



Supporting Online Material for

Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA

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This PDF file includes:

Materials and Methods
Figs. S1 to S6
Tables S1 to S6
References

SUPPORTING ONLINE MATERIAL

Materials And Methods

A. Evidence for Climate Change in Yosemite Region.

Evidence from various independent sources point to an increase in average temperature at the state level (S1) and locally in the area of Yosemite National Park and the transect (S2).

Direct evidence of warming in the area was obtained from weather station data available from NCDC (<http://www.ncdc.noaa.gov/oa/ncdc.html>) and WRCC (<http://www.wrcc.dri.edu/>). Average monthly minimum temperature in Yosemite Valley has experienced a general increase during the last century whereas maximum temperature shows slight or no increase (Fig. S1). Linear regression of monthly averages of minimum temperature for the Yosemite Headquarters station indicate a general increase of 3.9 C in January and 5.3 C in July. A similar analysis done by Millar *et al.* (S2) but combining data from two other stations (Sacramento, CA and Mina, NV) revealed an average increase of 3.7 C when using annual averages of minimum temperature. Millar *et al.* (S2) also registered changes in vegetation growth recorded in tree rings and invasion of snowfield slopes that match tightly with changes in minimum temperature and also variability in precipitation. LaDochy *et al.* (S1) performed an analysis of climate trends at the state level using weather station data from 1950 – 2000 and found an average warming of 1.0 C during this period. Comparison of interpolated climate surfaces for California indicate considerable spatial variation in both the magnitude and direction of climate change (S3).

B. Sampling Design and Field Methods

We identified the field sites visited by the 1914–1920 Grinnell Survey from a combination of their original field notes and maps that are archived at the Museum of Vertebrate Zoology (MVZ; <http://mvz.berkeley.edu/Grinnell/>). Written descriptions enabled us to precisely relocate and resample many of the same sites. Field teams spent a minimum of 10 days at each site, and sampled each of the major habitats within a radius of approximately 1 km (chaparral, woodland, forest, meadow, riparian, talus, etc.). Most sites were surveyed one time during the 3-year period, but several were revisited two or more times. All field notes, photographs, datasheets, and maps are archived in the Museum of Vertebrate Zoology.

During the Grinnell period, small mammals were detected by sight, or by capture in traps, or were taken by shotgun with light shot. Trapped specimens were generally caught with smaller museum special snap traps, larger rat traps, Macabee™ gopher traps, mole traps, or steel traps of various sizes. They did not use a standardized protocol for trapping. Rather, they assessed the potential species to be sampled and used the appropriate traps in suitable conditions. Grinnell *et al.* typically recorded what types of traps were used, for how many nights, and what species were caught on each night. Traplines were left out from 1-14 nights (mean for the west slope was 4.6 nights) and contained in average 24 mouse/rat traps (Table S1). For occupancy analyses we only

include captures from mouse and rat traps with recorded effort; captures based on specialized trapping, such as gopher, mole, steel and tree traps, were excluded. Many specimens of more common species were discarded, but are recorded as such in the field notes. Most animals that were kept were preserved as study skin plus skull, but some were preserved as complete skeletons or in formaldehyde.

For the resampling effort, it was not feasible to establish a standardized trapping design for small mammals (e.g., grid or parallel lines of traps set at uniform distance intervals with a common bait) given the diversity of habitats at each site, the differences in major habitats across the elevational transect, and the range in food habits of focal taxa. Rather, we standardized trap effort (number of traps and nights trapped) for each habitat. Each mammal live trap and pitfall trap line at a site was “run” for a minimum of 4 consecutive days/nights. We used primarily Sherman live traps, supplemented with Tomahawk live traps, with a minimum of 40 traps (40 Sherman live traps, sometimes supplemented with 10 Tomahawk live traps) per trapline per night for the four consecutive nights. Traps were placed in “likely” spots within each habitat (e.g., grass tunnels of *Microtus*). Pocket gophers were trapped using commercial Macabee™ gopher traps. Pitfall traps were used for shrews. Two meandering lines, each comprising of 25 32-oz. plastic cups, were placed in the ground at approximately 10 m intervals using a 10.2 cm soil auger. These were run during the same trapping interval. The diversity of traps and methods employed and habitats visited ensured that the full range of target taxa was sampled. For all our analyses we only include captures from Sherman, Tomahawk, and pitfall cups in order to maintain consistency with historical trapping methods.

Captured animals were identified, sexed, and weighed, with reproductive data noted for most individuals. All trap lines or stations were georeferenced by hand-held GPS units, using the WGS-84 datum. Data are archived in fieldnotes for all individuals encountered, including those released as well as preserved. Voucher specimens of selected small mammals (rodents and shrews) were taken in accordance with permission granted by the National Park Service and Yosemite National Park. Specimens were archived in the collections of the Museum of Vertebrate Zoology, as were those collected during the original Grinnell-era surveys. Data for all specimens are available via the Museum’s website (<http://mvz.berkeley.edu>) under accession numbers 13817 (2003), 13948 (2004), 14091 (2005), and 14191 (2006).

C. Data Set Construction

The trapping effort and elevational range of sampling was similar between the Grinnell and contemporary periods. A total of 311 traplines where trapping effort could be quantified were identified in Grinnell’s time and 308 in the resurvey. For both periods, traplines were aggregated into sampling sites if they were within 2 km and 100 m elevation to reduce spatial autocorrelation (Table S1). The higher level of aggregation in the Grinnell period reflects our generally conservative approach to grouping traplines and greater uncertainty in the exact location and elevation of traplines (mean point-radius error of georeference for historical traplines was 323 ± 425.9 m). Accordingly, there was a larger number of both traplines (mean

4.8 vs 2.3) and traps (mean 111 vs 85) per site for the Grinnell period versus the re-survey. However, the mean number of trap-nights per site was similar; 4.1 for Grinnell survey and 3.3 for the re-survey. Most, but not all, sites were geographically matched between the Grinnell and re-survey periods.

Following aggregation, on the western slope of the transect there were 54 sites with traplines in Grinnell's time and 121 sites in the contemporary resurvey where trapping effort could be quantified, spanning elevational ranges of 57–3287 masl in the original survey and 48–3278 masl in the re-survey (Table S1). On the eastern slope there were 9 sites during Grinnell's time and 12 in the resurvey, spanning elevational ranges of 1981–2804 masl and 2155–3094 masl, respectively.

D. Estimation of the Probability of Detection, False Absence and Occupancy

We focus here on developing and comparing the elevational profiles of species occupancy in order to maximize use of available data. In reporting the past and present elevational ranges, we include additional observations and specimens for which effort was not quantifiable (e.g., specimens shot in Grinnell surveys or observational data in both periods). However, statistical analyses of detectability and occupancy across elevation are based solely on the species and sites (as enumerated above) for which trap effort and nightly detection records were quantified.

Although the overall survey methodology was similar between periods, differences in trap types and effort per site could confound interpretation of absences and, thus, overall comparisons. To control for these effects, we estimated detectability for each period and species from the temporal pattern of presence or “no-presence” records across sites, and incorporated any between-period difference in detectability into our analyses of changes in elevational range limits and profiles of occupancy probability (ψ). Given prior evidence for distinct elevational distributions of small mammals on the east versus west sides of the Sierra crest (S4), we used only the west slope records to estimate parameters. The analyses of detectability and ψ employed the likelihood framework and AIC model-averaging methods (S5) described in MacKenzie et al. (S6) and implemented in Program MARK version 5.1 (S7).

To estimate the probability of detection per trap night (p), we constructed 32 competing models with the following independent variables: era (Grinnell or resurvey), trend (linear decline in detections over sequential nights due to the collection of trapped individuals or to trap-shyness), trap effort (number of traps/100 and the \log_{10} of the number of traps), the interaction between era and trend, and the interactions between era and trap effort variables. We also built detection models with all additive combinations of these independent variables, as well as a constant model (.). The candidate model set is listed in Table S3.

We ran each p model with a ψ_{era} term and selected the best detection model with the lowest AIC score for each species. We used the parameter values to estimate the overall

probability of detection (S6) as $P^* = 1 - \prod_i (1 - p_i)$ for each site for each era based on its number of nights trapped and traps used. To estimate the probability of false absence (P_{fa}) across a set of sites in an elevational band where a species was detected in one era but not the other, we first calculated the probability of a false absent for each site $P_{fa(site)} = 1 - P_{(site)}^*$ and then obtained the product of these values across the set of sites in question as $P_{fa} = \prod_{site} (1 - P_{fa(site)})$.

To estimate elevational profiles of occupancy (ψ) for each era, we again constructed a set of competing likelihood models incorporating era (Grinnell or present), elevation represented as linear (elev) or quadratic (elev + elev²) functions, and interactions between era and elevation functions. This resulted in eight competing ψ models. Five models had between-era effects: era, era+elev, era*elev, era+elev+ elev², and era*(elev+ elev²). Three models had no era effects: elev, elev+elev², and constant (.). These are listed in Table S3 and illustrated in Figure S2.

The eight occupancy models were each run with a set of 14 detection functions that included the best model for each species (Table S3). This resulted in a total of 112 models per species in the occupancy model set. Models were compared using AIC_c (corrected for small sample size) scores (S5). Occupancy profiles were estimated across the range of elevations sampled by model-averaging ψ at 100-m increments using the AIC weights (w) of the 112 models. Occupancy-elevation profiles for each species appear in Fig. S3. Finally, cumulative AIC weights were calculated for each occupancy model.

E. Estimation of Species Richness and Turnover

To estimate species richness and between-era turnover as a function of elevation, we calculated species richness for the total transect, Yosemite National Park alone, and each of the 5 lifezones proposed by Grinnell, for each time period using presence/absence data from all the mammals captured within these areas. The software EstimateS v. 8.0 was used to estimate species richness metrics from replicated sample-based incidence data and between-era turnover from similarity metrics (S8). This methodology allows controlling for different sampling efforts at each time period. We calculated five non-parametric estimators of total species richness that infer species not recorded: Incidence Coverage Estimator (ICE), Chao1, Chao2, Jack1, and Jack2 to estimate the asymptote of the species accumulation curve. Two similarity metrics that control for effort and correct for unobserved species were estimated using replicated presence/absence data, in practice, occurrence records across multiple sites within a lifezone, the Park, or the entire transect: “Chao-Sorensen” and “Chao-Jaccard” each estimate the probability of choosing two individuals, one from each of the two samples, which belong to a species shared between the samples (S9, S10). Following Wilson et al. (S11), we report the mean and standard error across the five non-parametric estimators of total richness and the two similarity indices (Table S4). Individual estimators follow the same trends and they are shown in Figure S4. To test the hypothesis of a change in species richness between the two time periods we employed a

repeated-measures one-way ANOVA with time as a factor and lifezones as the subjects on which repeated measures were taken.