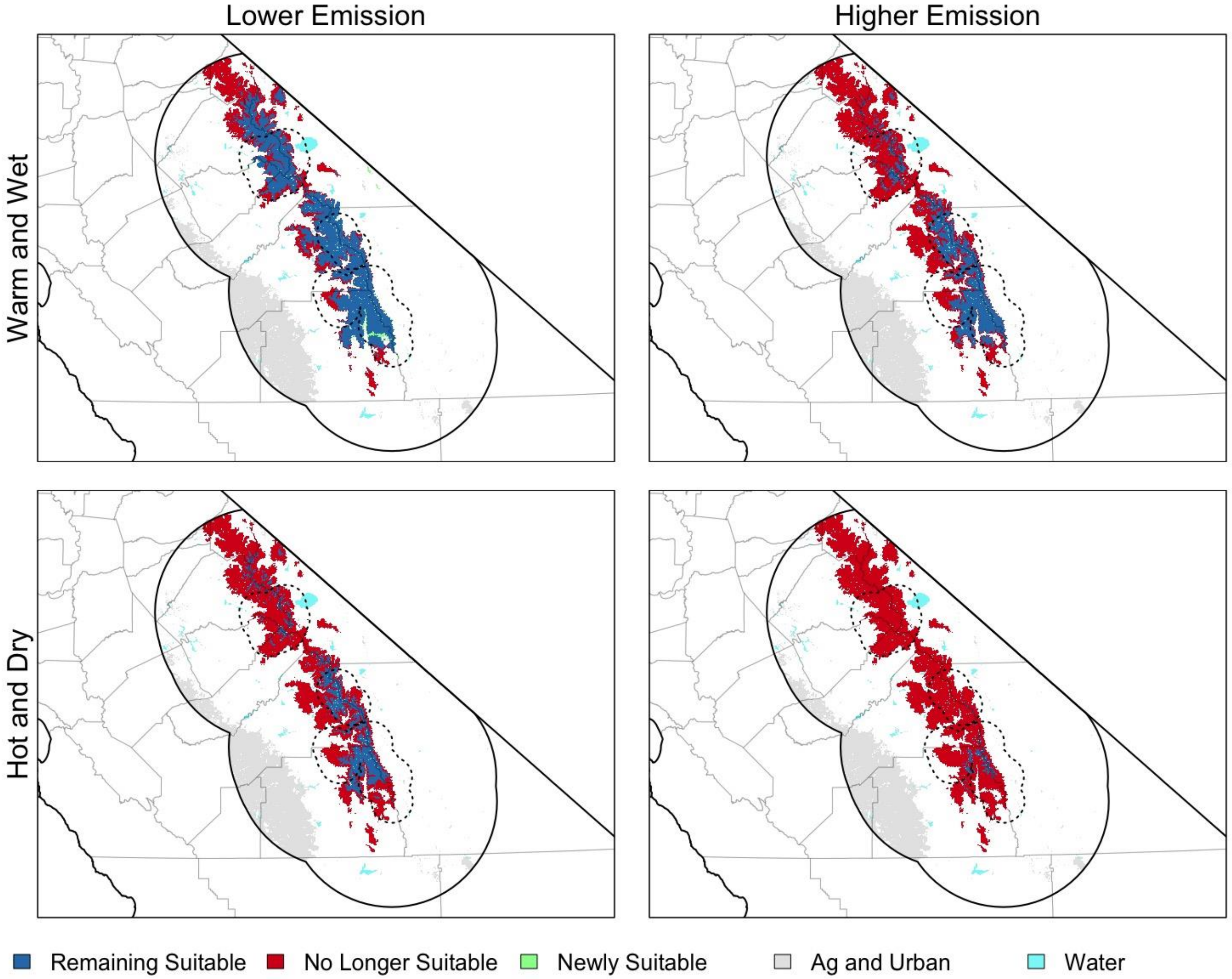

Figure 8. An example of projected change in climatically suitable habitat for a taxon (*Tamias alpinus*), under four climate scenarios for the 2080s. Dotted boundary depicts a species-specific dispersal threshold for *T. alpinus* around known occurrence locations. Change in climatically suitable area over time is calculated within this plausible dispersal area. Solid boundary depicts a 100-km buffer around occurrence locations. State boundary is shown in black. County lines are shown in gray.

We assumed that the species is the taxonomic level at which organisms adapt to climate. Species Distribution Models (SDMs) were fit to the full range of climatic conditions experienced across all records for the species. In other words, our modeled estimates of climatic tolerance assumed that subspecies share the same climatic tolerance as their full species counterparts. Because the phylogenic relationships within the California vole (*Microtus californicus*) is an area of current study[24], for this species SDMs were fit at the level of the currently-designated subspecies.

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[24] Conroy, C.J. and Neuwald, J.L. (2008) Phylogenetic study of the California vole, *Microtus californicus*. Journal of Mammalogy, 89,755.

Table 6. Table of 33 candidate variable combinations with Pearson's correlation coefficients less than 0.64 and up to four predictor variables per model. The best model was selected using AICc model selection. See text for variable abbreviations.

AET	AET + TMX	PCK + RUN + TMX
AET + PCK	CWD	PCK + TMN
AET + PCK + RUN	CWD + PCK	PCK + TMX
AET + PCK + RUN + TMN	CWD + PCK + RUN	PPT
AET + PCK + RUN + TMX	CWD + RUN	PPT + TMN
AET + PCK + TMN	PCK	PPT + TMX
AET + PCK + TMX	PCK + PPT	RUN
AET + RUN	PCK + PPT + TMN	RUN + TMN
AET + RUN + TMN	PCK + PPT + TMX	RUN + TMX
AET + RUN + TMX	PCK + RUN	TMN
AET + TMN	PCK + RUN + TMN	TMX

Sea Level Rise

Species with low elevation coastal occurrences, < 4 m above current sea level, were evaluated for vulnerability to sea level rise. For each taxon we used the lowest elevation occurrence record as the species' tolerance threshold to inundation events and saline groundwater. Combined tidal surge and storm surge on the California coast can exceed 2 m[25]. Burrowing species may be directly vulnerable to effects of saltwater intrusion on their fossorial environment. Non-burrowing species may be impacted by sea level rise via effects of salt water on vegetation. As with the species distribution model, we assumed the species is the taxonomic level at which organisms adapt tolerance to inundation and salt water intrusion, however results are presented at both the level of the species and subspecies. Occurrence records for each species were reduced to one record per unique coordinate value pair; multiple records with identical latitude/longitude values were collapsed. High-resolution coastal LiDAR surfaces were used to extract elevation values for each coastal occurrence record (5 m horizontal resolution, 1 mm vertical resolution)[26]. We evaluated each taxon's vulnerability to sea level rise as the percent of unique occurrence locations that would fall below the elevational threshold under a scenario of 1 m of sea level rise. For context, global sea level is projected to rise by 0.5 – 5 m by the end of the 21st century[27,28,29].

Overall Climate Change Vulnerability Score

The overall climate change vulnerability score (CCVS) for each taxon was calculated as the weighted arithmetic mean of its projected geographic response score, exposure/niche breadth score, and qualitative vulnerability score. The CCVS is modeled after NatureServe's Climate Change Vulnerability Index (CCVI), but uses a modified set of inputs and calculations. The CCVS has potential values between -80 and 100, with higher values indicating greater vulnerability to climate change, zero indicating a neutral response to climate change, and negative values indicating a potential positive response to climate change. Weights for each vulnerability component represent our assessment of the relative strength of inference derived from these different approaches to vulnerability assessment (50% projected geographic response, 20% exposure/niche breadth, 30% qualitative vulnerability). Studies have shown that correlative SDMs can be powerful tools

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[25] Cayan D.R., Bromirski P.D., Hayhoe K., Tyree M., Dettinger M.D., & Flick R.E. (2008) Climate change projections of sea level extremes along the California coast. Climatic Change, 87, 57–73.

[26] NOAA Coastal Services Center Coastal Inundation Digital Elevation Models. https://coast.noaa.gov/slrdata/

[27] Rahmstorf S. (2007) Projecting Future Sea-Level Rise. Science, 315, 368–370.

[28] Pfeffer W.T., Harper J.T., & O'Neal S. (2008) Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science*, 321, 1340–1343.

[29] Hansen J., Sato M., Hearty P. *et al.* (2015) Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming is highly dangerous. Atmospheric Chemistry and Physics Discussions, 15, 20059–20179.

for predicting climate change vulnerability for some taxa[30,31,32], but more work is needed to understand the environmental and taxon-specific conditions that influence the predictive performance of these models. The qualitative and exposure/niche breadth metrics used in this report, adapted from Young *et al*. (2011)[33], are appealing for their simplicity and straightforwardness, but have not yet been tested for their ability to predict species response to climate change.

We explicitly document the formulas used in our calculations so these methods may be easily critiqued and improved upon. We present these formulas as imperfect estimates of the relative contributions and interactions between many variables in determining taxon-specific vulnerability to climate change. We anticipate that, as climate change and climate change science progresses, methods for assessing species' vulnerability to climate change will improve. As with Young *et al*. 2011, we make the spreadsheet used as a tool for our calculations freely available to the public. All data and inputs used in these CCVS calculations are made publically available for re-analysis.

We use the following arithmetic and logical operations to calculate each taxon's CCVS. Formulae for these operations are integrated into the publically available spreadsheet tool we use for these calculations. Variable notations and explanations are given in Table 9. We discretized CCVS with thresholds shown in Table 7.

CCVS = 0.5 × Projected Geographic Response + 0.2 × Exposure/Niche Breadth + 0.3 × Qualitative Vulnerability

Table 7. Thresholds used for discretizing the CCVS.

Discrete Score	Quantitative Thresholds
Extremely Vulnerable	$60 \leq$ CCVS
Highly Vulnerable	$30 \leq$ CCVS < 60
Moderately Vulnerable	$10 \leq$ CCVS < 30
Less Vulnerable	$0 \leq$ CCVS < 10
May Benefit	CCVS < 0

Vulnerability from changes in the climatic suitability of habitat (SDM Vulnerability) is calculated as the average vulnerability between the no dispersal scenario and the maximum dispersal scenario. SDM Vulnerability has potential values ranging from -100 to 100. SDM Vulnerability of 100 indicates a complete loss of climatically suitable habitat. SDM Vulnerability of 0 indicates no change in climatic suitability. The minimum value for SDM Vulnerability is set at −100, equivalent to a doubling of suitable habitat area and no loss of suitability at occurrence locations.

SDM Vulnerability = $\max(-1 \times (A1a + A1b - 100) \div 2, -100)$

Projected geographic response can be interpreted as the percent of climatically suitable potential habitat projected to be lost to climate change, with negative values representing potential increase in climatically suitable habitat from climate change. For coastal species that are vulnerable to sea level rise, we allow high vulnerability to sea level rise to supersede vulnerability to changing terrestrial climate conditions. If the species has coastal occurrences vulnerable to sea level rise

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[30] Hijmans RJ, Graham C (2006) The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology, 12, 2272–2281.

[31] Pearman PB, Randin CF, Broennimann O et al. (2008) Prediction of plant species distributions across six millennia. Ecology Letters, 11, 357–369.

[32] Dobrowski SZ, Thorne JH, Greenberg JA, Safford HD, Mynsberge AR, Crimmins SM, Swanson AK (2011) Modeling plant ranges over 75 years of climate change in California, USA: Temporal transferability and species traits. Ecological Monographs, 81, 241–257.

[33] Young, B., Byers, E., Gravuer, K., Hall, K., Hammerson, G., & Redder, A. (2011). Guidelines for using the NatureServe climate change vulnerability index. NatureServe, Arlington, VA.

($A2 > 0$), the Projected Geographic Response is calculated as the maximum of A2 and SDM Vulnerability. If the species has no coastal occurrences vulnerable to sea level rise ($A2 = 0$), the Projected Geographic Response is set equal to SDM Vulnerability. Projected Geographic Response has possible values ranging from -100 to 100, with 0 equivalent to no change, higher positive values indicating greater vulnerability, and higher negative values indicating potential positive response.

$\text{IF } (A2 > 0) \text{ Projected Geographic Response} = \max(A2, \text{SDM Vulnerability})$
$\text{IF } (A2 = 0) \text{ Projected Geographic Response} = \text{SDM Vulnerability}$

Exposure/niche breadth is calculated as taxon's projected thermal and hydrologic exposure to climate change (the relative magnitude of projected change in its environment) relative to its thermal and hydrologic niche breadth (the range of conditions the taxon currently experiences throughout its environment). Potential values for exposure/niche breadth range from 0 to 100. Higher values indicate greater vulnerability. The maximum value is set at 100, indicating that exposure is greater than or equal to niche breadth. We discretized exposure/niche breadth scores following thresholds in Table 8.

$$\text{Exposure/Niche Breadth} = \min(100 \times (|A3a| \div (A3b + A3c) + |A4a| \div (A4b \times 2)), 100)$$

Table 8. Thresholds used for discretizing exposure/niche breadth scores.

Discrete Score	**Quantitative Thresholds**
Extremely Vulnerable	$50 \leq$ Exposure/Niche Breadth
Highly Vulnerable	$30 \leq$ Exposure/Niche Breadth < 50
Moderately Vulnerable	$10 \leq$ Exposure/Niche Breadth < 30
Less Vulnerable	$0 \leq$ Exposure/Niche Breadth < 10

Qualitative Vulnerability is calculated as the mean of 19 discretized qualitative variables adapted from Young *et al*. 2011[34] and scaled from -100 to 100. The variables are: natural barriers to dispersal, anthropogenic barriers to dispersal, impact of climate change mitigation, dispersal and movement, physiological thermal niche, physiological hydrological niche, dependence on disturbance regime, dependence on ice or snow, restriction to rare landscape features, other species generate habitat, dietary versatility, other species for dispersal, pathogens and natural enemies, sensitivity to competition, interspecific interactions, measured genetic variation, genetic bottlenecks, phenological response, documented response to climate change (see Table 9 for a list of variables and their notation). All variables are as defined by the NatureServe CCVI 3.0 guidelines, with modification to allow for the possibility that taxa may respond positively to climate change (for example if a species range or population has already been documented as expanding in response to climate change). Categorical scores for each qualitative variable are discretized into numerical scores as follows: "greatly increases vulnerability to climate change" receives a score of 3, "increases vulnerability to climate change" receives a score of 2, "somewhat increases vulnerability to climate change" receives a score of 1, "neutral" receives a score of 0, "greatly decreases vulnerability to climate change" receives a score of –3, "decreases vulnerability to climate change" receives a score of –2, "somewhat decreases vulnerability to climate change" receives a score of –1, "unknown" receives a score of N/A. At least 13 variables must be classified in a category other than "unknown" for a taxon to receive a score.

$$\text{Qualitative Vulnerability} = \text{mean}(B2a, B2b, B3, C1a, C2aii, C2bii, C2c, C2d, C3, C4a, C4b, C4d, C4e, C4f, C4g, C5a, C5b, C6, D1) \times 100 \div 3$$

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[34] Young, B., Byers, E., Gravuer, K., Hall, K., Hammerson, G., & Redder, A. (2011). Guidelines for using the NatureServe climate change vulnerability index. *NatureServe, Arlington, VA.*

Table 9. Quantitative and expert-assessed categorical variables used to calculate climate change vulnerability scores (CCVS) suitable for interspecific comparison of climate change vulnerability among mammal taxa.

Variable	Notation	Explanation
Projected Geographic Response		
Projected percent of occurrence locations remaining suitable	A1a	Percent of occurrence locations for target taxon (species or subspecies) projected to remain suitable under future climate conditions (2070 – 2099). Lower values indicate greater vulnerability to climate change.
Projected percent change in climatically suitable habitat area	A1b	Projected percent change in climatically suitable habitat area for the target taxon under future climate conditions (2070 – 2099). Calculated within a species-specific maximum dispersal distance around occurrence records of the target taxon (species or subspecies). Larger negative values indicate greater vulnerability to climate change. Positive values indicate a potential positive response to climate change if the species is able to disperse to newly suitable habitat.
Projected loss to sea level rise	A2	Percent of occurrence locations that will no longer be suitable after 1 m sea level rise. Calculated at the level of the target taxon (species or subspecies). Higher values indicate greater vulnerability to sea level rise.
Quantitative Exposure and Niche Breadth		
Thermal exposure	A3a	Mean change in mean annual temperature [°C] at occurrence locations from current (1981 – 2010) to projected future conditions (2070 – 2099). Calculated at the level of the target taxon (species or subspecies).
Thermal niche geographic breadth	A3b	Difference between the 2.5% quantile and 97.5% quantile in current (1981 – 2010) mean annual temperature [°C] at occurrence locations. Calculated at the level of the full species.
Thermal niche seasonal breadth	A3c	Value of the 95% quantile of the difference between mean summer (June, July, August) and mean winter temperature (December, January, February) at occurrence locations [°C]. Calculated at the level of the full species.
Hydrological exposure	A4a	Mean change in cumulative annual actual evapotranspiration [mm] at occurrence locations from current (1981 – 2010) to projected future conditions (2070 – 2099). Calculated at the level of the target taxon (species or subspecies).
Hydrologic niche geographic breadth	A4b	Difference between the 2.5% quantile and 97.5% quantile in current (1981 – 2010) cumulative annual actual evapotranspiration at occurrence locations [mm]. Calculated at the level of the full species.
Qualitative Categorical Variables[35]		
Natural barriers to dispersal	B2a	As defined by NatureServe CCVI.
Anthropogenic barriers to dispersal	B2b	As defined by NatureServe CCVI.
Impact of climate change	B3	As defined by NatureServe CCVI.

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[35] Expert-assessed categorical variables included in CCVS analysis conform to NatureServe CCVI version 3.0 guidelines (http://www.natureserve.org/sites/default/files/guidelines_natureserveclimatechangevulnerabilityindex_r3.0_15_apr2015.pdf) and variable notation, with modification to allow for scoring categorical variables as decreasing a species vulnerability to climate change.

mitigation		
Dispersal and movement	C1a	As defined by NatureServe CCVI.
Physiological thermal niche	C2aii	As defined by NatureServe CCVI.
Physiological hydrological niche	C2bii	As defined by NatureServe CCVI.
Dependence on disturbance regime	C2c	As defined by NatureServe CCVI.
Dependence on ice or snow	C2d	As defined by NatureServe CCVI.
Restriction to rare landscape features	C3	As defined by NatureServe CCVI.
Other species generate habitat	C4a	As defined by NatureServe CCVI.
Dietary versatility	C4b	As defined by NatureServe CCVI.
Other species for dispersal	C4d	As defined by NatureServe CCVI.
Pathogens and natural enemies	C4e	As defined by NatureServe CCVI.
Sensitivity to competition	C4f	As defined by NatureServe CCVI.
Interspecific interactions	C4g	As defined by NatureServe CCVI.
Measured genetic variation	C5a	As defined by NatureServe CCVI.
Genetic bottlenecks	C5b	As defined by NatureServe CCVI.
Phenological response	C6	As defined by NatureServe CCVI.
Documented response to climate change	D1	As defined by NatureServe CCVI.

Each taxon was also given a discrete score for sensitivity and adaptive capacity. Sensitivity and adaptive capacity is calculated as the average of a subset of 14 of the 19 discrete variables used to calculate the qualitative vulnerability score. We discretized exposure/niche breadth scores following thresholds in Table 10.

Sensitivity and Adaptive Capacity = mean(C1a, C2aii, C2bii, C2c, C2d, C3, C4a , C4b, C4d, C4e, C4f, C4g, C5a, C5b, C6) × 100 ÷ 3

Table 10. Thresholds used for discretizing sensitivity and adaptive capacity scores.

Discrete Score	**Quantitative Thresholds**
Extremely Vulnerable	$50 \leq$ Sensitivity and Adaptive Capacity
Highly Vulnerable	$30 \leq$ Sensitivity and Adaptive Capacity < 50
Moderately Vulnerable	$10 \leq$ Sensitivity and Adaptive Capacity < 30
Less Vulnerable	$0 \leq$ Sensitivity and Adaptive Capacity < 10
May Benefit	Sensitivity and Adaptive Capacity < 0

RESULTS

Overall results are presented in the Executive Summary. This section provides detail on each of the 20 taxa selected for this report by the CDFW.

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Mount Lyell Shrew (*Sorex lyelli*)

Figure 9. A shrew (Genus: *Sorex*). Illustration from Kays, RW, and DE Wilson. Mammals of North America. Princeton University Press, 2009. Species experts were not aware of the existence of a photograph of a live Mount Lyell shrew.

This poorly-known shrew is found on moist soils at high-elevations of the Southern Sierra. Model outputs indicate it ranges from highly vulnerable to extremely vulnerable to climate change. The magnitude of projected impacts of the two Hot and Dry scenarios is greater than for the Warm and Wet scenarios. This is perhaps not surprising, given the species' association with mesic-wet vegetation communities. High Emission scenarios are projected to have a greater impact on the shrew than Low Emission scenarios. The general pattern of response of the shrew to climate change is projected to be a general retraction upwards in elevation within its currently suitable range. Mount Lyell itself may or may not remain suitable, based on the future climate scenario.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 22 geographically unique occurrence locations for *Sorex lyelli*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 10), which was projected to be 1661 km^2 for *Sorex lyelli*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 11). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.00499 kg, and time to first reproduction of 0.627 years, we estimate median natal dispersal distance to be 0.0829 km, and potential dispersal velocity for the species to be 0.132 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Sorex lyelli's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 11).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 4.13°C (range = 0.56 – 8.14°C) and 734.61 mm/year (range = 291.81 – 1186.65 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.50°C (range = 2.75 – 6.61°C) and 80.60 mm/year (range = -156.66 – 330.47 mm/year). Our SDM projected that 10.53 – 47.37% of known occurrence locations will remain suitable for *Sorex lyelli* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -95.79 and -41.95%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 11. Components of the climate change vulnerability score for *Sorex lyelii*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Index**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	47.37%	58.05%	100.00%	Extremely Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	10.53%	13.00%	100.00%	Extremely Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	31.58%	40.97%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	10.53%	4.21%	100.00%	Highly Vulnerable	Moderately Vulnerable	Extremely Vulnerable

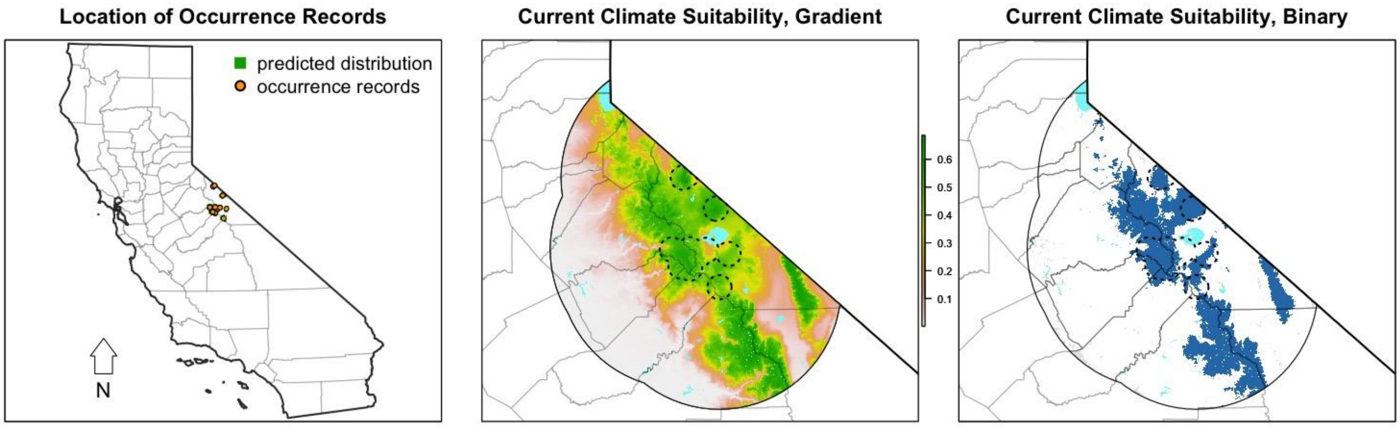

Figure 10. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

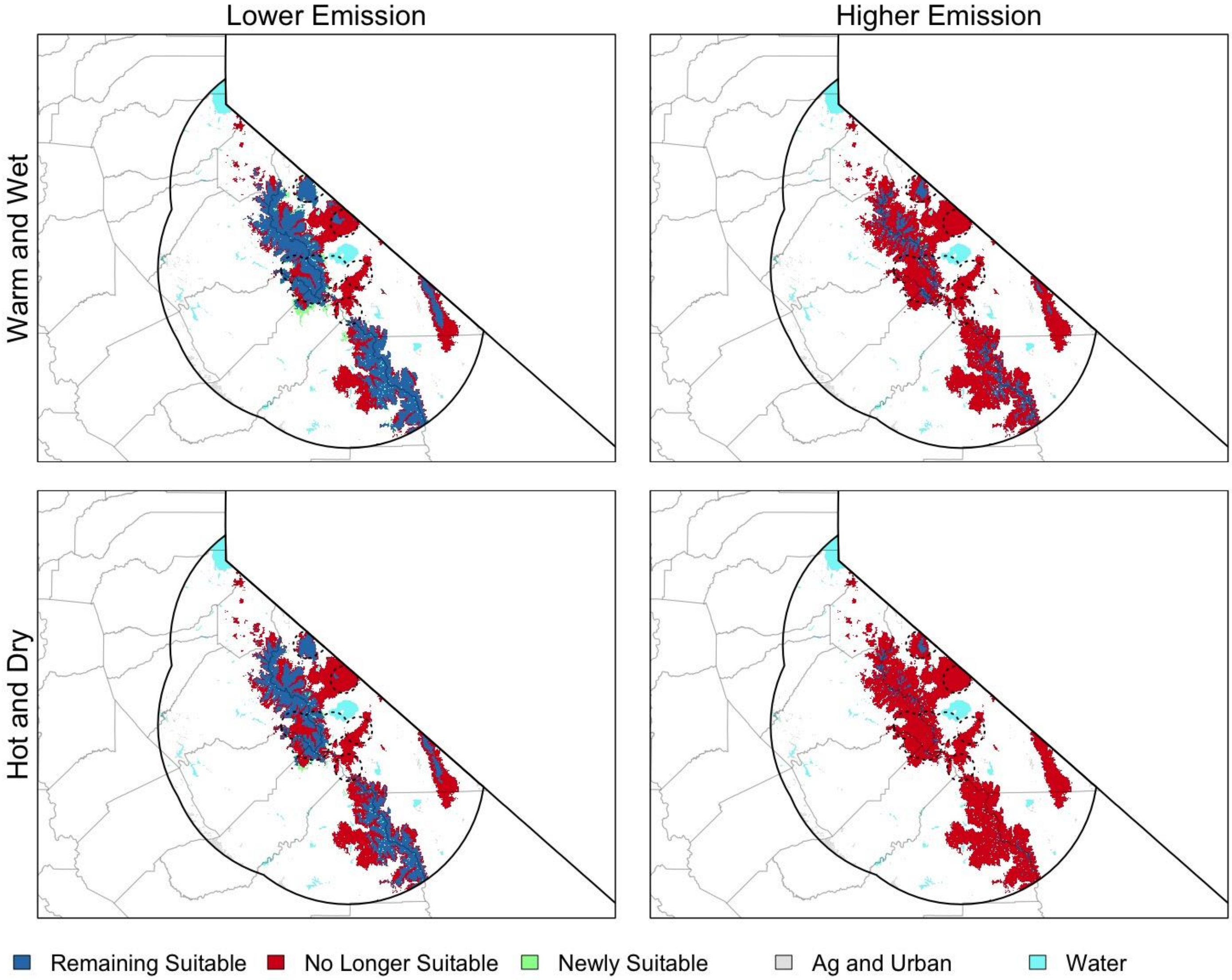

Figure 11. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Southern California Salt Marsh Shrew (*Sorex ornatus salicornicus*)

Figure 12. An ornate shrew (*Sorex ornatus*) © Creative Commons https://creativecommons.org/lice

The Southern California salt marsh shrew occurs only in coastal salt marshes of Los Angeles, Orange, and Ventura counties. While the subspecies is confined to coastal salt marsh, its full-species counterpart occurs on valley foothill, montane riparian, woodland, chaparral, grassland, and emergent wetland habitats. The Southern California salt marsh shrew is projected to be extremely vulnerable to climate change impacts, regardless of scenario. The models for climatically suitable habitat area suggest the subspecies has fairly broad tolerance to climates within Southern California. However, most of these areas would not provide the salt marsh vegetation composition, structure, and prey base to which this shrew is adapted. Focusing just on the immediate coastal areas in which the shrew currently occurs or could disperse to in the future, the projections are even more grim: essentially no habitat appears to be suitable for the shrew in the future. The climate change impacts would add to the impacts that have already occurred due to extensive habitat loss to agriculture and urbanization.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 171 geographically unique occurrence locations for *Sorex ornatus*, including 10 for *Sorex ornatus salicornicus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 13), which was projected to be 69 km^2 for *Sorex ornatus salicornicus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 14). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.00531 kg, and time to first reproduction of 0.627 years, we estimate median natal dispersal distance to be 0.0857 km, and potential dispersal velocity for the species to be 0.137 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (-1.00 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 15). Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Sorex ornatus salicornicus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 12).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 16.95°C (range = 15.72 – 17.56°C) and 319.39 mm/year (range = 278.58 – 365.60 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.80°C (range = 2.69 – 5.10°C) and -12.36 mm/year (range = -118.44 – 113.09 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Sorex ornatus salicornicus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -100.00%. One meter of sea level rise was projected to cause the loss of 10.00% of known occurrence locations. The overall climate change vulnerability score was projected to be extremely vulnerable under all four climate scenarios.

Table 12. Components of the climate change vulnerability score for *Sorex ornatus salicornicus*.

	Terrestrial Climate Change Model Results		Sea Level Rise, 1 meter	Climate Change Vulnerability Score		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	0.00%	90.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
High Emission, Warm and Wet	0.00%	0.00%	90.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	0.00%	90.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	90.00%	Highly Vulnerable	Moderately Vulnerable	Extremely Vulnerable

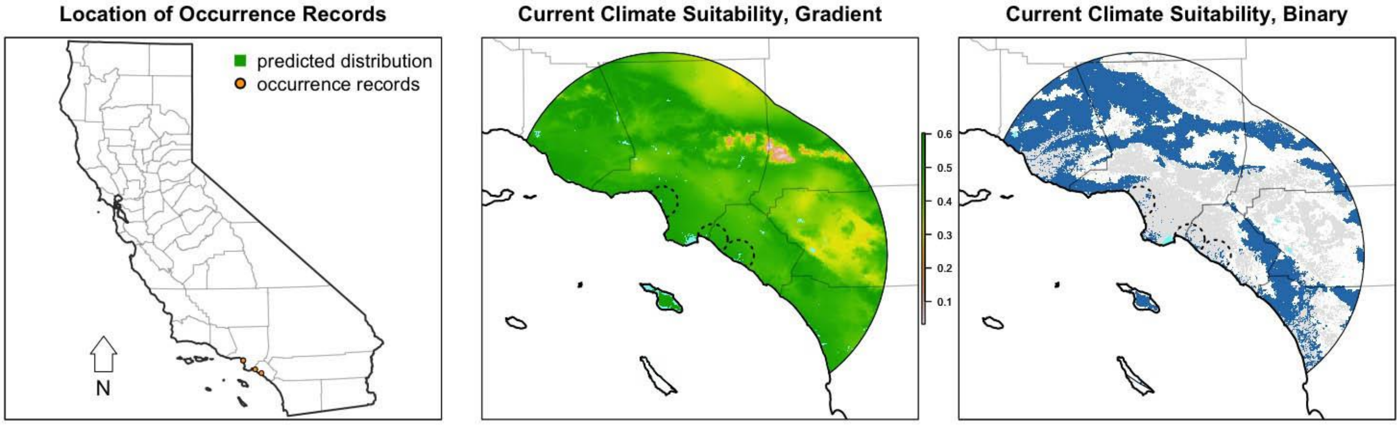

Figure 13. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

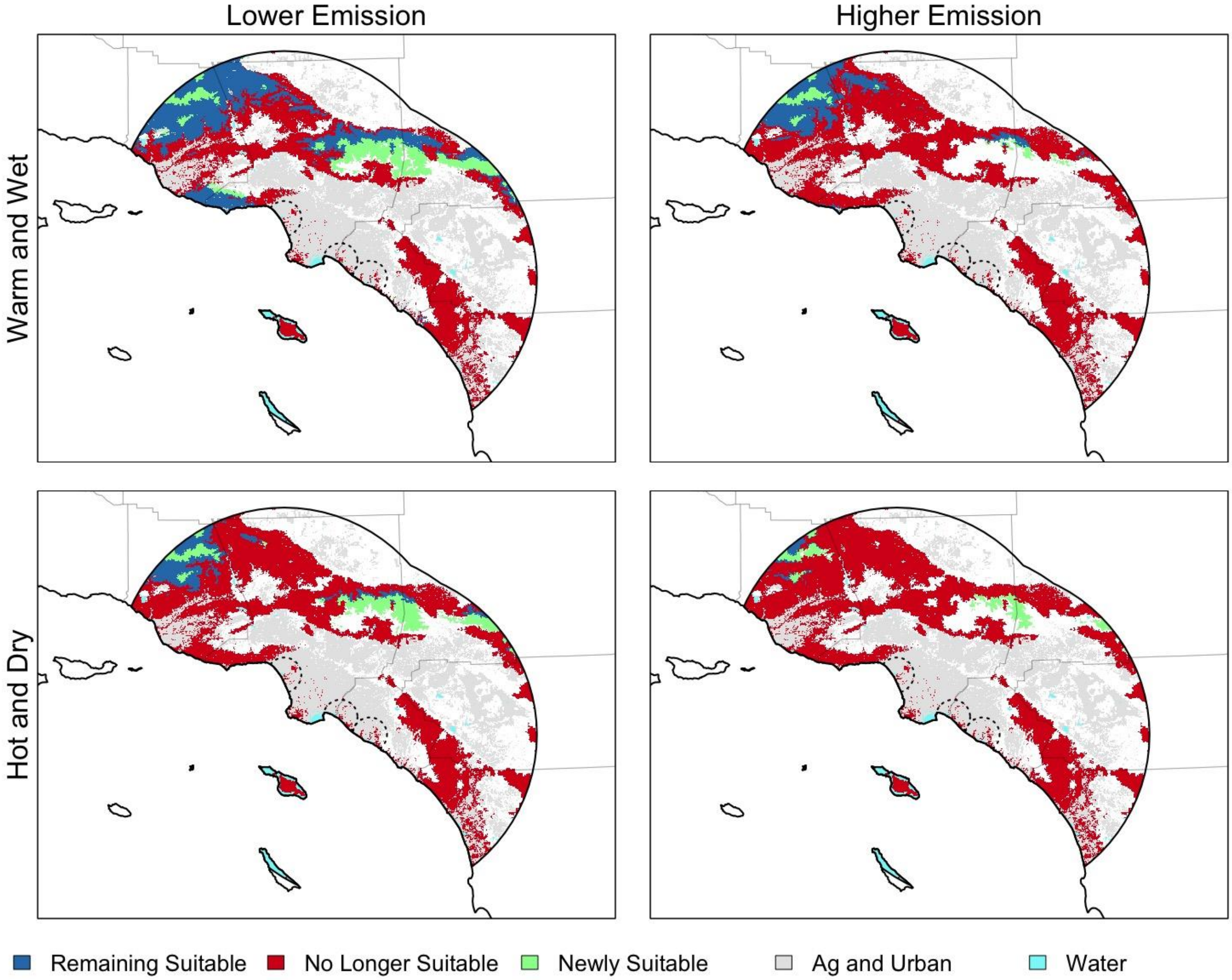

Figure 14. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

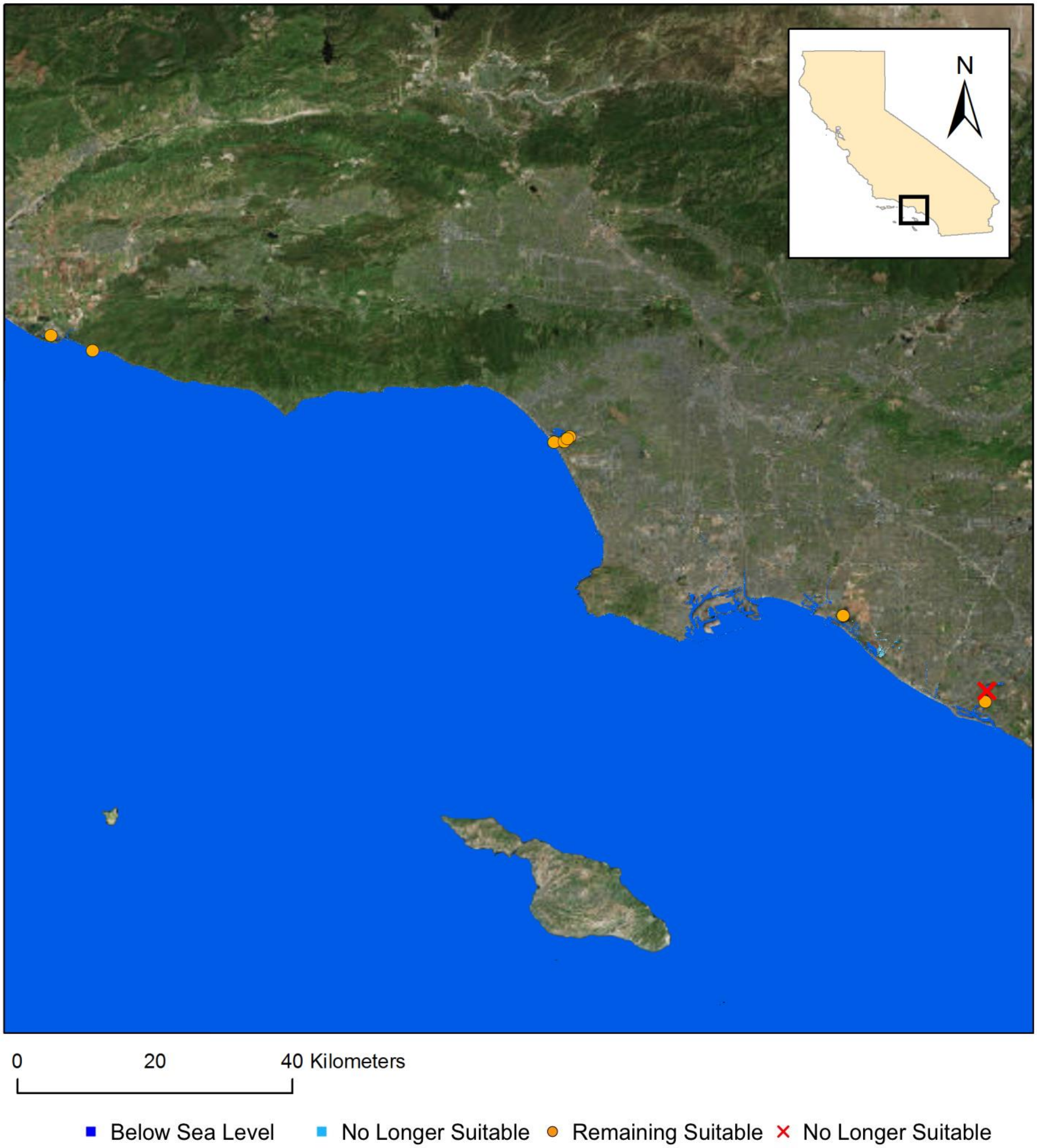

Figure 15. Projected loss of habitat from one meter of sea level rise for *Sorex ornatus salicornicus.* Areas with elevations between -1.00 m, the lowest elevation occurrence for the taxa, and 0.00 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

Salt Marsh Wandering Shrew (*Sorex vagrans halicoetes*)

Figure 16. A wandering shrew (*Sorex vagrans*) © William Leonard.

This shrew is confined to small remnant stands of coastal salt marsh in the southern San Francisco Bay in San Mateo, Santa Clara, Alameda and Contra Costa counties. While the subspecies is confined to coastal salt marsh, its full-species counterpart occurs on valley foothill, montane riparian, aspen, wet meadow, annual and perennial grasslands, fresh and saline emergent wetlands, chaparral, and wooded habitats. It is projected to be extremely vulnerable to climate change impacts, regardless of scenario. The models for climatically suitable habitat area suggest the subspecies could occur along the coast in the San Francisco Bay Area and along the northern portions of the Central Coast. However, many of these areas do not currently provide the salt marsh vegetation composition, structure, and prey base to which this vole is adapted. Unless sea level rise expands the extent of salt marsh habitat in these areas, it seems doubtful that these currently unoccupied areas could support the shrew in the future. In addition, about one-third of currently suitable locations would be impacted by the projected sea level rise in the Bay Area. The climate change impacts would add to impacts that have already occurred due to extensive habitat loss to agriculture and urbanization.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 150 geographically unique occurrence locations for *Sorex vagrans,* including 22 for *Sorex vagrans halicoetes*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 17), which was projected to be 116 km^2 for *Sorex vagrans halicoetes*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 18). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.00599 kg, and time to first reproduction of 1.14 years, we estimate median natal dispersal distance to be 0.0914 km, and potential dispersal velocity for the species to be 0.08 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (0.30 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 19). Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Sorex vagrans halicoetes's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 13).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 15.13°C (range = 13.15 – 15.63°C) and 470.59 mm/year (range = 377.41 – 703.70 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 2.93°C (range = 1.43 – 4.78°C) and 136.39 mm/year (range = -55.94 – 304.08 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Sorex vagrans halicoetes* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -92.88%. One meter of sea level rise was projected to cause the loss of 30.43% of known occurrence locations. The overall climate change vulnerability score was projected to be extremely vulnerable under all four climate scenarios.

Table 13. Components of the climate change vulnerability score for *Sorex vagrans halicoetes*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	7.12%	69.57%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
High Emission, Warm and Wet	0.00%	0.00%	69.57%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	0.00%	69.57%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	69.57%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable

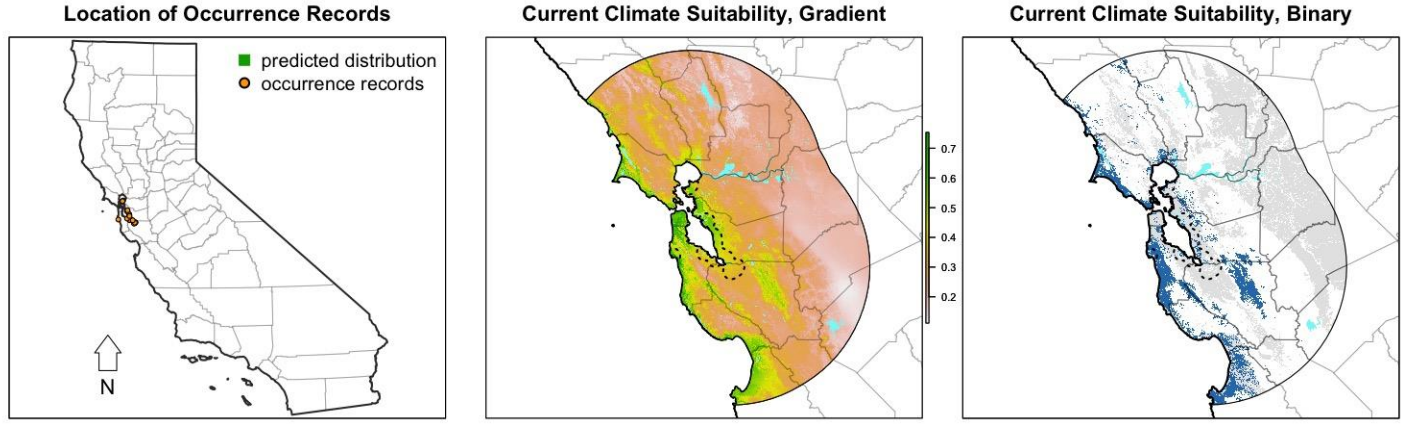

Figure 17. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

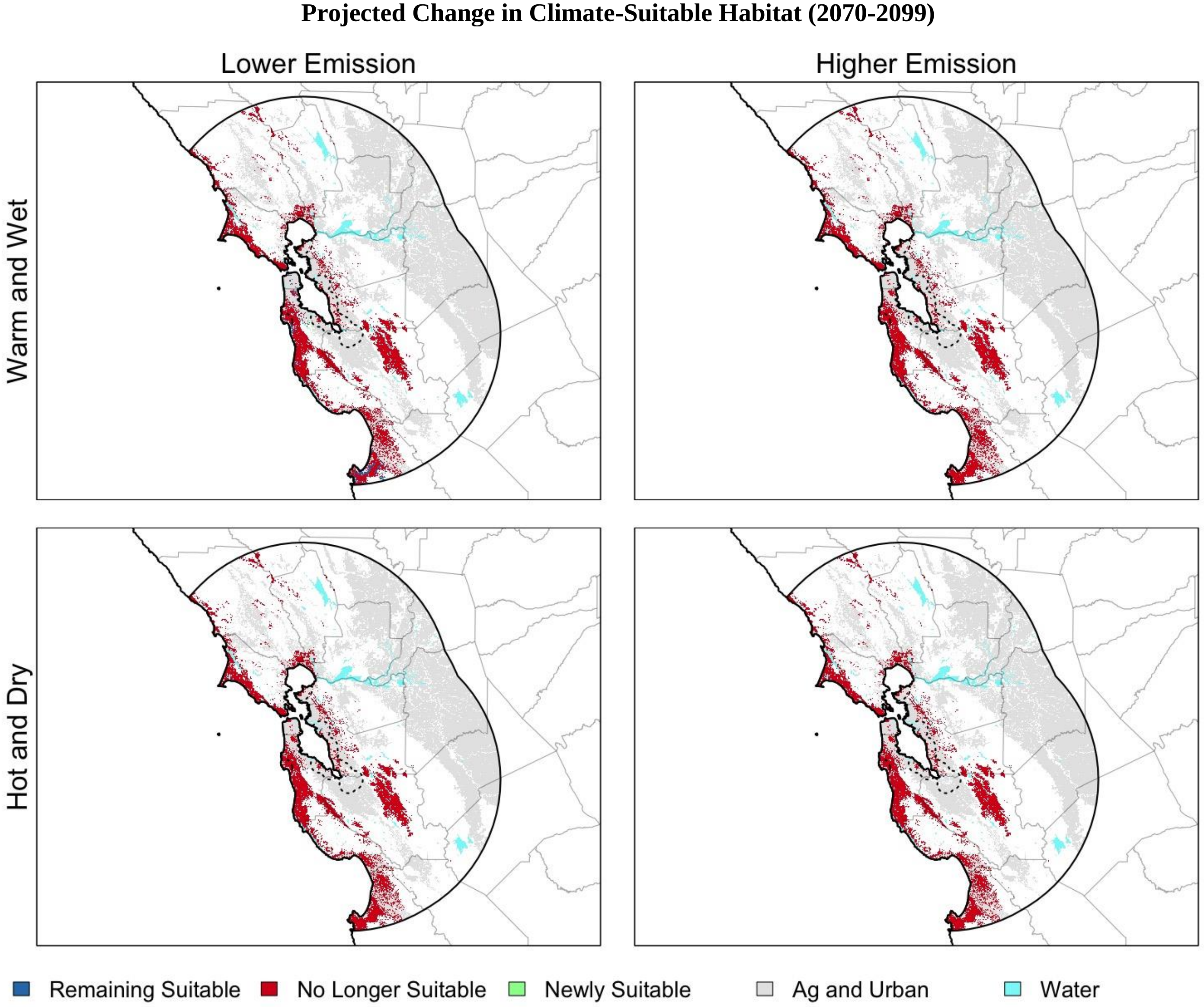

Figure 18. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

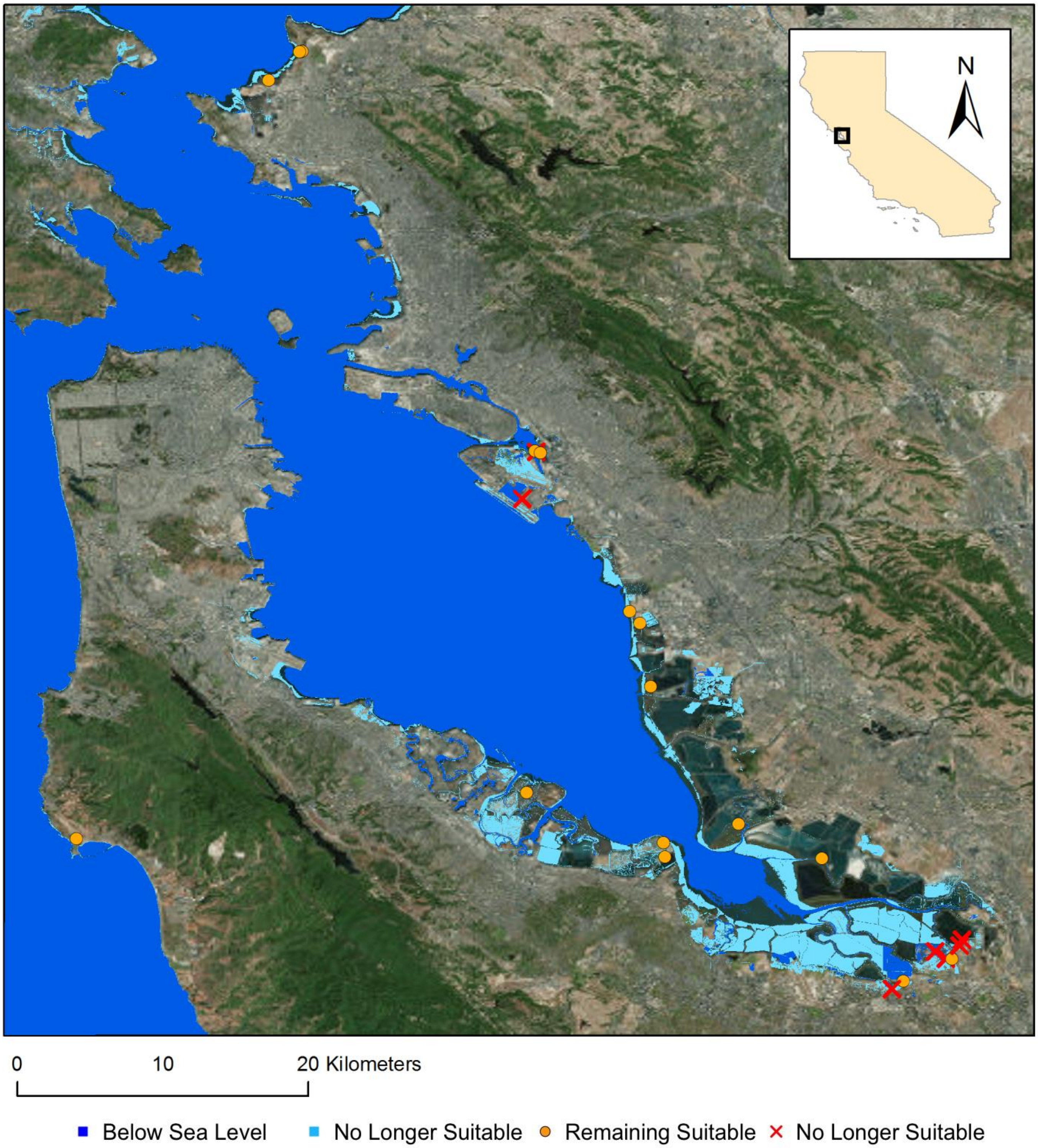

Figure 19. Projected loss of habitat from one meter of sea level rise for *Sorex vagrans halicoetes.* Areas with elevations between 0.30 m, the lowest elevation occurrence for the taxa, and 1.30 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

American Pika (*Ochotona princeps*)

Figure 20. An American pika (*Ochotona princeps*). Photo by Joe Pontecorvo, joepontecorvo.com.

The American pika occupies broken rock debris (talus) fields in cold climates throughout western North America. With its thick coat of fur and high resting metabolic rate, the species is well adapted to survival under the snow in winter. These same adaptations limit the amount of time that pikas can spend foraging when summer temperatures are too hot. In California, rising summer temperatures appear to have contributed to the species' extirpation from 15% of historically occupied sites. Model outputs indicate the pika is highly vulnerable or extremely vulnerable to climate change impacts. The projected impacts are greatest under the High Emission, Hot and Dry scenario, with 0% of both current locations and currently suitable area remaining suitable for the pika. Slightly less severe impacts are associated with the Low Emission, Hot and Dry scenario and the High Emission, Warm and Wet scenario, in which 8% - 10% of locations remain suitable into the future and about 11% to 12% of area remaining suitable. The Low Emission, Warm and Wet scenario resulted in relatively less severe impacts, with 42% of known locations and 27% of area remaining suitable. These model outputs are consistent with previous climate change model projections of future habitat suitability for the American pika in California, which suggested greatly reduced climatically suitable area within the state under a variety of scenarios by the end of the 21st century.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 497 geographically unique occurrence locations for *Ochotona princeps*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 21), which was projected to be 19938 km^2 for *Ochotona princeps*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 22). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.158 kg, and time to first reproduction of 1.03 years, we estimate median natal dispersal distance to be 0.535 km, and potential dispersal velocity for the species to be 0.521 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Ochotona princeps's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 14).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 3.05°C (range = -4.02 – 9.30°C) and 873.73 mm/year (range = 254.77 – 3023.28 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.41°C (range = 2.72 – 6.41°C) and 30.99 mm/year (range = -228.15 – 303.07 mm/year). Our SDM projected that 0.00 – 42.22% of known occurrence locations will remain suitable for *Ochotona princeps* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -72.58%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 14. Components of the climate change vulnerability score for *Ochotona princeps*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	42.22%	27.42%	100.00%	Highly Vulnerable	Highly Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	8.00%	11.13%	100.00%	Highly Vulnerable	Highly Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	9.56%	11.88%	100.00%	Moderately Vulnerable	Highly Vulnerable	Extremely Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	100.00%	Highly Vulnerable	Highly Vulnerable	Extremely Vulnerable

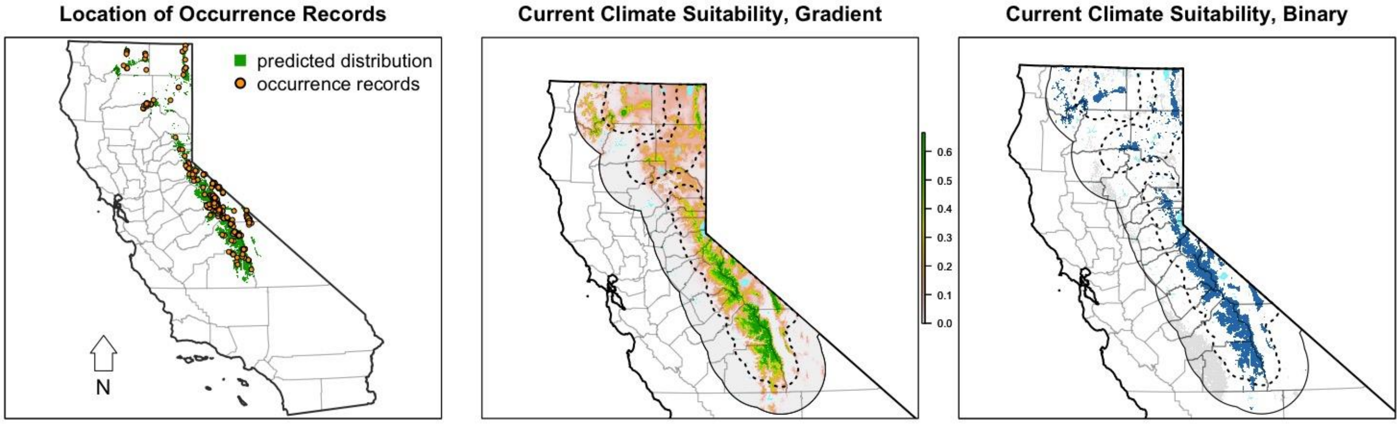

Figure 21. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

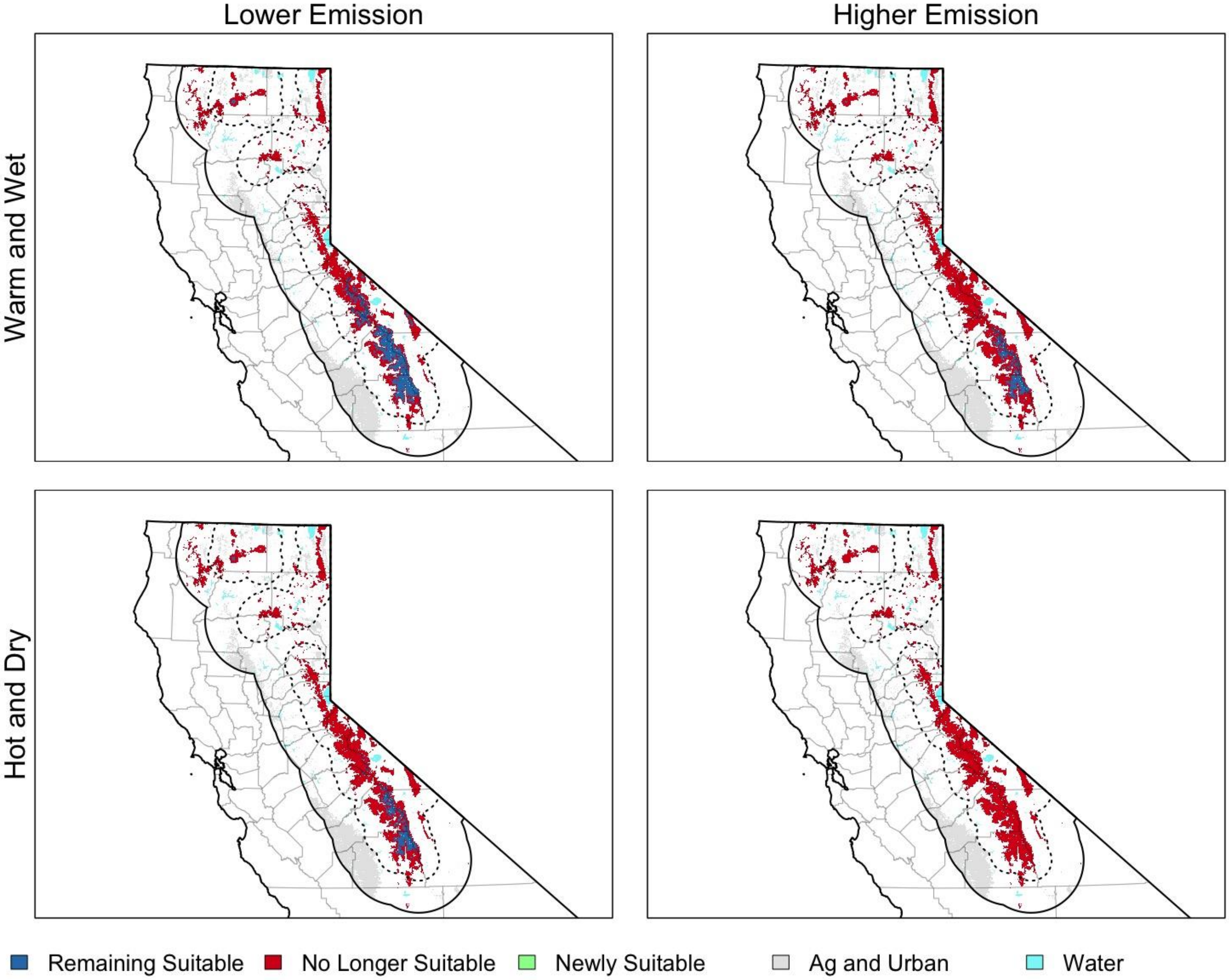

Figure 22. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. “Lower Emission”: RCP4.5. “Higher Emission”: RCP8.5. “Hot and Dry”: MIROC-ESM. “Warm and Wet”: CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

Point Reyes Mountain Beaver (*Aplodontia rufa phaea*)

Figure 23. A mountain beaver (*Aplodontia rufa*). Photo by Jared Hobbs.

The Point Reyes mountain beaver (*Aplodontia rufa phaea*), endemic to Point Reyes National Seashore, occurs at the periphery of the distribution of mountain beavers. *A. rufa phaea* comprises the most southern occurrences of mountain beavers (*A. rufa*) in coastal California. Mountain beavers' inability to form concentrated urine requires them to consume one quarter of their body weight in water daily and contributes to their extremely narrow hydrologic niche breadth. Though *A. rufa* occurs on slopes of all aspects throughout most of the species' range, *A. rufa phaea* is entirely restricted to north facing slopes with thick vegetation cover. Model output indicates this subspecies is extremely vulnerable to the effects of climate change, regardless of the scenario. The species' limited dispersal ability may make it difficult for the Point Reyes mountain beaver to reach climatically-suitable areas that may occur in the future to the north of its current range. Despite its occurrence in relatively low-lying coastal areas, sea level rise does not appear to pose a substantial threat to the Point Arena mountain beaver.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 379 geographically unique occurrence locations for *Aplodontia rufa*, including 13 for *Aplodontia rufa phaea*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 24), which was projected to be 547 km^2 for *Aplodontia rufa phaea*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 25). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.806 kg, and time to first reproduction of 2.27 years, we estimate median natal dispersal distance to be 1.29 km, and potential dispersal velocity for the species to be 0.569 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (1.72 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 26). Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Aplodontia rufa phaea's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 15).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 13.88°C (range = 13.27 – 15.12°C) and 920.58 mm/year (range = 799.68 – 1065.36 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.57°C (range = 2.14 – 5.27°C) and 2.50 mm/year (range = -278.41 – 253.73 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Aplodontia rufa phaea* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -98.80%. One meter of sea level rise was projected to cause the loss of 7.14% of known occurrence locations. The overall climate change vulnerability score was projected to be extremely vulnerable for all four climate scenarios.

Table 15. Components of the climate change vulnerability score for the Point Reyes mountain beaver (*Aplodontia rufa phaea*).

	Species Distribution Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	1.20%	92.86%	Moderately Vulnerable	Highly Vulnerable	Extremely Vulnerable
High Emission, Warm and Wet	0.00%	0.00%	92.86%	Moderately Vulnerable	Highly Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	0.00%	92.86%	Moderately Vulnerable	Highly Vulnerable	Extremely Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	92.86%	Highly Vulnerable	Highly Vulnerable	Extremely Vulnerable

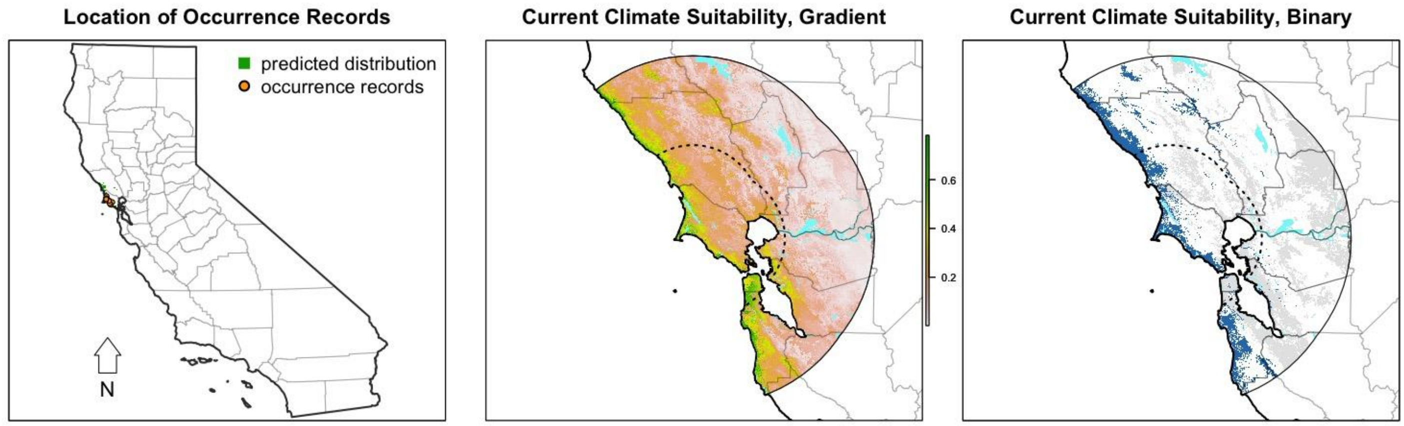

Figure 24. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

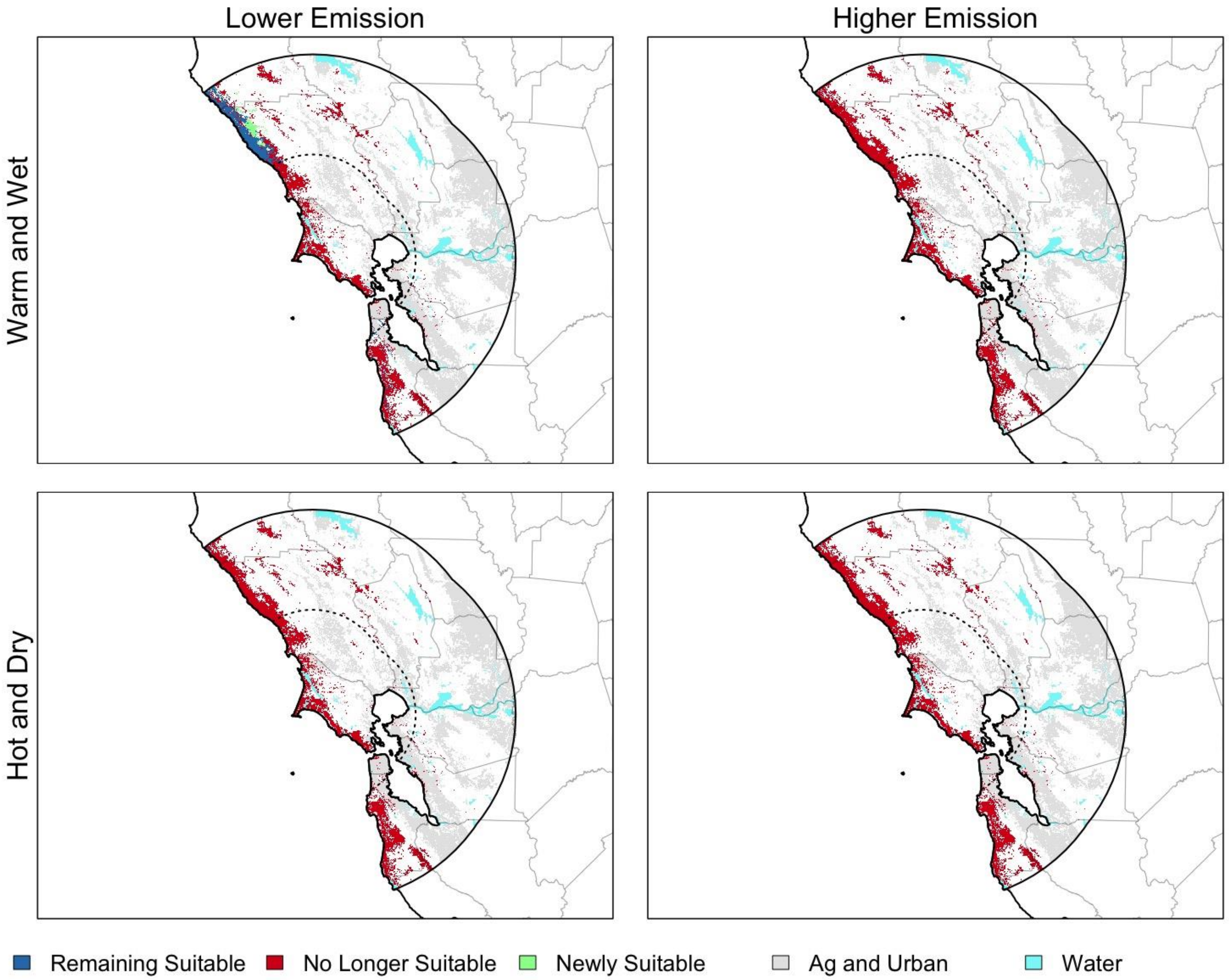

Figure 25. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

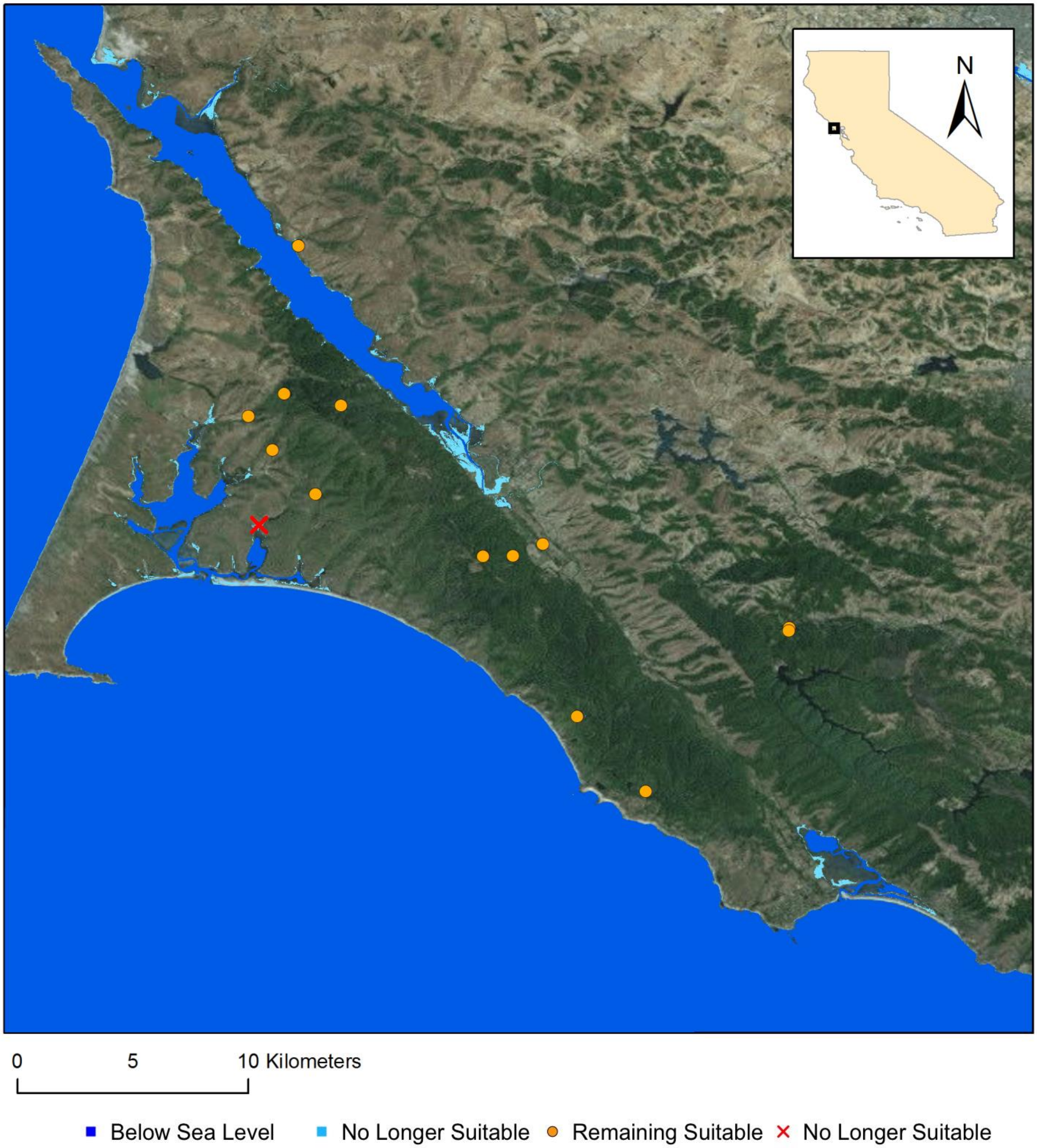

Figure 26. Projected loss of habitat from one meter of sea level rise for *Aplodontia rufa phaea.* Areas with elevations between 1.72 m, the lowest elevation occurrence for the taxa, and 2.72 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

Belding’s Ground Squirrel (*Urocitellus beldingi*)

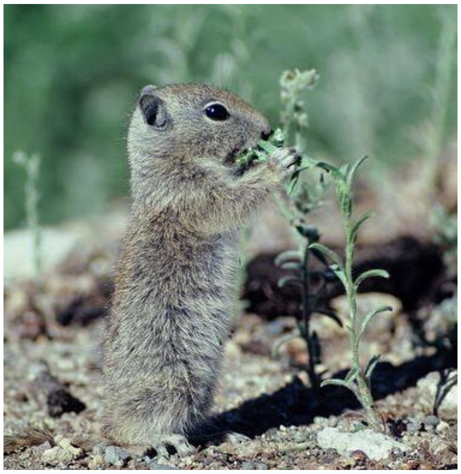

Figure 27. A Belding's ground squirrel (*Urocitellus beldingi*). Photo © Wardene Weisser, Ardea.com.

Belding’s ground squirrels occupy alpine dwarf-shrub, wet meadow, perennial and annual grassland, and open, grassy stands of bitterbrush and sagebrush, with distribution in California spanning the Sierra Nevada north of the Kings River to the Oregon border. The species also occurs in irrigated and agricultural areas. This is a relatively large-bodied diurnal rodent adapted to life at higher elevations. The species uses evaporative cooling and convection to avoid heat stress. In California, changing hydrology is thought to have contributed to the species’ extirpation from 42% of historically occupied sites. Model outputs indicate it is highly vulnerable to climate change impacts under all scenarios. The general projected response of the species to future climate scenarios is a retraction southward and upward in elevation within its currently occupied geographic range in the Sierra Nevada. Though models suggest that high elevation habitat south of the Kings River will be climatically suitable in the future, the species’ contemporary absence from this area suggests the species may not be able to disperse on its own to colonize this area.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 87 geographically unique occurrence locations for *Urocitellus beldingi*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 28), which was projected to be 21903 km^2 for *Urocitellus beldingi*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 29). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.273 kg, and time to first reproduction of 1.15 years, we estimate median natal dispersal distance to be 0.719 km, and potential dispersal velocity for the species to be 0.623 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species’ natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Urocitellus beldingi's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon’s overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 16).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 5.13°C (range = -0.50 – 12.99°C) and 824.00 mm/year (range = 220.70 – 1999.36 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.14°C (range = 2.57 – 5.93°C) and 14.88 mm/year (range = -224.72 – 264.57 mm/year). Our SDM projected that 36.21 – 67.24% of known occurrence locations will remain suitable for *Urocitellus beldingi* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -84.18 and -48.90%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to be highly vulnerable under all four climate scenarios.

Table 16. Components of the climate change vulnerability score for *Urocitellus beldingi*.

	Terrestrial Climate Change Model Results		Sea Level Rise, 1 meter	Climate Change Vulnerability Score		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	67.24%	51.10%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	48.28%	22.91%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	56.90%	42.69%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	36.21%	15.82%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable

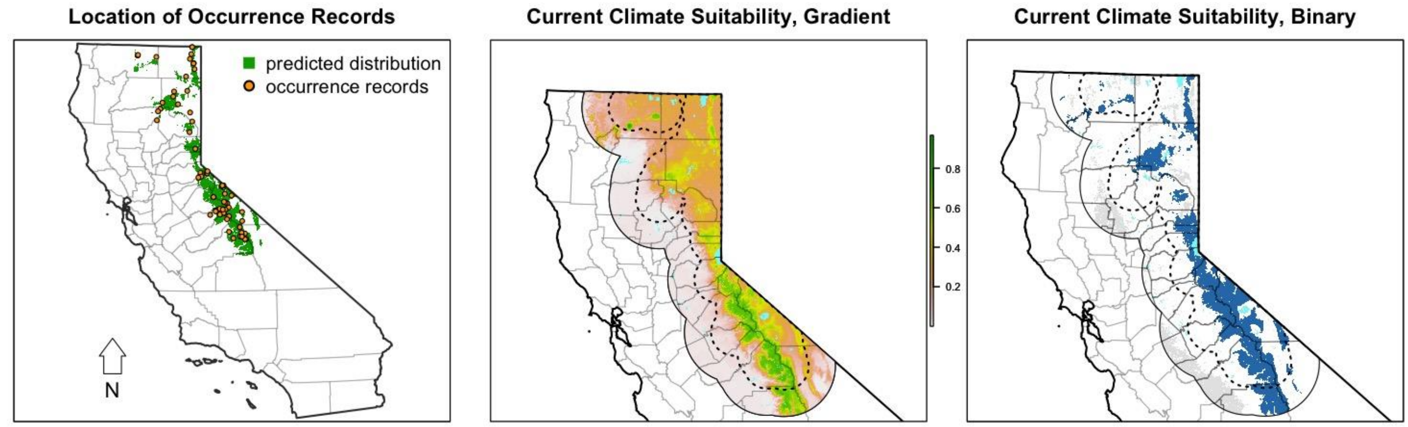

Figure 28. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

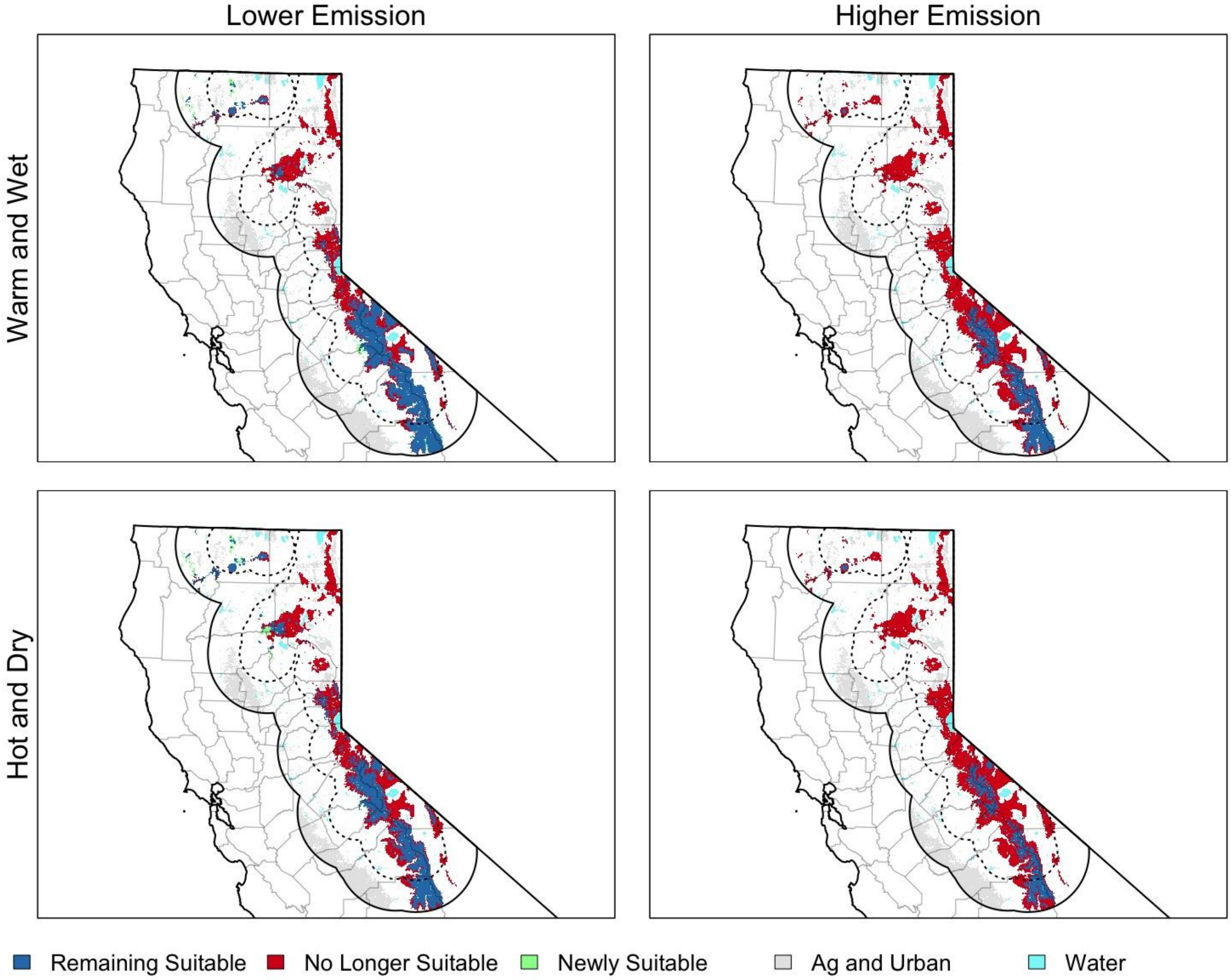

Figure 29. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

San Bernardino Golden-Mantled Ground Squirrel (*Callospermophilus lateralis bernardinus*)

Figure 30. A golden-mantled ground squirrel (*Callospermophilus lateralis*). Photo by Glen and Martha Vargas © California Academy of Sciences.

This large-bodied diurnal rodent subspecies occupies forest openings, open forests, and meadow edges in the San Bernardino Mountains, where it is endemic. Resurveys of historical sites in Yosemite indicate that the range of this subspecies' full-species counterpart in Yosemite contracted upward during the 20th century, disappearing from lower elevation sites and losing 16% of its elevational range. Model outputs suggest this subspecies is extremely vulnerable to the effects of climate change. Distribution model outputs suggest that all of the species habitat will become climatically unsuitable, irrespective of the scenario considered. The species is already at conservation risk due to small population size and restricted geographic range. Vulnerability to climate change substantially adds to the threats to this subspecies

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 422 geographically unique occurrence locations for *Callospermophilus lateralis*, including 15 for *Callospermophilus lateralis bernardinus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 31), which was projected to be 387 km^2 for *Callospermophilus lateralis bernardinus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 32). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.175 kg, and time to first reproduction of 1.15 years, we estimate median natal dispersal distance to be 0.566 km, and potential dispersal velocity for the species to be 0.491 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Callospermophilus lateralis bernardinus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 17).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 8.16°C (range = 4.62 – 10.93°C) and 782.27 mm/year (range = 620.71 – 1097.50 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.38°C (range = 3.36 – 5.59°C) and -137.02 mm/year (range = -360.28 – 151.92 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Callospermophilus lateralis bernardinus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -100.00%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 17. Components of the climate change vulnerability score for *Callospermophilus lateralis bernardinus*.

	Terrestrial Climate Change Model Results		Sea Level Rise, 1 meter	Climate Change Vulnerability Score		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
High Emission, Warm and Wet	0.00%	0.00%	100.00%	Highly Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable

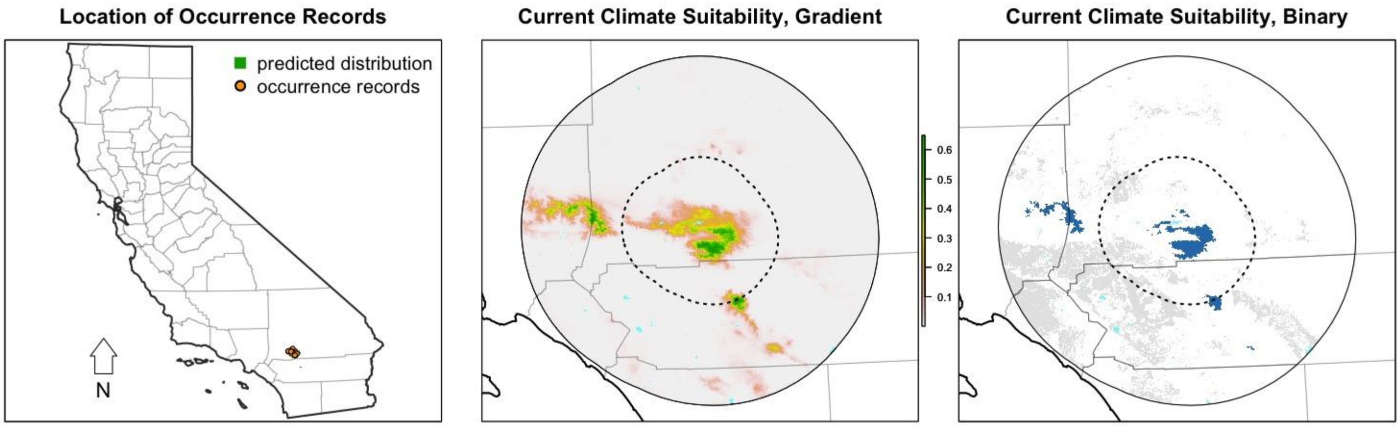

Figure 31. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

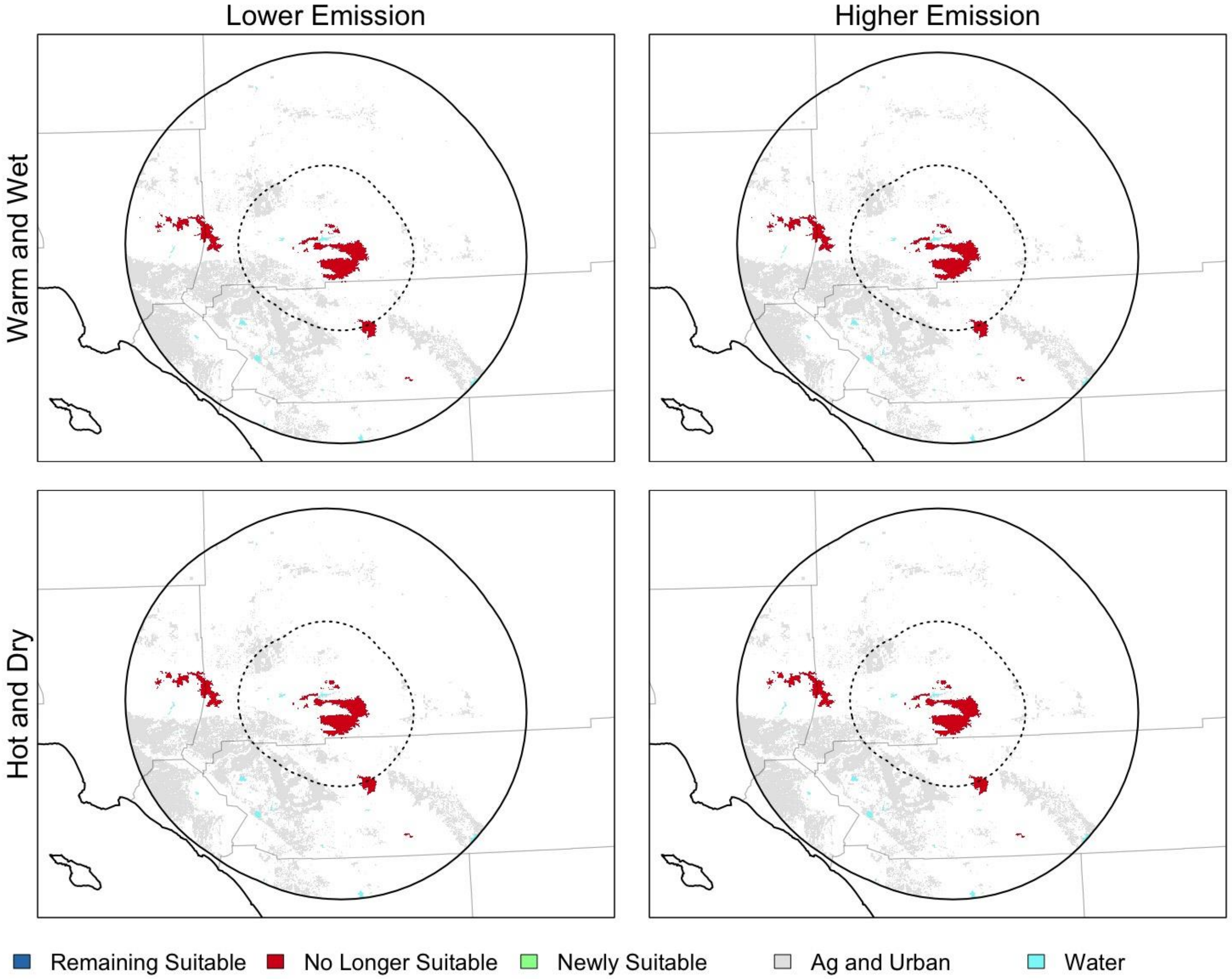

Figure 32. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

Alpine Chipmunk (*Tamias alpinus*)

Figure 33. An alpine chipmunk (*Tamias alpinus*). Photo by Risa Sargent.

This high-elevation, small-bodied chipmunk occurs on cliffs, talus slopes, and fell-fields in alpine dwarf-shrub habitat, at high elevations in the southern Sierra Nevada from the vicinity of Yosemite National Park south to Olanche Peak. Resurvey of historical sites in Yosemite indicates that the species range contracted upslope substantially during the 20th century, disappearing from 92% of its former elevational range. Model outputs suggests the Alpine chipmunk is moderately to extremely vulnerable to climate change. The overall pattern of response of the Alpine chipmunk to climate change projections is to retract upwards in elevation within more southerly portions of the Sierra Nevada. Warm and Wet scenarios are projected to be more favorable than Hot and Dry Scenarios. High Emission scenarios would have a greater impact than Low Emission scenarios. Substantial areas outside the current geographic range of the species are modeled to be climatically suitable. However, essentially none of these areas are projected to be suitable under future climate scenarios, nor are new areas of suitability projected to develop in the future.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 77 geographically unique occurrence locations for *Tamias alpinus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 34), which was projected to be 6186 km^2 for *Tamias alpinus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 35). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.0365 kg, and time to first reproduction of 0.949 years, we estimate median natal dispersal distance to be 0.243 km, and potential dispersal velocity for the species to be 0.256 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Tamias alpinus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 18).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 2.36°C (range = -1.15 – 5.22°C) and 989.43 mm/year (range = 402.26 – 1576.67 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.96°C (range = 2.23 – 6.06°C) and -19.44 mm/year (range = -299.86 – 276.19 mm/year). Our SDM projected that 2.67 – 92.00% of known occurrence locations will remain suitable for *Tamias alpinus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -95.69 and -15.08%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and extremely vulnerable.

Table 18. Components of the climate change vulnerability score for *Tamias alpinus*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	92.00%	84.92%	100.00%	Extremely Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	49.33%	50.25%	100.00%	Extremely Vulnerable	Moderately Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	28.00%	33.41%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	2.67%	4.31%	100.00%	Highly Vulnerable	Moderately Vulnerable	Extremely Vulnerable

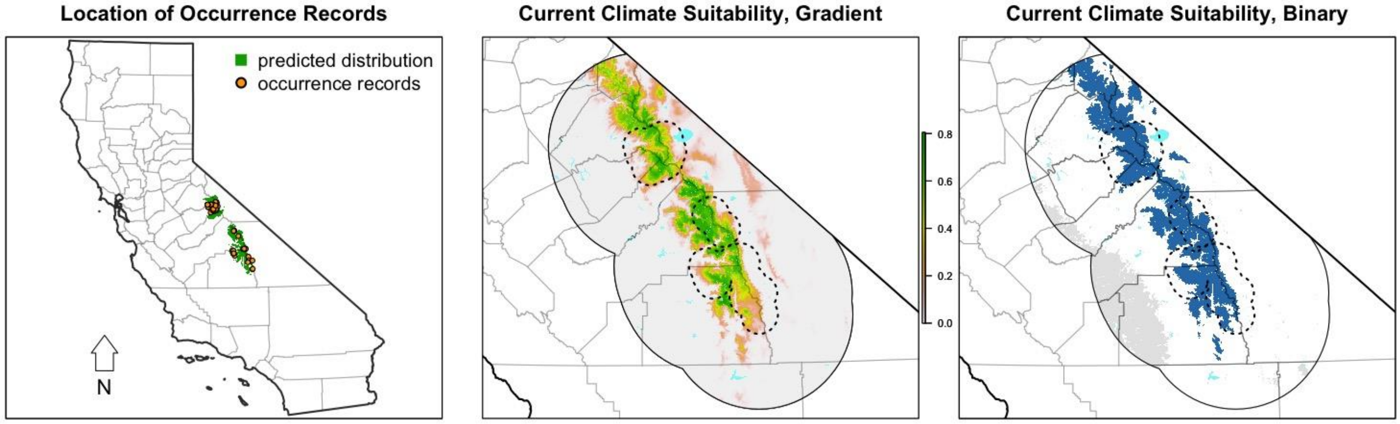

Figure 34. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

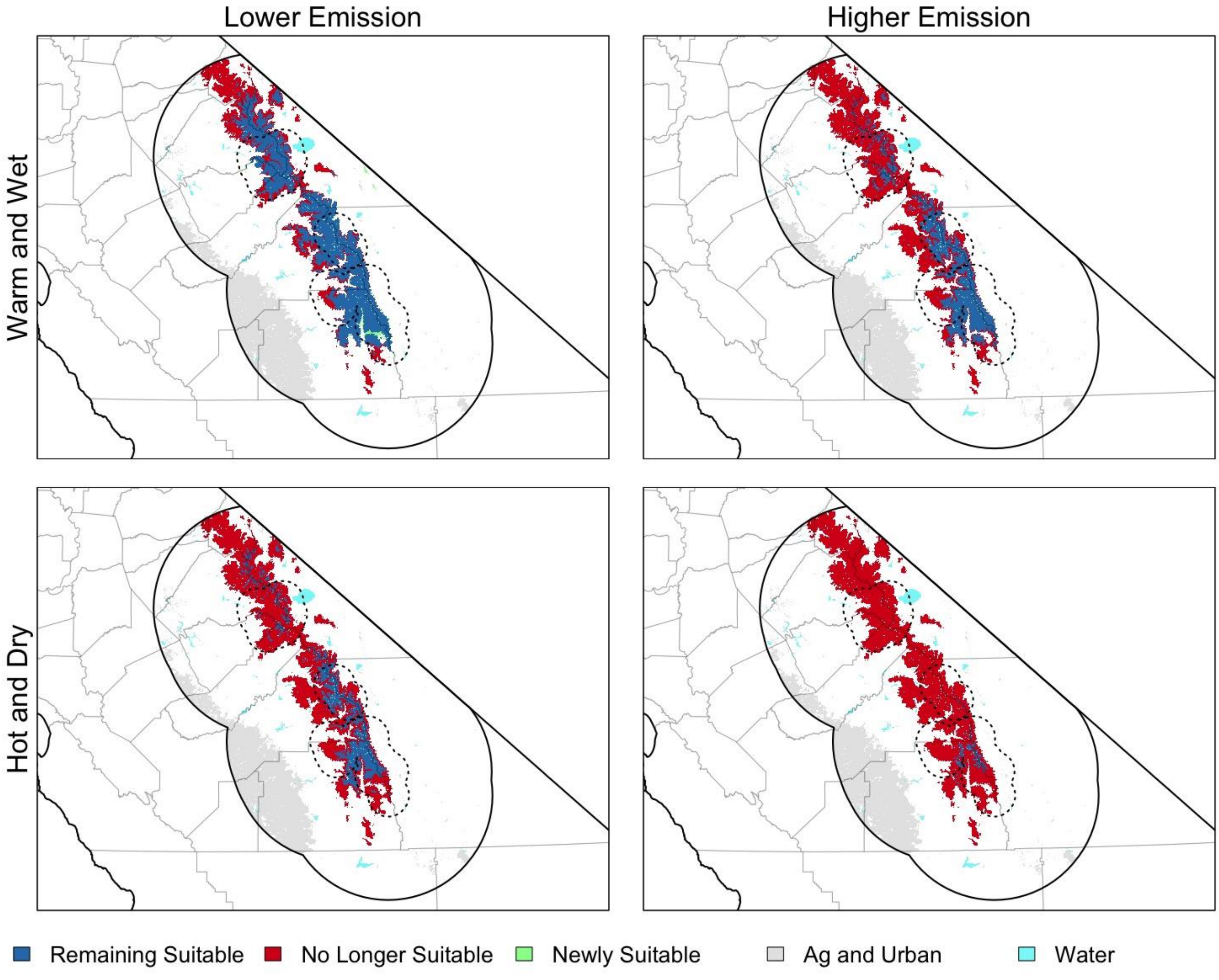

Figure 35. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

Mount Pinos Lodgepole Chipmunk (*Tamias speciosus callipeplus*)

This chipmunk is an isolated and endemic subspecies within the Transverse Range of Southern California, where it prefers open canopy forest habitat. Resurveys of historical sites in Yosemite indicate that the range of this subspecies' full-species counterpart in Yosemite contracted upward during the 20th century, disappearing from lower elevation sites and losing 4.5% of its elevational range. Model outputs indicate this chipmunk is highly to extremely vulnerable to climate change. Only under the Low Emission, Warm and Wet scenario would any climatically suitable habitat remain.

Figure 36. A Mount Pinos lodgepole chipmunk (*Tamias speciosus callipeplus*). Photo by Lee Hoy.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 266 geographically unique occurrence locations for *Tamias speciosus*, including 7 for *Tamias speciosus callipeplus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 37), which was projected to be 192 km^2 for *Tamias speciosus callipeplus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 38). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.0608 kg, and time to first reproduction of 0.945 years, we estimate median natal dispersal distance to be 0.32 km, and potential dispersal velocity for the species to be 0.338 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Tamias speciosus callipeplus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 19).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 7.07°C (range = 5.73 – 10.21°C) and 652.50 mm/year (range = 493.66 – 762.93 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.01°C (range = 2.81 – 5.40°C) and -210.26 mm/year (range = -357.02 – -41.81 mm/year). Our SDM projected that 0.00 – 66.67% of known occurrence locations will remain suitable for *Tamias speciosus callipeplus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -100.00 and -94.65%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 19. Components of the climate change vulnerability score for *Tamias speciosus callipeplus*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	66.67%	5.35%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	0.00%	0.00%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable

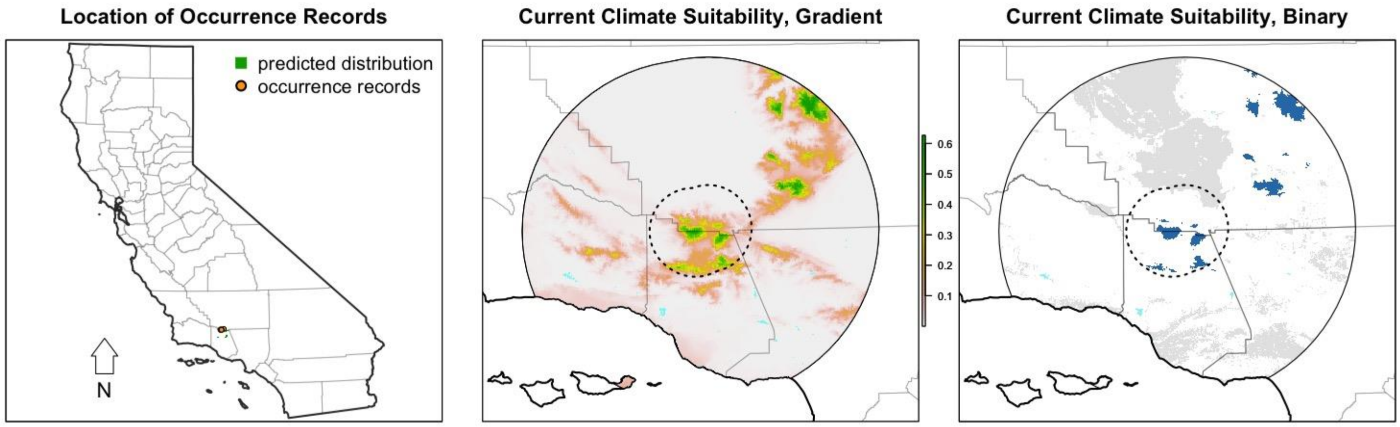

Figure 37. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

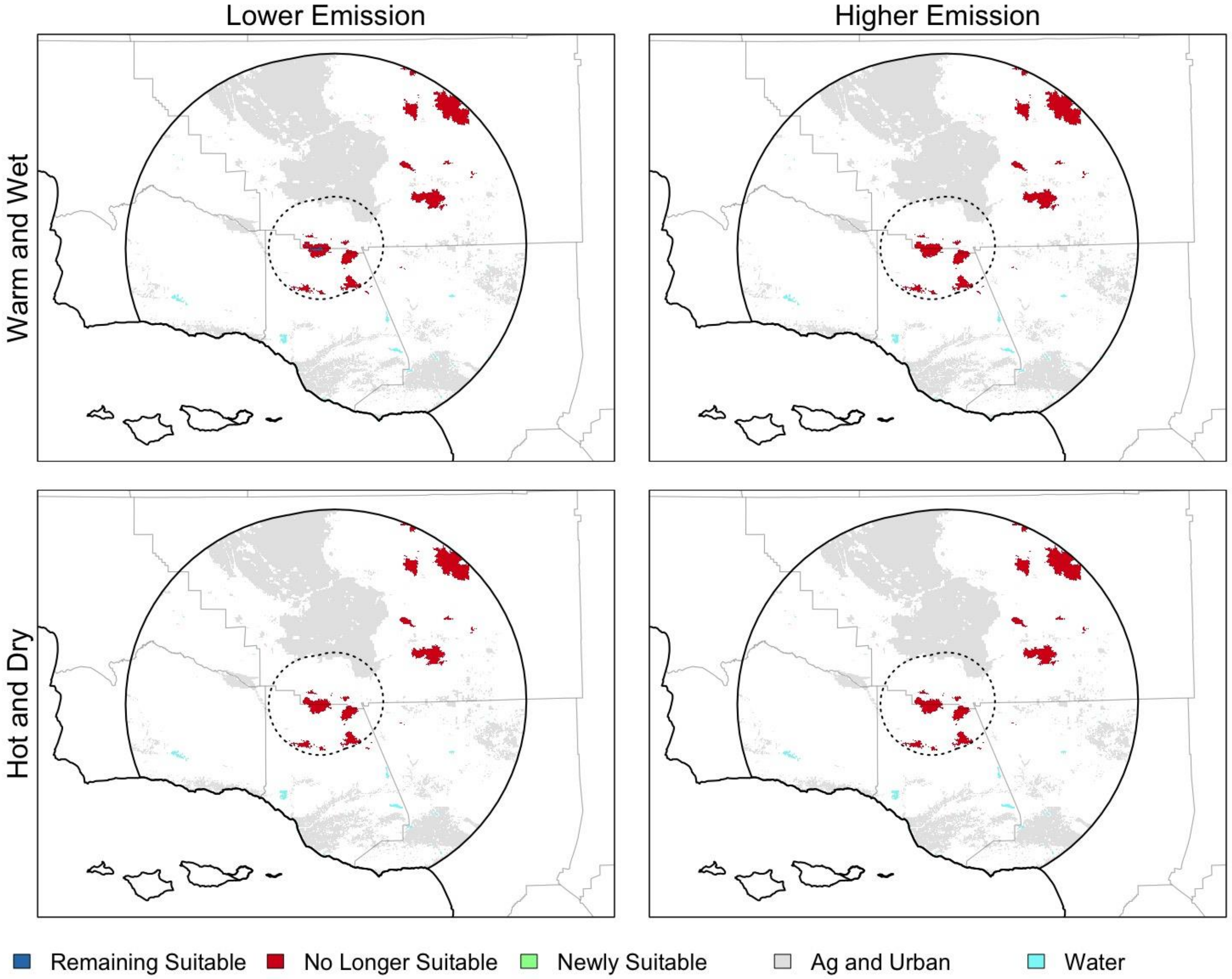

Figure 38. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

Western Jumping Mouse (*Zapus princeps*)

Figure 39. A western jumping mouse (*Zapus princeps*). Photo © Stuart Wilson.

This nocturnal granivore occurs in wet areas in a variety of coniferous forest, riparian, and grasslands habitat, with a patchy distribution throughout the Sierra and mountains of northern California. Resurveys of historical sites in Yosemite indicate that the range of this species in Yosemite contracted upward during the 20th century, disappearing from lower elevation sites and losing 14% of its elevational range. Model outputs indicate it is highly to extremely vulnerable to climate change. Under the High Emission, Hot and Dry scenario essentially all climatically suitable habitat for the species is projected to disappear.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 103 geographically unique occurrence locations for *Zapus princeps*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 40), which was projected to be 28873 km^2 for *Zapus princeps*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 41). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' omnivorous diet, a mean adult mass of 0.0272 kg, and time to first reproduction of 0.601 years, we estimate median natal dispersal distance to be 0.207 km, and potential dispersal velocity for the species to be 0.344 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species’ natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Zapus princeps's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon’s overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 20).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 6.15°C (range = 1.48 – 14.42°C) and 1119.84 mm/year (range = 360.85 – 2813.75 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.77°C (range = 2.24 – 5.54°C) and -69.50 mm/year (range = -359.04 – 220.36 mm/year). Our SDM projected that 0.00 – 65.48% of known occurrence locations will remain suitable for *Zapus princeps* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -97.07 and -41.93%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 20. Components of the climate change vulnerability score for *Zapus princeps*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	65.48%	58.07%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	25.00%	31.60%	100.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	19.05%	23.87%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	0.00%	2.93%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Extremely Vulnerable

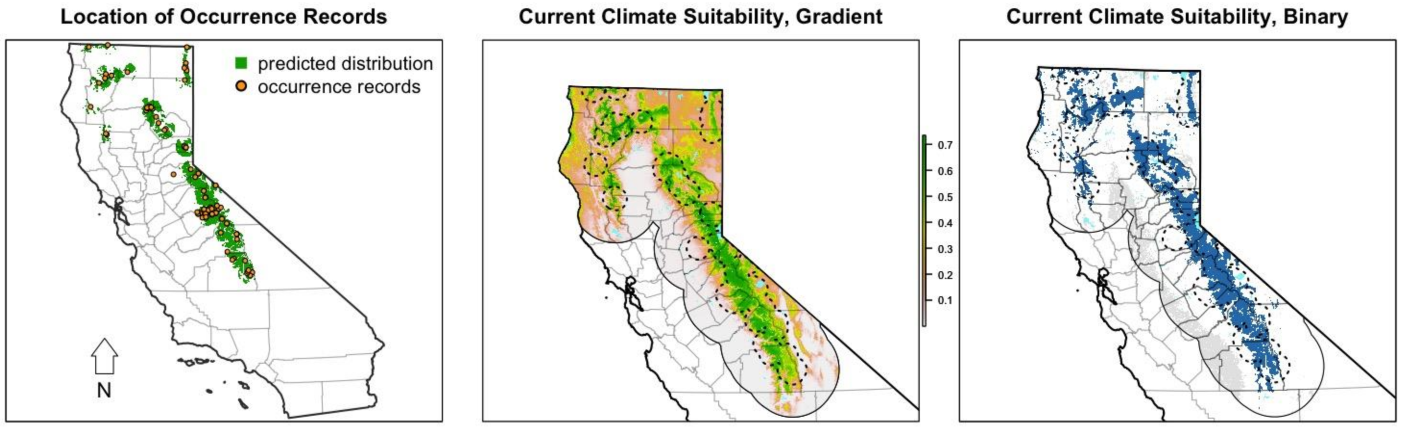

Figure 40. Occurrence record locations and predicted current climatic suitability. Dashed boundary is the predicted species-specific maximum dispersal threshold around occurrence locations. Solid boundary is a 100-km buffer around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

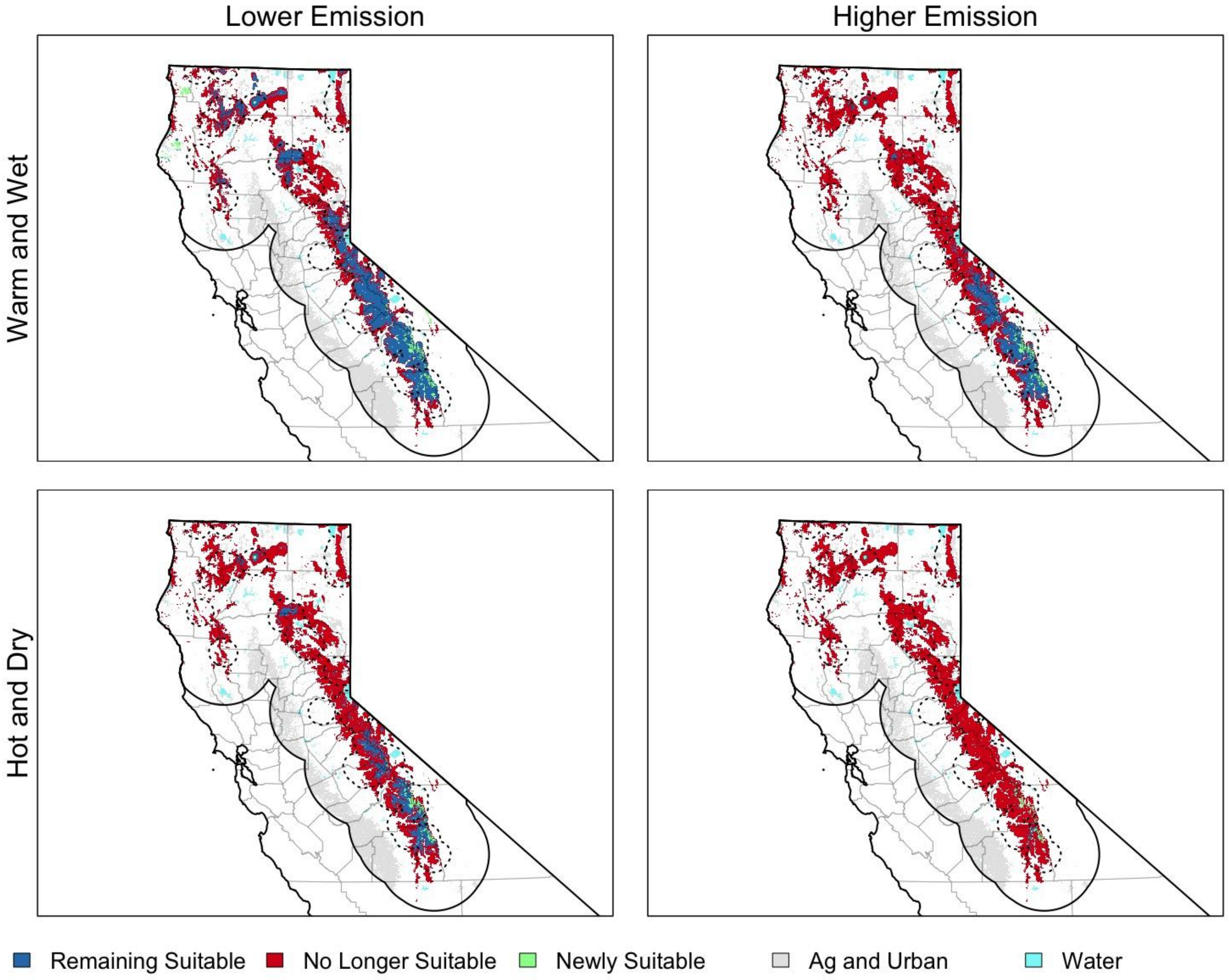

Figure 41. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Solid boundary depicts 100-km buffer around occurrence records. Dashed boundary depicts species-specific dispersal limitation boundary around occurrence records.

California Red Tree Vole (*Arborimus pomo*)

Figure 42. A red tree vole (Genus: *Arborimus*). Photo © Michael Durham.

The California red tree vole occurs in Douglas-fir, redwood, and montane hardwood-conifer habitats throughout the north coast, where it specializes in eating the needles of Douglass-fir and grand fir. While occurrence data suggests the species is largely restricted to the fog belt, distribution model outputs suggest that more-inland habitat should also be climatically suitable, perhaps indicating that including fog data could improve model performance for this species. Model output indicates the species is moderately to highly vulnerable to climate change. A large proportion (69% - 89%) of the species' known range is projected to become unsuitable under the four climate change scenarios. The more modest reductions (36% - 41%) in climatically-suitable area rely on areas not currently known to be occupied either remaining suitable or becoming newly suitable in the future. In addition to climatic suitability, a critical requirement for areas remaining or becoming suitable in the future is prevalence of Douglas-fir or grand fir.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 261 geographically unique occurrence locations for *Arborimus pomo*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 43), which was projected to be 31264 km^2 for *Arborimus pomo*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 44). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.0325 kg, and time to first reproduction of 0.121 years, we estimate median natal dispersal distance to be 0.228 km, and potential dispersal velocity for the species to be 1.88 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (-1.00 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 45). Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Arborimus pomo's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 21).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 12.75°C (range = 11.22 – 15.03°C) and 1485.47 mm/year (range = 948.81 – 3060.97 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 2.00°C (range = 0.72 – 3.42°C) and 54.65 mm/year (range = -283.66 – 375.39 mm/year). Our SDM projected that 10.80 – 30.80% of known occurrence locations will remain suitable for *Arborimus pomo* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -41.39 and -35.93%. One meter of sea level rise was projected to cause the loss of 1.14% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and highly vulnerable (Table 21).

Table 21. Components of the climate change vulnerability score for *Arborimus pomo*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	30.80%	64.07%	98.86%	Less Vulnerable	Less Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	20.00%	63.08%	98.86%	Moderately Vulnerable	Less Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	23.20%	58.61%	98.86%	Moderately Vulnerable	Less Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	10.80%	62.51%	98.86%	Highly Vulnerable	Less Vulnerable	Highly Vulnerable

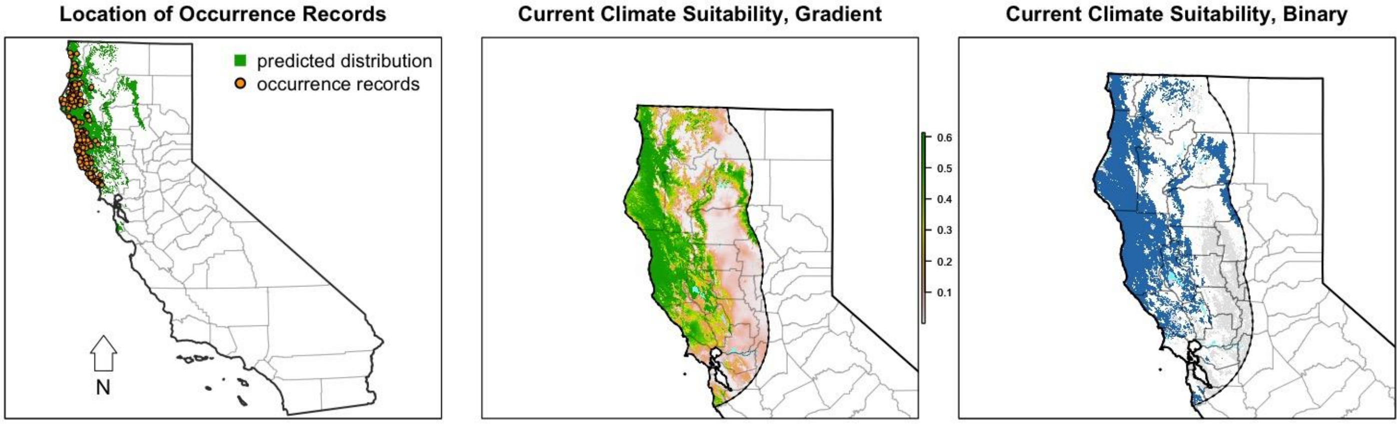

Figure 43. Occurrence record locations and predicted current climatic suitability. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

Projected Change in Climate-Suitable Habitat (2070-2099)

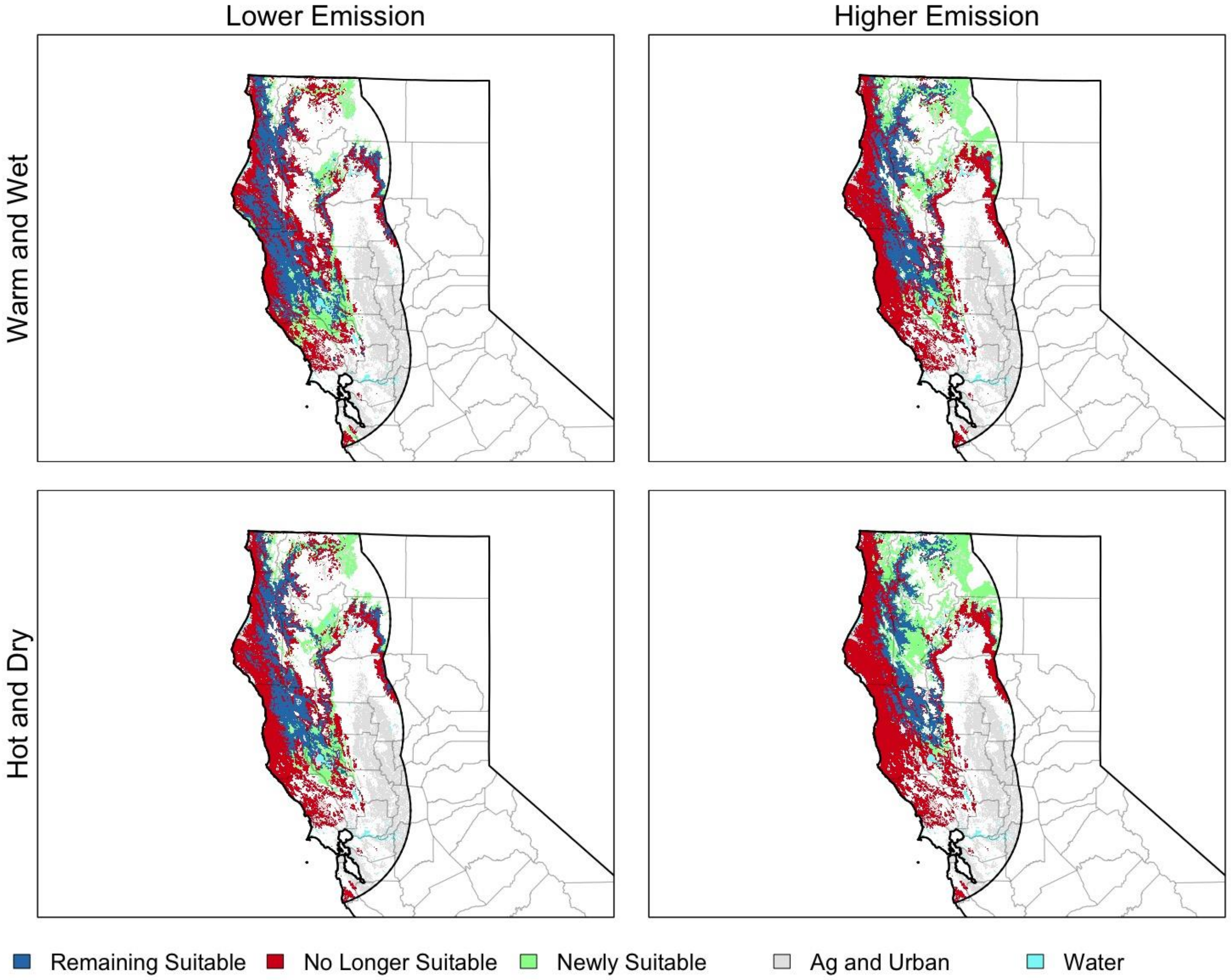

Figure 44. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

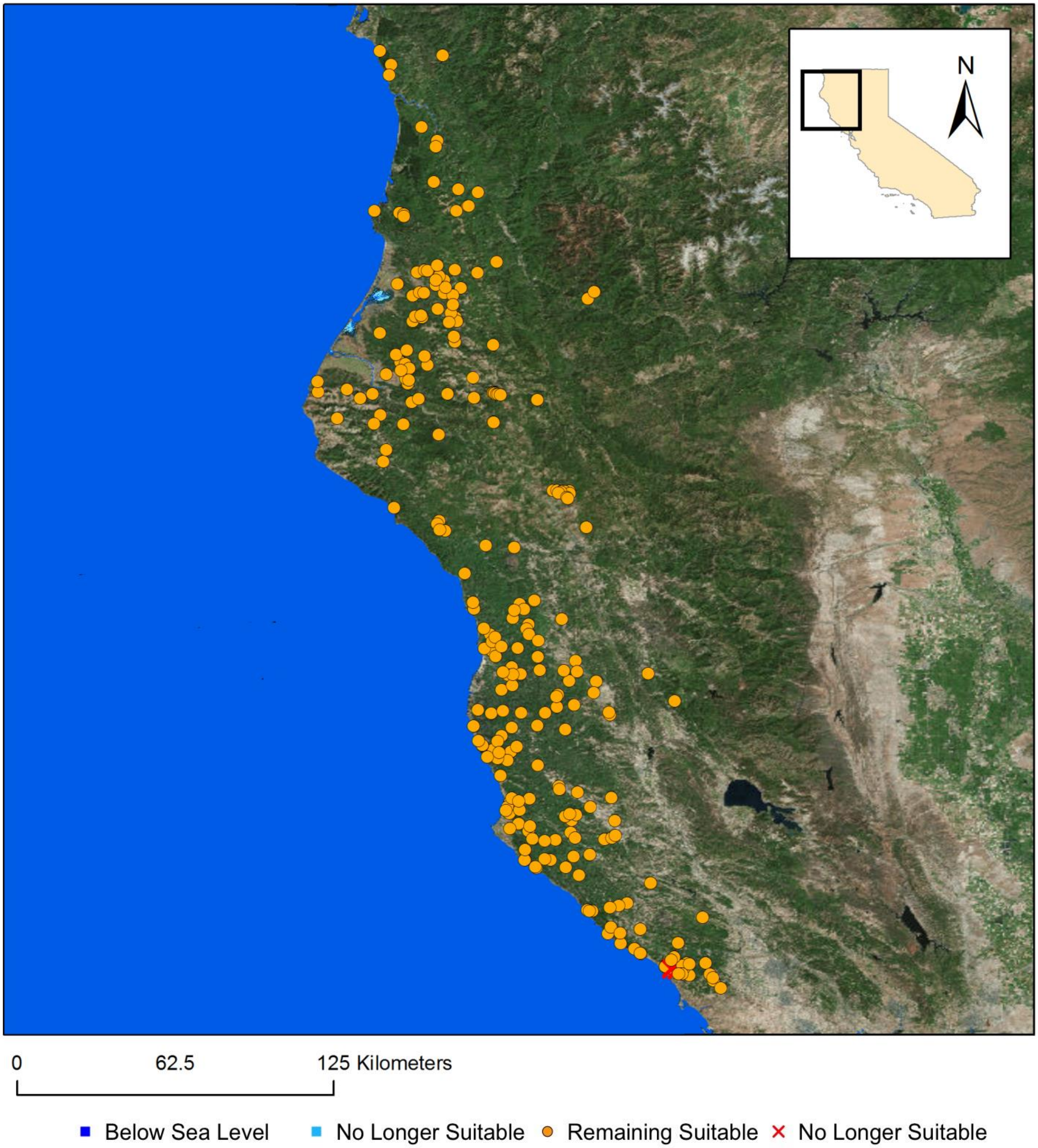

Figure 45. Projected loss of habitat from one meter of sea level rise for *Arborimus pomo.* Areas with elevations between -1.00 m, the lowest elevation occurrence for the taxa, and 0.00 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

Monterey Vole (Microtus californicus halophilus)

Figure 46. A California vole (*Microtus californicus*). Photo by Ron Wolf.

This subspecies occurs only in coastal marsh habitat in Monterey County. Model outputs indicate it is highly to extremely vulnerable to climate change. The very short generation time of this vole produced large annual dispersal distances in the model, which in turn probably overpredicted climatically suitable habitat. In particular, habitat modeled as suitable on the east side of the Sierra Nevada would likely never be available to this subspecies. Model projections indicating 0% of Monterey vole locations remaining climatically suitable under all of the scenarios suggest this subspecies could be highly impacted by future climate change. Ten percent of occurrence locations are projected to be vulnerable to sea level rise. The climate change impacts would add to the impacts associated with extensive habitat lost to agriculture and urbanization.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 10 geographically unique occurrence locations for *Microtus californicus halophilus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 47), which was projected to be 6478 km^2 for *Microtus californicus halophilus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 48). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.0574 kg, and time to first reproduction of 0.0652 years, we estimate median natal dispersal distance to be 0.31 km, and potential dispersal velocity for the species to be 4.75 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (-1.00 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 49). Twenty-seven climate change vulnerability criteria were evaluated using information on the species’ natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Microtus californicus halophilus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon’s overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 22).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 13.56°C (range = 13.37 – 14.04°C) and 428.75 mm/year (range = 389.65 – 495.86 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.82°C (range = 2.33 – 5.66°C) and 157.00 mm/year (range = -38.41 – 333.61 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Microtus californicus halophilus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -88.32 and -30.62%. One meter of sea level rise was projected to cause the loss of 10.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between highly vulnerable and extremely vulnerable.

Table 22. Components of the climate change vulnerability score for *Microtus californicus halophilus*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	69.38%	90.00%	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Warm and Wet	0.00%	26.71%	90.00%	Extremely Vulnerable	Moderately Vulnerable	Extremely Vulnerable
Low Emission, Hot and Dry	0.00%	67.43%	90.00%	Extremely Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	0.00%	11.68%	90.00%	Extremely Vulnerable	Moderately Vulnerable	Extremely Vulnerable

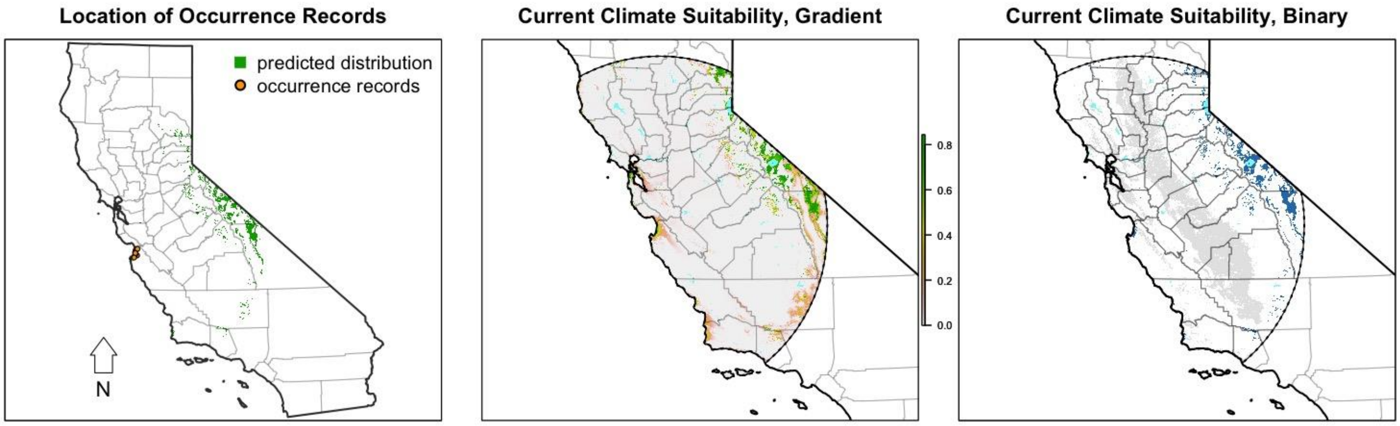

Figure 47. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

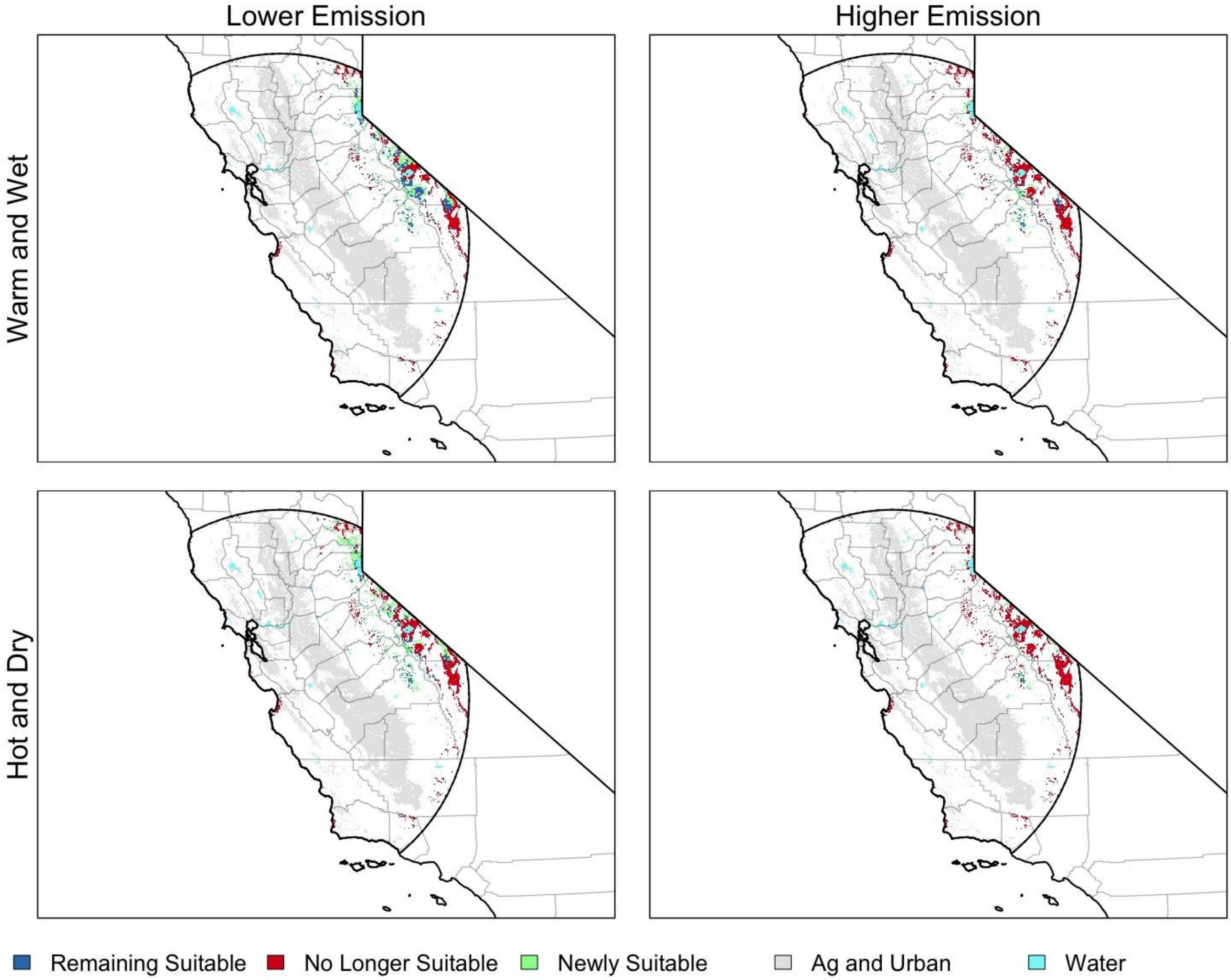

Figure 48. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. “Lower Emission”: RCP4.5. “Higher Emission”: RCP8.5. “Hot and Dry”: MIROC-ESM. “Warm and Wet”: CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

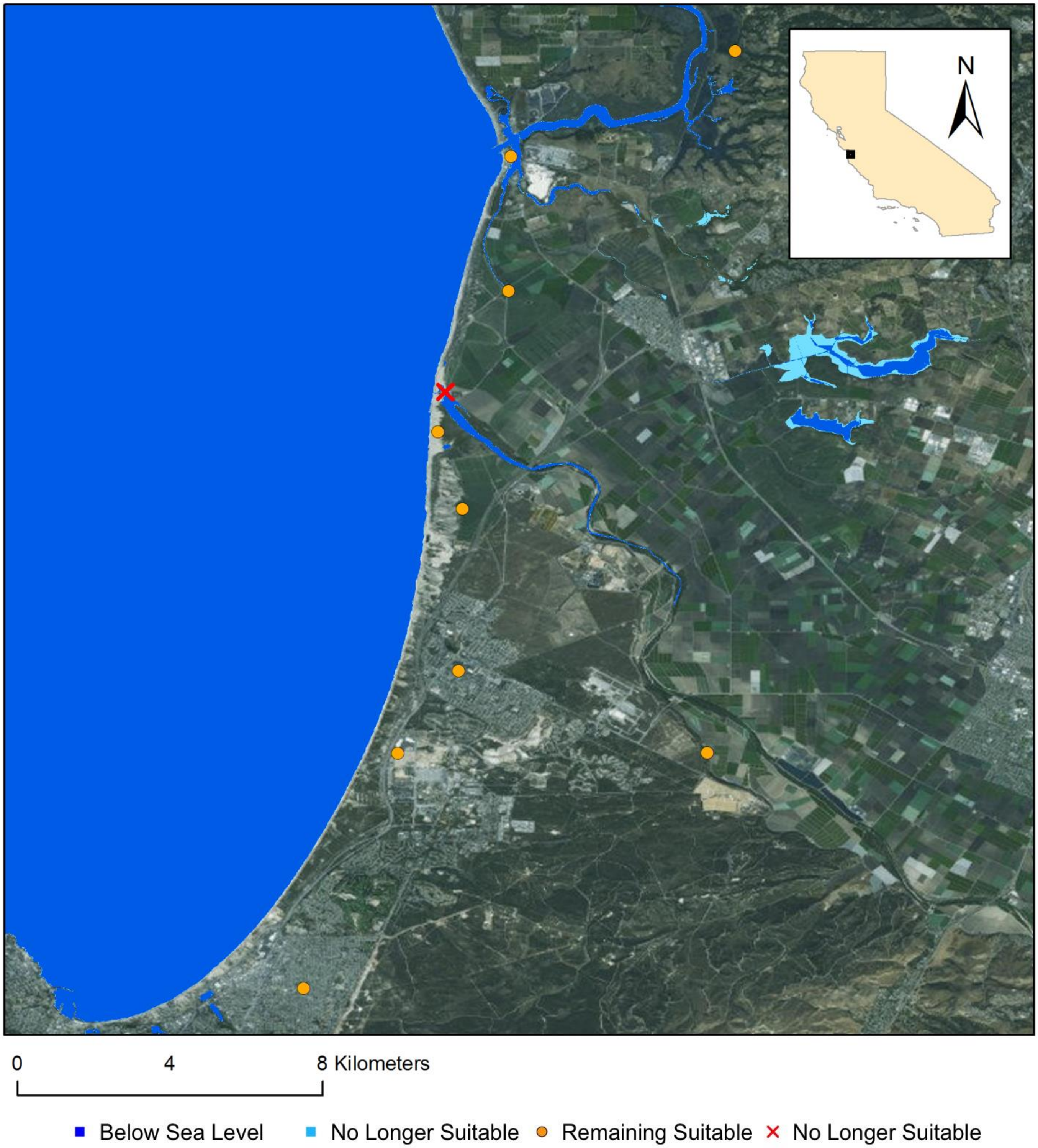

Figure 49. Projected loss of habitat from one meter of sea level rise for *Microtus californicus halophilus.* Areas with elevations between -1.00 m, the lowest elevation occurrence for the taxa, and 0.00 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

Marsh Vole (*Microtus californicus paludicola*)

Figure 50. A California vole (*Microtus californicus*). Photo by Ron Wolf.

The marsh vole occurs only in marsh habitat of Contra Costa and Alameda counties. The Marsh vole's climatically suitable habitat and future habitat projections could not be modeled due to too few locality records (n = 2). The species sensitivity and adaptive capacity score indicate the species is moderately vulnerable. However, the species highly restricted geographic range likely compounds this vulnerability. The expected climate change impacts would add to the impacts associated with extensive urbanization.

There were too few record locations to parameterize distribution models for this species (n = 2). Given the species' herbivorous diet, a mean adult mass of 0.0574 kg, and time to first reproduction of 0.0652 years, we estimate median natal dispersal distance to be 0.31 km, and potential dispersal velocity for the species to be 4.75 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Microtus californicus paludicola's* sensitivity and adaptive capacity.

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 14.81°C (range = 14.76 – 14.87°C) and 566.57 mm/year (range = 535.64 – 597.49 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.31°C (range = 1.82 – 5.11°C) and 53.16 mm/year (range = -142.15 – 224.17 mm/year). One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations (Table 23).

Table 23. Components of the climate change vulnerability score for *Microtus californicus paludicola*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	N/A	N/A	100.00%	Insufficient Information	Moderately Vulnerable	Insufficient Information
High Emission, Warm and Wet	N/A	N/A	100.00%	Insufficient Information	Moderately Vulnerable	Insufficient Information
Low Emission, Hot and Dry	N/A	N/A	100.00%	Insufficient Information	Moderately Vulnerable	Insufficient Information
High Emission, Hot and Dry	N/A	N/A	100.00%	Insufficient Information	Moderately Vulnerable	Insufficient Information

San Pablo Vole (*Microtus californicus sanpabloensis*)

Figure 51. A California vole (*Microtus californicus*). Photo by Ron Wolf.

This subspecies occurs only in coastal marsh habitat of Contra Costa County. Model outputs indicate it is moderately to highly vulnerable to climate change. The very short generation time of this vole produced large annual dispersal distances in the model, which in turn probably overpredicted climatically suitable habitat. In particular, habitat modeled as suitable in the Sierra Nevada foothills, on the east side of the Sierra Nevada, and in the North Coast Range would likely never be available to this subspecies. Model projections indicate 0% of San Pablo vole locations will remain climatically suitable under all of the scenarios, suggesting this subspecies could be highly impacted by future climate change. Seventeen percent of occurrence locations are projected to be vulnerable to sea level rise. The climate change impacts would add to the impacts associated with extensive habitat lost to agriculture and urbanization.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 12 geographically unique occurrence locations for *Microtus californicus sanpabloensis*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 52), which was projected to be 1289 km^2 for *Microtus californicus sanpabloensis*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 53). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.0574 kg, and time to first reproduction of 0.0652 years, we estimate median natal dispersal distance to be 0.31 km, and potential dispersal velocity for the species to be 4.75 km/yr. Loss of habitat to sea level rise was evaluated by setting the lower elevation extent of occurrence records (0.95 m) as the lower elevation threshold for the species and projecting the percent of occurrence records that would no longer be suitable under a one meter sea level rise scenario (Figure 54). Twenty-seven climate change vulnerability criteria were evaluated using information on the species’ natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Microtus californicus sanpabloensis's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon’s overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 24).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 14.71°C (range = 14.66 – 14.78°C) and 611.62 mm/year (range = 597.85 – 624.70 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.44°C (range = 1.97 – 5.22°C) and 32.66 mm/year (range = -169.36 – 210.09 mm/year). Our SDM projected that 0.00 – 0.00% of known occurrence locations will remain suitable for *Microtus californicus sanpabloensis* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between +53.18 and +362.42%. One meter of sea level rise was projected to cause the loss of 16.67% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and highly vulnerable.

Table 24. Components of the climate change vulnerability score for *Microtus californicus sanpabloensis*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	0.00%	289.49%	83.33%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	0.00%	153.18%	83.33%	Highly Vulnerable	Moderately Vulnerable	Moderately Vulnerable
Low Emission, Hot and Dry	0.00%	462.42%	83.33%	Highly Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Hot and Dry	0.00%	360.14%	83.33%	Extremely Vulnerable	Moderately Vulnerable	Highly Vulnerable

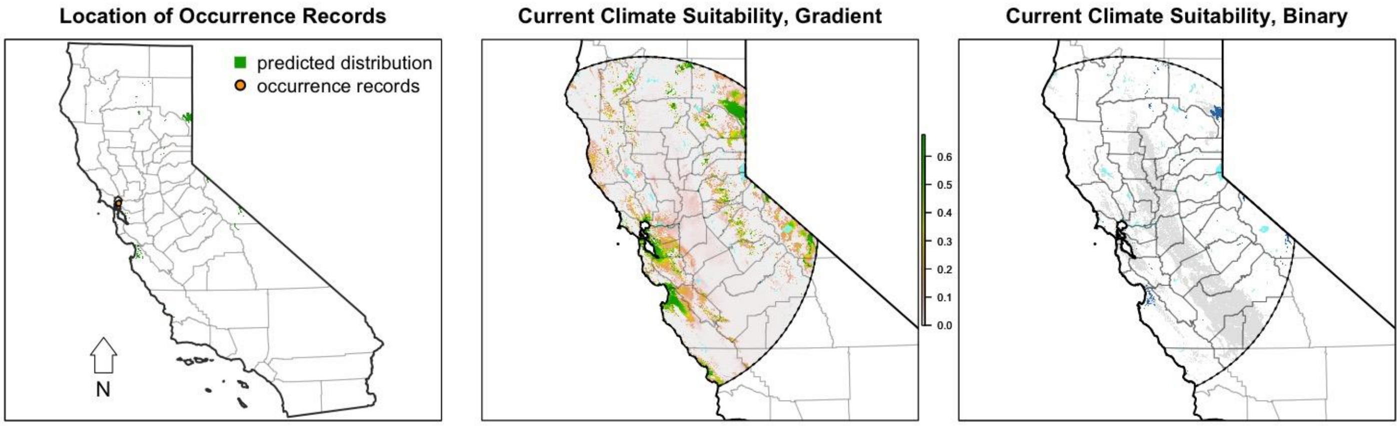

Figure 52. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

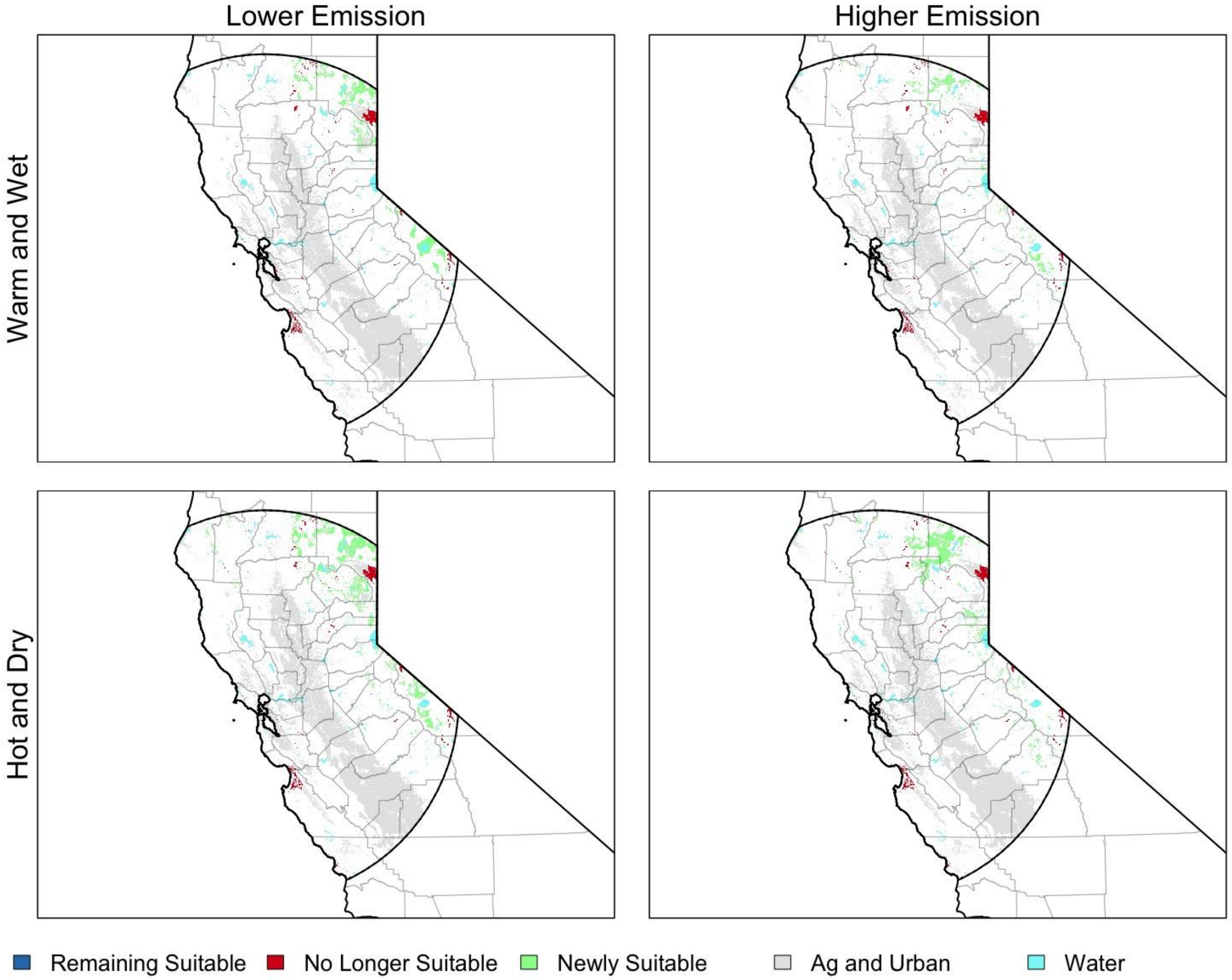

Figure 53. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

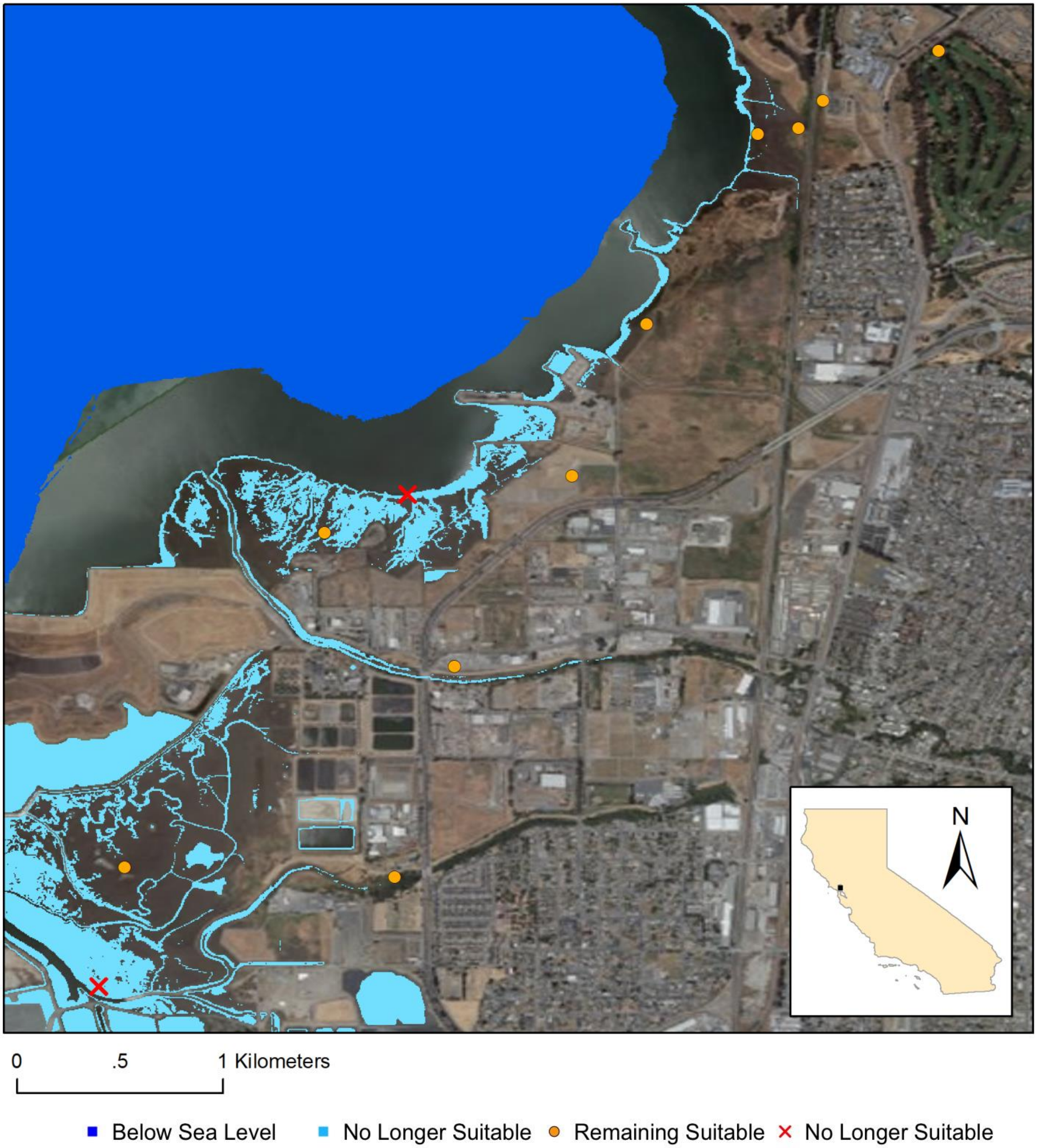

Figure 54. Projected loss of habitat from one meter of sea level rise for *Microtus californicus sanpabloensis.* Areas with elevations between 0.95 m, the lowest elevation occurrence for the taxa, and 1.95 m are classified as no longer suitable. Light blue marks area of land projected to be no longer suitable due to sea level rise. Crosses mark documented occurrence locations projected to be no longer suitable due to sea level rise.

Montane Vole (*Microtus montanus*)

Figure 55. A Montane vole (*Microtus montanus*). Photo by Roger Barbour.

This vole occurs in the Sierra, White Mountains, Cascades, and Great Basin regions, where is requires moderately dense herbaceous vegetation for cover. Resurvey of historical sites in Yosemite indicates that the species elevational range in Yosemite did not change during the 20th century. The montane vole is projected to be moderately to highly vulnerable to climate change, with greater impact anticipated under the High Emission scenarios than under the Low Emission scenarios. The general pattern of response of the vole to climate change is projected to be a general retraction upwards in elevation within its currently suitable range

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 143 geographically unique occurrence locations for *Microtus montanus*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 56), which was projected to be 52207 km^2 for *Microtus montanus*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 57). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 0.0428 kg, and time to first reproduction of 0.0682 years, we estimate median natal dispersal distance to be 0.265 km, and potential dispersal velocity for the species to be 3.88 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Microtus montanus's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 25).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 6.89°C (range = 0.71 – 13.91°C) and 828.50 mm/year (range = 138.19 – 2904.01 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.99°C (range = 2.47 – 5.72°C) and -10.58 mm/year (range = -242.73 – 224.46 mm/year). Our SDM projected that 21.10 – 55.05% of known occurrence locations will remain suitable for *Microtus montanus* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -83.64 and -34.44%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and highly vulnerable.

Table 25. Components of the climate change vulnerability score for *Microtus montanus*.

	Terrestrial Climate Change Model Results		Sea Level Rise, 1 meter	Climate Change Vulnerability Score		
Climate Change Scenario	Percent Occurrence Locations Remaining Suitable	Percent Area Remaining Suitable	Percent Occurrence Locations Remaining Suitable	Exposure/ Niche Breadth	Sensitivity and Adaptive Capacity	Overall Climate Change Vulnerability Score
Low Emission, Warm and Wet	55.05%	65.56%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	29.36%	22.55%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	51.38%	53.63%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Hot and Dry	21.10%	16.36%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable

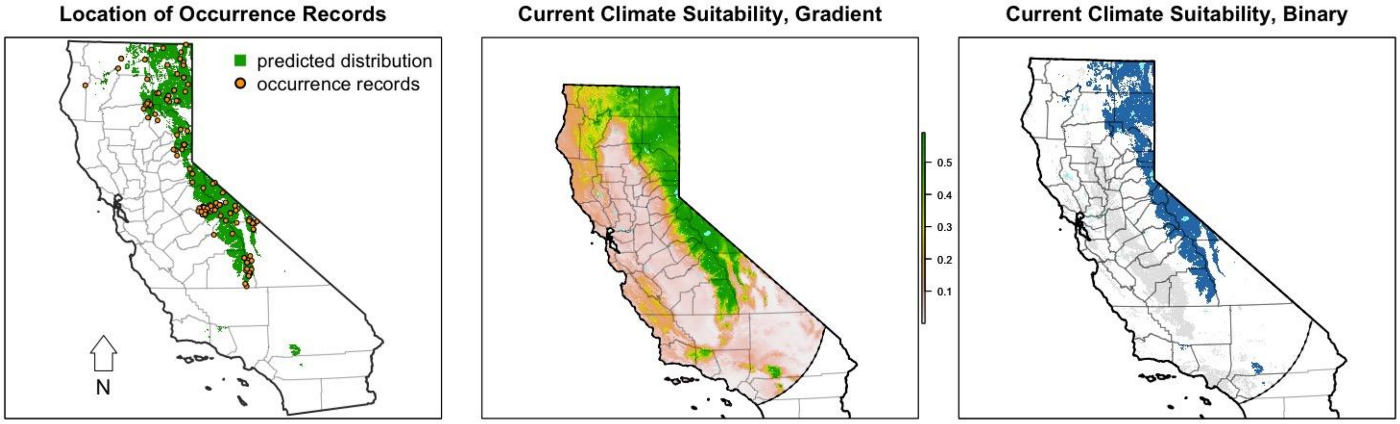

Figure 56. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

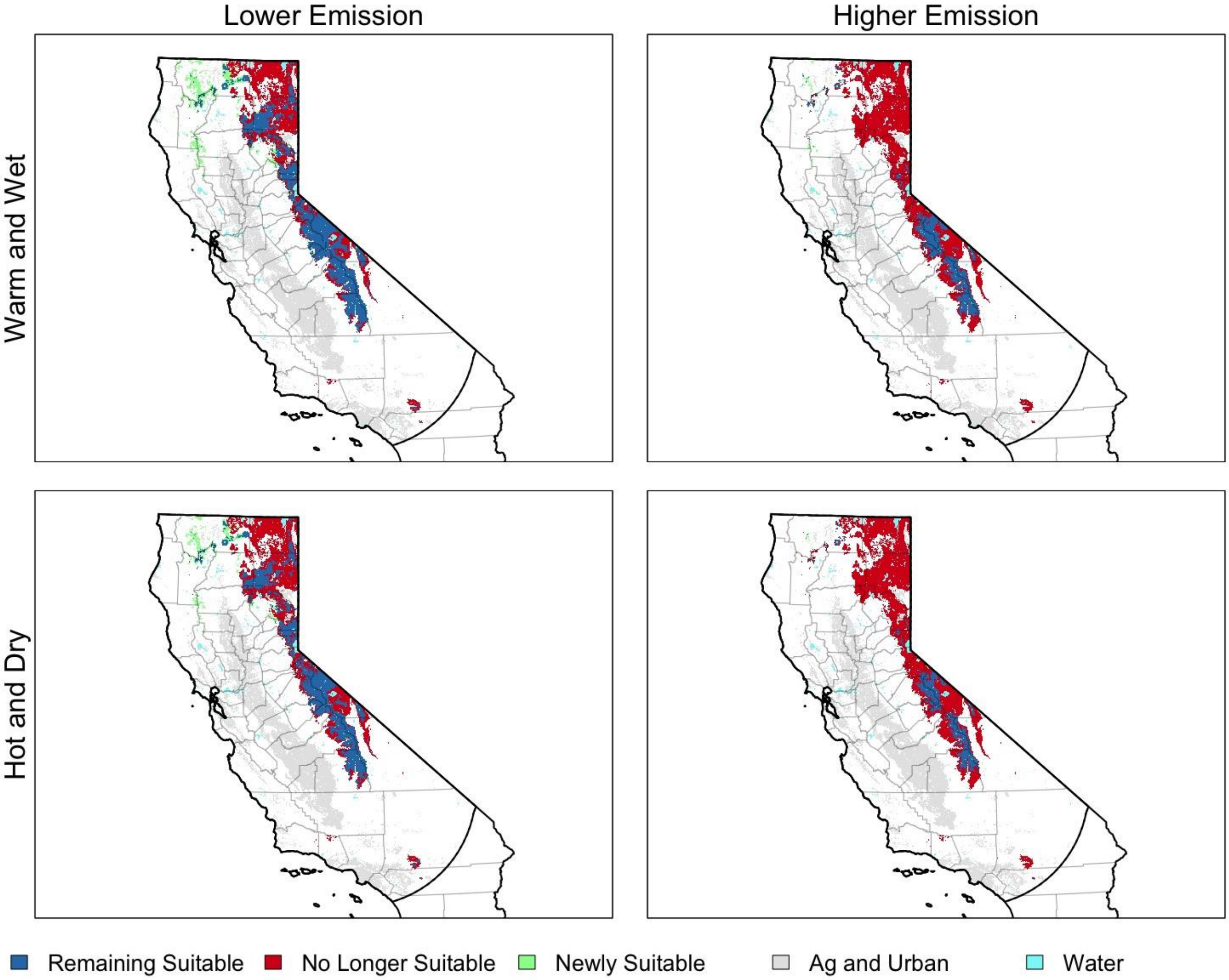

Figure 57. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

San Joaquin Kit Fox (*Vulpes macrotis mutica*)

Figure 58. A San Joaquin kit fox (*Vulpes macrotis mutica*). Photo © Donald Quintana.

This highly mobile, medium-sized carnivore occurs in grassland and scattered shrub habitats of the San Joaquin Desert as well as surrounding foothill and valley areas. The species dispersal ability makes it conceivable that it could move to occupy any area of suitable habitat. Model outputs indicate this subspecies of kit fox is moderately or less vulnerable to climate change. Although up to 74% of occurrence locations are projected to become climatically unsuitable, the species may also benefit from an upslope expansion of its climatically suitable area into nearby foothill habitat. Whether such areas are actually occupied by the San Joaquin kit fox in the future will depend on many other ecological factors, including interactions with competitors, predators, and prey.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 1382 geographically unique occurrence locations for *Vulpes macrotis*, including 1343 for *Vulpes macrotis mutica*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 59), which was projected to be 119040 km^2 for *Vulpes macrotis mutica*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 60). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' carnivorous diet, a mean adult mass of 4.5 kg, and time to first reproduction of 1.25 years, we estimate median natal dispersal distance to be 13.2 km, and potential dispersal velocity for the species to be 10.5 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Vulpes macrotis mutica's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 26).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 17.24°C (range = 13.76 – 20.03°C) and 225.08 mm/year (range = 145.25 – 592.56 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.02°C (range = 1.64 – 4.70°C) and 23.35 mm/year (range = -52.71 – 98.33 mm/year). Our SDM projected that 26.01 – 99.13% of known occurrence locations will remain suitable for *Vulpes macrotis mutica* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between +12.53 and +32.61%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between less vulnerable and moderately vulnerable.

Table 26. Components of the climate change vulnerability score for *Vulpes macrotis mutica*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	99.13%	118.04%	100.00%	Moderately Vulnerable	Less Vulnerable	Less Vulnerable
High Emission, Warm and Wet	75.73%	131.80%	100.00%	Highly Vulnerable	Less Vulnerable	Moderately Vulnerable
Low Emission, Hot and Dry	92.15%	132.61%	100.00%	Moderately Vulnerable	Less Vulnerable	Less Vulnerable
High Emission, Hot and Dry	26.01%	112.53%	100.00%	Highly Vulnerable	Less Vulnerable	Moderately Vulnerable

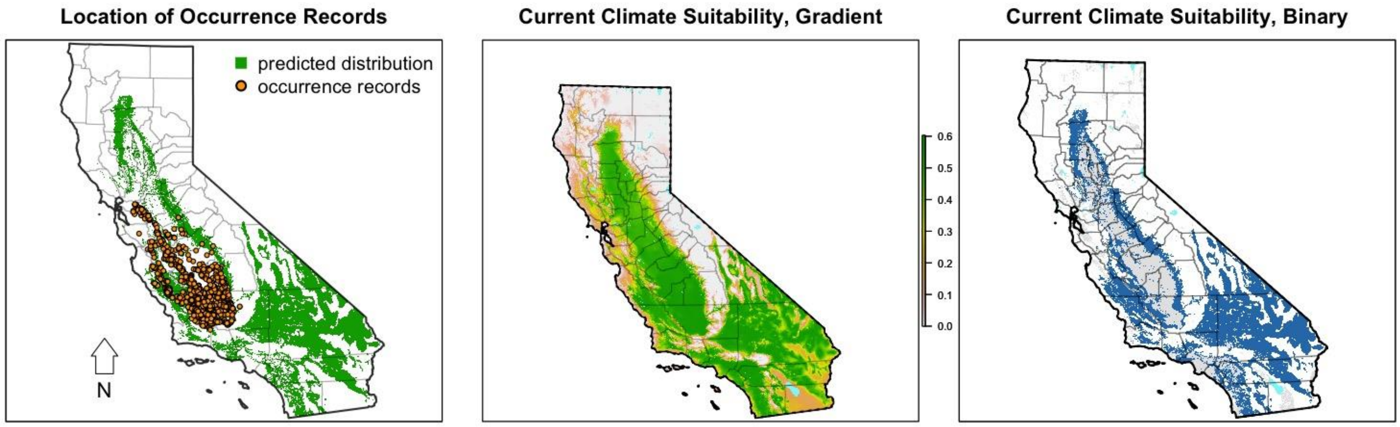

Figure 59. Occurrence record locations and predicted current climatic suitability. The species-specific dispersal boundary for this taxa extends outside of state boundaries.

Projected Change in Climate-Suitable Habitat (2070-2099)

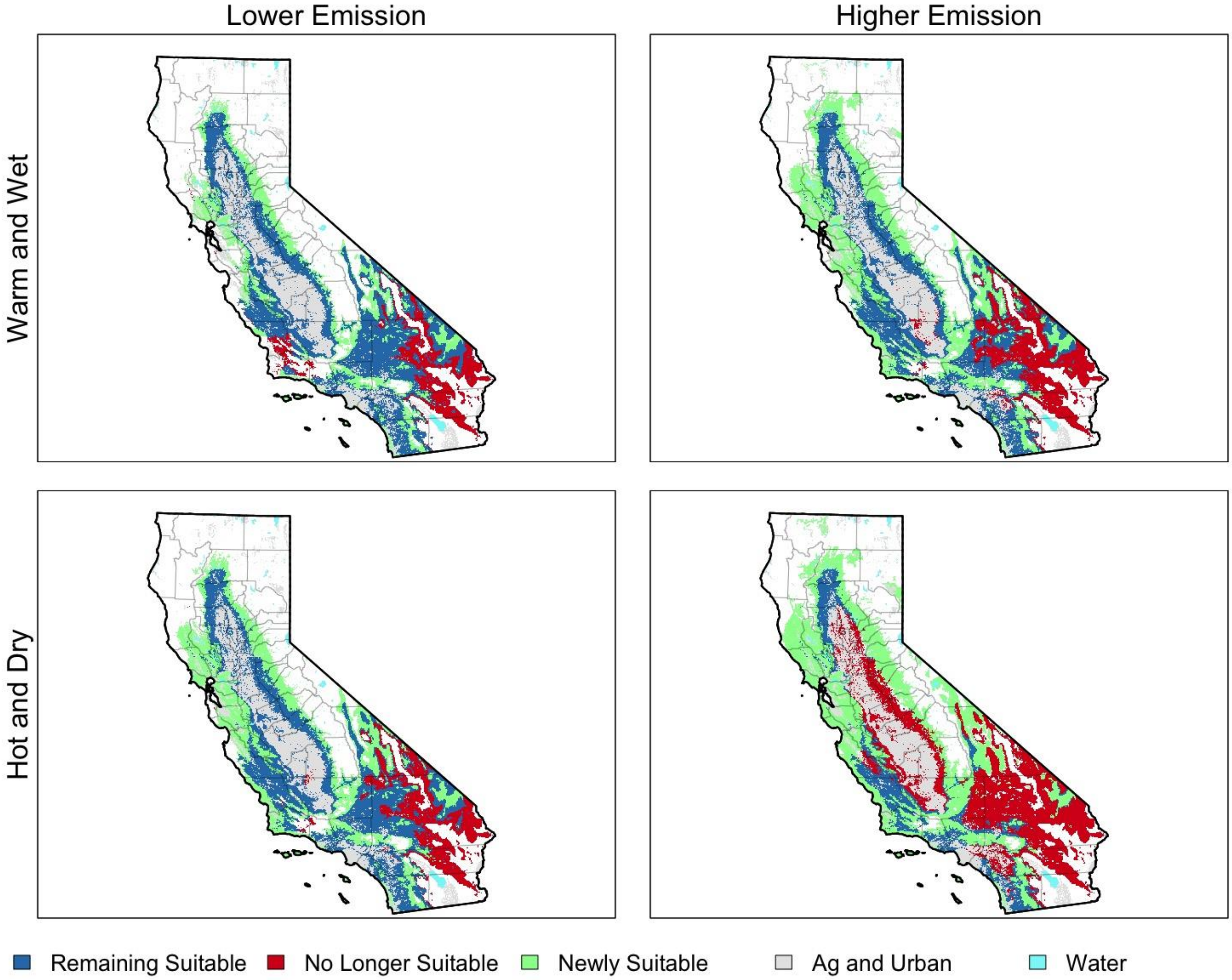

Figure 60. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. The species-specific dispersal boundary for this taxa extends outside of state boundaries.

Sierra Nevada Red Fox (*Vulpes vulpes necator*)

Figure 61. A Sierra Nevada red fox (*Vulpes vulpes necator*). Photo by Keith Slausen, USFS/PSW.

This highly mobile, medium-sized carnivore occurs in a variety of habitats in the Sierra, Klamath, and Cascade ranges. The species dispersal ability makes it conceivable that it could move to occupy any area of suitable habitat. Model outputs suggest the species is moderately, less, or highly vulnerable to climate change. The High Emission, Hot and Dry scenario is projected to result in about a 50% reduction of climatically suitable habitat. Reductions in areas of currently suitability under the other scenarios are balanced, in part or completely, by increases in area of suitability in the northwestern part of the state. The models suggest areas of climatic suitability in the western Klamath Mountains and North Coast Ranges, including new areas of suitability in the future. Whether the Sierra Nevada red fox could expand its geographic into the northwestern ranges would depend on many ecological factors.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 216 geographically unique occurrence locations for *Vulpes vulpes,* including 207 for *Vulpes vulpes necator*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 62), which was projected to be 69778 km^2 for *Vulpes vulpes necator*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 63). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' carnivorous diet, a mean adult mass of 4.82 kg, and time to first reproduction of 0.88 years, we estimate median natal dispersal distance to be 14 km, and potential dispersal velocity for the species to be 15.9 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species’ natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Vulpes vulpes necator's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon’s overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 27).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 7.17°C (range = -2.27 – 17.34°C) and 1038.21 mm/year (range = 127.84 – 2160.21 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.63°C (range = 2.20 – 5.24°C) and -8.34 mm/year (range = -299.20 – 281.82 mm/year). Our SDM projected that 53.25 – 95.27% of known occurrence locations will remain suitable for *Vulpes vulpes necator* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -48.68 and +8.35%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between less vulnerable and highly vulnerable.

Table 27. Components of the climate change vulnerability score for *Vulpes vulpes necator*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	95.27%	108.35%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Less Vulnerable
High Emission, Warm and Wet	85.80%	83.19%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
Low Emission, Hot and Dry	83.43%	85.37%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Hot and Dry	53.25%	51.32%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable

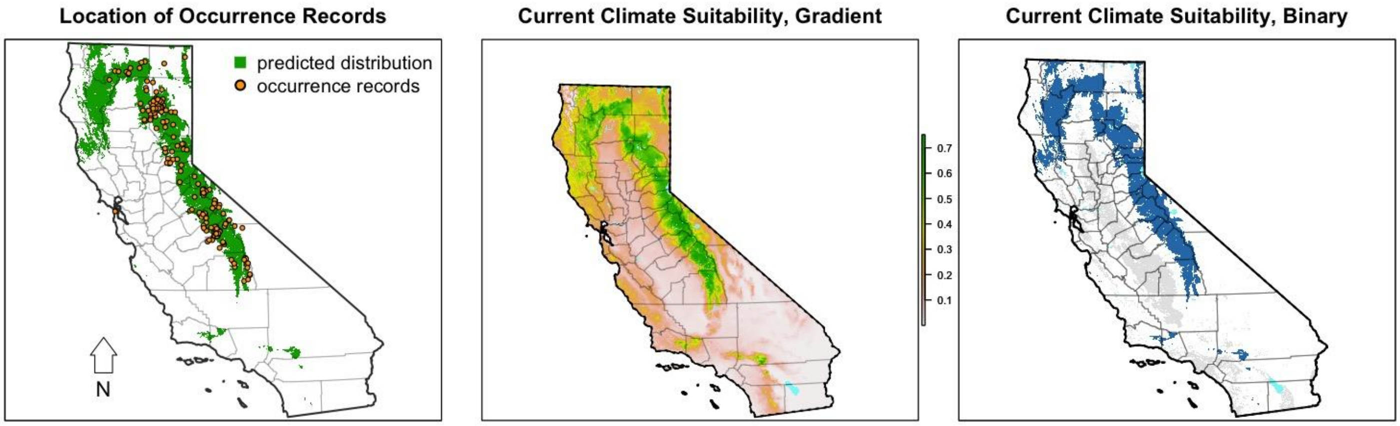

Figure 62. Occurrence record locations and predicted current climatic suitability. The species-specific dispersal boundary for this taxa extends outside of state boundaries.

Projected Change in Climate-Suitable Habitat (2070-2099)

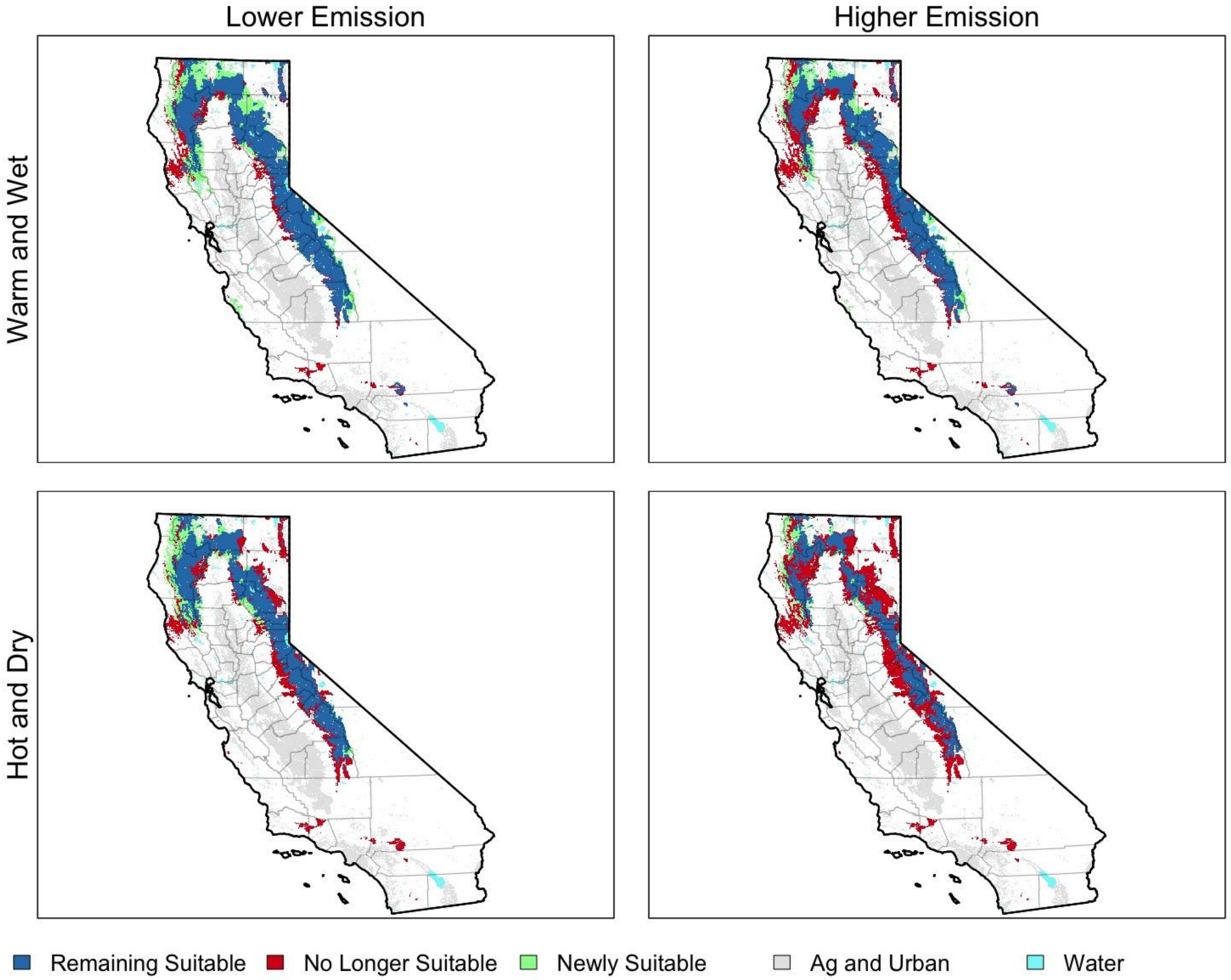

Figure 63. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. The species-specific dispersal boundary for this taxa extends outside of state boundaries.

Humboldt Marten (Martes caurina humboldtensis)

Figure 64. A Humboldt marten (*Martes caurina humboldtensis*). Photo by Keith Slauson.

This small carnivore subspecies occurs in evergreen forests of the North Coast Range. Model output suggests it is less vulnerable, moderately vulnerable, or highly vulnerable to climate change. Distribution models suggest that the Humboldt marten would benefit (increase area of climatically suitable habitat) under wet climate scenarios, but would be adversely impacted (decrease area of climatically suitable habitat) under drier future climate scenarios. Under the wet scenarios, suitable habitat is projected to increase in extent around the currently suitable areas in the southern portion of its coastal range. Under the hot dry scenarios, suitable habitat on the coast is projected to retract into the core area currently known to be occupied by the subspecies. Distribution models map large areas of suitable climate where the Humboldt marten is not currently known to occur. These include areas in the southern coastal part of the Humboldt marten's presumed historical range, as well as areas within the geographic range of the Sierran subspecies of the Pacific marten (*Martes caurina sierra*). Given the current understanding of Humboldt marten's requirements for forest structure (large decadent trees with cavities for denning, dense shrub layers) that do not occur in much of the coastal forests of northern California, it is not surprising that the species does not currently occur in a large proportion of the coastal area predicted as currently climatically suitable.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 312 geographically unique occurrence locations for *Martes caurina*, including 120 for *Martes caurina humboldtensis*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 65), which was projected to be 32944 km^2 for *Martes caurina humboldtensis*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 66). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' carnivorous diet, a mean adult mass of 0.874 kg, and time to first reproduction of 1.25 years, we estimate median natal dispersal distance to be 3.06 km, and potential dispersal velocity for the species to be 2.45 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Martes caurina humboldtensis's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 28).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 11.73°C (range = 7.29 – 14.00°C) and 2758.91 mm/year (range = 990.00 – 3992.41 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 0.56°C (range = -0.68 – 1.86°C) and -868.86 mm/year (range = -1167.74 – -573.27 mm/year). Our SDM projected that 22.94 – 99.08% of known occurrence locations will remain suitable for *Martes caurina humboldtensis* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -82.51 and +47.85%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between less vulnerable and highly vulnerable.

Table 28. Components of the climate change vulnerability score for *Martes caurina humboldtensis*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	99.08%	147.85%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Less Vulnerable
High Emission, Warm and Wet	98.17%	115.06%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
Low Emission, Hot and Dry	84.40%	50.54%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Hot and Dry	22.94%	17.49%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable

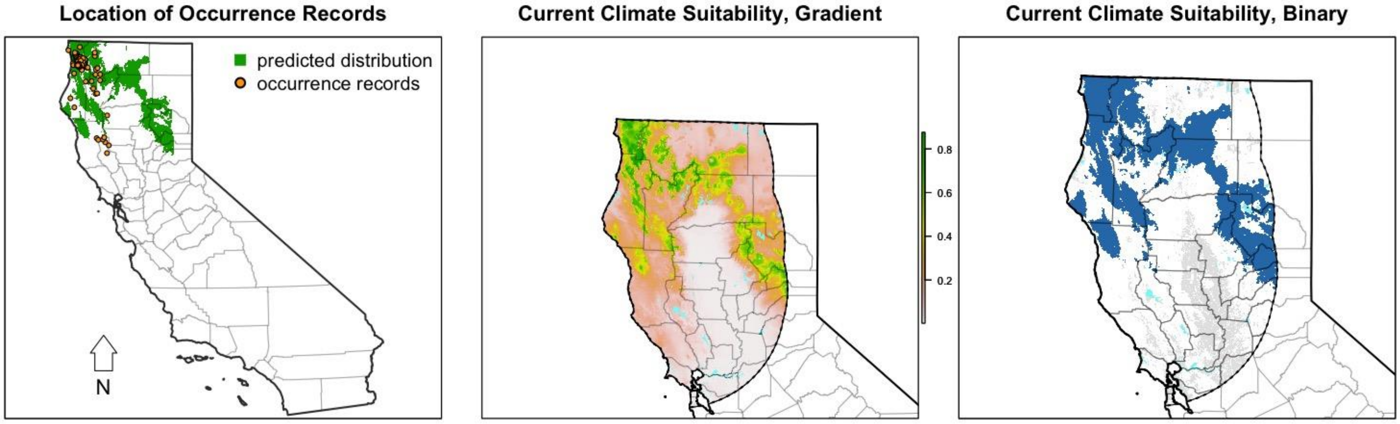

Figure 65. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

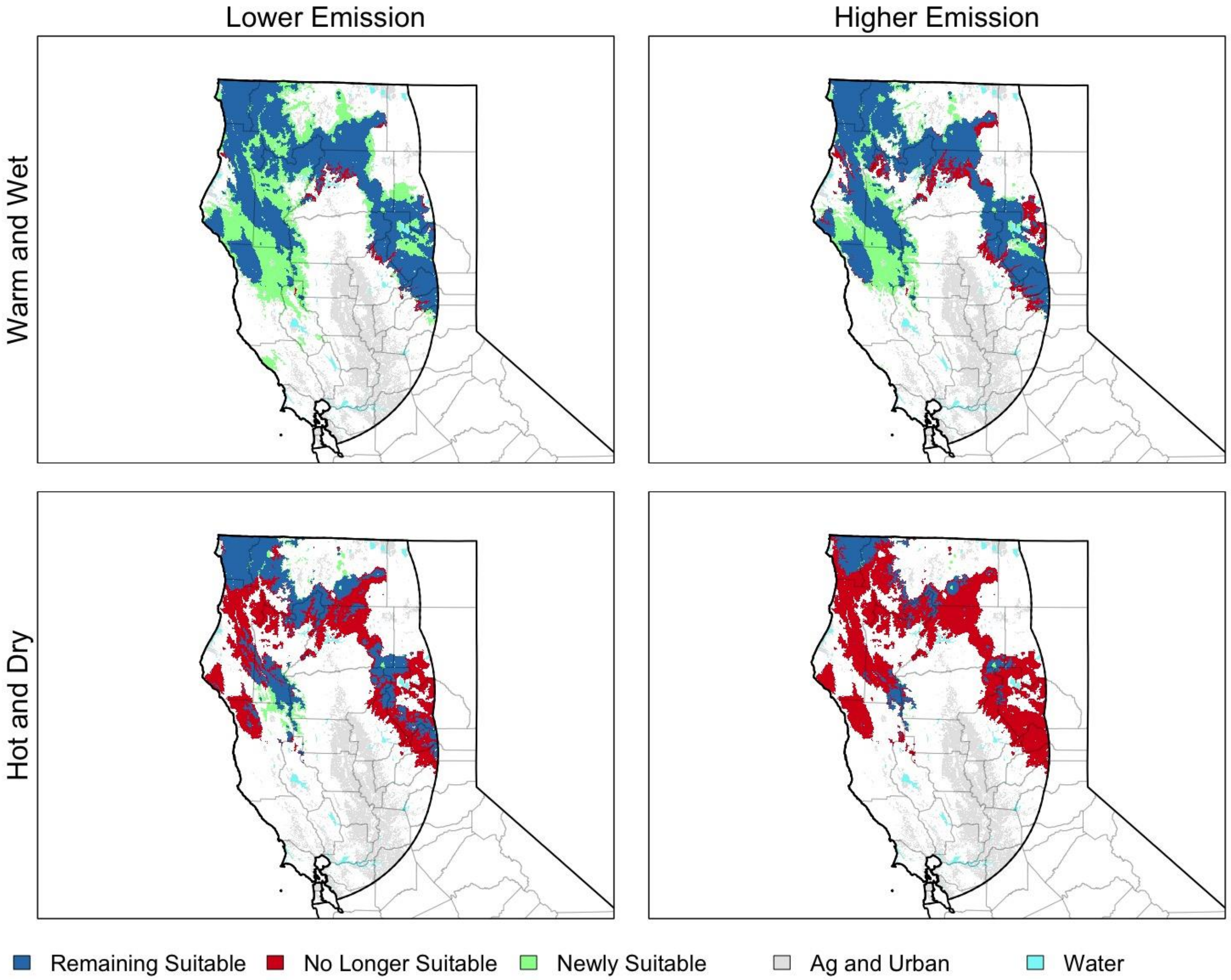

Figure 66. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

Sierra Nevada Marten (*Martes caurina sierrae*)

Figure 67. An American marten (*Martes caurina*). Photo by Larry Colwell.

This small carnivore subspecies occurs in evergreen forests of the Sierra as well as interior ranges of Northern California. Model output suggests it is moderately to highly vulnerable to climate change. Distribution models suggest that the Sierra Nevada marten would benefit (increase area of climatically suitable habitat) under wet climate scenarios, but would be adversely impacted (decrease area of climatically suitable habitat) under drier future climate scenarios. Hot and dry futures are projected to cause Sierra Nevada martens to retract into high elevation refugia, whereas warm/wet futures appear to provide modestly expanded climatically suitable areas. The Sierra Nevada marten is known to rely on deep snow cover to provide a competitive advantage over the Pacific fisher (*Pekania pennant*) in winter, allowing the marten to persist in areas where the larger-bodied fisher is excluded. It is unclear whether sufficient snow cover would exist in the modeled warm/wet futures to provide this competitive advantage to the marten.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 312 geographically unique occurrence locations for *Martes caurina*, including 130 for *Martes caurina sierrae*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 68), which was projected to be 51994 km^2 for *Martes caurina sierrae*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 69). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' carnivorous diet, a mean adult mass of 0.874 kg, and time to first reproduction of 1.25 years, we estimate median natal dispersal distance to be 3.06 km, and potential dispersal velocity for the species to be 2.45 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Martes caurina sierrae's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 29).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 6.26°C (range = -0.20 – 12.68°C) and 1216.44 mm/year (range = 345.76 – 2808.66 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 3.84°C (range = 2.33 – 5.59°C) and -131.48 mm/year (range = -447.38 – 185.10 mm/year). Our SDM projected that 15.22 – 97.83% of known occurrence locations will remain suitable for *Martes caurina sierrae* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -83.74 and +38.61%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and highly vulnerable.

Table 29. Components of the climate change vulnerability score for *Martes caurina sierrae*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	97.83%	138.61%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	89.13%	111.13%	100.00%	Highly Vulnerable	Moderately Vulnerable	Moderately Vulnerable
Low Emission, Hot and Dry	54.35%	46.79%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
High Emission, Hot and Dry	15.22%	16.26%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable

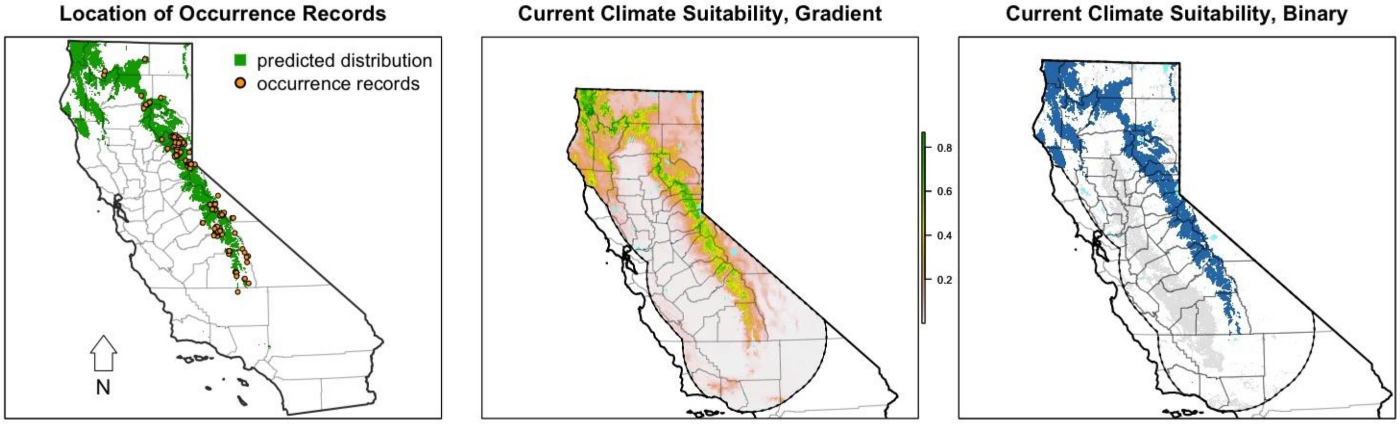

Figure 68. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

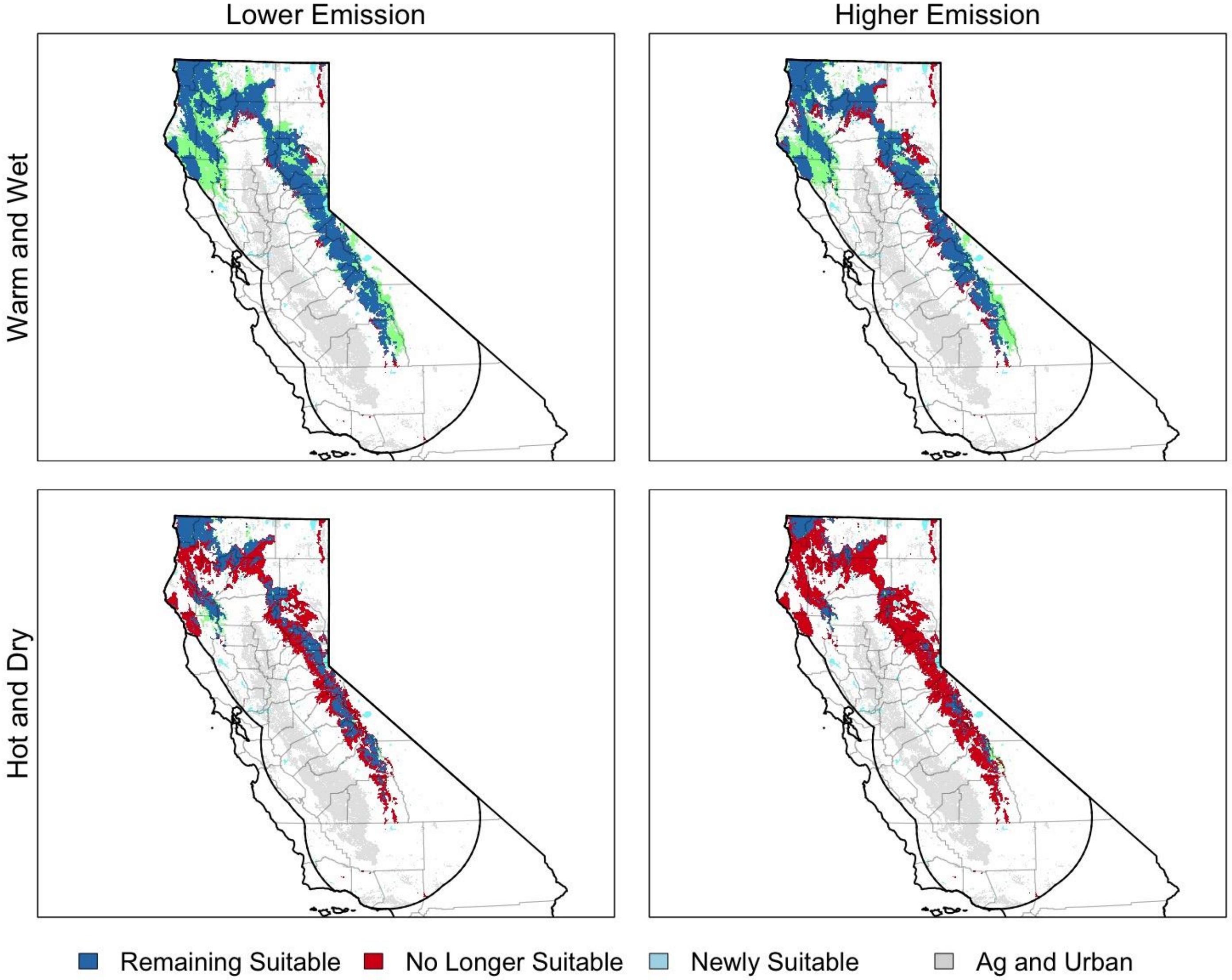

Figure 69. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

Desert Bighorn Sheep (*Ovis canadensis nelsoni*)

Figure 70. A Desert bighorn sheep (*Ovis canadensis nelsoni*). Photo by Andrew Barna.

This large, highly-mobile ungulate occurs in Southern Californian desert environments, where is relies on rocky, steep terrain to evade predators. Model outputs suggest the species is moderately to highly vulnerable to climate change. Hot and Dry scenarios appear to be more favorable than Warm and Wet scenarios. The desert bighorn's response to climate change is projected to mostly consist of retraction into the southern part of its range, rather than shifting to new geographic areas, although some expansion into the central Mojave Desert is projected to occur under the Hot and Dry scenarios.

To score climate change vulnerability we combined metrics of exposure, niche breadth, projected habitat shifts from species distribution models (SDMs), projected loss of habitat to sea level rise, and trait-based vulnerability to calculate a climate change vulnerability score (CCVS). SDMs were fit using Maxent and 77 geographically unique occurrence locations for *Ovis canadensis*, including 33 for *Ovis canadensis nelsoni*. We used the occurrence records, along with current climate conditions and estimated dispersal capacity, to model the current climatically suitability range (Figure 71), which was projected to be 117791 km^2 for *Ovis canadensis nelsoni*. We projected changes in habitat suitability by 2070 – 2099 under four future climate change scenarios (Figure 72). Areas in the projected current and future ranges that were occupied by urban infrastructure or agriculture were masked out in grey. Given the species' herbivorous diet, a mean adult mass of 74.6 kg, and time to first reproduction of 2.09 years, we estimate median natal dispersal distance to be 14.9 km, and potential dispersal velocity for the species to be 7.14 km/yr. Twenty-seven climate change vulnerability criteria were evaluated using information on the species' natural history, habitat requirements, physiology, and interactions with other species. We drew from peer-reviewed literature and from California Wildlife Habitat Relationships documents to assess *Ovis canadensis nelsoni's* sensitivity and adaptive capacity. We used the species distribution models, projected loss of habitat to sea level rise, and current land use to develop map-based assessments of its exposure to changing climate. Finally, we scored each taxon's overall climate vulnerabilities for the four future climates of this study, to derive cross-taxa comparable assessments of climate change vulnerability (Table 30).

Current (1981 – 2010) mean annual temperature and precipitation values at occurrence locations were 14.23°C (range = -1.39 – 23.57°C) and 337.57 mm/year (range = 79.06 – 1161.10 mm/year). The mean projected changes in annual temperature and precipitation from the 1981 – 2010 period to the 2070 – 2099 period at occurrence locations were projected to be 4.07°C (range = 2.76 – 5.65°C) and -56.96 mm/year (range = -145.25 – 54.44 mm/year). Our SDM projected that 47.37 – 94.74% of known occurrence locations will remain suitable for *Ovis canadensis nelsoni* and that the change in suitable area within the feasible maximum dispersal boundary for the species will be between -61.98 and -12.31%. One meter of sea level rise was projected to cause the loss of 0.00% of known occurrence locations. The overall climate change vulnerability score was projected to range between moderately vulnerable and highly vulnerable.

Table 30. Components of the climate change vulnerability score for *Ovis canadensis nelsoni*.

	Terrestrial Climate Change Model Results		**Sea Level Rise, 1 meter**	**Climate Change Vulnerability Score**		
Climate Change Scenario	**Percent Occurrence Locations Remaining Suitable**	**Percent Area Remaining Suitable**	**Percent Occurrence Locations Remaining Suitable**	**Exposure/ Niche Breadth**	**Sensitivity and Adaptive Capacity**	**Overall Climate Change Vulnerability Score**
Low Emission, Warm and Wet	73.68%	54.17%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Warm and Wet	47.37%	38.02%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Highly Vulnerable
Low Emission, Hot and Dry	94.74%	86.89%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable
High Emission, Hot and Dry	89.47%	87.69%	100.00%	Moderately Vulnerable	Moderately Vulnerable	Moderately Vulnerable

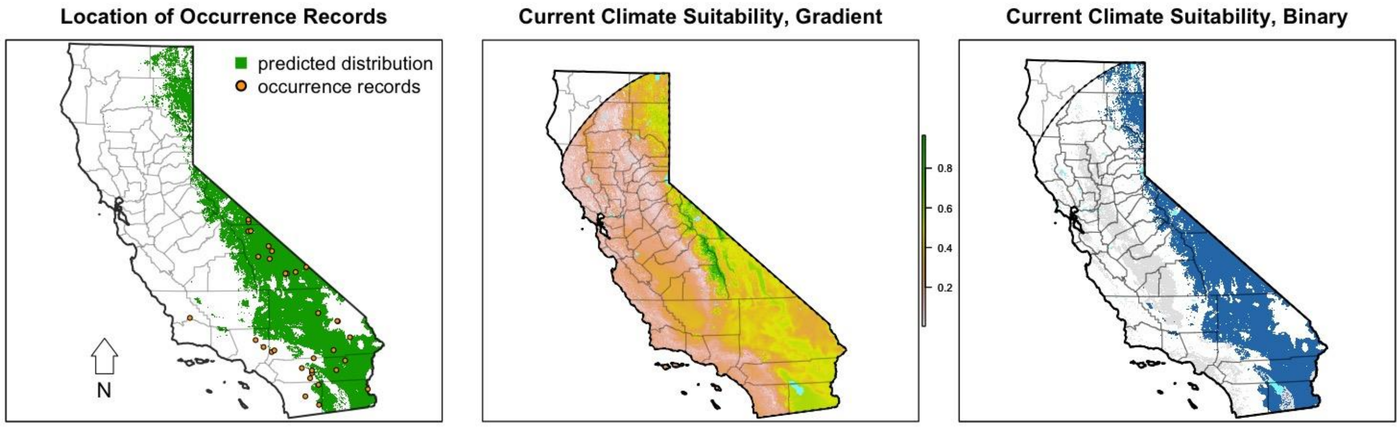

Figure 71. Occurrence record locations and predicted current climatic suitability. Boundary is the predicted species-specific maximum dispersal threshold around occurrence locations.

Projected Change in Climate-Suitable Habitat (2070-2099)

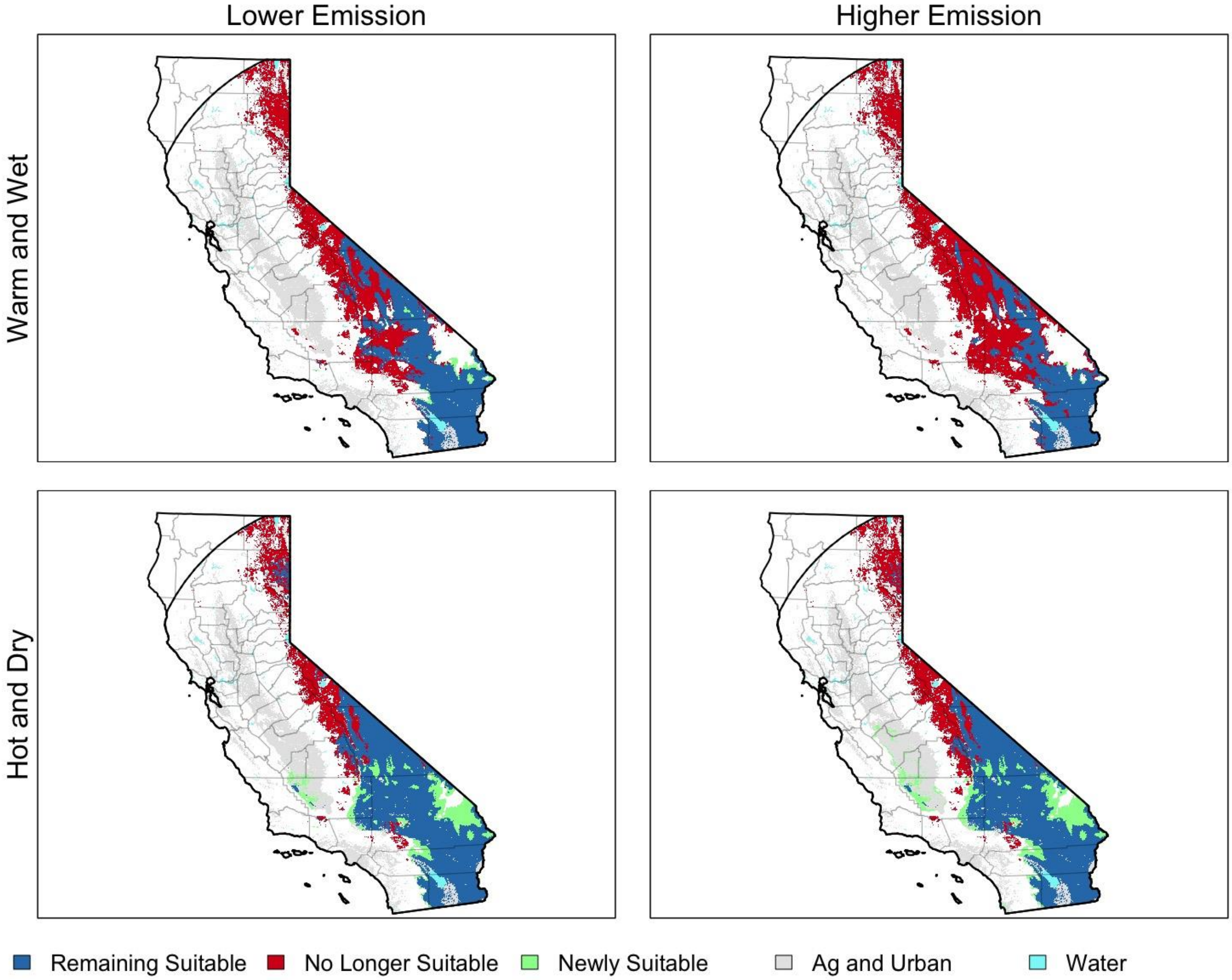

Figure 72. Projected changes in future climate-suitable habitat for the end of the century (2070-2099) under four climate change scenarios. "Lower Emission": RCP4.5. "Higher Emission": RCP8.5. "Hot and Dry": MIROC-ESM. "Warm and Wet": CNRM-CM5. Boundary depicts species-specific dispersal limitation boundary around occurrence records.

APPENDIX

Table S1. Climate variable contributions for species distribution models for taxa modeled in this report. Species distribution models were fit at the level of the full species, except in the case of *Microtus californicus* subspecies (see methods for species distribution model). Variable abbreviations and definitions are given in the methods section of this report and in the table of acronyms at the beginning of the report. Blank cells indicate a variable was not included in the best performing SDM for that species.

	Percent Variable Contribution						
Taxa	TMN	TMX	PPT	RUN	AET	PCK	CWD
Sorex lyelli	100						
Sorex ornatus		41.2	58.8				
Sorex vagrans		35		37.9	27.1		
Ochotona princeps		100					
Aplodontia rufa		25.6			70.6	3.8	
Urocitellus beldingi	80.1		5.4			14.6	
Callospermophilus lateralis		100					
Tamias alpinus		24.8	3.6			71.6	
Tamias speciosus		100					
Zapus princeps		78.8	21.2				
Arborimus pomo	85.4					14.6	
Microtus californicus halophilus		64.4		35.6			
Microtus californicus sanpabloensis		38.5		61.5			
Microtus montanus	100						
Vulpes macrotis		100					
Vulpes vulpes	64.5		35.5				
Martes caurina	12.3		74.2			13.5	
Ovis canadensis		47.3			52.7		