

Final Project Performance Report
State Wildlife Grant Program
F14AF00632

California Department of Fish and Wildlife

High-Elevation Species and Natural Communities in the Northern Sierra Nevada



Pictured above: Northern Sierra Nevada high elevation habitat with three focal community types shown: meadows, talus, and conifer.

1. State: California

Grant number: F14AF00632 (G1498071)

Grant name: High-Elevation Species and Natural Communities in the Northern Sierra Nevada

2. Report Period: July 1, 2016- June 30, 2017

Report due date: September 30, 2017

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3. Location of work: Congressional districts 1, 4, and 8. Northern Sierra Nevada highlands: Shasta, Lassen, Tehama, Plumas, Butte, Sierra, Nevada, Placer, El Dorado, Amador, Alpine, Calaveras, Madera, Mariposa, Tuolumne, and Mono Counties.

4. Objectives:

1. Better understand present status and trends, and model future trends with climate change in high-elevation species and communities in the Sierra Nevada.
2. Develop management and restoration recommendations and strategies for these species and communities.

5. Part of Larger Project: This is a new project not related to any other current grant.

6. Describe how the objectives were met: We assessed species occupancy and habitat characteristics in three focal community types: meadows, talus, and conifer. We designed and conducted surveys, and performed analysis of three focal species that appear to be especially vulnerable to climate change: Belding's ground squirrel (*Urocitellus beldingi*), gray-headed American pika (*Ochotona princeps schisticeps*), and whitebark pine (*Pinus albicaulis*). Whitebark pine is a vital tree line food source and habitat for multiple wildlife species. We visited or conducted occupancy and habitat surveys at 253 random stratified sites in the northern Sierra Nevada of California, including 46 sites which were deemed to be inappropriate habitat or inaccessible for safety reasons once approached in the field. We used aerial imagery to assess habitat type at 14,524 random stratified study sites. Occupancy analyses confirmed that all three focal species are restricted to cold climates. Objective results are contained in Appendix A (CDFW NCR High Elevation Species and Natural Communities Project: Summary of Analysis).

7. Discuss differences: There are no differences between work anticipated in grant proposal and that actually carried out.

8. List any publications or in-house reports resulting from this work: No publications or in-house reports have yet resulted from this work.

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Appendix A

CDFW NCR High Elevation Species and Natural Communities Project: Summary of Analyses

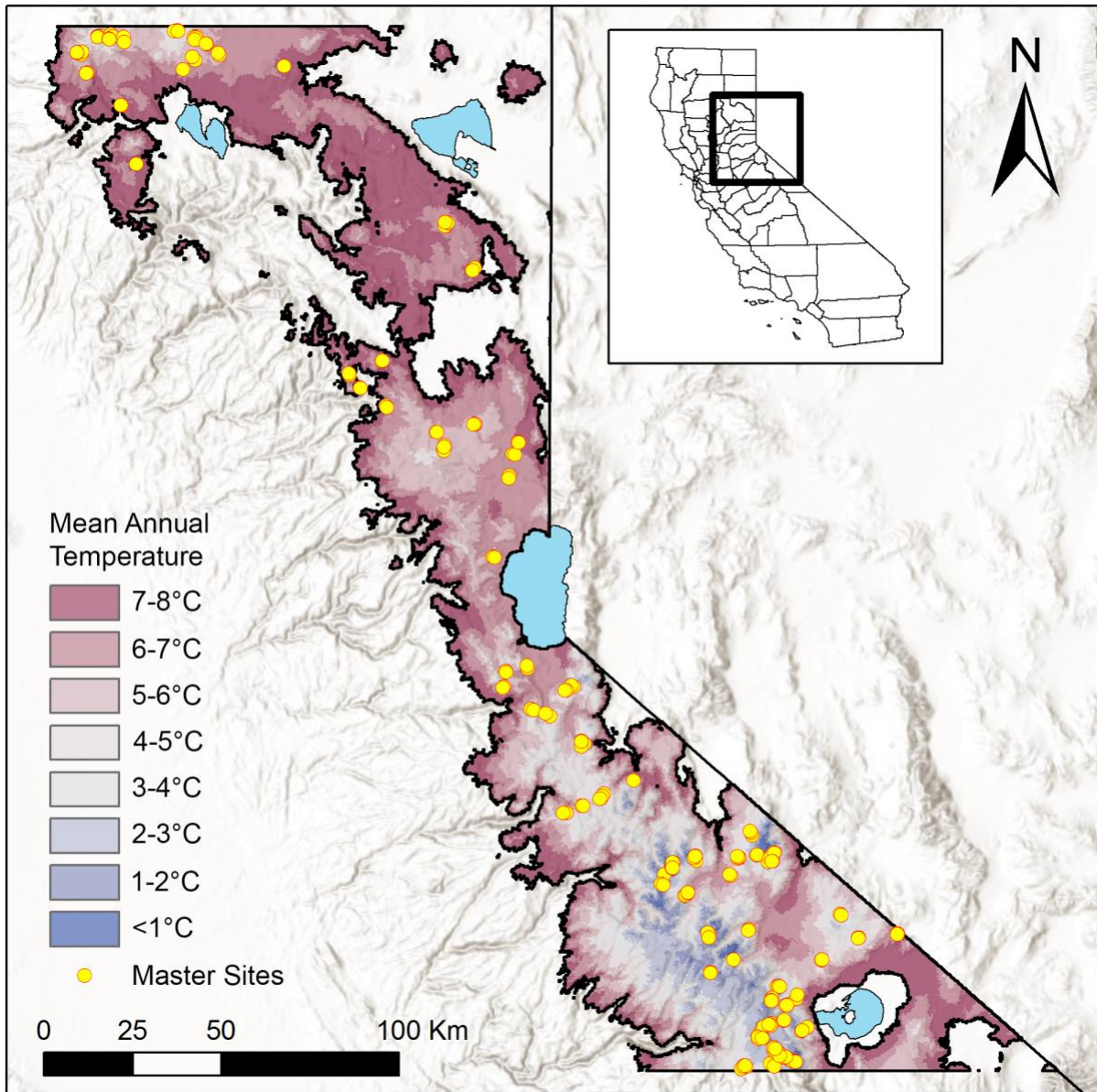


Fig 1. Location of plots surveyed from 2015-2016 for the CDFW High Elevation Species and Natural Communities Project. Background regions are colored by mean-annual-temperature strata. Study area boundary is black. Conifer surveys were completed at 80 plots. Talus surveys were completed 77 plots. Meadow surveys were completed at 67 plots.

Executive Summary

We report findings from the first statistically representative, geospatially randomized assessment of high elevation species occupancy in the northern Sierra Nevada. We assessed species occupancy and habitat characteristics in three focal community types: meadows, talus, and conifer. We emphasized surveys for and analysis of three focal species that appear to be especially vulnerable to climate change: Belding's ground squirrel, American pika, and whitebark pine. Whitebark pine is a vital tree line food source and habitat for multiple wildlife species. We visited or conducted occupancy and habitat surveys at 253 random stratified sites in the northern Sierra Nevada of California, including 46 sites which were deemed to be inappropriate habitat or inaccessible for safety reasons once approached in the field. We used aerial imagery to assess habitat types at 14,524 random stratified study sites. Occupancy analyses confirmed that all three focal species are restricted to cold climates. Mean annual temperature emerged as the best predictor of observed occupancy patterns for each of the three focal species. We used nested models of habitat occurrence and species occupancy to estimate the extent of currently occupied habitat and to forecast climate-mediated changes in distribution and occupancy. Our models forecast that regional temperature increases in the range of 2 – 6°C will result in drastic decline in the area of habitat occupied for these species: 60 – 97% decline for American pika, 80 – 100% decline for Belding's ground squirrel, and 86 – 100% decline for whitebark pine. Power analyses indicate that additional surveys of current occupancy are required for Belding's ground squirrel and American pika if we wish to achieve $\geq 80\%$ power to detect a 50% decline in future occupancy. We explore management strategies and potential sources of resilience for our focal species and communities.

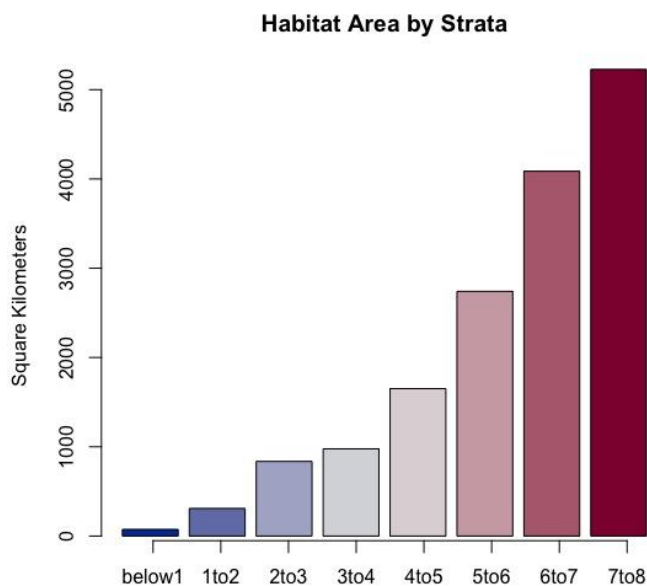


Fig 2. Area of each mean annual temperature strata within our study area.

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Talus and American Pika

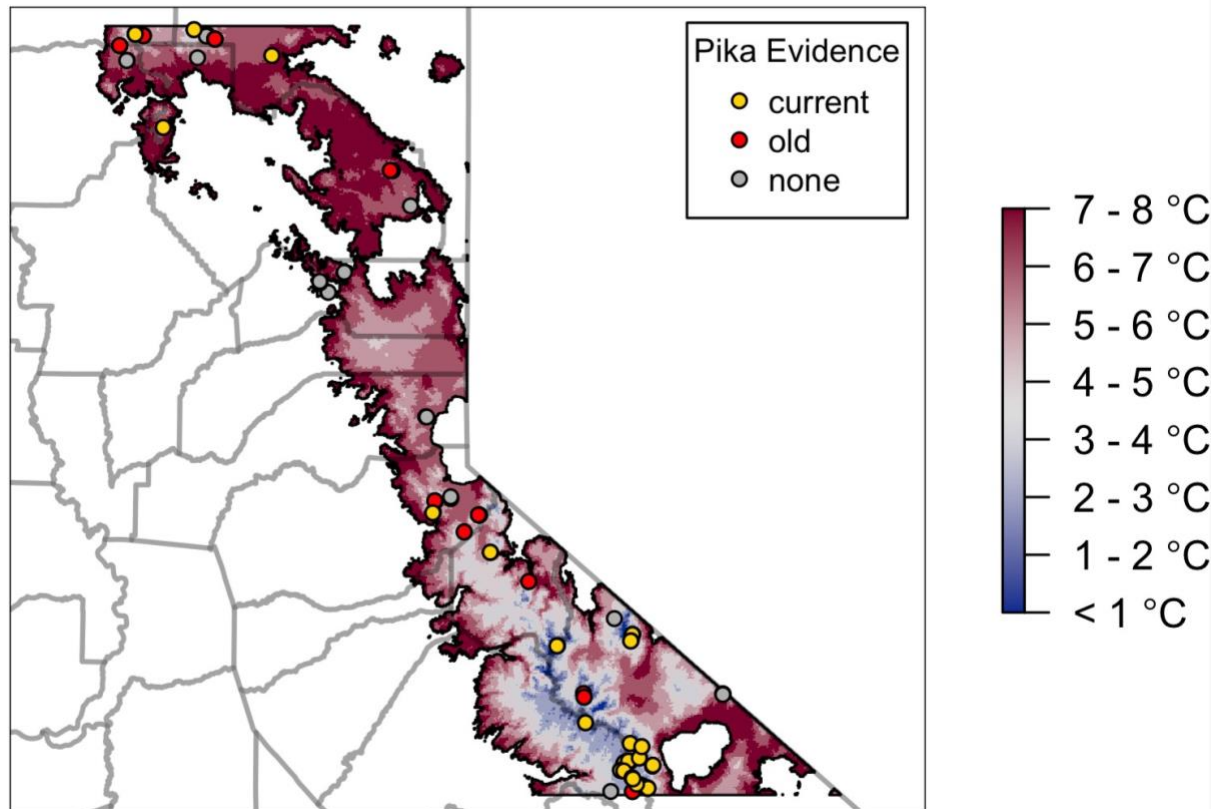


Fig 3. Location of talus plots surveyed for American pika ($n = 77$) from 2015-2016 for the CDFW High Elevation Species and Natural Communities Project. Background regions are colored by mean-annual-temperature strata. Project area boundary is black. State and county boundaries are grey.

The gray-headed American pika (*Ochotona princeps schisticeps*, a Species of Greatest Conservation Need [SGCN]) was petitioned for listing under the US and California Endangered Species Acts. In response, USFWS and CDFW acknowledged that climate change is impacting pikas, but declined to list them as threatened or endangered, citing uncertainty in model projections. In lieu of listing, in the memorandum attached to the 2013 status review, the California Fish and Game Commission called for research, stating, “the Department also believes it will be imperative for our agency and the scientific community to study and monitor the distribution and abundance of American pika over the next few decades” (CDFW 2013).

Talus surveys were conducted at study plots (50-m radius) with at least 45 m² of apparently suitable talus habitat for the American pika, as judged from aerial imagery and visual inspection in the field. Evidence of current pika occupancy was detected at 38% (29/77) of plots surveyed. An additional 21% (16/77) of plots had old evidence of pika occupancy but no current evidence. No evidence of current or past occupancy was detected at 42% (32/77) of plots surveyed. Pika detection was driven primarily by detection of current pika sign (e.g. feces, haypiles) as opposed to direct detection (i.e. seeing, hearing), with direct detections comprising 30% of all current pika detections (25/83). The simplest (no-covariate) occupancy model yielded a 48.2% probability (95% CI = [40.3%, 56.2%]) of detection per 5-minute interval. Rescaling the

probability of detection to our 30-minute survey period the detection probability becomes 98.1% (95% CI = [95.5%, 99.3%]). American pikas are highly detectable.

Belding's ground squirrel were detected in two talus study plots. Yellow-bellied marmot were detected at 11 talus plots. Bushy-tailed woodrat were detected in nine talus plots. Golden-mantled ground squirrel were detected in eight talus plots. Clark's nutcracker were detected in 25 talus plots.

Model Selection

To reduce the total number of candidate models we first selected the top-performing combination of detection covariates using a null model for occupancy and then used the resulting top-performing combination of detection predictors in our subsequent evaluation of occupancy models. For detection probability models, we combined all possible uncorrelated (Spearman's $R < 0.8$) first and second-order combinations of candidate predictors to generate 31 candidate detection models, with up to 3 predictor variables per model. Candidate predictors of detection included hour of day (hod), day of year (doy), temperature at time of survey (Temp_deg_C), and average wind speed at time of survey (Avg_wind_m_per_sec). The top performing model received 0.4 overall Akaike information criterion (AIC) model weight and outperformed the next best performing model by a difference in AIC scores of 2.1. We used the top-performing combination of detection variables in subsequent occupancy model selection.

For occupancy models, we combined all possible uncorrelated (Spearman's $R < 0.8$) first and second-order combinations of candidate predictors to generate 71 candidate occupancy models, with up to 3 predictor variables per model. Candidate predictors of occupancy included mean annual temperature (MAT), mean annual precipitation (MAP), mean annual snow pack depth (PCK), forb cover within the 50-m radius plot (PctForb), graminoid cover within the 50-m radius plot (PctGram), and suitable talus cover within the 50-m radius plot (PctSuitTalus; 0.2 – 1-m rock diameter). The resulting modeled relationships between occupancy and predictor variables were qualitatively consistent among many choices of top-performing detection models, including the null detection model.

Table 1. Model selection table for top-performing models of American pika detection probability. Shown are thirteen models that outperformed the null model and the null model.

Model formula	Δ AIC	cumWt
mod23:~ hod + Temp_deg_C + I(hod^2) ~ 1	0.000	0.395
mod15:~ Temp_deg_C + I(Temp_deg_C^2) ~ 1	2.139	0.531
mod24:~ hod + Temp_deg_C + I(Temp_deg_C^2) ~ 1	3.345	0.605
mod5:~ Temp_deg_C ~ 1	3.416	0.677
mod31:~ Avg_wind_m_per_sec + Temp_deg_C + I(Temp_deg_C^2) ~ 1	3.892	0.733
mod29:~ doy + Temp_deg_C + I(Temp_deg_C^2) ~ 1	4.138	0.783
mod8:~ hod + Temp_deg_C ~ 1	4.200	0.832
mod11:~ doy + Temp_deg_C ~ 1	5.079	0.863
mod13:~ Avg_wind_m_per_sec + Temp_deg_C ~ 1	5.412	0.889
mod17:~ hod + doy + Temp_deg_C ~ 1	5.586	0.914
mod20:~ hod + Avg_wind_m_per_sec + Temp_deg_C ~ 1	6.200	0.931
mod30:~ Avg_wind_m_per_sec + Temp_deg_C + I(Avg_wind_m_per_sec^2) ~ 1	7.029	0.943
mod25:~ doy + Avg_wind_m_per_sec + Temp_deg_C ~ 1	7.078	0.955
NULL Model. mod1:~1 ~ 1	7.722	NA

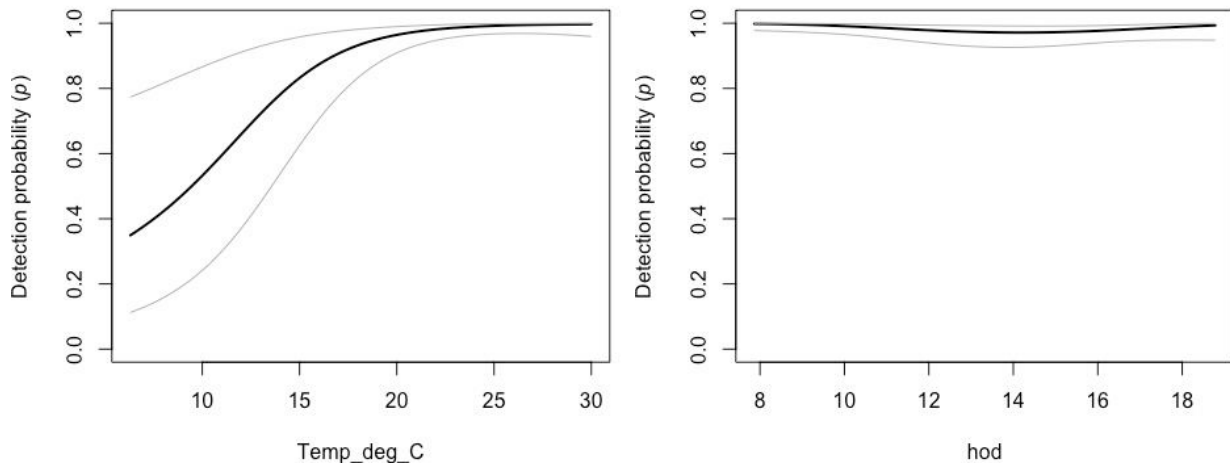


Fig 4. Marginal response curves for probability of current pika detection and 95% confidence intervals over thirty person-minute search intervals as a function of the top two performing predictor variables and the ensemble model composed of the ten top performing models (smallest such set with cumulative model weight > 0.9; variable importance for Temp_deg_C = 1.00, hod = 0.58). All marginal responses depict probability of occupancy when other predictor variables are held at their mean value. The modeled low detection probability during cold ambient temperatures appears to be driven by a relatively small number of surveys. Overall model results and projections were not qualitatively affected by this potentially spurious relationship.

Table 2. Model selection table for top-performing models of American pika occupancy. Included are all models with $\Delta AIC < 10$ and the null model.

model	ΔAIC	cumWt
mod34: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctForb + PctSuitTalus	0.000	0.331
mod11: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctSuitTalus	1.315	0.502
mod38: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctGram + PctSuitTalus	2.188	0.612
mod42: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctSuitTalus + PCK	2.201	0.722
mod43: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctSuitTalus + I(MAT^2)	2.320	0.826
mod30: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + MAP + PctSuitTalus	2.519	0.920
mod44: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctSuitTalus + I(PctSuitTalus^2)	3.423	0.980
mod9: ~ hod + Temp_deg_C + I(hod^2) ~ MAT + PctForb	9.744	0.982
mod2: ~ hod + Temp_deg_C + I(hod^2) ~ MAT	9.803	0.985
Null Model ~ 1	35.717	NA

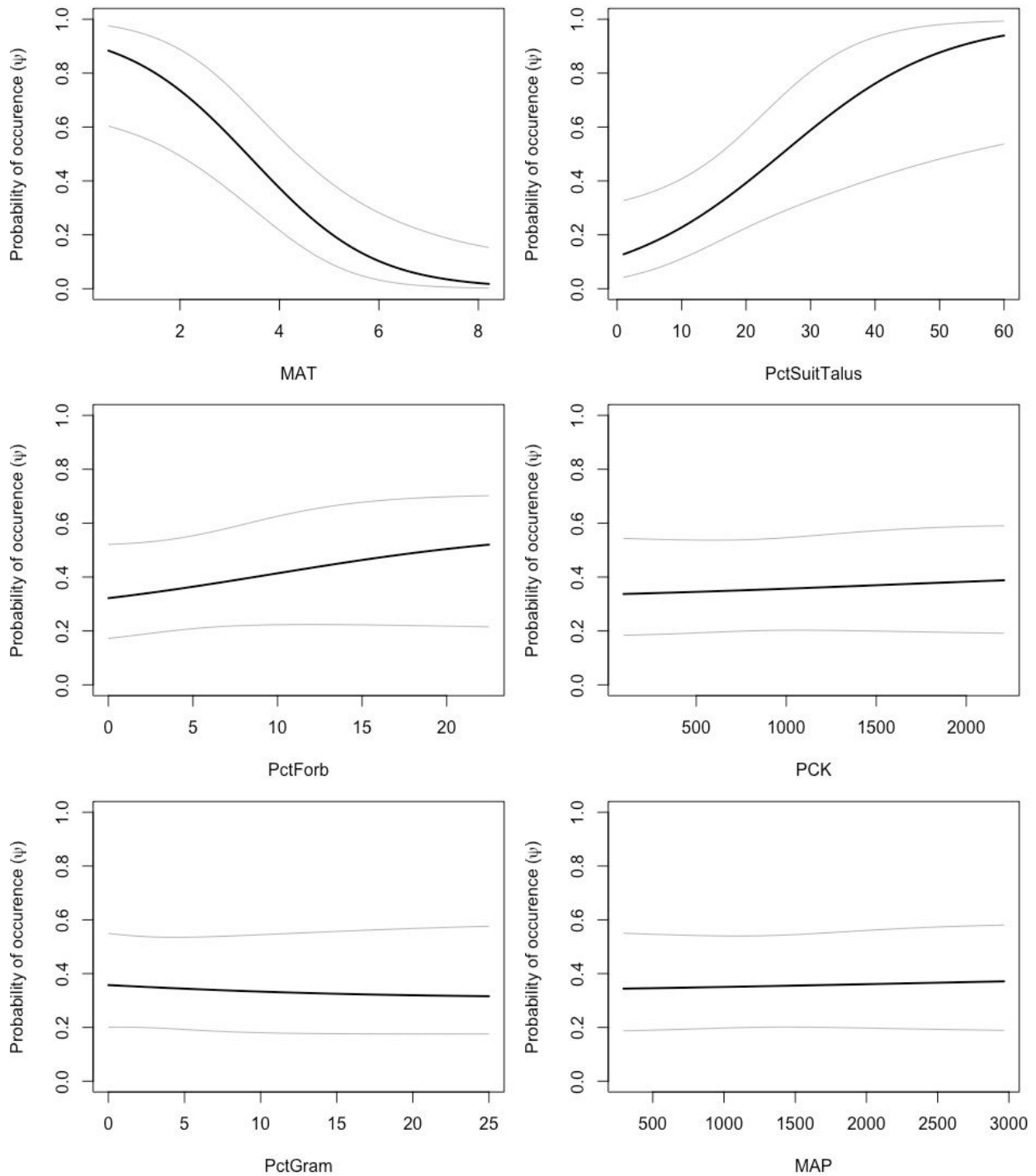


Fig 5. Marginal response curves for probability of current pika occupancy and 95% confidence intervals as a function of predictor variables and the ensemble model composed of the top nine performing models ($\Delta AIC < 10$, cumulative model weight = 0.99; variable importance for MAT = 1.00, PctSuitTalus = 0.99, PctForb = 0.34, PCK = 0.11, PctGram = 0.11, MAP = 0.09). All marginal responses depict probability of occupancy when other predictor variables are held at their mean value.

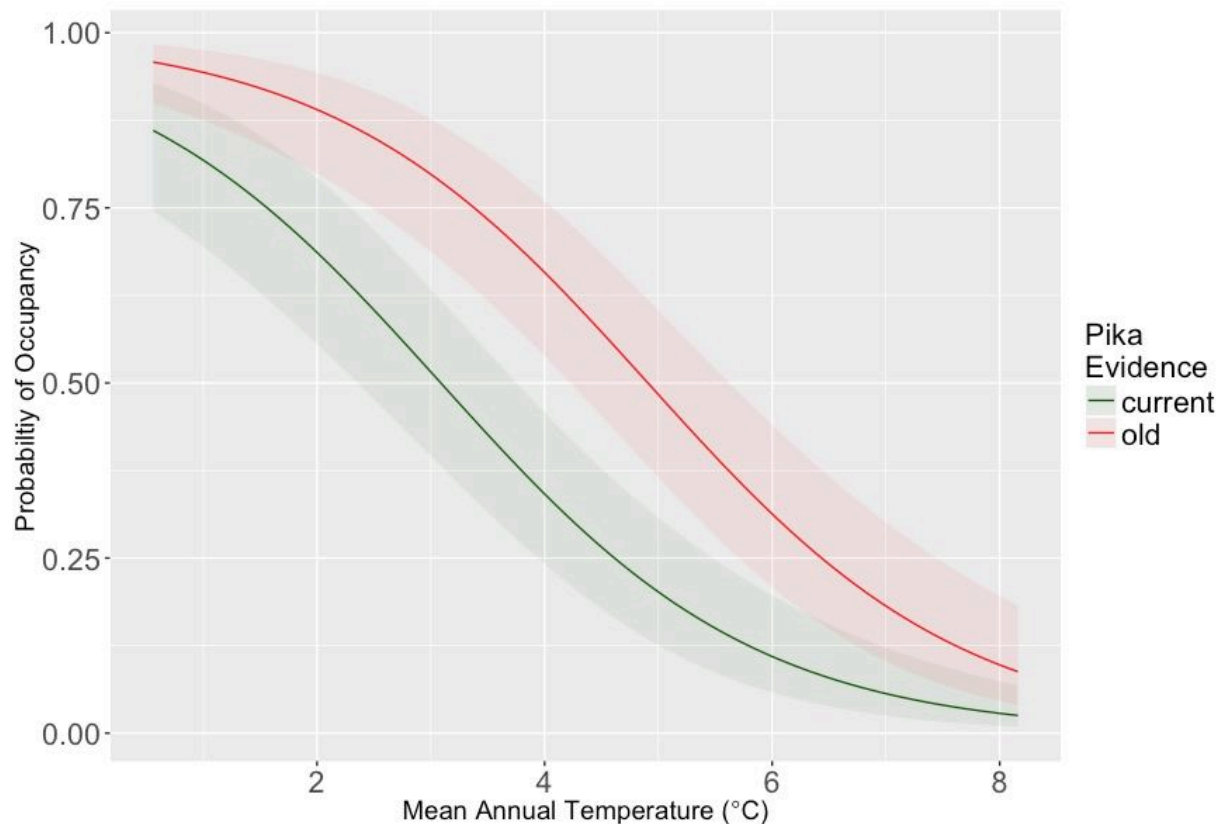


Fig 6. Modeled probability of occupancy and 95% confidence intervals as functions of mean annual temperature (MAT) for current and old pika occupancy. Type of pika evidence was a significant ($p < 0.005$) predictor of occupancy in the model that included mean annual temperature and type of pika occupancy as additive predictor terms. Currently occupied sites were 1.82°C cooler than formerly occupied sites at the same probability of occupancy. Current pika evidence includes seeing and hearing pikas as well as fresh pika sign (fecal pellets and haypiles). Old sign is indicative of past pika occupancy and could include both sites that were consistently occupied and sites that were episodically occupied.

Projected Occupancy and Distribution

We modeled probability of talus habitat occurrence across the study area. The model was parameterized using maxent and 12,814 study plots where presence of talus within a 50-m radius was assessed using aerial imagery (538 plots with talus). Predictor variables included climate (mean annual temperature, mean annual snowpack, mean annual precipitation; 270-m resolution), topography (slope, aspect [i.e. “northness”], vector ruggedness measure [vrm] with a 630-m focal area, and three topographic position indices [tpi] with respective focal areas of 90 m, 270 m, and 630 m; all based on 30-m resolution elevation data), and National Land Cover Dataset (NLDC) land cover category (30-m resolution). The resulting model had an area under the curve AUC score of 0.84, as assessed against the training data. The resulting model indicated

that probability of talus occurrence is associated with colder mean annual temperature, moderate topographic roughness, and barren NLDC land cover class.

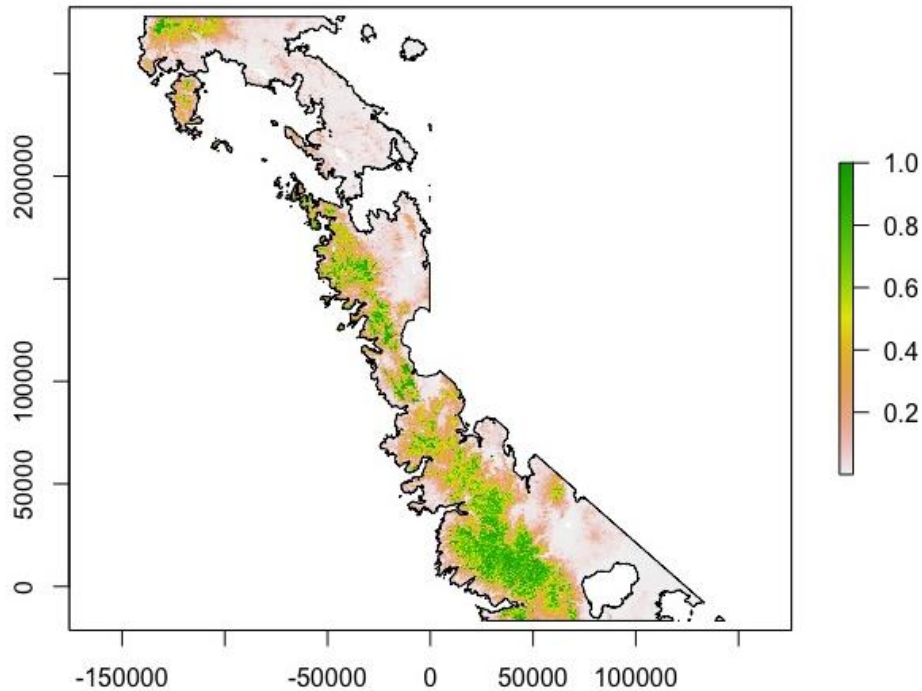


Fig 7. Modeled probability of talus habitat occurrence ($\geq 45 \text{ m}^2$ of talus within 50-m radius study plots) across the study area. Probability of talus occurrence is positively associated with colder mean annual temperature, moderate topographic roughness, and barren NLDC land cover class.

We combined our model of habitat occurrence with our model of pika occupancy within talus habitat to produce a nested model of pika occupancy across the study area. The resulting nested model predicted that 97 km^2 of habitat within our study area is currently occupied by pikas. A 2°C increase in mean annual temperature is projected to result in a 60% decline in the area of habitat occupied by pikas within our study area. A 4°C increase in mean annual temperature is projected to result in an 88% decline in the area of habitat occupied by pikas within our study area. A 6°C increase in temperature is projected to result in a 97% decline in the area of habitat occupied by pikas within our study area. For context, global temperatures are likely to rise by $1.3^\circ\text{C} - 5.7^\circ\text{C}$ by the end of the 21st century and by $1.1^\circ\text{C} - 14.1^\circ\text{C}$ by 2300 (66% confidence intervals for range of emission scenarios, Rogelj et al. 2012).

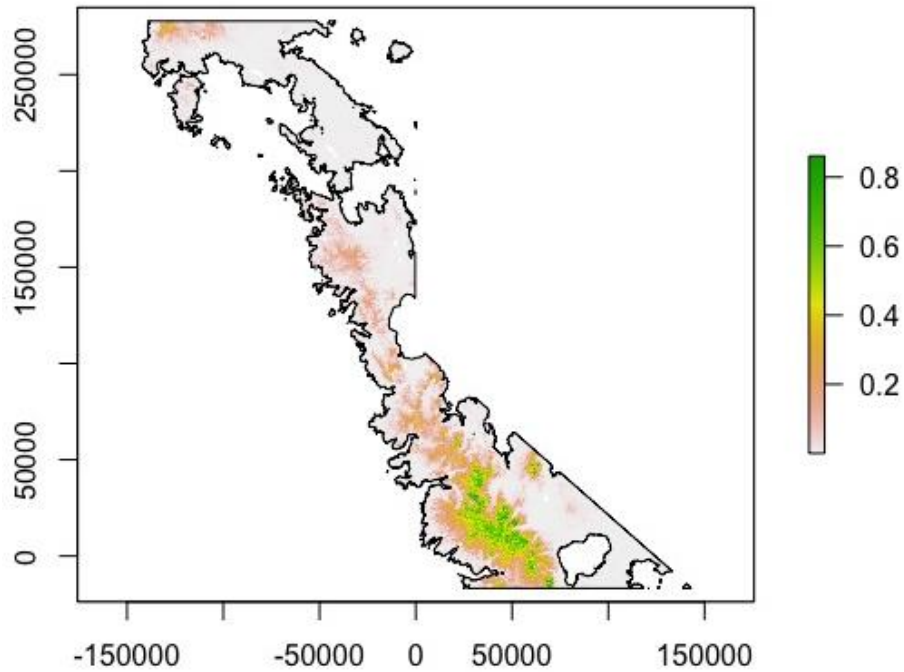


Fig 8. Modeled current probability of pika occupancy within 50-m study plots as predicted by our nested model of talus habitat and pika occupancy within talus habitat.

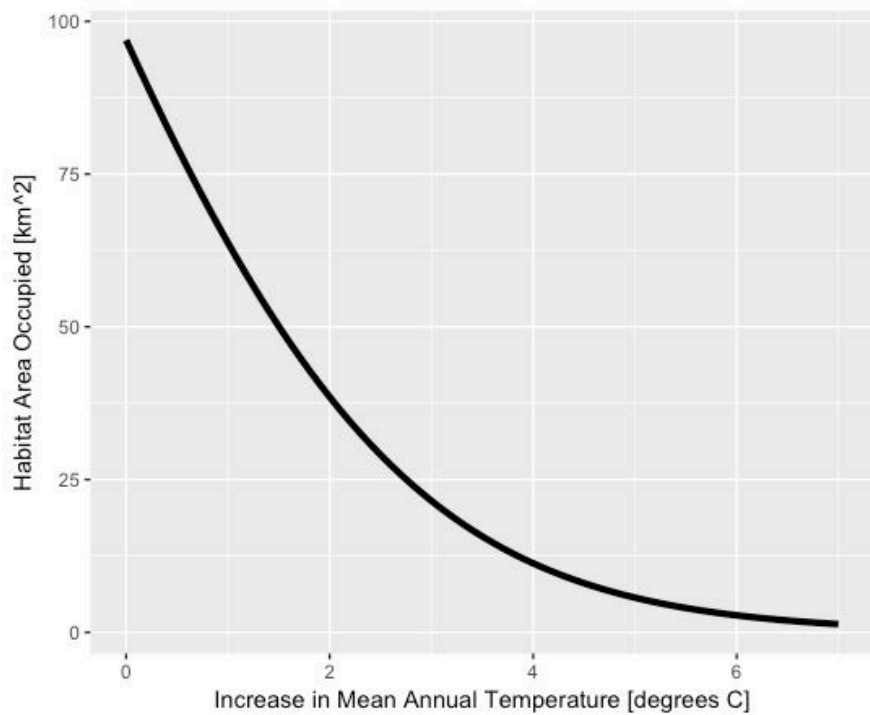


Fig 9. Modeled decline in habitat area occupied by pikas within our northern Sierra Nevada study area as a function of increase in mean annual temperature. Modeled decline is based on nested models of pika occupancy and talus habitat occurrence.

Power to Detect Future Decline

The primary purpose of an occupancy monitoring programs is to be able to detect changes in occupancy. We calculate our power to detect a 50% decline in pika occupancy throughout our study region, given our sample size of 77 sites and the no-covariate model. Our sample of 77 sites yields a 75% probability that a 50% decline in occupancy would be detected by a resurvey of these sites. This is generally considered an inadequate ability to detect change in occupancy. Given the present sample stratification, we would need to sample about 116 sites (about 40 additional sites) to achieve a 90% probability of detecting a 50% decline in occupancy. We could achieve the same power to detect decline in occupancy with fewer additional surveys required if we judiciously shift our sample stratification to de-emphasize surveys in the two warmest strata.

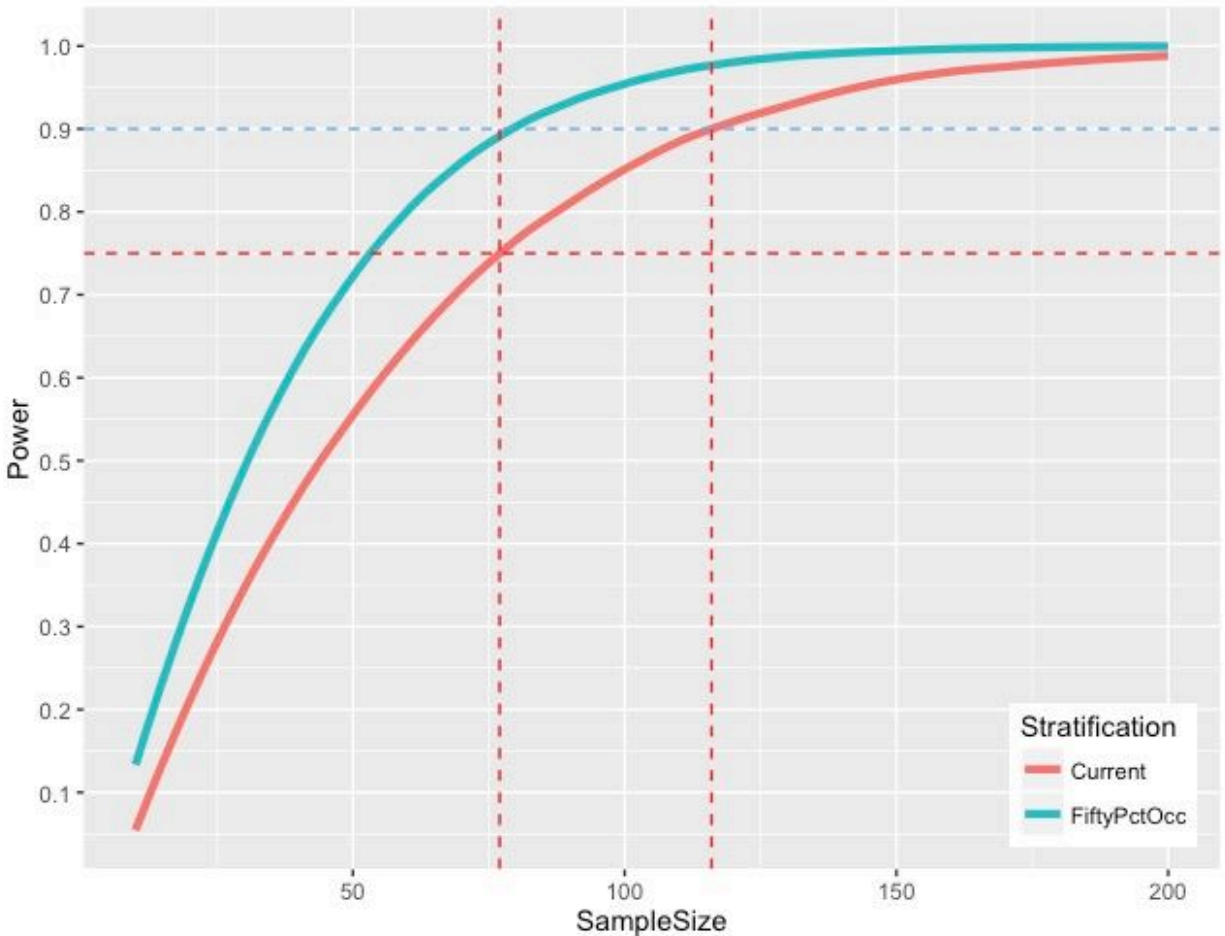


Fig 10. Power to detect a 50% decline in *O. princeps* occupancy as a function of sample size and proportion of sites occupied (alpha = 0.05). The current sample stratification results in a 36% rate of site occupancy and a relatively low power to detect changes in abundance (red lines). A sample stratification that results in a higher proportion of sites occupied (i.e. higher proportion of surveys in lower-temperature, higher-elevation sites) would achieve higher power with the same sample size. To achieve 90% power to detect a 50% decline in occupancy we could either survey an additional 39 sites following our current site stratification, or we could achieve the same power with fewer additional surveys by shifting our stratification to de-emphasize surveys at the warmest and lowest-elevation strata. Teal line shows power to detect decline from a stratification that results in 50% rate of current site occupancy. Power was calculated by running 10,000 simulations for each sample size.

Radiocarbon Dating of Old Pika Feces

Pika feces can persist in talus fields, in locations protected from sunshine and moisture, long after pikas have become extirpated from those sites (Stewart and Wright 2012, Millar et al. 2014, Stewart et al. 2015). We used radiocarbon dating of old pika feces to determine the age range of old pika fecal pellets at sites no longer occupied by pikas. Extirpated sites with older pika fecal pellets tended to experience higher temperatures. Amongst random stratified sites surveyed as part of this project, extirpated sites with an older date of most recent possible pika

feces origin (95% confidence interval) tended to experience higher mean annual temperature ($N = 16$, linear regression, one-tailed p -value < 0.1). When radio carbon dates from extirpated sites surveyed as part of previous CDFW and UCSC surveys were included, the relationship between pellet age and mean annual temperature became statistically significant ($N = 43$, linear regression, one-tailed p -value < 0.05).

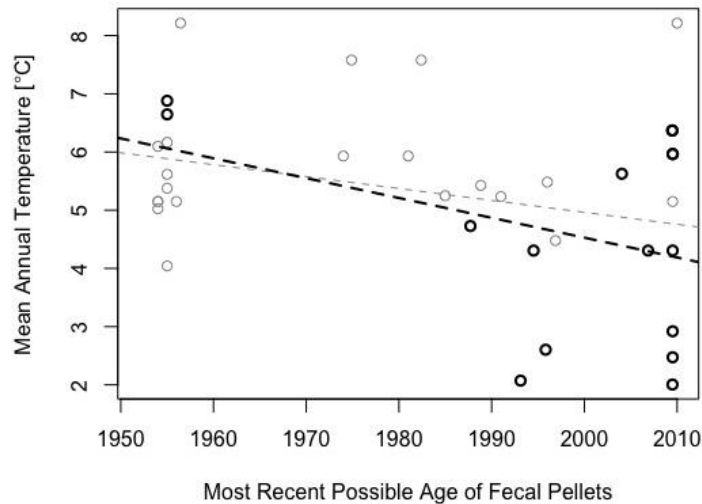


Fig 11. Most recent year of possible fecal pellet origin (95% confidence interval) and mean annual temperature at extirpated pika sites. Shown in black are random stratified sites surveyed as part of this project and a linear regression fit to this data ($N = 16$, one-tailed p -value < 0.1). Shown in grey are sites surveyed as part of as part of previous CDFW and UCSC surveys and linear regression fit to all sites ($N = 43$, one-tailed p -value < 0.05).

Assessing Historical Range Contraction

Weather station data indicate that mean annual temperature in the Sierra Nevada has risen by 1.08°C since the beginning of the 20th century (data aggregated by California Climate Tracker [dri.edu/monitor/cal-mon/], Abatzoglou et al. 2009, linear regression, $p < 0.000000001$). Applying this temperature differential to our nested model of pika occupancy resulted in a historical area of occupancy in our study area 43% greater than under current conditions or a 30% decline in occupancy since the beginning of the 20th century.

Data obtained through this project are consistent with the hypothesis of climate-mediated range contraction of the American pika (Figs 6 & 11). The widespread occurrence of old pika feces at sites with warmer temperatures than currently occupied sites suggests that warmer climate conditions contributed to the extirpation of these sites (Fig 12). An alternative hypothesis is that old fecal pellets found at these sites were deposited by isolated dispersers that never reproduced and that these sites have never been suitable for pikas. However, given the often abundant evidence of past pika occupancy at these sites, it appears unlikely that juvenile dispersers could fully account for past pika evidence at these sites. Likewise, the pattern of warmer temperatures at extirpated sites with older pika feces (Fig 11) is suggestive of upslope range contraction where sites became sequentially extirpated as they experienced warming. An alternative hypothesis to explain this pattern is that sites with warmer temperatures experienced

less frequent pika colonization events by virtue of warmer sites being more distant from source pika populations.

While data from this project (i.e. random stratified surveys of 50-m radius plots) cannot serve by themselves as definitive evidence of range contraction, data obtained through this project did contribute to documentation of pika range contraction in the north Lake Tahoe Area. Pika occupancy surveys and radiocarbon data from this project contributed to a peer-reviewed paper which details the apparent climate-mediated extirpation of the American pika from a 165 km² area at the center the pikas range in the north Lake Tahoe area (Stewart et al. in press).

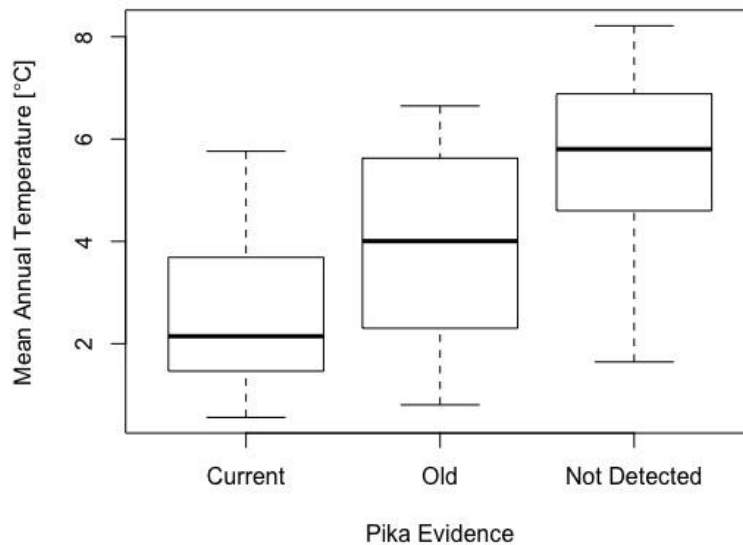


Fig 12. Mean annual temperature at sites with either current pika occupancy, old evidence of pika occupancy, or no evidence of current or past occupancy detected. Difference between adjacent categories are statistically significant (Mann-Whitney, current vs. old: $p < 0.05$, old vs. not detected, $p < 0.005$).

Management Opportunities

Management opportunities for American pika appear to be relatively sparse. Pika habitat is not in widespread danger from development, logging, or recreation. Reversing climate change would constitute the most concrete management action for conservation of pikas and other climate change vulnerable species (i.e. ~16% of global species, Urban 2015). Monitoring of pikas is called for to assess shifts in distribution and abundance. Although our report does not address grazing, grazing has been reported to potentially affect pikas (Millar 2011).

One potential management option that could increase resilience for pikas and other species vulnerable to climate change are strategic translocation programs. Translocation could provide benefits by establishing or reestablishing pika populations in vacant suitable habitat, by enhancing genetic connectivity, or by conferring adaptive traits from one population to another. Pika populations persisting in anomalously warm conditions (Beever et al. 2008) may possess genetic adaptations, that if transferred to other populations, could make those populations more resilient to climate change (Harris et al. 2006). Fortunately, new advances in genomic techniques

are continually improving the ability to identify population-level adaptive variation in non-model organisms (Funk et al. 2012). Even small amounts of immigration should be sufficient to increase genetic variation for selection to act upon, in addition to lowering the frequency of deleterious alleles (Mills and Allendorf 1996).

Meadows and Belding's Ground Squirrel

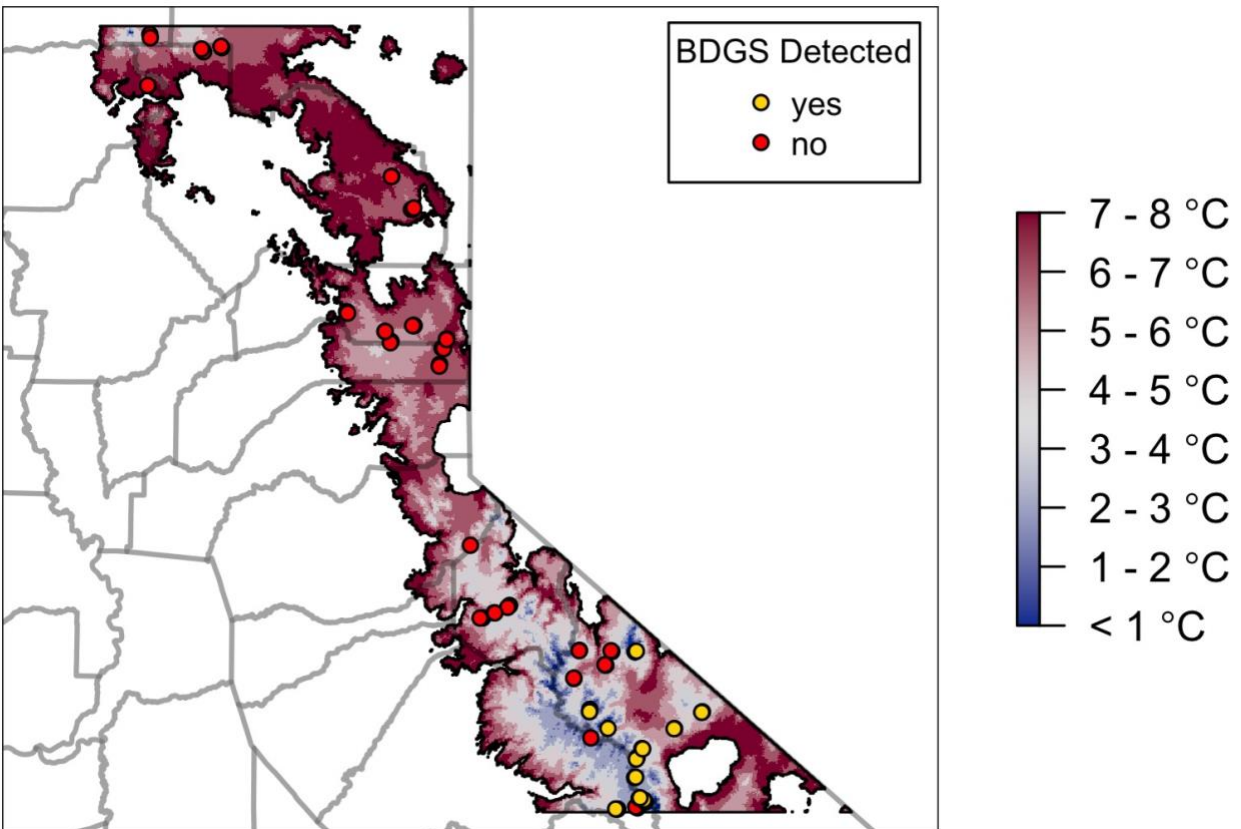


Fig 13. Location of plots surveyed for Belding's ground squirrels ($n = 67$) from 2015-2016 for the CDFW High Elevation Species and Natural Communities Project. Background is colored by mean annual temperature strata. Project area boundary is black. State and county boundaries are grey.

Belding's ground squirrel (*Urocyon beldingi*) appears highly vulnerable to climate change: the species has disappeared from 42% of historical record sites and its pattern of site extirpation is largely explained by increased winter temperature (Morelli et al. 2012).

Meadow surveys were conducted at study plots (50-m radius) with at least 10% meadow cover, as judged from aerial imagery and visual inspection in the field. Belding's Ground Squirrels were detected at 27% (18 of 67) of meadow survey plots. One plot was surveyed twice, during 2015 and 2016, and *U. beldingi* was detected in that plot during both survey years. The simplest (no-covariate) occupancy model yielded a 51% probability (95% CI = [41%, 61%]) of detection per 5-minute interval. Rescaling the probability of detection to our 30-minute survey period the detection probability becomes 99% (95% CI = [96%, 100%]). Belding's ground squirrels are highly detectable.

Clark's nutcrackers were detected at 13 of 67 meadow plots. Yellow-bellied marmot and golden-mantled ground squirrel were each detected at one meadow plot. American pika were detected at two meadow plots.

All of our *U. beldingi* detections occurred in the southern portion of our study area. This pattern is not indicative of complete lack of occupancy in the northern portions of our study

area—recent records of Belding’s ground squirrel occupancy span the latitudinal distribution of our study area, though they are particularly sparse in the north. Historical resurvey of *U. beldingi* sites do, however, indicated that a large proportion (42%) of historical sites have become extirpated over the last century, apparently as result of climate change. The proportion of sites extirpated was particularly high throughout the northern half of our study area, where temperatures are warmer (Morelli et al. 2012).

Model Selection

To reduce the total number of candidate models we first selected the top-performing combination of detection covariates using a null model for occupancy and then used the resulting top-performing combination of detection predictors in our subsequent evaluation of occupancy models. For detection probability models, we combined all possible uncorrelated (Spearman’s $R < 0.8$) first and second-order combinations of candidate predictors to generate 17 candidate detection models, with up to 3 predictor variables per model. Candidate predictors of detection included hour of day (hod), day of year (doy), and temperature at time of survey (Temp_deg_C). The top performing model received 0.4 overall AIC model weight and outperformed the next best performing model by a difference in AIC scores of .144. We used the top-performing combination of detection variables in subsequent occupancy model selection.

For occupancy models, we combined all possible uncorrelated (Spearman’s $R < 0.8$) first and second-order combinations of candidate predictors to generate 35 candidate occupancy models, with up to 2 predictor variables per model. Candidate predictors of occupancy included mean annual temperature (MAT), mean annual temperature (MAP), mean annual snow pack depth (PCK), forb cover within the 50-m radius plot (Pct.forb), graminoid cover within the 50-m radius plot (Pct.graminoid), and percent tree cover within the 50-m radius plot (Pct.tree), and percent shrub cover within the 50-m radius plot (Pct.shrub).

Table 3. Model selection table for top-performing models of Belding’s ground squirrel detection probability. Shown are four models with $\Delta AIC < 10$ and the null model.

Model formula	ΔAIC	cumWt
mod11: \sim doy + Temp deg C + hod \sim 1	0.000	0.399
mod5: \sim doy + Temp deg C \sim 1	0.144	0.771
mod13: \sim doy + Temp deg C + I(Temp deg C ²) \sim 1	1.201	0.990
mod16: \sim Temp deg C + hod + I(Temp deg C ²) \sim 1	8.945	0.994
Null Model: \sim 1 \sim 1	20.2	NA

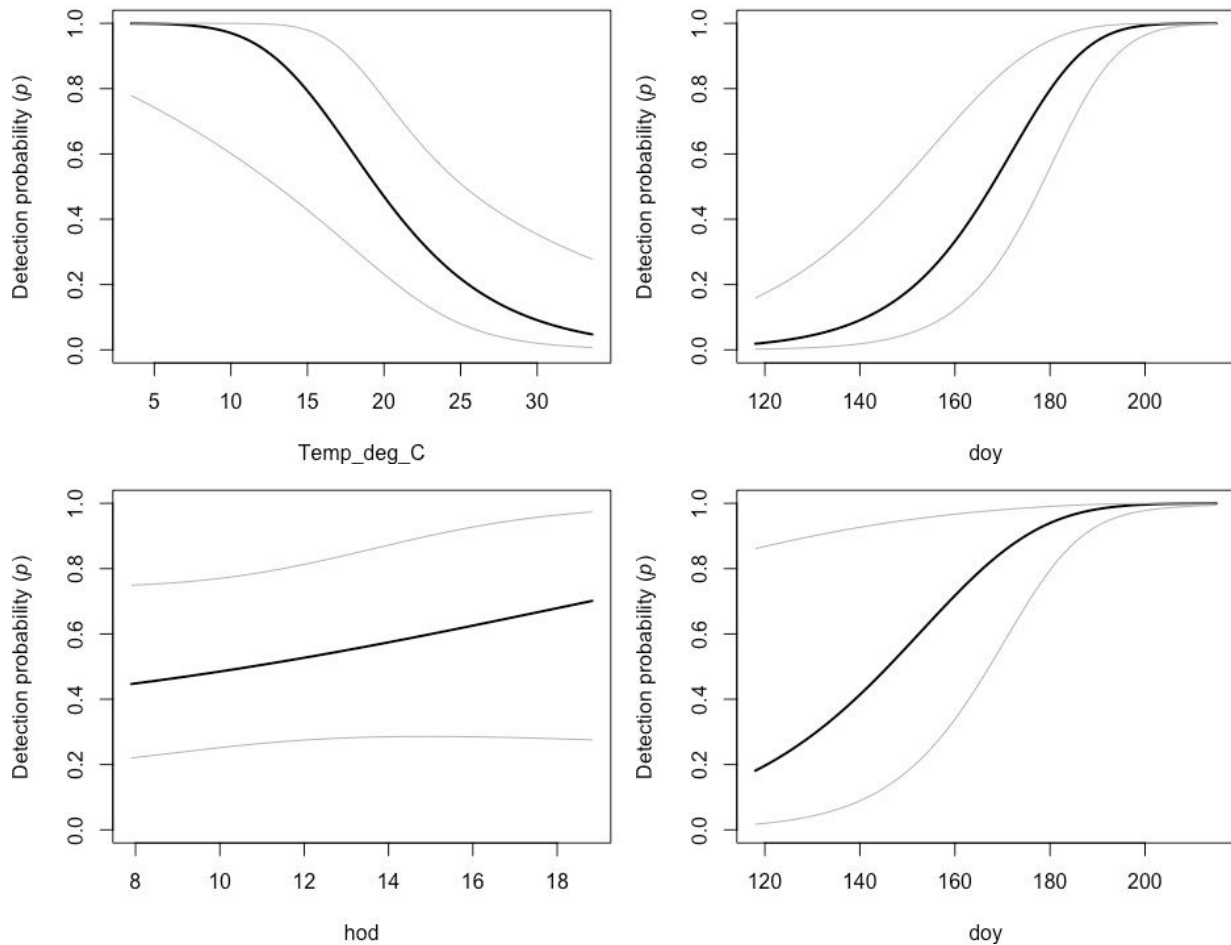


Fig 14. First three plots: marginal response curves for probability of Belding’s ground squirrel detection and 95% confidence intervals over thirty person-minute search intervals as a function three predictor variables and the ensemble model composed of the four top-performing models ($\Delta AIC < 10$, cumulative model weight = 0.99; variable importance for Temp_deg_C = 1.00, doy = 1.00, hod = 0.52). All marginal responses depict probability of occupancy when other predictor variables are held at their mean value.

Modeled detection probability as a function of temperature at the time of survey suggests that Belding’s ground squirrels become less active in response to high temperatures. Modeled detection probability as a function of day of the year (doy) suggests that surveys conducted earlier in the season may have been of marginal utility. Last (bottom right) plot shows how the marginal response curve for doy changes after accounting for probability of site occupancy (i.e. using the ensemble occupancy model below, Table 4).

Table 4. Model selection table for top-performing models of Belding's ground squirrel occupancy. Included are all models with $\Delta AIC < 10$ and the null model.

model	ΔAIC	cumWt
mod9: \sim doy + Temp deg C + hod \sim MAT + MAP	0.000	0.239
mod10: \sim doy + Temp deg C + hod \sim MAT + Pct.graminoid	0.438	0.431
mod12: \sim doy + Temp deg C + hod \sim MAT + Pct.tree	0.602	0.608
mod14: \sim doy + Temp deg C + hod \sim MAT + PCK	1.514	0.721
mod15: \sim doy + Temp deg C + hod \sim MAT + I(MAT ²)	1.834	0.816
mod13: \sim doy + Temp deg C + hod \sim MAT + Pct.shrub	2.017	0.904
mod2: \sim doy + Temp deg C + hod \sim MAT	4.022	0.936
mod11: \sim doy + Temp deg C + hod \sim MAT + Pct.forb	4.054	0.967
mod23: \sim doy + Temp deg C + hod \sim Pct.graminoid + Pct.shrub	7.756	0.972
mod6: \sim doy + Temp deg C + hod \sim Pct.tree	7.833	0.977
mod26: \sim doy + Temp deg C + hod \sim Pct.forb + Pct.tree	8.783	0.980
mod30: \sim doy + Temp deg C + hod \sim Pct.tree + Pct.shrub	8.941	0.982
mod18: \sim doy + Temp deg C + hod \sim MAP + Pct.tree	8.958	0.985
mod22: \sim doy + Temp deg C + hod \sim Pct.graminoid + Pct.tree	9.039	0.988
mod4: \sim doy + Temp deg C + hod \sim Pct.graminoid	9.800	0.990
mod31: \sim doy + Temp deg C + hod \sim Pct.tree + PCK	9.827	0.991
Null Model: \sim doy + Temp deg C + hod \sim 1	13.443	NA

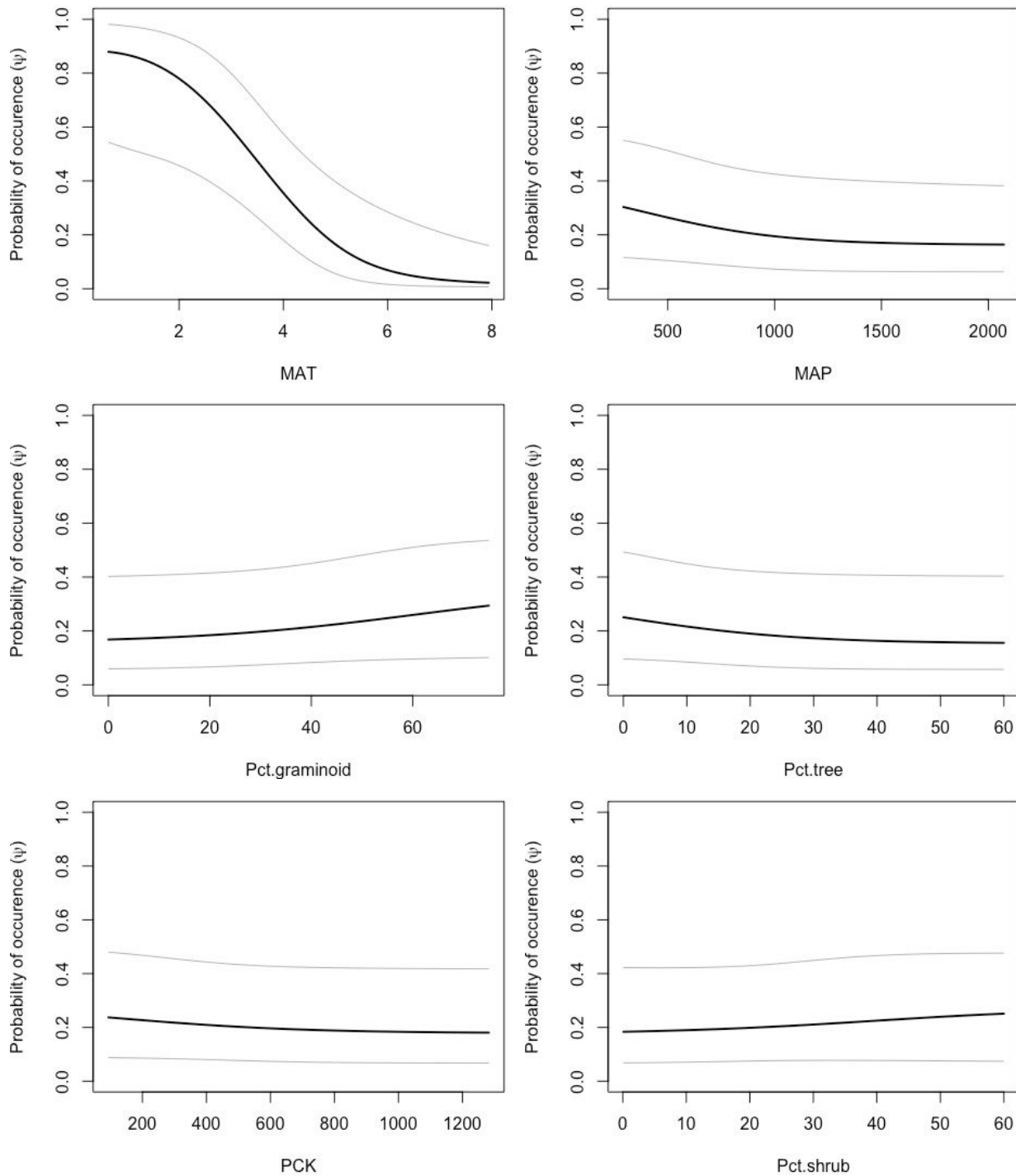


Fig 15. Marginal response curves for probability of current Belding’s ground squirrel occupancy and 95% confidence intervals as a function of predictor variables and the ensemble model composed of the top 16 performing models ($\Delta AIC < 10$, cumulative model weight = 0.99; variable importance: MAT = 0.98, MAP = 0.24, Pct.graminoid = 0.20, Pct.tree = 0.20, PCK = .11, Pct.shrub = 0.10, Pct.forb = 0.03). All marginal responses depict probability of occupancy when other predictor variables are held at their mean value.

Projected Occupancy and Distribution

We modeled probability of meadow habitat occurrence across the study area. The model was parameterized using maxent and 10,059 study plots where presence of meadow habitat within a 50-m radius was assessed using aerial imagery (368 plots with meadow habitat). Predictor variables included climate (mean annual temperature, mean annual snowpack, mean annual precipitation; 270-m resolution), topography (slope, aspect [i.e. “northness”], vector ruggedness measure [vrm] with a 630-m focal area, and three topographic position indices [tpi] with respective focal areas of 90 m, 270 m, and 630 m; all based on 30-m resolution elevation data), and NLDC land cover category (30-m resolution). The resulting model had an AUC score of 0.85, as assessed against the training data. The resulting model indicated that probability of meadow occurrence is associated with moderate mean annual temperature and precipitation, neutral or negative topographic position index, flat slope, and herbaceous NLDC land cover class.

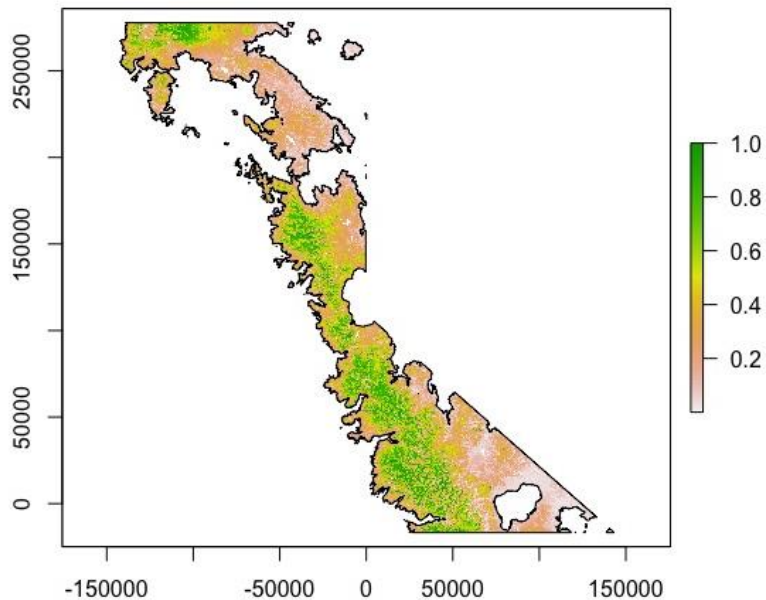


Fig 16. Modeled probability of meadow presence ($\geq 10\%$ meadow cover within 50-m radius study plots) across the study area.

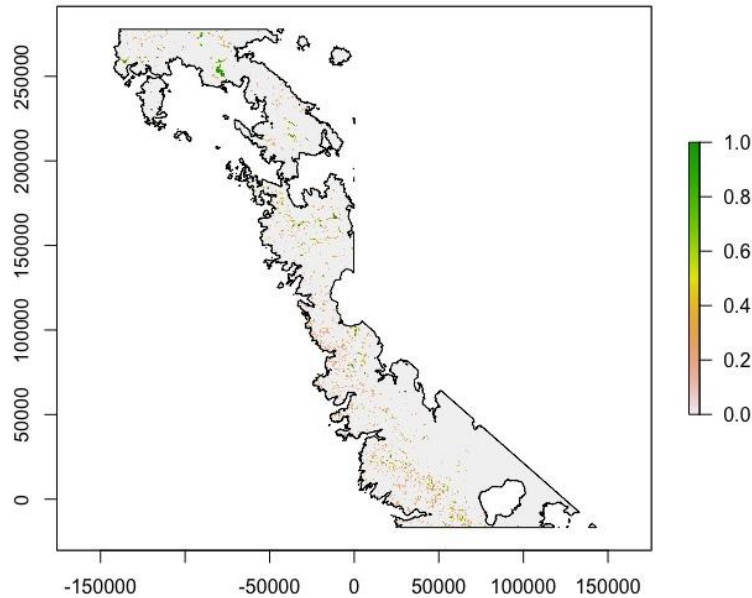


Fig 17. Proportion of land area covered by meadows across the study area as derived from the Sierra Nevada Multi-Source Meadow Polygons Compilation (v 1.0) produced by the UC Davis Center for Watershed Science. Examination of aerial imagery readily reveals many small areas of meadow habitat that are not included in this layer. Note stark contrast with the previous figure.

We combined our model of meadow habitat occurrence with our model of Belding’s ground squirrel occupancy within meadow habitat to produce a nested model of Belding’s ground squirrel occupancy across the study area. The resulting nested model predicted that 54.5 km² of meadow habitat within our study area is currently occupied by Belding’s ground squirrels. We caution that Belding’s ground squirrels also occupy habitat types other than meadow, such as sagebrush, and that these projections should be interpreted accordingly. A 2°C increase in mean annual temperature is projected to result in a 79.5% decline in the area of meadow habitat occupied by Belding’s ground squirrels within our study area. A 4°C increase in mean annual temperature is projected to result in a 97.1% decline in the area of meadow habitat occupied by Belding’s ground squirrels within our study area. A 6°C increase in temperature is projected to result in a 99.7% decline in the area of meadow habitat occupied by Belding’s ground squirrels within our study area. For context, global temperatures are likely to rise by 1.3°C – 5.7°C by the end of the 21st century and by 1.1°C – 14.1°C by 2300 (66% confidence intervals for range of emission scenarios, Rogelj et al. 2012).

Weather station data indicate that mean annual temperature in the Sierra Nevada has risen by 1.08°C since the beginning of the 20th century (data aggregated by California Climate Tracker [dri.edu/monitor/cal-mon/], Abatzoglou et al. 2009, linear regression, $p < 0.000000001$). Applying this temperature differential to our nested model of Belding’s ground squirrel occupancy resulted in a historical area of occupancy in our study area 89% greater than under current conditions or a 47% decline in occupancy since the beginning of the 20th century.

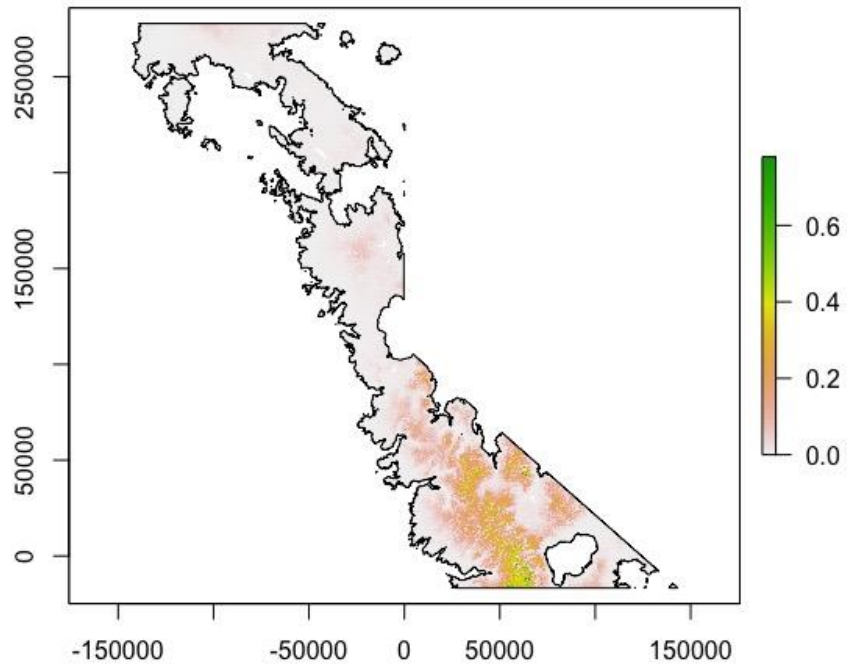


Fig 18. Modeled current probability of Belding's ground squirrel occupancy within 50-m study plots as predicted by our nested model of meadow habitat and Belding's ground squirrel occupancy within meadow habitat.

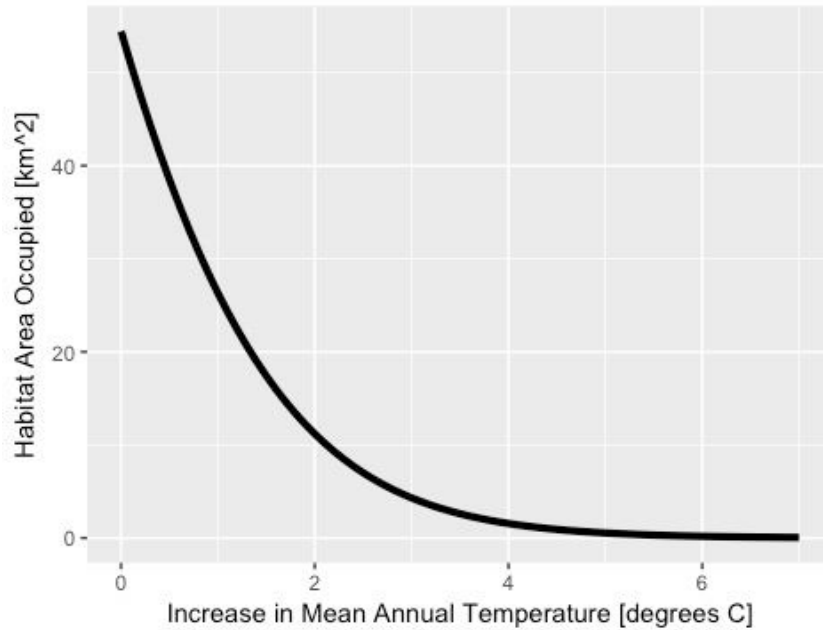


Fig 19. Modeled decline in meadow habitat area occupied by Belding’s ground squirrels within our northern Sierra Nevada study area as a function of increase in mean annual temperature. Modeled decline is based on our nested models of Belding’s ground squirrel occupancy and meadow habitat occurrence. We caution that our model is representative of Belding’s ground squirrel occupancy with meadow habitat only and that Belding’s ground squirrels also use sagebrush habitat.

Probability of Belding’s ground squirrel occupancy was significantly higher when the adjacent Wildlife Habitat Relationship (WHR) type was sagebrush ($p < 0.05$). The qualitative relationship is robust to accounting for various combinations of other explanatory variables.

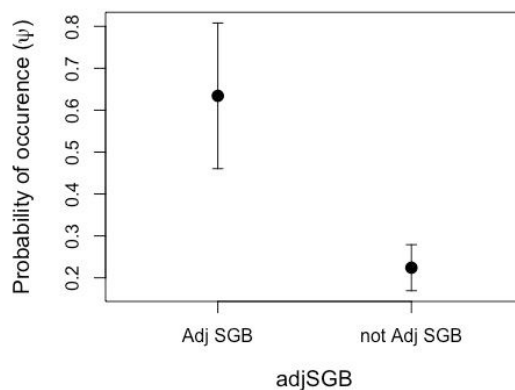


Fig 20. Probability of Belding’s ground squirrel occupancy as a function of whether there was sagebrush habitat adjacent to meadow surveys. Whiskers depict standard error from the mean. Shown is occurrence probability derived from the model with adjacent WHR type as the sole explanatory variable.

Power to Detect Future Decline

The primary purpose of an occupancy monitoring program is to be able to detect changes in occupancy. We calculate our power to detect a 50% decline in Belding's ground squirrel occupancy throughout our study region, given our sample size of 67 sites and the no-covariate model. Our sample of 67 sites yields a 48% probability that a 50% decline in occupancy would be detected by a resurvey of these sites. This is generally considered an inadequate ability to detect change in occupancy. Given the present sample stratification, we would need to sample about 190 sites (about 120 additional sites) to achieve a 90% probability of detecting a 50% decline in occupancy. We could achieve the same power to detect decline in occupancy with fewer additional surveys required if we judiciously shift our sample stratification to de-emphasize surveys in the two warmest strata.

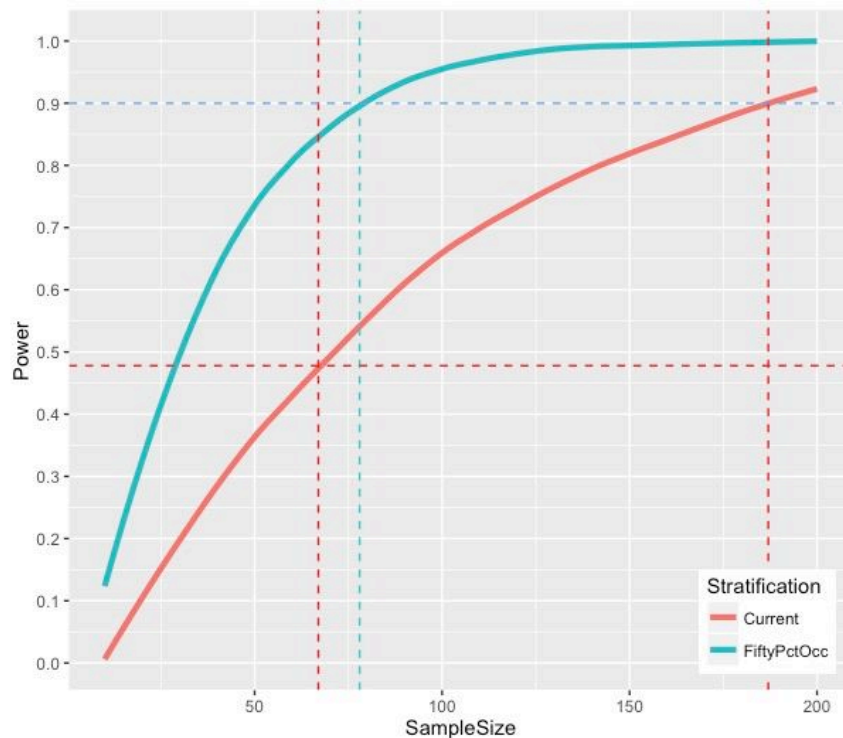


Fig 21. Power to detect a 50% decline in *U. beldingi* occupancy as a function of sample size and proportion of sites occupied ($\alpha = 0.05$). The current sample stratification results in a 27% rate of site occupancy and a relatively low power to detect changes in abundance (red lines). A sample stratification that results in a higher proportion of sites occupied (i.e. higher proportion of surveys in lower-temperature, higher-elevation sites) achieves higher power for the same sample size. To achieve 90% power to detect a 50% decline in occupancy we could either survey an additional 120 sites following our current site stratification, or we could achieve the same power with far fewer additional surveys by shifting our stratification to de-emphasize surveys at the warmest and lowest-elevation sites. Teal line shows power to detect decline from a stratification that results in 50% rate of current site occupancy. Power was calculated by running 10,000 simulations for each sample size.

Management Opportunities

Belding's ground squirrels thrive in and around healthy subalpine meadows, so further efforts at restoring meadows – particularly at appropriately cool elevations near areas supporting big sagebrush (i.e., notably east-side meadows), as shown by our report – should benefit the species. Healthy meadow hydrology is likely to be important to Belding's ground squirrels not just because ground water supports plants on which they feed, but also because ground water availability affects the animal's ability to thermoregulate via evaporative cooling (Hudson and Deavers 1973). Thus meadow restoration may improve the species' capacity to cope with warming temperatures. Land managers should pay attention to restoring locations accessible to existing populations, and to maintaining dispersal linkages between meadows.

Whitebark Pine

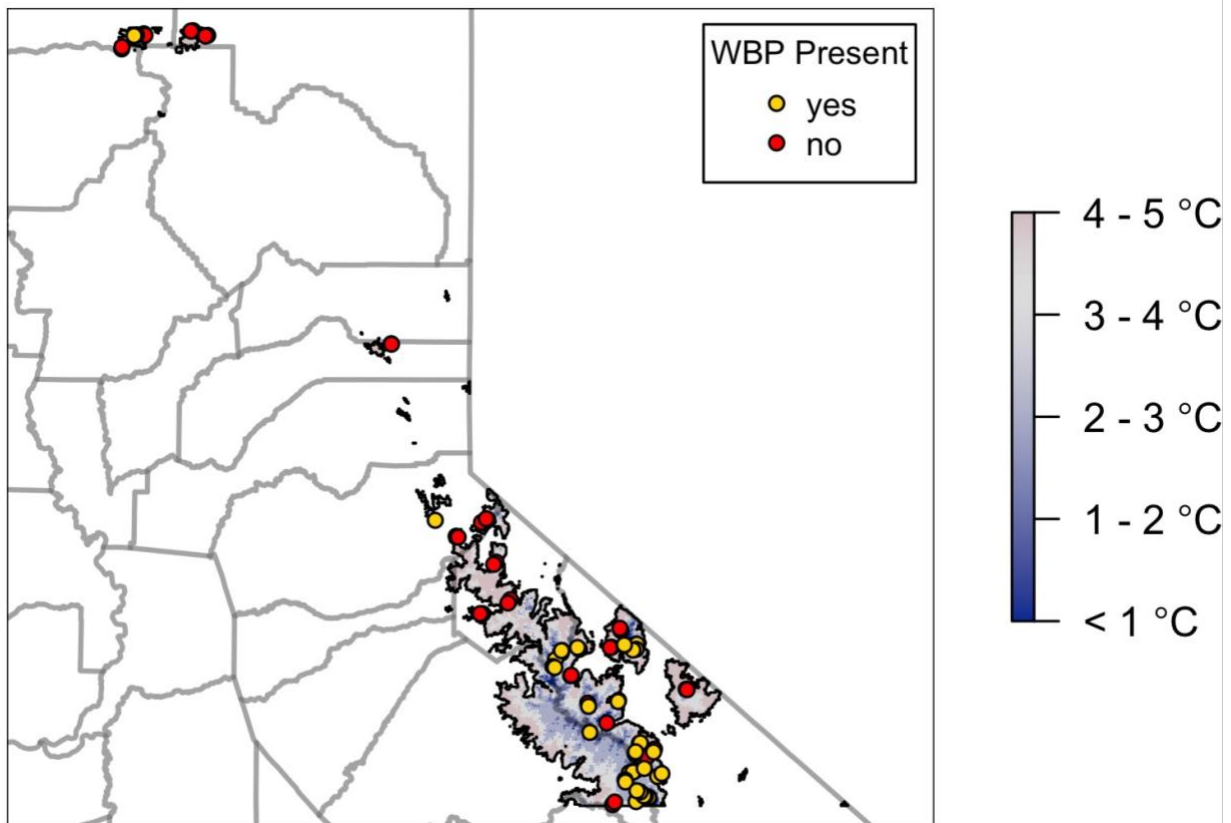


Fig 22. Location of conifer plots surveyed for whitebark pine ($n = 80$) from 2015-2016 for the CDFW High Elevation Species and Natural Communities Project. Background is colored by mean annual temperature strata. Study area (black) for whitebark pine was truncated to areas with $\text{MAT} \leq 5^\circ\text{C}$ due to the paucity of historical whitebark pine occurrence in areas with higher temperatures. State and county boundaries are grey.

Whitebark pine is listed as globally endangered by the IUCN and as “warranted but precluded” by the US Fish and Wildlife Service. Whitebark pine communities serve as important habitat - providing vital food and shelter and supporting prey populations (Tomback et al. 2001) – for numerous animals, including the following California bird and mammal species of greatest conservation need (Shuford and Gardali 2008, Osborn and Spencer 2013) and climate-change-vulnerable species (Siegel et al. 2014, Gardali et. al. 2012, Osborn and Spencer 2013): alpine chipmunk, lodgepole chipmunk, Belding’s ground squirrel, porcupine, Sierra Nevada snowshoe hare, Sierra Nevada red fox, American marten, Cooper’s hawk, northern goshawk, prairie falcon, American peregrine falcon, golden eagle, gray-crowned rosy-finch, red crossbill, and pine grosbeak. Additionally, whitebark pine is one of our most important species establishing tree-line – that severely climate-limited boundary above which trees cannot survive – and serves as an ecosystem engineer species (holding and modifying soils, modifying moisture, temperature, and wind microclimates) and a keystone species upon which other subalpine species depend, thereby facilitating tree-line and subalpine community response to climate change and promoting biodiversity (Tomback 2009).

Whitebark pine surveys were conducted at study plots (50-m radius) with at least one mature coniferous tree, as judged from aerial imagery and visual inspection in the field. Surveys for white bark pine were limited to areas with mean annual temperature $\leq 5^{\circ}\text{C}$. Whitebark pines were detected at 53% (42 of 80) of plots surveyed.

Clark's nutcracker were detected in 28 whitebark pine study plots. Yellow-bellied marmot were detected in two whitebark pine plots. Belding's ground squirrel were detected in eight whitebark pine plots. Golden-mantled ground squirrel were detected in one whitebark pine plot. American pika were detected in eight whitebark pine plots.

Model Selection

We combined all possible uncorrelated (Spearman's $R < 0.8$) first and second-order combinations of candidate predictors to generate 26 candidate models of whitebark pine occurrence, with up to 3 predictor variables per model. Given the focal species and our relatively small 50-m radius search area we assumed detection probability was one and we used logistic regression to model occurrence probability. Candidate predictors of occurrence included mean annual temperature (MAT), mean annual temperature (MAP), mean annual snow pack depth (PCK), and percent rock cover within the 50-m radius study plot. The top performing model received 0.122 overall AIC model weight and outperformed the next best performing model by a difference in AIC scores of .009.

Table 5. Model selection table for top-performing models of whitebark pine occurrence. Shown are thirteen models with $\Delta\text{AIC} < 10$ and the null model.

Model Formulas	ΔAIC	Cum.Wt
~ UnderstoryCovrPctROCK + MAT	0.000	0.122
~ MAT	0.009	0.244
~ MAT + I(MAT ²)	0.426	0.343
~ UnderstoryCovrPctROCK + MAT + I(MAT ²)	0.747	0.427
~ MAP + UnderstoryCovrPctROCK + MAT	0.811	0.508
~ PCK + UnderstoryCovrPctROCK + MAT	1.050	0.580
~ MAP + MAT	1.131	0.650
~ MAP + MAT + I(MAP ²)	1.251	0.715
~ PCK + MAT	1.348	0.777
~ MAP + MAT + I(MAT ²)	1.370	0.839
~ PCK + MAT + I(PCK ²)	1.452	0.898
~ PCK + MAT + I(MAT ²)	1.615	0.953
~ UnderstoryCovrPctROCK + MAT + I(UnderstoryCovrPctROCK ²)	1.894	1.000
Null Model: ~ 1	56.977	NA

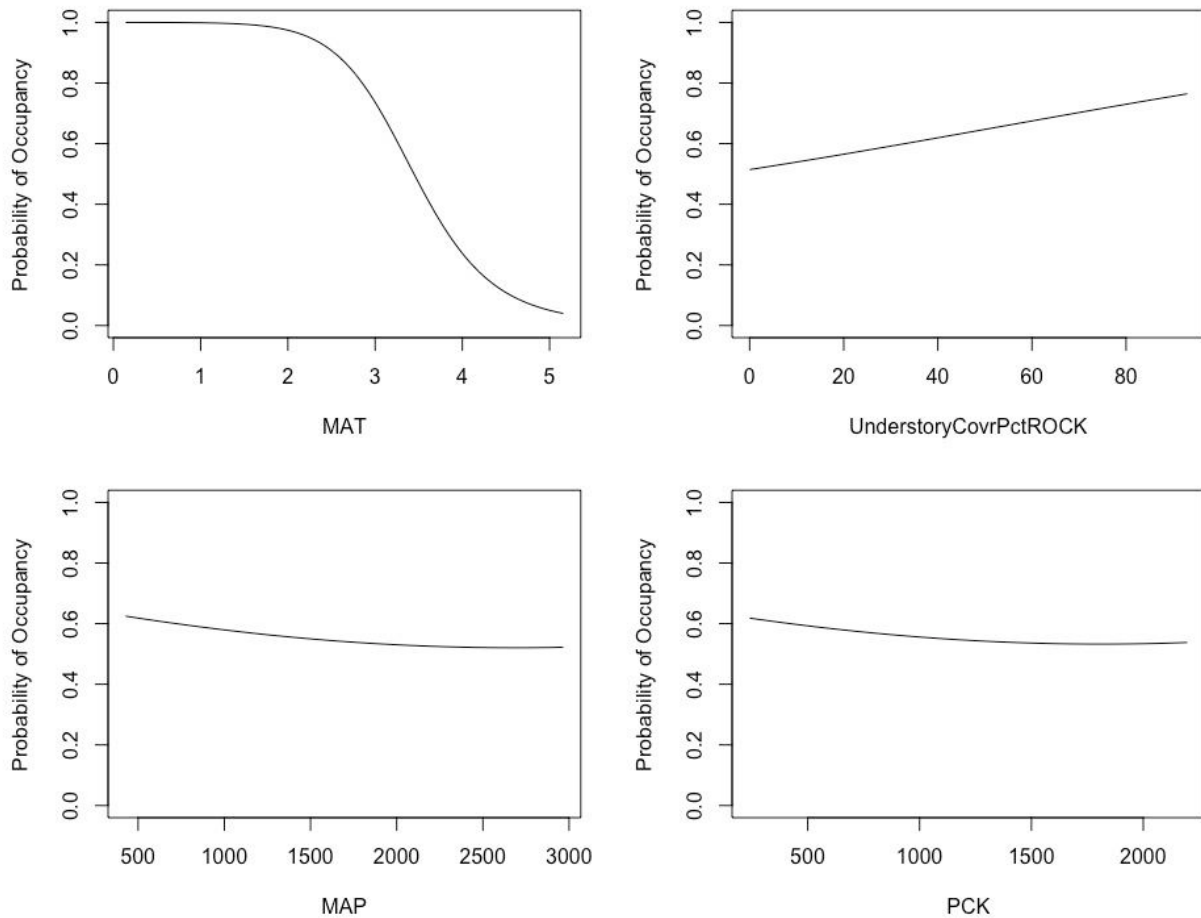


Fig 23. Marginal response curves for probability of current whitebark pine occurrence as a function of predictor variables and the ensemble model composed of the top thirteen performing models ($\Delta AIC < 10$, cumulative model weight = 1.00; variable importance: MAT = 1.00, UnderstoryCovrPctROCK = 0.41, MAP = 0.28, PCK = 0.25). All marginal responses depict probability of occupancy when other predictor variables are held at their mean value.

Projected Occupancy and Distribution

We modeled probability of conifer occurrence across the study area. The model was parameterized using maxent and 3,977 study plots where presence of conifers within a 50-m radius was assessed using aerial imagery (2,635 plots with conifers). Predictor variables included climate (mean annual temperature, mean annual snowpack, mean annual precipitation; 270-m resolution), topography (slope, aspect [i.e. “northness”], vector ruggedness measure [vrm] with a 630-m focal area, and three topographic position indices [tpi] with respective focal areas of 90 m, 270 m, and 630 m; all based on 30-m resolution elevation data), and NLDC land cover category (30-m resolution). The resulting model had an AUC score of 0.64, as assessed against the training data. The resulting model indicated that probability of conifer occurrence is associated with moderate mean annual temperature and precipitation, neutral topographic position index, flat slope, and coniferous NLDC land cover class.

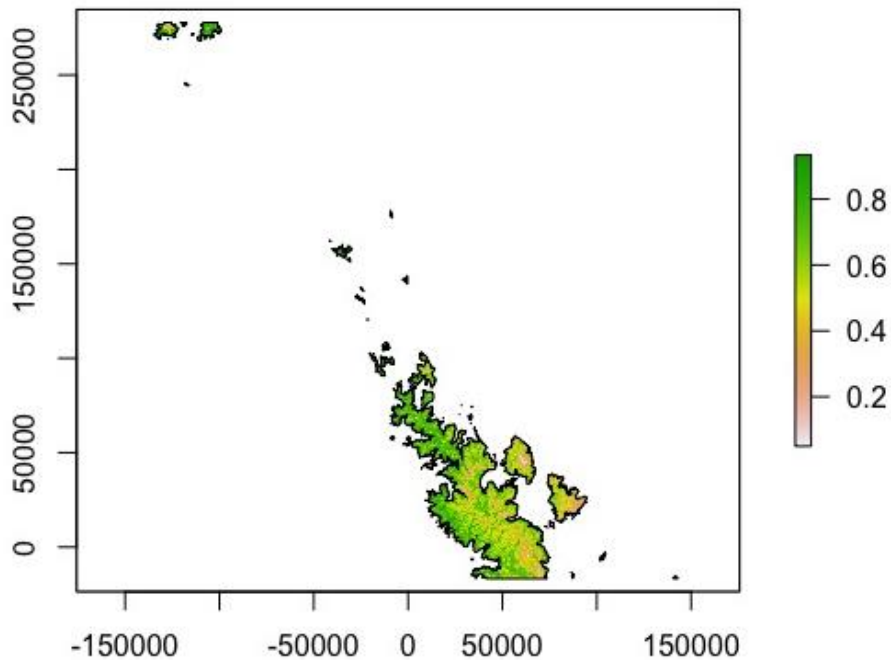


Fig 24. Modeled probability of conifer occurrence within 50-m radius study plots across the study area.

We combined our model of conifer occurrence with our model of whitebark pine occupancy within plots with conifers to produce a nested model of whitebark pine occupancy across the study area. The resulting nested model predicted that 97.0 km² of habitat within our study area is currently occupied by whitebark pine. A 2°C increase in mean annual temperature is projected to result in an 86.4% decline in the area of habitat occupied by whitebark pine within our study area. A 4°C increase in mean annual temperature is projected to result in a 99.6% decline in the area of habitat occupied by whitebark pine within our study area. A 6°C increase in temperature is projected to result in a 100.0% decline in the area of habitat occupied by whitebark pine within our study area. For context, global temperatures are likely to rise by 1.3°C – 5.7°C by the end of the 21st century and by 1.1°C – 14.1°C by 2300 (66% confidence intervals for range of emission scenarios, Rogelj et al. 2012). We urge caution in interpreting these projections as whitebark pine are long-lived trees and ecological processes governing climatic niches may take time to unfold.

Weather station data indicate that mean annual temperature in the Sierra Nevada has risen by 1.08°C since the beginning of the 20th century (data aggregated by California Climate Tracker [dri.edu/monitor/cal-mon/], Abatzoglou et al. 2009, linear regression, $p < 0.000000001$). Applying this temperature differential to our nested model of whitebark pine occurrence resulted in a historical area of occurrence in our study area 99% greater than under current conditions or a 50% decline in occurrence since the beginning of the 20th century. We urge caution in interpreting these projections as whitebark pine are long-lived trees and ecological processes governing climatic niches may take time to unfold.

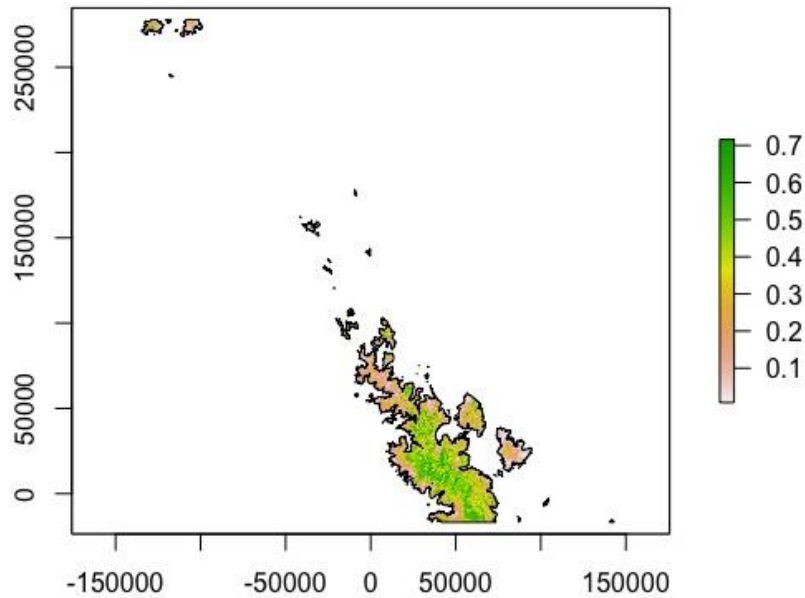


Fig 25. Modeled current probability of whitebark pine occupancy within 50-m study plots as predicted by our nested models of conifer presence and whitebark pine occupancy within plots that contain conifers.

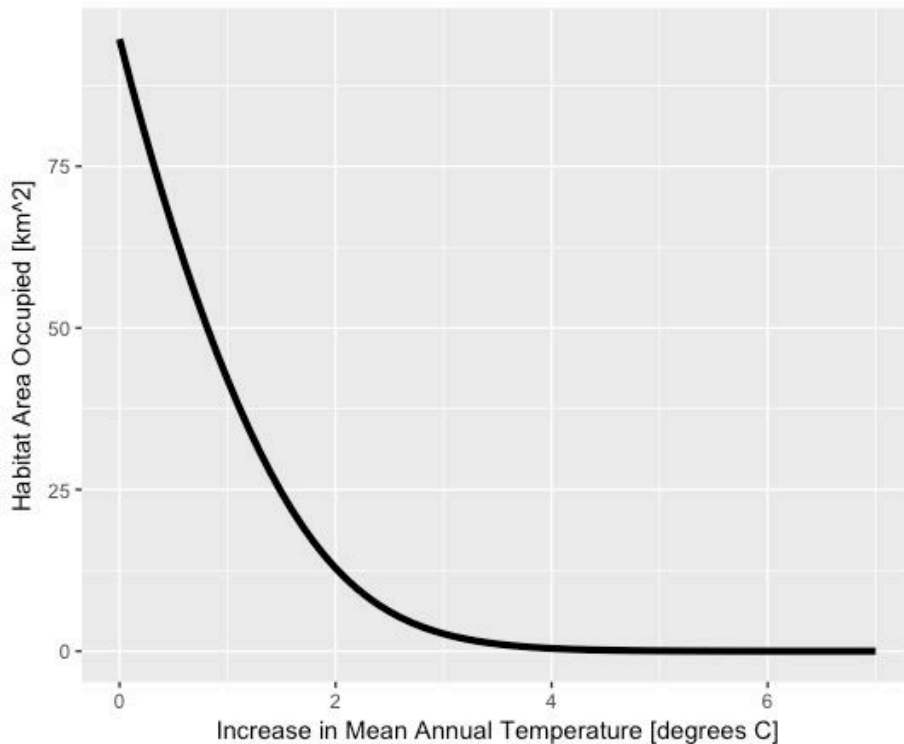


Fig 26. Modeled decline in area occupied by whitebark pine within our northern Sierra Nevada study area as a function of increase in mean annual temperature. Modeled decline is based on nested models of whitebark pine occupancy within plots that contain at least one conifer and conifers occurrence within study plots.

Power to Detect Future Decline

The primary purpose of an occupancy monitoring programs is to be able to detect changes in occupancy. We calculate our power to detect a 50% decline in whitebark occurrence throughout our study region, given our sample size of 80 sites and the no-covariate model. Our sample of 80 sites yielded a 94% probability that a 50% decline in occupancy would be detected by a resurvey of these sites. This is generally considered an adequate ability to detect change in occupancy over time. Additional surveys would provide increased statistical confidence.

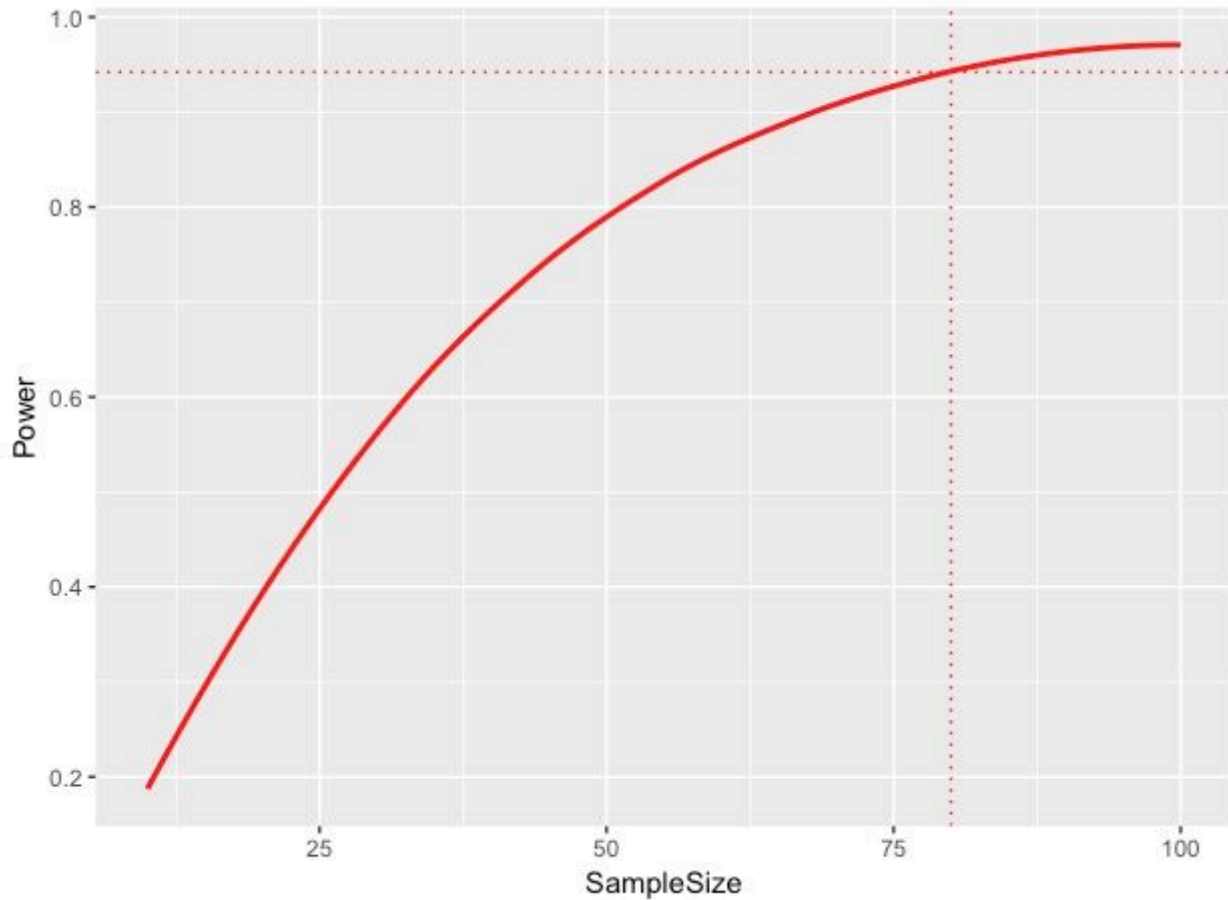


Fig 27. Power to detect a 50% decline in *P. albicaulis* occurrence as a function of sample size and observed probability of sites occurrence for the current stratification ($\alpha = 0.05$, $\psi = 0.54$). With our current sample size of 80 sites surveyed our power to detect a 50% decline in occurrence in a future resurvey is 94%. Power was calculated by running 10,000 simulations for each sample size.

Pests and Disease

Pests and disease related mortality have contributed to widespread whitebark pine diebacks in the eastern portion of the species range, but have not previously appeared to be a significant cause of mortality within our northern Sierra Nevada study region. At each whitebark pine study plot, we conducted timed surveys (20 person-minute) for evidence for pests and disease. Definitive evidence of mountain pine beetle infestation was found on whitebark pine trees at up to 3150 m elevation (Figs 28 & 29). We did not detect definitive evidence of white pine blister rust within our study area.

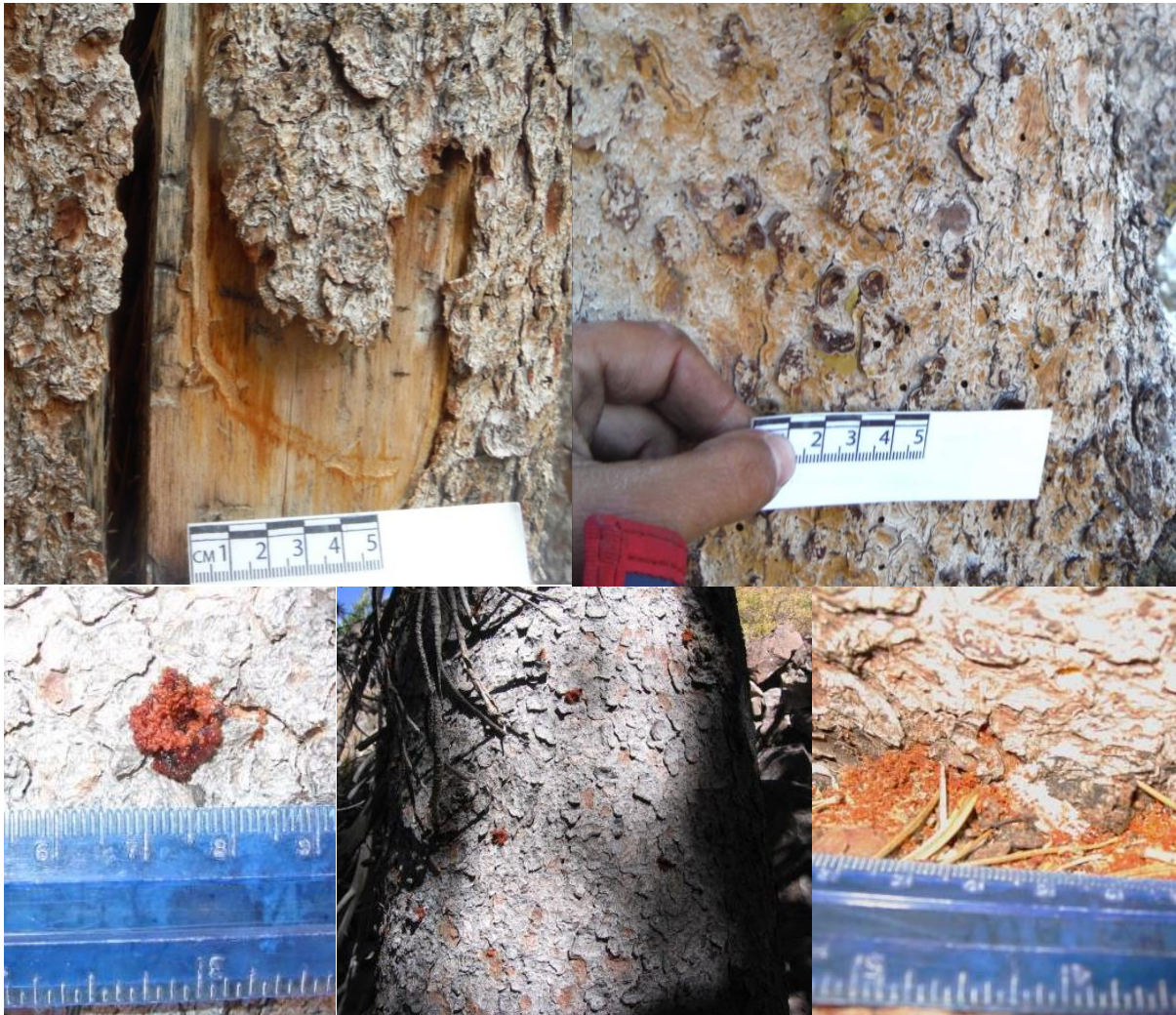


Fig 28. Types mountain pine beetle evidence observed on whitebark pine trees in our study area: Top row: j-hook gallery, exit holes. Bottom row: pitch tubes (two photos), wood dust at base of tree from boring. Not shown: stem stress or death.

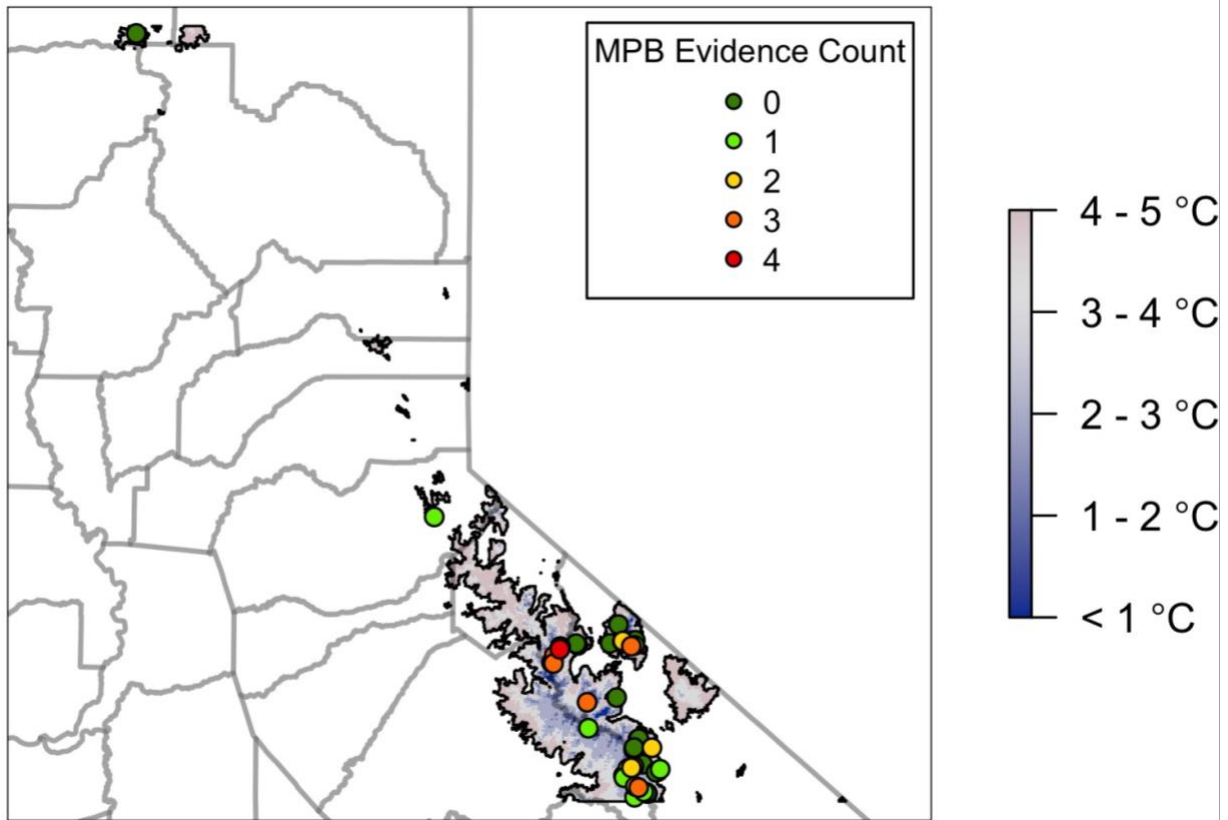


Fig 29. Number of types of mountain pine beetle evidence detected on whitebark pine trees within 50-m study plots. Types of evidence include: (1) pitch tubes or exit holes, (2) stem stress or death, (3) j-hook galleries, and (4) wood dust at base of tree or on bark below holes.

Historical Resurveys

We revisited and confirmed current occupancy within 1 km of 16 historical whitebark pine occurrence locations (Table 6). Current whitebark pine occupancy was detected within 1 km of all historical locations where resurveys were attempted.

Table 6. Resurveys of historical whitebark pine occurrence locations. We confirmed current occupancy of whitebark pine at or near all 16 historical occurrence locations where resurveys were attempted. Resurveys were conducted within 1 km of historical record location centroids.

Historical Year	Revisit Year	Revisit Latitude	Revisit Longitude	WBP Present
1931	2015	40.48046	-121.50439	yes
1930s, 1940s	2015	38.41417	-119.27725	yes
1930s, 1940s	2016	38.39358	-119.60482	yes
1863	2015	38.33627	-119.6344	yes
1968	2016	37.9836	-119.28751	yes
1930s, 1940s	2016	37.9452	-119.33102	yes
1929	2016	37.91073	-119.26788	yes
1971	2014	38.68214	-119.98991	yes
1939	2015	38.32901	-119.63521	yes
1944	2015	37.87742	-119.35513	yes
1940	2015	37.91182	-119.26481	yes
1929	2015	37.90839	-119.25883	yes
1961	2016	37.96191	-119.27063	yes
1968	2016	37.98277	-119.28446	yes
1968	2017	37.98370	-119.28450	yes
1933	2017	37.97620	-119.26930	yes

Management Opportunities

Our projections suggest whitebark pine may be the most susceptible of all three focal species to warming climate. Periodic monitoring of status and distribution are needed, and our randomized survey locations will be valuable for future comparison. Detailed resurvey of historical vegetation type mapping (VTM) and forest inventory and analysis (FIA) plots, to see how stand characteristics have changed over time, would allow assessment of how whitebark pine has already responded to climate change. We did not detect strong evidence of white pine blister rust on whitebark pine within our study area at present. We observed mountain pine beetle infestations and killing of whitebark pines, at elevations up to 3150 m elevation.

References

- Abatzoglou, J. T., K. T. Redmond, and L. M. Edwards. 2009. Classification of Regional Climate Variability in the State of California. *Journal of Applied Meteorology and Climatology* 48:1527–1541.
- California Department of Fish and Wildlife. 2013. Status review of the American pika (*Ochotona princeps*) in California. Sacramento, CA. Abatzoglou, J. T., K. T. Redmond, and L. M. Edwards. 2009. Classification of Regional Climate Variability in the State of California. *Journal of Applied Meteorology and Climatology* 48:1527–1541.
- Bever, E. A., J. L. Wilkening, D. E. McIvor, S. S. Weber, and P. F. Brussard. 2008. American Pikas (*Ochotona princeps*) in Northwestern Nevada: A Newly Discovered Population at a Low-elevation Site. *Western North American Naturalist* 68:8–14.

- Funk, W. C., J. K. McKay, P. A. Hohenlohe, and F. W. Allendorf. 2012. Harnessing genomics for delineating conservation units. *Trends Ecol Evol.* 27:489–496.
- Harris, J. A., R. J. Hobbs, E. S. Higgs, and J. Aronson. 2006. Ecological restoration and global climate change. *Restoration Ecology* 14:170–176.
- Hudson, J. W., and D. R. Deavers. 1973. Thermoregulation at high ambient temperatures of six species of ground squirrels (*Spermophilus* spp.) from different habitats. *Physiological Zoology* 46:95–109.
- Millar, C. I. 2011. Influence of Domestic Livestock Grazing on American Pika (*Ochotona princeps*) Haypiling behavior in the Eastern Sierra Nevada and Great Basin. *Western North American Naturalist* 71:425–430.
- Millar, C. I., K. Heckman, C. Swanston, K. Schmidt, R. D. Westfall, and D. L. Delany. 2014. Radiocarbon dating of American pika fecal pellets provides insights into population extirpations and climate refugia. *Ecological Applications* 24:1748–1768.
- Mills, L. S., and F. W. Allendorf. 1996. The one migrant per generation rule in conservation and management. *Conservation Biology* 10:1509–1518.
- Morelli, T. L., A. B. Smith, C. R. Kastely, I. Mastroserio, C. Moritz, and S. R. Beissinger. 2012. Anthropogenic refugia ameliorate the severe climate-related decline of a montane mammal along its trailing edge. *Proceedings of the Royal Society B* 279:4279–86.
- Rogelj, J., M. Meinshausen, and R. Knutti. 2012. Global warming under old and new scenarios using IPCC climate sensitivity range estimates. *Nature Climate Change* 2:248–253.
- Stewart, J. A. E., J. D. Perrine, L. B. Nichols, J. H. Thorne, C. I. Millar, K. E. Goehring, C. P. Massing, and D. H. Wright. 2015. Revisiting the past to foretell the future: summer temperature and habitat area predict pika extirpations in California. *Journal of Biogeography* 42:880–890.
- Stewart, J. A. E., and D. H. Wright. 2012. Assessing persistence of the American pika at historic localities in California's northern Sierra Nevada. *Wildlife Society Bulletin* 36:759–764.
- Stewart, J. A. E., D. H. Wright, and K. A. Heckman. (in press). Apparent Climate-Mediated Loss and Fragmentation of Core Habitat of the American Pika in the Northern Sierra Nevada, California, USA. *PLOS One*.
- Urban, M. C. 2015. Accelerating extinction risk from climate change. *Science* 348:571–573.