RESEARCH AND EDUCATION ACTIVITIES:

**Goals**

Blah

Blah

Blah

**Resurveys of small mammals and avifauna**

Processes for capturing and analyzing historical data from field notes -> design of resurveys -> resurvey database. Also considerable effort on improving digital capture and sharing of associated images.

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 5O latitude (35.42O to 40.73O) and 4O longitude (-118.12O to -122.30O), 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.

KAREN: Numbers of specimens prepared with tissues – MVZ 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

**Analyses of observed changes in elevation**

Development of occupancy modeling to control for differences in survey methods/effort from historical to present and to estimate detectability, and thus probability of false absence. Incorporation of these into statistically robust estimates of range fluctuations, including simulations to evaluate performance [Tingley]

**Understanding observed changes in elevation**

– download and cleaning of historical and modern records; evaluation of available climate and vegetation layers from historic to present. Comparisons of alternative SDMs for predicting observed responses from the past to the present [Smith]. Testing of whether observed vegetation change predicts responses of small mammals, via WHR classifications [Santos]. Evaluation of temperature vs precipitation change as drivers of observed changes in elevation ranges [Tingley, Rowe]. Tests of whether climate +/or species interactions are related to range changes [Rubidge]

**Analyses of phenotypic and genetic change**

Given large series of specimens from early 20th C surveys and again 100 years later, wanted to compare changes in phenotype and genetic diversity over time to contribute to . Phenotypes and genotypes compared for species of lizard (Sceloporus occidentalis) and small mammals (Peromyscus and Tamias) across the Yosemite SN. Development of new methods, employing next-gen sequencing, for exome-scale sequencing of museum skins [Rowe et al.; bi et al.]. SN-wide analyses of morphometric change for contracting vs stable species of chipunks [Assis, USP] and ground squirrels [Eastman et al.]

**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.

**FINDINGS:**

**Analytical methods**:

Comparison of historical and present distribution 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 changes 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.**

[General – mostly upwards shifts, but considerable variability of response across taxa, species and SN transects. ]

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 shifting one or both elevation limits upwards, with an average shift of ~500m over the 90 year period between surveys. 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 remainder 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. [add Figure?]. 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.; Figure-Species range shifts bar graphs- aka Figure3). 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), water shrew (S. palustris), lodgepole chipmunk (T. speciosus). 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 review).

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 (Tamais) with differing response, especially Tamais 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.f 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). 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) [insert Figure?]. This sets the stage for population-genomic comparisons of contracting vs stable species, 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 [K&K]**

Web site etc.

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 notes.

Many of the projects and analyses listed above rely a number of GIS layers and accurate specimen informatics processed by Michelle Koo (staff). GIS and informatics work for this period included extensive GIS and specimen data acquisition, georeferencing and preparation. Several high resolution GIS data layers have been researched and acquired to overlay with re-survey sites to act as covariates in comparing change of species

distribution over time. These include the following: GloPEM-AVHRR (Global Production Efficiency Model, a model of net primary productivity based on AVHRR and other remote- sensed data); Landscan (Oak Ridge National Lab), high resolution global ambient population density dataset; MODIS-NDVI Vegetation Continuous Fields (percentage tree and percentage herbaceous cover); CalVeg 1977 historic vegetation types for California;

and CalVeg 2002 vegetation types for California. Specimen data acquisition included primary mammal species occurrence records from MVZ that have been validated with archival research and integrated with records from the MaNIS portal. These were spatially and statistically vetted to produce presence-data for 144 taxa. Preliminary work to acquire the species occurrence records for the bird samples are underway.

We also further processed high resolution (800 m) PRISM climate models to rasters of various aggregate and averaged climate variables for modeling and further analysis.

Among them are 19 bioclimatic variables and 6 comparative variables for averaged decadal

(1900 through 2007) and era (historic, 1910-1930; modern, 1970-2007) time spans.

Additional Activities

GBM Parks – edited by KMCR

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.

**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 4 MVZ staff (none paid by this grant, 2 females), 3 post-doctoral researchers (paid), 4 graduate students (1 paid (Morgan Tingley), 3 funded from other sources), 24 undergraduate students (13 paid, 11 volunteer; 17 females, 7 minority)

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.

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**Contributions within Discipline**:

Our findings will make a major contribution to current research in the ecological relationship between species distributions and climate. Our techniques and findings will provide a unique opportunity to empirically test the changes in species' distributions predicted by climate- envelope modeling, and in that context has attracted the interest of the California Energy Commission. Our specific approach is also serving as a model for several other research groups interested in conducting similar re-surveys of vertebrate diversity in California and

the western US. Utilizing similar data collection and analysis techniques will facilitate drawing comparisons among the conclusions from these studies, providing a deeper understanding of the larger-scale underlying processes

**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:**

Resources for research & education

YEAR 4 (2010)

Work is still in progress to install a web-based GIS server to enable collaborative networking of GIS tools for use by both personnel associated with the Grinnell Project directly and with off-site collaborators. In addition, web-based mapping of Grinnell Project results will help visualize project results and goals for the public. This work was not funded by NSF but was established by researchers associated with the Grinnell Project and will provide a critical component to testing model predictions addressed in the Grinnell Project research. We are considering various online portals and options for spatial data sharing to agencies, conservation organizations as well as public viewing that will ensure provenance and data integrity. This servert will include all GIS layers detailed under ?GIS and Informatics? activities.

Additional funds obtained from NPS will be used to develop an online web portal to provide data from NPS properties collected under this NSF grant. This portal will provide dynamic queries for all specimen and capture records, and metadata, providing a central and real-time updating database for any interested parties, including parks staff, researchers and the general public.

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, 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 have been prepared and submitted to 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.

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. A presentation of the initial results of this research to policy-makers and biologists from CA state agencies and NGOs at a forum on ?California Public Lands and Climate Change? attracted strong interest.