Final Report for Period: 02/2011 - 01/2012
Submitted on: 07/20/2012
Principal Investigator: Moritz, Craig C.
Award ID: 0640859
Organization: U of Cal Berkeley
Submitted By:
Moritz, Craig - Principal Investigator
Title:
The Grinnell Project: Using a Unique Historical Record to Document Responses of Mammals and Birds to 100 Years of Climate Change

Project Participants

Senior Personnel

Name: Moritz, Craig
Worked for more than 160 Hours: Yes
Contribution to Project:
Oversight of entire project; guidance of sampling design, analyses and preparation of publications. Participation in field work

Name: Beissinger, Steven
Worked for more than 160 Hours: Yes
Contribution to Project:
Participation in project design and execution - especially statistical analyses using occupancy modelling; chair of dissertation committee for Morgan Tingley

Name: Cicero, Carla
Worked for more than 160 Hours: Yes
Contribution to Project:
Participation in field work for avian species' resurveys; oversight of MVZ database development to accommodate GRP data

Name: Conroy, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:
Participation and leading of field trips for mammal resurveys & curation of mammal specimens and associated data entry

Name: Patton, James
Worked for more than 160 Hours: Yes
Contribution to Project:
Field and laboratory work and supervision of Emily Rubidge; lead mammalogist on project

Name: Koo, Michelle
Worked for more than 160 Hours: Yes
Contribution to Project:
GIS data, database organization

Post-doc

Name: Perrine, John
Worked for more than 160 Hours: Yes
Contribution to Project:
Field and laboratory work; logistics manager and director of field work for Lassen transect; data mining and entry; postdoc direct funded by project until move to Cal Poly San Luis Obispo as Asst. Professor

Name: Rowe, Kevin

Worked for more than 160 Hours: Yes

Contribution to Project:

Field data collection, especially for Sth Sierra transect mammals, data analysis, publication preparation for Sierra-wide mammals

Name: Morelli, Toni Lyn

Worked for more than 160 Hours: Yes

Contribution to Project:

Field assistance (mammals, Southern Sierra; ground squirrel resurveys Sierra Nevada. Analysis of ground squirrel data and landscape genetic related to project.

Name: Bi, Ke

Worked for more than 160 Hours: Yes

Contribution to Project:

Development and application of population genomic methods applicable to historical skins and modern tissues; testing for changes on demography and associated selection on contracting vs stable species of chipmunks

Graduate Student

Name: Rubidge, Emily

Worked for more than 160 Hours: Yes

Contribution to Project:

Spatial modelling and genetic analyses of declining (Tamias alpinus) vs stable (T. speciosus) species of chipmunks across the Yosemite transect. NSERC funded postgrad with support for field and lab work from this NSF grant

Name: Tingley, Morgan

Worked for more than 160 Hours: Yes

Contribution to Project:

Field sampling across Lassenand Sth Sierra transects, lead for avian resurveys of study, development of occupancy methods for analyses of changes in species distributions

Name: Wommack, Beth

Worked for more than 160 Hours: Yes

Contribution to Project:

Field sampling and specimen preparation of bird samples, Lassen NP.

Name: Assis, Anna

Worked for more than 160 Hours: Yes

Contribution to Project:

Evolutionary morphometric analyses of phenotypic change in multiple species of chipmunks; graduate student at University of Sao Paulo, Brazil with independent fellowship from FAPESP

Undergraduate Student

Name: Setsuda, Rika

Worked for more than 160 Hours: Yes

Contribution to Project:

Field sampling, Lassen NP

Name: Shultz, Allison

Worked for more than 160 Hours: Yes

Contribution to Project:

Field sampling of aves, Lassen NP

Name: Lipps, Ashley

Worked for more than 160 Hours: Yes
Contribution to Project:
Field sampling and specimen preparation, Lassen NP

Name: Lovett, Katharine
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds)

Name: Najar, Nadje
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds)

Name: Castillo, Jessica
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds and mammals), molecular determination of species identification

Name: Hanna, Zachary
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds and mammals)

Name: Wu, Joanna
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds and mammals)

Name: Tiee, Madeline
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (mammals)

Name: Weinstein, Sara
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (mammals)

Name: Feo, Teresa
Worked for more than 160 Hours: Yes
Contribution to Project:
Field assistant (birds)

Name: Title, Pascal
Worked for more than 160 Hours: No
Contribution to Project:
georeferencing, field assistance - herps, Southern Sierra

Name: Park, Hannah
Worked for more than 160 Hours: No
Contribution to Project:
field assistance - mammals, Southern Sierra

Name: Wait, Daniel
Worked for more than 160 Hours: Yes
Contribution to Project:

field assistance - bird surveys, Southern Sierra; independent study on morphological variation in Calfornia Ground Squirrels

Name: Penalba, Joshua

Worked for more than 160 Hours: No

Contribution to Project:

field assistance - birds, Southern Sierra

Name: Takahashi, Maressa

Worked for more than 160 Hours: No

Contribution to Project:

field assistance - birds, Southern Sierra

Name: Phuong, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

comparative phylogeography of Sierran mammals, field assistance - mammals, Southern Sierra; 4th year Honours project on molecular systematics and species delimitation of California Ground Squirrel

Name: Eastman, Lindsey

Worked for more than 160 Hours: Yes

Contribution to Project:

morphological change in Sierran mammals; 4th year Honours project on genetic change in Belding's ground squirrel

Name: Lim, Marisa

Worked for more than 160 Hours: Yes

Contribution to Project:

comparative phylogeography of Sierran mammals, field assistance (mammals, Southern Sierra); 4th year Hons project on genetics of California Ground Squirrel

Name: Kastely, Christina

Worked for more than 160 Hours: Yes

Contribution to Project:

field assistance ground squirrel surveys Sierra Nevada; 4th year Honours project on variation in vocalisation of Belding's ground squirrel

Name: Mastroserio, Ilaria

Worked for more than 160 Hours: No

Contribution to Project:

field assistance ground squirrel surveys Sierra Nevada

Name: Chan, Jeni

Worked for more than 160 Hours: No

Contribution to Project:

field assistance ground squirrel surveys Sierra Nevada

Name: Keeler, Max

Worked for more than 160 Hours: No

Contribution to Project:

field assistance ground squirrel surveys Sierra Nevada

Technician, Programmer

Name: Rowe, Karen

Worked for more than 160 Hours: Yes

Contribution to Project:

Field and logistical support for south Sierra surveys; coordination of data mining and entry for small mammal resurveys; analyses of potential for resurveys of Great Basin and Mohave National Parks (via additional USDI-NPS grant)

Name: Smith, Adam

Worked for more than 160 Hours: Yes

Contribution to Project:

field assistance - mammals, Southern Sierra; spatial modelling of species distributions from past to present. Supported by grant from CA Energy Commission

Other Participant

Name: Bowie, Verna

Worked for more than 160 Hours: Yes

Contribution to Project:

Field site logistics and sampling, Lassen NP

Name: Ratcliff, Felix

Worked for more than 160 Hours: No

Contribution to Project:

Name: Varma, Anand

Worked for more than 160 Hours: No

Contribution to Project:

Photographer, doing photo history of project & specimens, Lassen NP

Name: Whittaker, Kellie

Worked for more than 160 Hours: Yes

Contribution to Project:

Field sampling of amphibians, Lassen NP

Name: Wilcox, Jeff

Worked for more than 160 Hours: No

Contribution to Project:

Field sampling, Lassen NP

Name: Winters, Jessica

Worked for more than 160 Hours: No

Contribution to Project:

Field sampling, Lassen NP

Name: Chiao, Cindy

Worked for more than 160 Hours: No

Contribution to Project:

Field sampling, Lassen NP

Name: Trapaga, Ann

Worked for more than 160 Hours: No

Contribution to Project:

field assistance - birds and mammals, Southern Sierra

Research Experience for Undergraduates

Organizational Partners

San Diego Natural History Museum

Discussions are underway for SDNHM to expand the resurvey of Joseph Grinnell's California fauna surveys in extreme southern California.

University of Sao Paulo

Participation by Prof. G. Marroig and his student, Anna Paula Assis, in morphometric analyses of chipmunks in relation to environmental change

Other Collaborators or Contacts

Felisa Smith - University of New Mexico - regarding collaborative sampling of mammals at Grinnell sites in Death Valley, CA

Phil Duffy, LBL and Bill Collins, LNL - regarding climate modeling and analysis - both historic and future

Phil Unitt and Scott Tremor - San Diego Natural History Museum - collaborative sampling along the San Jacinto transect

Eric Rickart and Rebecca Rowe - Utah Museum of Natural History - collaborative sampling within the Great Basin

Les Chow - NPS (Sequoia-Kings Canyon) - facilitation of field work in Yosemite NP, field work assistance

Jim Thorne - University of California, Davis - collaboration with climate change modeling and plants, digitization of the Weislander vegetation maps

Connie Millar - USFS - collaborative work on climate change and plants, pika surveying

Miriam Zeldich - Museum of Paleontology, University of Michigan - collaborative project on morphological change in alpine chipmunks

The project has four additional post-docs supported by additional funding sources who are contributing to the Grinnell Project

1. Toni Lyn, NSF Postdoctoral Fellowship in Biology, Using Landscape Genetics to Understand the Effect of Environmental Change on California Mammals

2. Pete Epanchin, California Energy Commission (PIER). Assessing Long-term Dynamics of Bird Distributions in Relation to Climate Change: From Grinnell to Present. (Steve Beissinger PI with Craig Moritz Co-PI)

3. Adam Smith, California Energy Commission (PIER). Testing Methods for Predicting Species' Responses to 20th Century Climate Change in California. (PI Craig Moritz and Co-PI Steve Beissinger).

4. Maria Jo?o Ferreira dos Santos, California Energy Commission (PIER)

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Throughout the project, we gave high priority to training students, especially undergraduates from the diverse student body at UC Berkeley. Thus the total personnel trained to date includes 5 MVZ staff (1 paid by this grant, 3 females), 3 post-doctoral researchers (2 paid; 1 female), 4 graduate students (1 paid (Morgan Tingley), 3 funded from other sources), 23 undergraduate students (13 paid, 11 volunteer; 17 females, 7 minority), and 11 non-student volunteers (6 females; 2 minority). We have continued the use of specimens for educational purposes, including a course on museum and curatorial methods for undergraduates, volunteers and under-represented groups in the sciences (including the Berkeley Biology Scholars Program), and multiple graduate and undergraduate research projects, not funded by this grant. Based on results from the project,
Steve Beissinger (PI) organized and led a graduate seminar entitled 'Species' Response to Climate Change' that attracted 12 graduate students, 3 postdocs, and 4 faculty members. Similarly Moritz lead a sophomore seminar (20 students) on the same topic and gave a guest lecture in a new course on Global Change Biology. Of course, we routinely highlight our research, including the GRP, in all of our teaching, including course on Introductory Biology (Moritz), Conservation Biology (Beissinger), Molecular Ecology (Moritz) and Evolution (Moritz).

Outreach Activities:

Throughout the course of the project, all faculty, postdocs and graduate students have presented invited talks on this research through public lectures and presentations at conferences. Public lectures include Bohemian Grove, California Academy of Science, the Tanner Lecture at the Museum of Brigham Young University and Oakland Museum of California, and we also gave many talks to conservation managers; e.g. the Sierra Nevada Alliance, California Department of Fish and Game, USDI Desert Managers Workshop, California Department of Fish and Game, California Energy Commission (PIER), California Partners in Flight/PRBO, National Audubon Society, Sierra Foothills chapter, etc. Conference talks include Society for Conservation Biology (symposium), Ecological Society of America (multiple), NAS Sackler Symposium, American Society of Mammalogists, Society for the Study of Evolution. Invited seminars are too numerous to list, but averages about 10 per year and a wide range of institutions from ivy league universities to community colleges. There has also been intensive interest from the media throughout the project and we have accommodated as much of this as possible. Prominent media includes NPR, ABC news, Wired magazine, New York Times, LA Times, SF Chronicle and the Sacramento Bee , and the High Country News. Finally, we were funded by several western National Parks to compile species records and associated media from our historical records and to undertake planning for resurveys of the Great Basin and Mohave parks (Joshua Tree, Mohave NP, Death Valley, Lake Mead, Great Basin). The MVZ has rich holdings for these sites from the 1st half of the 20th C (http://mvz.berkeley.edu/Grinnell/GBMojave/index.html) and, given extreme warming since then, and consistent predictions of more to come, resurveys of these parks should have high priority.

Journal Publications

Parra, J.L. and W. B. Monahan, "Variability in 20th century climate change reconstructions and its consequences for predicting geographic responses of California mammals", Global Change Biology, p. 2215, vol. 14, (2008). Published, 10.1111/gcb.2008.14.issue-10

Moritz, C; Patton, JL; Conroy, CJ; Parra, JL; White, GC; Beissinger, SR, "Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA", SCIENCE, p. 261, vol. 322, (2008). Published, 10.1126/science.116342

Tingley, M.W., W.B. Monahan, S.R. Beissinger, and C. Moritz, "Birds track their Grinnellian niche through a century of climate change", Proceedings of the National Academy of Science, p. 19637, vol. 106, (2009). Published, 10.1073/pnas.0901562106

Tingley, M.W. and S. R. Beissinger, "Detecting range shifts from historical species occurrences: new perspectives on old data", Trends in Ecology and Evolution, p. 625, vol. 24, (2009). Published, DOI: 10.1016/j.tree.2009.05.009

Rubidge E.M., Monahan W.B., Parra J.L., Cameron S.E. & Brashares J.S., "The role of climate, habitat, and species co-occurrence as drivers of change in small mammal distributions over the past century.", Global Change Biology, p. 696, vol. 17, (2011). Published,

Yang, DS; Conroy, CJ; Moritz, C, "Contrasting responses of Peromyscus mice of Yosemite National Park to recent climate change", GLOBAL CHANGE BIOLOGY, p. 2559, vol. 17, (2011). Published, 10.1111/j.1365-2486.2011.02394.

Eastman, LM; Morelli, TL; Rowe, KC; Conroy, CJ; Moritz, C, "Size increase in high elevation ground squirrels over the last century", GLOBAL CHANGE BIOLOGY, p. 1499, vol. 18, (2012). Published, 10.1111/j.1365-2486.2012.02644.

Rubidge, EM; Patton, JL; Lim, M; Burton, AC; Brashares, JS; Moritz, C, "Climate-induced range contraction drives genetic erosion in an alpine mammal", NATURE CLIMATE CHANGE, p. 285, vol. 2, (2012). Published, 10.1038/NCLIMATE141

Tingley, M.W., M.S. Koo, C. Moritz, A.C. Rush and S.R. Bessinger, "The push and pull of climate change causes heterogenous shifts in avian elevational ranges", Global Change Biology, p. , vol. , (2012). Accepted,

Morelli, T.L., A. Smith, C. Kastely, I. Mastrocerio, C. Moritz and S. Beissinger, "Anthropogenic refugia ameliorate the severe climate-correlated decline of a montane mammal", Proceedings of the Royal Society of London, Seris B, p. , vol. , (2012). Accepted,

Bi, K., D. Vanderpool, S. Singhal, T. Lynderoth, C. Moritz, J.M. Good., "Transcriptome-based exon capture enables highly cost-effective comparative genomic data collection at moderate evolutionary scales", BMC Genomics, p. , vol. , (2012). Accepted,

Books or Other One-time Publications

Web/Internet Site

URL(s):
mvz.berkeley.edu/Grinnell/
Description:
This site provides background, and access to reports and specimen accessions for each major transect subjected to resurvey

Other Specific Products

Contributions

Contributions within Discipline:

Obtaining direct evidence for impacts of environmental change, including, but not limited to, climate change remains an important undertaking if we are to develop robust predictions for the future of biodiversity. This study has done just that ? using extensive, community-scale resurveys of mammalian and avian diversity relative to early 20th C records to document changes in species distributions and phenotypic and genetic diversity in the Sierra Nevada of California. As expected under the ?na?ve? warming-impact hypothesis, small mammals show predominantly upwards shifts, resulting in expansion of some formerly low elevation species and, of more concern, contractions of several high elevation species. For the latter, there are now additional studies underway to extend surveys and improve understanding of proximate causes of population extinctions. Comparisons of shifts in species ranges with shifts in their preferred habitat types explains some of the dynamics of (expanding) low elevation species, perhaps reflecting fire-related dynamics; however, coarse-scale habitat change does not explain contractions of high elevation species. Thus, there remains considerable heterogeneity in species? responses, even among closely related taxa, which we cannot as yet explain. This is especially clear in species rich taxa such as chipmunks and ground squirrels, where we are now undertaking detailed comparative ecological, genetic and phenotypic analyses. Birds, in general, do not support the na?ve warming hypothesis, as despite many range shifts, there are as many shifts down as up. However, by considering changes in precipitation and temperature at a local scale, and how these changes relate to the inferred species optimum, we were able to explain much of the heterogeneity. One hypothesis worthy of further consideration is that for birds at least, much of the range dynamics relates to changes in productivity, and indirect ecological process), rather than direct physiological limits. Thus, our analyses of resurvey data point to the need for a more sophisticated and multidimensional approach to understanding impacts of climate change.

Contributions to Other Disciplines:

Given that we now have extensive collections of specimens spanning the Sierra Nevada and a century, there is strong interest in how these can be exploited to answer diverse questions in evolution and population genomics. To take on example of the former, a student from University of Sao Paulo is using the collections of several species of chipmunk to develop and test methods in evolutionary morphometrics for detecting evolutionary response to climate change. On the population genomics front, we have developed a novel transcriptome-enabled method for screening thousands of exons from both decades old museum skins and modern tissues in species previously lacking genomic resources. In addition, we have developed powerful bioinformatics pipelines using probabilistic SNP-calling and which rigorously detects and filters out post-mortem DNA damage. The ability to harvest reliable genome-scale data from museum skins in a cost-effective way and for taxa previously lacking genomic resources greatly enhances the value of museum collections, including many now extinct or inaccessible populations and species

Contributions to Human Resource Development:

This project has contributed to the training and professional development of graduate and undergraduate students, including students of demographic groups currently under-represented in the sciences. For details, see section on Training & Development.

Contributions to Resources for Research and Education:

A major goal of the Grinnell Resurvey Project is to build a new benchmark dataset of distributions of small mammals and birds across the Sierra Nevada, including, for small mammals, comprehensive collections of specimens of non-threatened taxa. This goal has been met, and the specimens accessioned in the MVZ as a generally available resource. As important as the specimens themselves is the associated tissues and field-notes, also accessioned in the MVZ. All data pertaining to these specimens is publically available on the MVZ web site (see accession numbers under ?Activities?. The avian resurvey data is also entered (as observations) in the MVZ database and this, along with the associated Access databases will be released publically once remaining publications from the respective graduate students are accepted.
Additional funds were obtained from NPS to provide park-specific data on historical species occurences and related images and field notes. The first phase of this is complete (see http://mvz.berkeley.edu/Grinnell/). Much more can be done to develop this for public education, but this will require separate funding. In a separate activity, an NSF-RCN is focused on how the ARCTOS-hosted data on museum specimens etc. can be used to support undergraduate education, and the GRP resources now available would be ideal for this.

Contributions Beyond Science and Engineering:

History & Philosophy of Science.- The concept behind the Grinnell Project has stimulated a group of historians of science from US Davis (Jim Grisemer) and UC Berkeley (C. Carson) to embark on a formal analysis of the philosophy and operations of the MVZ in its early stages, and of the contributions of Grinnell and colleagues to the development of ecological, conservation and ecological science. To date, 2 postdocs, 1 graduate student and 3 undergraduates have been engaged in assessing the content of the MVZ archives and field notes in relation to these goals and proposals to support this was funded by NSF (SES 0749738). A postdoc working with Grisemer, Ayalet Shavit, has prepared two publications

based on her observations of the workings of the Grinnell Project group. Postdoc Mary Sullivan, employed through the collaborative NSF grant has made extensive use of the GRP in the course of her research on how research and education are conducted in the MVZ
Public policy.- Our results are already helping to inform the public policy debate on the relationship between climate change and the conservation of biological diversity, especially on public lands such as National Parks, National Forests, and State Parks. For example, the initial results of the Yosemite Resurvey were featured in a widely promulgated report on impacts of climate change in National Parks from the National Parks Conservation Association and have been influential in development of the California Climate Adaptation Strategy.

Conference Proceedings

Categories for which nothing is reported:

Any Book
Any Product
Any Conference

FINDINGS:

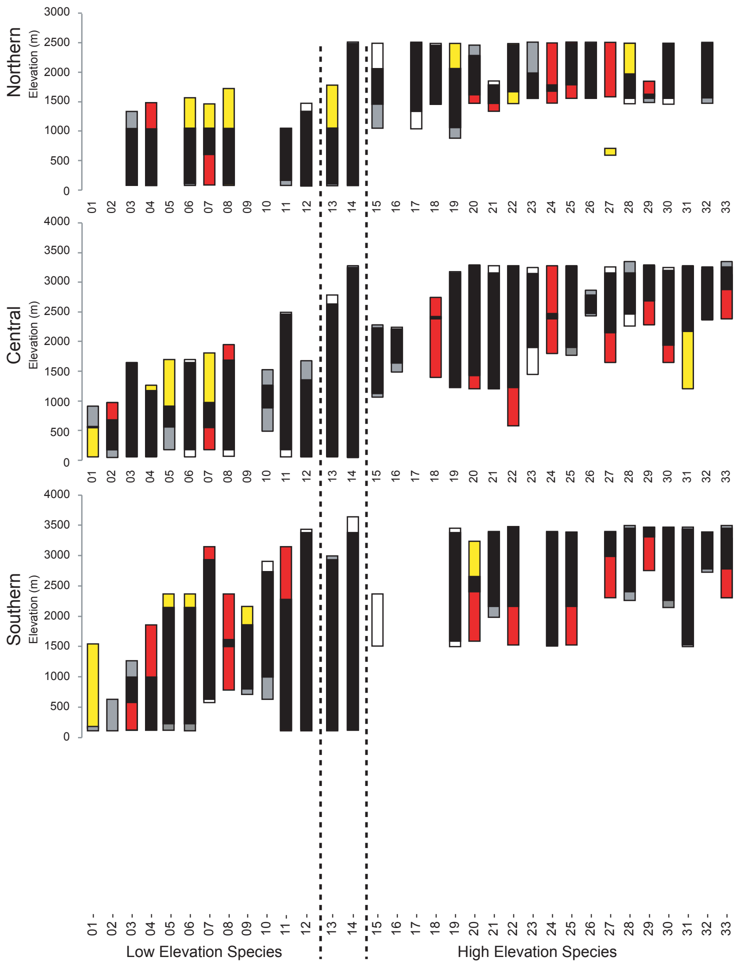
Analytical methods:

Comparison of historical vs present distributions of species are prone to error because of differences in sampling design and methods and errors in location and/or species identity. In the case of the Grinnell Resurvey Project, the latter are minimized as we have access to the extensive field notes and historical maps (location and sampling effort) and the specimens themselves (species identity). Relative to other studies of range change over time, our prime innovation was to employ occupancy modeling in order to control statistically for differences in sampling effort and detectability of species within and across time periods (Tingley & Beissinger 2009). This is especially important to estimate the probability of non-detection when a species is in fact present (i.e. false absences, pfa). In addition, we modeled species probability of occupancy as a function of elevation and time period, with appropriate tranforms and covariates. Thus in all our analyses of changes in species elevational range and for spatial modeling in a presence/absence framework, we restrict inference of "absence" to cases where pfa is low. Extensive simulations of this occupancy-based strategy (Tingley et al. in press) demonstrate that it is appropriately conservative (type I error < 2%) while maintaining reasonable overall power (>80%).

Changes in elevational ranges.

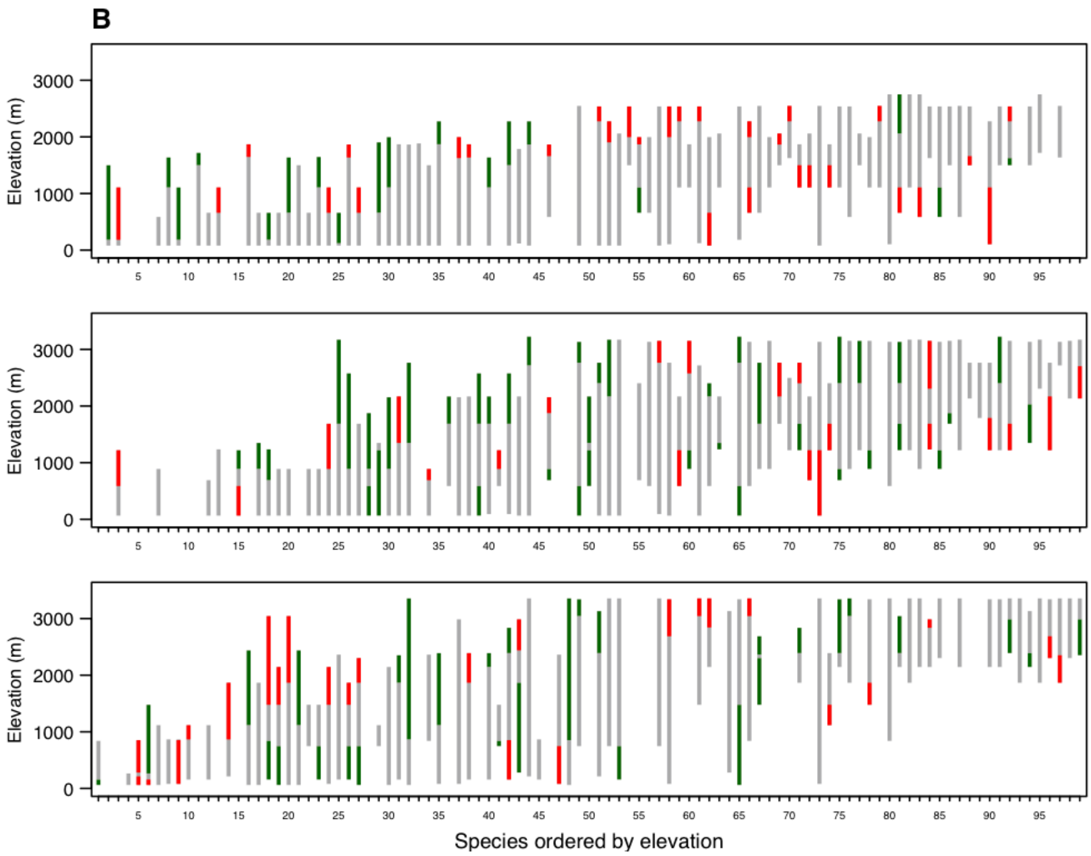
For small mammals, we obtained statistically robust data across the three major transects for 33 species. Across the central (Yosemite) transect, approximately half the species shifted one or both elevation limits upwards, with an average shift of ~500m over the 90 year period between surveys (Moritz et al. 2008). This translated into mostly upwards expansions of a few (3) formerly low elevation species and range contractions of several (n = 8) high elevation species. The remaining species were mostly static, with just 2 species showing downwards expansions. This overall trend towards upwards shifts and contractions of high elevation species is associated with a regional increase of minimum temperatures of ~ 3C, consistent with the typical lapse rate of temperature with elevation. That said, not all shifts are necessarily associated with temperature increase; several low elevation taxa that expanded upwards were thought to be responding to fire-related vegetation dynamics. The most remarkable upwards colonization was a ~1km colonization by the eastern subspecies of the pinon mouse, *Peromyscus truei* from its typical pinon-juniper habitat on the east slope, across the Sierra crest to high elevation conifer forests (Yang et al. 2011). In a subsequent study, postdoc Maria Santos tested whether range dynamics of the Yosemite small mammals could be explained in general by vegetation change. By matching historical (1930's Weislander) and current vegetation maps, and using the California Wildlife Habitat Relations models of habitat preferences, she demonstrated that expansions of low-mid elevation species were tracking vegetation change, whereas contracting species were not (Santos et al, in review). Thus, climate change remains the strongest hypothesis for the latter. Despite these individual range fluctuations, Yosemite National Park did not change in species richness, attesting to the robustness of biodiversity in protected areas that span elevational gradients (Moritz et al. 2008).

Expansion of the small mammal resurveys across the three major transects, spanning Lassen, Yosemite and Sequoia-Kings regions, revealed considerable heterogeneity of species' responses across regions (Rowe et al., in prep.; see Figure). Consistent with initial results for Yosemite, the dominant signature is upwards shifts of range limits, especially of lower limits ("lagging edges") of high elevation species, leading to range contraction of these taxa. By contrast, low elevation species were more heterogeneous in response. These trends occur across the three transects, for which the most consistent change in climate is increased minimum temperatures and mean annual precipitation. Historical climate variables for the upper and lower limits of species ranges suggest that changes in minimum temperatures are more reliable predictors of the direction of species' elevational shifts than mean annual temperature, maximum temperature or mean annual precipitation. Of high elevation species, nocturnal, short-lived and obligate hibernators were most likely to show upwards range contractions. Species that contracted at their lower limits consistently across at least two transects included the alpine chipmunk (*T. alpinus*), Belding's ground squirrel (*U. beldingii*), Pacific jumping mouse (*Z. princeps*), long-tailed vole (*M. longicaudus*), bushy-tailed woodrat (*N. cinerea*), and the water shrew (*S. palustris*). Other high elevation taxa showed more heterogeneous responses across transects, perhaps due to region-specific changes in seral dynamics, or interacting effects of local changes in temperature and precipitation. Further targeted surveys of the Belding's ground squirrel across its Sierra Nevada range by postdoc Toni Lyn Morelli revealed that it has disappeared from 45% of its historical locations and colonized none. Again, these precipitous declines across the SW of the species range are primarily at lower warmer elevations, with the intriguing exception of anthropogenically "improved" habitats (irrigated areas, campgrounds etc.) (Morelli et al. in press).



One of the most remarkable features of these data is the heterogeneity of responses among closely related (ie congeneric) species. This applies to common taxa such as chipmunks, ground squirrels, shrews, voles and field mice. In general, we gained some insight into this from statistical analyses of potentially predictive life history and ecological traits, but much remains to be explained. In response, we have initiated a series of comparative studies of chipmunk species with differing response, especially *T. alpinus* (consistent and strong contractions) vs. *T. speciosus*, another high elevation species but which has remained relatively stable in elevational range. PhD student Emily Rubidge undertook comparative distribution modeling, including both climate variables and the presence of congeners, and found that climate alone best explained the contraction of *T. alpinus*, but that the presence of congeners (competition?) improved models for *T. speciosus* (Rubidge et al. 2010). Other studies in progress are comparing changes in diet and habitat use (e.g. using stable isotopes + field studies) and genetic/phenotypic comparisons (see below).

For birds, resurveys across the three Sierra regions employed variable-distance point counts, whereas the Grinnell period data were primarily daily accounts of area surveys and/or collected specimens. Though the original surveys were less quantitative, they still permit occupancy-based analyses of species presence/absence, against which the resurveys can be compared. Overall, across the 77 resurvey transects we obtained robust data for 99 species of which 53 were common to all three regions. Compared to the small mammals, changes in upper or lower elevation range limits of birds were frequent (83%) but less elevationally coherent; shifts downwards were as common as shift upwards (Tingley et al. in press; see Figure). The expectation of coherent upwards



shift reflect the naïve hypothesis that increasing temperate is the primary determinant of shift in elevational range. Yet, changes in both temperature and precipitation can affect range limits, either directly through physiological limits, or indirectly through habitat requirements or biotic interactions. The direction and magnitude of 20TH C changes in precipitation and temperature vary with elevation and latitude across the Sierra study region. When we considered local changes in both precipitation and temperature, the proportion of explained changes in range limits increased from 51% (temperature only) to 83%, reflecting the "push and pull" of climate change (Tingley et al. in press). As for small mammals, there is also considerable among-species variation in response to climate change. Avian Species were significantly more likely to shift elevational ranges than their ecological counterparts if they had small clutch sizes, defended all-purpose territories, and were year-round residents In principle, species are most likely to respond to changes in climate where the local effect is to move away from, rather than towards the optimum conditions (niche tracking). To test this hypothesis, we estimated the optimum conditions as the centroid of multivariate climate space occupied species-wide, and vectors of local climate change relative to this centroid (Tingley et al. 2009). Of the 53 species tested, 91% showed niche-tracking, consistent with our predictions. Intriguingly, lower elevation species responded more strongly on the precipitation axis, whereas higher elevation species responded primarily to temperature change. We hypothesise that this reflects changes in net primary productivity, which also is more constrained by precipitation at low elevation and temperature at high elevation, in which case range limits are primarily determined by indirect (ecological), than direct (physiological) effects. Further work could test this model through a combination a mechanistic models and incorporation of changes in NPP (or proxies thereof) in statistical models.

A further aim was to use the historical vs current distribution records to test performance of spatial distribution models when extrapolated over time, as it widely done for predicting impacts of future climate change. This depends on the veracity of the historical as well as present climate layers (ie the predictor variables), as we put considerable effort into evaluating different methods of extrapolation given sparse early 20th C weather records for the Sierra Nevada (Parra & Monahan 2008). Independently funded postdoc, Adam Smith, undertook this using the GRP small mammal data, developing SDMs using 6 widely employed methods and using species-wide occurrence (presence-only from museums) and evaluating the results against the GRP presence/absence data from the Sierra Nevada. An important innovation was to use the occupancy-derived estimates of detectability to reliably infer absences. In the events, these experiments, forecasting from historical observations/climate to the present, and vice versa, revealed relatively little difference among modeling methods, though with the widely used MaxENT model producing highly consistent results. However, there was considerable heterogeneity among species in model performance, and high accuracy (AUC) within a time period did not reliably predict accuracy across time periods (Smith et al., in prep.).

Change in phenotype and genetic diversity.

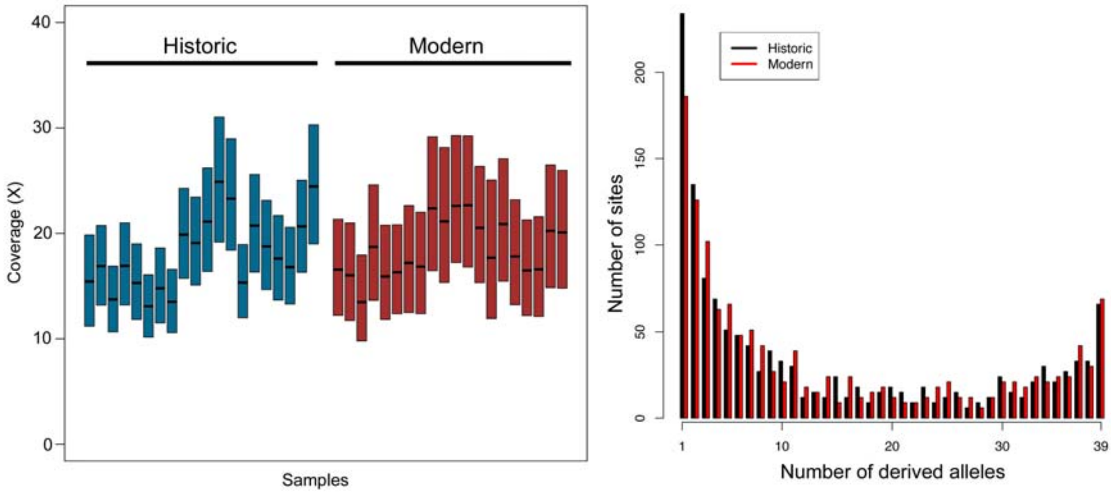
To gain more insight into proximate effects and causes of range changes, we have examined changes in phenotype and genetic diversity in contracting vs stable species of small mammals for which we have large series of specimens from both time periods.

Focusing on ground squirrels (GS), undergraduate Lindsey Eastman compared skull length (correlated with overall body size) and tooth-row length in two contracting species (Belding's and Golden-mantled GS) and one stable (Californian GS). Intriguingly, both contracting species showed significant increases in body size, even after controlling for difference in elevational range, whereas the Californian GS showed no change (Eastman et al. 2012). In contrast to skull length, often a plastic trait, there were no changes in tooth-row length. Preliminary comparative analyses of chipmunks indicate the same patter, with significant increases in skull length, especially the rostrum, in a contracting species (*T. alpinus*) and only minor shifts its relatively stable congener, *T. speciosus* (Assis & Patton, unpublished). Ongoing work, involving a graduate student (A.-P. Assis) and her faculty advisor (M. Garroig) from the University of Sao Paulo) is focused on applying evolutionary, quantitative genetic models to further understand these changes in phenotypes.

Genetic diversity.

Our initial study of changes in genetic diversity in relation to range changes have focused on comparison of the alpine (*T. alpinus*) and lodgepole (*T. speciosus*) chipmunks (Rubidge et al. 2012). In particular, we were interested to see whether the observed contraction and fragmentation of geographic range of the former within Yosemite National Park was accompanied by significant reduction and restructuring of genetic diversity. In accord with predictions, analyses of microsatellite diversity in population samples of historical skins vs modern samples of the two species demonstrated a significant reduction of overall diversity and increased among-population differentiation in *T. alpinus* and no change in *T. speciosus*. Thus, the observed range changes in the former reflect local population extinction and range fragmentation, rather than wholesale movement of populations. This study highlights the demographic challenges faced by contracting montane species, especially if historical trends are continued with future climate change.

While analyses using a small set of microsatellite loci are informative about recent demography, they do not inform adaptive responses or potential loss of evolutionary capacity. In response we have explored use of next-gen sequencing to undertake genomic analyses of museum skins vs modern samples. In our first foray, we demonstrated that small samples from museum skins can be used to generate extensive and accurate genomic data via Illumina sequencing (Rowe et al. 2011). To enable population genomics via sequence-reduction (exon capture), we then sequenced and assembled a transcriptome for *T. alpinus* (and *U. beldingi*) and, from this, developed an array-based exon capture system that enables highly efficient exome sequencing across all chipmunk species (Bi et al., in press). In further experiments (Bi et al., in prep.), we have applied this custom-capture array to population samples of early 20th C skins and shown equivalent or superior exome-scale sequencing efficiency to that from modern samples, and developed bioinformatics pipelines to detect and remove post-mortem DNA damage effects (ie. C-> T and G -> A, transitions). This sets the stage for population-genomic comparisons of contracting vs stable species (see Figure below), the ultimate goal of which is to identify genes or pathways under selection and thus direct phenotypic and ecological analyses of proximate causes of vulnerability to climate change. The new capacity for cost-effective "skinomics" also has the potential to dramatically increase the utility of well-curated collections of birds and mammals, such as that in the MVZ.



Data integration & sharing

Data generated from the Grinnell Resurvey Project has been gathered into a single publically-accessible webpage linked directly from the MVZ homepage (http://mvz.berkeley.edu/Grinnell/). This website includes a layperson description of the project and individual transects, links to annual reports, photo retakes, news coverage, personnel, and the specimen records, gathered into transect-based projects for both the resurveys (e.g., http://arctos.database.museum/project/grinnell-resurvey-project-yosemite-transect) and the historical surveys (http://arctos.database.museum/project/historic-grinnell-survey-yosemite-transect). These projects contain dynamically updated information on specimen numbers, other projects that have used the specimens, publications, and associated media and field

From October 2010 – September 2011, additional funding was received from the National Park Service to complete a planning project for resurvey work within the Great Basin and Mojave Desert regions. Using the methods developed as part of this grant, the goals of the new project were to compile the existing records (including specimen records, historic photos, field notes, and additional data) for the birds, mammals, and herps of the region, develop climate-based species distribution models for these species, identify potential resurvey sites based on these records and predictions, and develop a proposal to seek extramural funding for on- the-ground resurveys. This grant also provided funding to develop an online web portal to provide data compiled as part of the NPS grant to relevant parties (e.g., http://arctos.database.museum/project/historic-grinnell-survey-death-valley-national-park). This portal provides dynamic queries for all specimens, metadata, and project reports generated as part of the NPS grant. We have also incorporated data collected as part of this NSF grant in this web portal, providing a central and real-time updating database for any interested parties, including parks staff, researchers and the general public.

RESEARCH AND EDUCATION ACTIVITIES:

ACTIVITIES

Goals

The core goals of this project – the Grinnell Resurvey Project (GRP) - are, through resurveys of early 20^{th} C MVZ collecting sites, to:

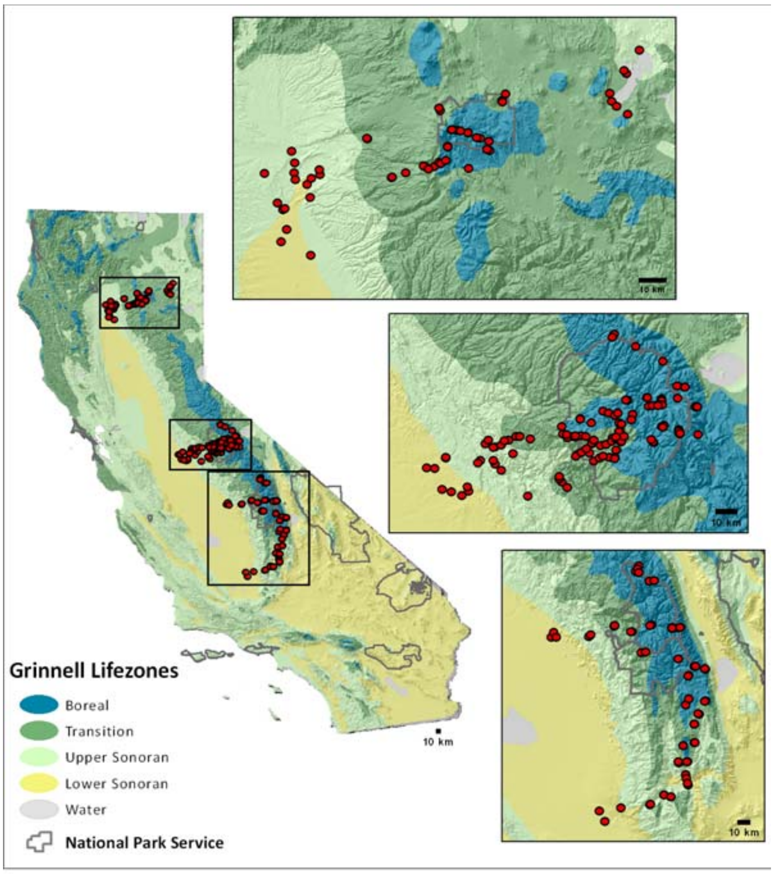
1. Document changes in the distribution of small mammals and birds across the steep elevational gradients of the Sierra Nevada in California

2. Understand causes of changes in elevational limits, and improve thereby prediction of future impacts, and

3. Provide another specimen- and data-rich baseline of faunal distributions against which predictions of impacts of further environmental change can be assessed.

Resurveys of small mammals and avifauna

We completed surveys of birds and small mammals along three elevation transects across the Sierra Nevada Mountains of California, from North to South: Lassen, Yosemite, and Southern Sierra regions. These surveys spanned over 5^{0} latitude (35.42^{0} to 40.73^{0}) and 4^{0} longitude (-118.12^{0} to -122.30^{0}), providing comprehensive voucher-backed surveys of birds and small mammals for four National Parks (Lassen Volcanic NP, Yosemite NP, Kings Canyon NP, Sequoia NP), eight National Forests (Lassen NF, Plumas NF, Tahoe NF, El Dorado NF, Stanislaus NF, Sierra NF, Inyo NF, and Sequoia NF) and numerous other state, federal and private land holdings. Small mammal surveys included 162 localities for 79,122 trap-nights and confirmed detection of 60 mammal



species. A total of 251 bird surveys were conducted at 84 localities with 46,855 observations of 223 bird species recorded.

In relation to goal (3), we made extensive collections of small mammals, with a total of 7766 specimens (including tissues and associated data) now accessioned in the MVZ with the following accession numbers:

Northern (Lassen) – 19 accessions (14183, 14330, 14331, 14339, 14345, 14824, 14152, 14177, 14190, 14202, 14329, 14335, 14336, 14341, 14346, 14382, 14383, 14384, 14388); 1982 tissues from 1989 specimens

Central (Yosemite) – 6 accessions (13908, 13957, 14258, 13817, 13948, 14091); 4432 tissues from 4666 specimens

Southern (Sequoia) – 14 accessions (14457, 14587, 14765, 14462, 14471, 14481, 14583, 14591, 14598, 14599, 14606, 14607, 14619, 14757); 1108 tissues from 1111 specimens.

These resurveys were designed on the basis of analyses and data-mining of specimen records and locality data/attributes from MVZ field notes. These data on location, habitat type, trapping method/effort and daily capture records were extracted from historical field notes and assembled into a custom Access database, which also includes corresponding resurvey data.

Analyses of observed changes in elevation

Despite the increasing number of studies using resurveys of historical collecting sites to document changes in species distributions, the analyses of such data remain rather ad hoc and often fail to control for inevitable differences in survey design, methods etc (Tingley & Beissinger 2009). We put considerable effort into developing and applying occupancy modeling to control for differences in survey methods/effort from historical to present and to estimate detectability, and thus probability of false absence. This included extensive simulations to evaluate type I and II error rates when assessing change in range limits from resurvey data (Tingley et al. in press).

Understanding observed changes in elevation

To evaluation the role of 20th C climate change in driving species' range fluctuations, we assembled available climate and vegetation layers from historic to present. These made use of an expert-interpolated climate database covering the relevant time periods (PRISM) and vegetation maps from the 1930s and present. For the first, we transformed the climate layers into Bioclim variables as typically used in distribution modeling. For the latter, our collaborator (J. Thorne, UC Davis) had previously digitized the early 20th C Weislander maps and developed a cross-walk (using California VTM classifications) to enable comparison with current vegetation. Using these, along with the observed range fluctuations, we then compared performance of alternative SDMs for predicting observed responses from the past to the present (Adam Smith) and testing whether observed vegetation change predicts responses of small mammals, via WHR classifications [Santos]. Our principle analyses evaluated whether temperature and/or precipitation change are major drivers of observed changes in elevation ranges (Tingley et al. in press; Rowe et al. in prep.]. In a further study of focal chipmunk species, we also tested whether climate +/or species interactions are the major determinants of range changes (Rubidge et al. 2009)

Analyses of phenotypic and genetic change

Given the presence of large series of specimens in the MVZ from early 20th C surveys and again 100 years later, we wanted to compare changes in phenotype and genetic diversity over time to contribute to understanding of proximate causes and effects of climate-driven changes in species' distributions. Phenotypes and genotypes compared for species of lizard (*Sceloporus occidentalis*) and small mammals (*Peromyscus* mice and *Tamias* chipmunks) across the Yosemite transect. Analyses of changes in skull dimensions were extended across all three major transects for contracting vs stable species of chipmunks (A.-P. Assis, in progress) and ground squirrels (Eastman et al. 2012). To assess genetic change accompanying range fluctuation, we are focusing on declining vs stable species of chipmunks, first using microsatellite analyses of historical skins vs modern specimens. To improve assessment of demographic change and, potentially to detect selection responses, we have also developed and tested cost-effective methods, employing next-generation sequencing, for exome-scale sequencing of museum skins [Rowe et al. 2011; Bi et al. in press, in prep.).

Data integration and sharing

Project has driven considerable background work on the MVZ DB and web sites to improve ability to integrate diverse data types and to package information on species records over time and of ancilliary data for various stakeholders, especially western National Parks. For the future, we see great potential to develop strong on-line education products using these digital assets.