Project Title:

Determining Landscape Connectivity and Climate Change Refugia Across the Sierra Nevada

Proposal by:

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Scope & Budget:

Location: Sierra Nevada
Duration in months: 18
Requested Funding: $97,381.90
Leveraged Funding: $121,927.10

Briefly summarize the goals of the project, what products will result, and how the products support decision-making and conservation delivery for natural resource management within the CA LCC.

We propose to use species distribution modeling, population genetics, and geospatial analysis of historical vs. modern vertebrate populations to identify climate change refugia and population connectivity across the Sierra Nevada. We have already obtained distribution and occupancy data for 27 Sierra Nevada mammals through the Grinnell Resurvey Project and are proposing to analyze these data as well as to finish collecting and analyzing genetic data for Belding's and California ground squirrels to identify and test climate change refugia. We predict that climate change refugia will increase persistence and stability of populations and, as a result, maintain higher genetic diversity. Additionally, connected climate change refugia will maintain gene flow between populations and thus species viability. Our two-tiered chronological approach (historical to modern and modern to future) will allow managers to identify these critical factors and to assess the need to include connectivity and refugia in climate change adaptation strategies. Results will help Sierra Nevada land managers to allocate limited resources, aid future scenario assessment at landscape scales, and develop a performance measure for assessing resilience. We are working with the U.S. Forest Service (USFS), the National Park Service (NPS), and California Department of Fish and Game (CDFG) to design this study. U.S. Geological Survey and USFS will be collaborating on the analysis of the data. We will communicate our results directly to CA LCC members to aid in decisions from immediate, small-scale adaptation projects to region-wide changes in use, development, and planning of state and federal lands. We will also extend our results to USFS, NPS, and DFG staff, as well as present them at state and national conferences; we will develop an accessible and user-friendly webpage on cal-adapt.org; and we will publish at least two peer-reviewed journal articles on the results of this research.

For continuing 2010 CA LCC projects, describe the accomplishments and outcomes to date, why additional funds are needed, and what this proposal will add to the project.

NEW PROJECT

Identify which National LCC Performance Measure(s), if any, your project addresses.

1. A risk and vulnerability assessment developed or refined for priority species and habitats. 2. Inventory and monitoring protocols developed or refined to capture data on fish and wildlife populations and their habitats to detect changes resulting from climate change. 3. A population and habitat assessment developed or refined to predict changes in species populations and habitats. 4. A biological planning and conservation design project developed in response to climate change. 5. A management evaluation action evaluated for effectiveness in response to climate change and research activities conducted to address information needs in response to climate change. 6. A conservation genetic project to improve and enhance conservation design and delivery for fish and wildlife populations in response to climate change.

List Partners

United States Forest Service United States Geological Survey National Park Service California Department of Fish and Game

Briefly describe how the project team (main PIs) provides the range of experience, expertise, and organizational capacity needed to accomplish the project. List recent and current projects (names, time-periods, PI time commitments, and total budgets). Also attach 1 page CVs for the principle investigator and/or project leaders per below under additional information.

Principal Investigator Craig Moritz will oversee the project. He is the Director of the Museum of Vertebrate Zoology and has three decades of experience working at the interface of evolutionary and conservation biology. Of particular relevance to the present proposal, he has published extensively on applications of genetics to examine responses of populations and species to past climate change and habitat fragmentation and also on combined application of bioclimatic modeling and phylogeography. He conceived and has led the MVZ's Grinnell Resurvey Project, which is examining responses of small mammals and birds to the past century of environmental change in California and which provides the foundation for the current project. This entailed regular interaction and collaboration with biologists from the National Parks Service, National Forest Service and CA State Parks. The project will also benefit from the broader resources and expertise of the MVZ and associated Faculty, including the collections, the biodiversity informatics (including GIS) facility, and the evolutionary genetics lab. Current and recent projects: Project Title: Collaborative Research: After the Crash: Factors Allowing Host Persistence Following Outbreaks of a Highly Virulent Disease Source of Funding: National Science Foundation Total Award Amount: $183,678 Award Period: September 2007 – August 2012 Project Title: Track 2, GK-12: Exploring California Biodiversity Source of Funding: National Science Foundation Total Award Amount: $2,072,996 Award Period: March 2006 – February 2011 Project Title: The Grinnell Project: Using a Unique Historical Record to Document Responses of Mammals and Birds to 100 Years of Climate Change Source of Funding: National Science Foundation Total Award Amount: $570,304 Award Period: February 2007 – January 2011 Project Title: Testing spatial modeling methods using GRP data Source of Funding: CA-PIER Total Award Amount: $124,747 Award Period: September 2009 – March 2011 Project Title: California climate adaptation study Source of Funding: CA-PIER Total Award Amount: $135,660 Award Period: July 2010 – December 2011 Project Title: An Integrative Approach to Understanding Speciation in Salamanders of the Ensatina Eschscholtzii Complex Source of Funding: National Science Foundation Total Award Amount: $286,002 Award Period: February 2007 – January 2011 Project Title: Moorea Biocode Project Source of Funding: Gordon and Betty Moore Foundation Total Award Amount: $939,382 Award Period: January 2008 – September 2011 Project Title: Historical Climate Change and Prediction of Endemism in the Central Corridor of the Brazilian Atlantic Rainforest Source of Funding: National Science Foundation Total Award Amount: $586,016 Award Period: October 2008 – September 2011 Project Title: Shaping Evolutionary Biology in Berkeley's Museum of Vertebrate Zoology Source of Funding: National Science Foundation Total Award Amount: $332,841 Award Period: October 2008 – September 2011 Project Title: Cytonuclear Interactions in a Hybrid Parthenogenetic Gecko (Heteronotia binoei) Source of Funding: National Science Foundation Total Award Amount: $11,200 Award Period: November 2008 – October 2010 Project Title: Genome Dynamics in Parthenogenetic Geckos

of the Heteronotia Binoei Complex Source of Funding: National Science Foundation Total Award Amount: $12,000 Award Period: July 2008 – June 2010 Project Title: ModelEco: Integrated Software for Species Distribution Analysis and Modeling Source of Funding: UC Merced Total Award Amount: $20,836 Award Period: January 2008 – December 2009 Project team member Toni Lyn Morelli has expertise in population genetics, mammal trapping, geospatial analysis, and animal behavior. She is currently a National Science Foundation postdoctoral fellow, working with the Grinnell Resurvey Project team to understand how Belding's ground squirrels are responding to the last century of climate and land use change in California. She divides her time between analyzing occupancy and species distribution data, analyzing genetic data, and conducting ground squirrel surveys in the Sierra Nevada and throughout California. Current project: Using Landscape Genetics to Understand the Effect of Environmental Change on California Mammals, National Science Foundation postdoctoral fellowship, Supervisors: Craig Moritz and Steve Beissinger, Museum of Vertebrate Zoology, U.C. Berkeley, 100% time from January 2010-December 2011, $143,000 Recent projects: - Research Ecologist for the U.S. Forest Service and member of the Westwide Climate Initiative, which seeks to develop adaptation options for addressing climate change through science/management partnerships, 2009 - Molecular ecology of endangered lemurs in Madagascar, graduate research funded through National Science Foundation, Stony Brook University, 2003-2008 Project team member Maria J Santos has experience in analysis of wildlife responses to habitat and modeling at the landscape scale, fundamental for the assessment of connectivity at the landscape scale. In her postdoctoral research, she has been focusing on understanding the habitat requirements of the 27 mammal species included in this project and how these habitat requirements may or may not have changed over the last 80 years. She is familiar with the data set that we will be using in the project, and her a priori knowledge of species habitat use is an asset to the project success. Current projects: Identify Vulnerable Species and Adaptation strategies in the Sierras of California using historical resurveys (Principal Investigators: Craig Moritz and James H. Thorne), California Energy Commission, Museum of Vertebrate Zoology University of California Berkeley and Information Center for the Environment University of California Davis. Recent projects: - Predicting Wildlife Movement associated with road and highway systems - Sustainable Transportation Institute and Center for Spatial Technologies and Remote Sensing, University of California Davis - Analysis of Hyperspectral remote sensing data to detect and map tree decline at Ft Benning, GA, US Army Corps of Engineers, and Center for Spatial Technology and Remote Sensing University of California Davis Lorraine Flint has expertise in downscaling climate data for application to regional water balance models to calculate the hydrologic response of watersheds and landscapes to current and future climates at very fine spatial scales. She has developed approaches for establishing impacts of future climate on stream temperature, water availability, and vegetation. Relevant ongoing projects include climate change and hydrology investigations for the State of California, including regional studies in the Sierra Nevada, Klamath River, Central Valley, and Russian River basins, evaluating impacts of climate change on wolverine and waterbird habitats, springtime snowmelt, runoff and recharge, and distribution of vegetation. Here is the other funded projects and time on each: Award or Application Title: Sierra Snowmelt Source of Funding: California Department of Water Resources Total Award Amount: $360K Award Period: 2008-2012 Person-months per year devoted to project: 2 Award or Application Title: Russian River Climate Change Source of Funding: Sonoma County Water Agency Total Award Amount: $420K Award Period: 2009-2012 Person-months per year devoted to project: 2 Award or Application Title: Adapting to Climate Change: "State of the Science" for North Bay Watersheds Source of Funding: North Bay Watershed Assn. Total Award Amount: $60K Award Period: 2010-2011 Person-months per year devoted to project: 1 Award or Application Title: Impact of climate change on future suitability of the Sierra Nevada for wolverines Source of Funding: USGS Biologic Resource Discipline Total Award Amount: $75K Award Period: 2010-2011 Person-months per year devoted to project: 1 Award or Application Title: Influence of Climate Change on Sediment Transport in the Sacramento Valley Watershed Source of Funding: Calfed Total Award Amount: $366K Award Period: 2011-2013 Person-months per year devoted to project: 2 Award or Application Title: Klamath River Basin Characterization Model Source of Funding: USGS Western Region Total Award Amount: $200K Award Period: 2009-2011 Person-months per year devoted to project: 2

Sponsored Projects Office
University of California, Berkeley
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Berkeley, CA 94704-5940

Principal Investigator: Craig Moritz, Ph.D.
Fellow:
Project Title: Determining Landscape Connectivity and Climate Change Refugia Across the Sierra Nevada

Please accept the enclosed proposal submitted on behalf of The Regents of the University of California Berkeley campus. Should this proposal be selected for funding, award documents should be issued using the information provided below.

Endorsed for the Regents by:

Patricia A. Gates 4/12/11
Patricia A. Gates
Associate Director

If you have any questions or need additional information regarding this proposal, please contact:

Christine Luppino

Phone: (510) 643-6113
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AWARDS SHOULD BE MADE TO:	CHECKS SHOULD BE MADE PAYABLE TO:
The Regents of the University of California c/o Sponsored Projects Office University of California, Berkeley 2150 Shattuck Avenue, Suite 313 Berkeley, CA 94704-5940 email address for electronics awards: spoawards@berkeley.edu Main Office: (510) 642-0120 Fax: (510) 642-8236 Website: http://spo.berkeley.edu	**The Regents of the University of California** CHECKS SHOULD BE SENT TO: Extramural Funds Accounting attn: Lori Cripps, Director University of California, Berkeley 2195 Hearst Avenue, Room 130 Berkeley, CA 94720-1103 Telephone: 510/642-1371 Fax: 510/643-8997

Determining Landscape Connectivity and Climate Change Refugia Across the Sierra Nevada
Principal Investigator: Craig Moritz

Project Description

Release of vast quantities of greenhouse gases into the atmosphere has increased annual mean temperatures, altered global precipitation, reduced polar ice caps, and changed plant composition[1,2]. As California's climate rapidly changes, land managers need to know how species distributions might be shifting to design effective climate change adaptation strategies. Recent studies have begun to examine the effect of climate and land use change on Sierra Nevada birds and mammals[3,4,5]. However, although most studies assume that the Sierra Nevada is a contiguous landscape with populations connected across its expanse, few studies have examined this assumption. Moreover, although the benefits of habitat connectivity are widely supported, including maintaining gene flow between populations and thus viability within species, few studies have analyzed it over spatial (10-10000 km^2) and temporal scales (decades) relevant to landscape-level conservation planning.

Another unaddressed issue is that most studies assume that low elevation populations will shift upslope in a simplistic and predictable manner. However, early studies indicate that there are many exceptions to this trend[3,6]. One possible explanation is that among heterogeneous landscapes there are certain areas of more stable or buffered climate, such as cold air drainages where cooler areas can be found at lower elevations[7] or high radiation, northern slopes at high elevations. Here, we call these areas **climate change refugia**. We predict that at a mesoscale, climate change refugia will increase persistence and stability of populations and, as a result, maintain higher genetic diversity. Populations within climate change refugia will be less likely to go extinct and will contain higher genetic diversity than those outside. Connected climate change refugia will maintain gene flow between populations and thus species viability, and the maintenance of this connectivity is emerging as a key management option.

We propose to use species distribution modeling, population genetics, and geographic analysis of historical vs. modern populations of California mammals to identify climate change refugia and their connectivity across the Sierra Nevada. We propose a two-tiered chronological approach: historical to modern: proof of concept on the existence of climate change refugia over time, and the role of connectivity in maintaining vertebrate populations; and modern to future: to assess the need to include connectivity in climate change adaptation strategies. We will determine connectivity through population genetic analysis of two species of ground squirrels, Belding's ground squirrel (*Urocitellus beldingi*), primarily a montane meadow specialist, and the California ground squirrel (*Otospermophilus beecheyi*), a generalist found at low to mid elevations. We will link the results of population genetics and species distribution modeling of historical vs. modern populations for these two target species and expand the modeling to 25 additional Sierra Nevada mammal species, aiming at identifying landscape features that are consistent with persistent populations and the degree of landscape level connectivity. We will expand our results to future projections of climate change refugia and draw conclusions on how to include connectivity into climate change adaptation strategies. This research will be an extension of the successful collaboration of the Grinnell Resurvey Project (GRP) with state and federal land managers in California, as that project's main funding is now ended. Most genetic and population data have already been collected; we are requesting funds to undertake additional analyses and modeling to expand the GRP results into outcomes usable by managers and planners. We will communicate our results directly to CA LCC members to aid in decisions from immediate, small-scale adaptation projects to region-wide changes in use, development, and planning of state and federal lands.

CA LCC Priorities addressed

Millions of dollars are spent annually to ameliorate habitat fragmentation and establish conservation corridors, with insufficient understanding for the effects of climate change. Our project will directly address conservation issues at scales relevant to designing LCC climate change adaptation strategies. Our project will identify conservation target areas (climate change refugia) and connectivity between them across the Sierra Nevada. Connectivity is key to the ability of species, and thus ecosystems, to adapt to climate change; thus, increasing landscape connectivity increases resilience. We will 1) identify climate change refugia and thus help managers to prioritize focal areas and landscape characteristics that maintain biodiversity; and 2) analyze population genetics and landscape connectivity to determine the importance of dispersal to the persistence of focal species. In addition, our use of historical data will provide

baselines for diversity and connectivity across the Sierra Nevada that will be relevant not only to assessing the current state but also expectations about how climate change will affect them into the future.

Our study will elucidate species responses to ongoing and future climate change in the Sierra Nevada. Through our research, we will identify projected future climate change refugia and the connectivity needs for a suite of Sierra Nevada mammal species. We will compare historical and modern genetic and distribution data to understand demographic responses to climate change, specifically dispersal and survival. Our results will incorporate several future climate change scenarios and projections, thus demonstrating uncertainty around predictions to aid in the management process. T. L. Morelli was part of a research team at the U.S. Forest Service that worked to help land managers incorporate uncertainty into the climate change adaptation process[8], so she is familiar with the difficulties, and the value, of this process.

These results will help Sierra Nevada land managers to allocate limited resources and aid future scenario assessment at landscape scales for adaptation planning, as well as help other land managers by developing a performance measure for assessing resilience. Habitat connectivity data will help identify the impact of development on animal populations and thus help to avoid conflicts between human infrastructure changes and biodiversity/conservation. Finally, this research will show whether ground squirrels can be used as an indicator species for California habitats.

Once climate change refugia are identified and habitat connectivity is elucidated, we will meet with CA LCC Sierra Nevada partners (e.g., Yosemite National Park staff, SEKI National Park staff, Inyo National Forest staff) to communicate results and help consult on how to develop climate change adaptation options according to the results. The co-P.I., T.L. Morelli, has collaborated with both Yosemite National Park staff and Inyo National Forest staff in the past and has published peer-reviewed articles on developing and implementing climate change adaptation options[9].

CA LCC Criteria addressed

As state and federal agencies move to incorporate climate change into decision-making (e.g., USFS Climate Change Performance Scorecard; NPS Climate Change Response Program), they are interested in understanding how populations are shifting around the landscape. Our analysis will identify modern and future climate change refugia and determine how these refugia are, or are not, connected across the Sierra Nevada. In fact, this project was originally born out of conversations with the U.S. Forest Service staff and their needs in managing extensive and diverse California habitats[10]. Thus, this project is directly designed to use the best available science to identify where conservation and management efforts should be targeted to address climate change impacts on Sierra Nevada animals. Finally, preliminary research from T.L. Morelli shows that one of the focal species for this project, the Belding's ground squirrel, may have disappeared from much of its historical range in California; this species may be an indicator of the status of montane meadows and further analysis is urgently needed to understand its status in the Sierra Nevada.

The proposed research is exceptional not only in its applicability but also in its breadth. The research will investigate connectivity and climate change refugia for 27 California mammals and will have relevance to populations across the California LCC and to other LCCs. Moreover, we will be combining data on population distribution, genetics, temperature, precipitation, topographic features, land use, and management unit for a truly integrated approach.

Our results will help managers to prioritize areas and landscapes within the California LCC network that are critical to maintaining biodiversity and thus to focusing climate adaptation efforts. Results will be widely communicated in presentations, meetings, and publications; this process has been ongoing with the Grinnell Resurvey Project's previous results and thus a system is already in place. We will also showcase our findings publicly through cal-adapt.org, the new California Vulnerability Assessment program website of our partner the CEC. This research will bring together a variety of CA LCC Steering Committee representatives, including U.S. Forest Service (USFS) employees from NFS and R&D, the National Park Service, U.S. Geological Survey, California Department of Fish and Game (CDFG), and U.C. Berkeley (UCB). We have field and personnel funding available in-kind support for analyses and field data from USFS, USGS, and CDFG.

Approach and Scope of Work

Climate Change Refugia: We will determine climate change refugia in two time periods: a) historical to modern, to assess the existence of climate change refugia over the last century; and b) modern to future, to be included as part of climate change adaptation strategies. Based on microsatellite analysis and occupancy modeling of Belding's and California ground squirrels, we will identify climate change refugia as areas where populations have been most stable through time as indicated by higher rates of genetic diversity. We will then test correlations between these climate change refugia, probability of occupancy[11], and the stability of the characteristics at these sites over the last century, as measured through a suite of landscape features (e.g., elevation, slope, aspect, habitat heterogeneity, vegetation type, cold-air drainages). We will examine the trends in temperature and precipitation over the last century for these areas, using 800-m PRISM data[12] downscaled to 270-m (in collaboration with Flint and Flint, USGS[13]. Climate data will be adjusted to specifically incorporate cold-air pooling[14] and used in a fine-scale hydrologic model that will provide hydrologic response to climate across the region, such as snowpack, runoff, and climatic water deficit. From these results we will develop predictions for where other climate change refugia can be found across the Sierra Nevada. We will test these predictions on 25 other mammal species for which we have adequate data on occupancy over time across the Sierra Nevada. Finally, using these climate change refugia and future climate projections, we will predict the viability of populations/lineages and connectivity to them under future climate change.

Habitat Connectivity: The initial research will focus on the two focal ground squirrels species. These species appear to be responding differently to the changes in California over the past century: the elevation range of the Belding's ground squirrel has contracted whereas California ground squirrel populations have either remained stable or expanded their range[3]. Furthermore, preliminary occupancy modeling of Belding's ground squirrels by the GRP as well as pilot research by T. L. Morelli suggest that range-wide responses mirror those from the Yosemite-specific analysis[3], with 45% of known historically occupied California sites now abandoned.

We will use microsatellite markers to examine the movement of individuals in both space (across the Sierra Nevada) and time (across the last century). Most genetic samples have already been collected; the rest will be collected in collaboration with Sarah Stock (NPS). Researchers at the Museum of Vertebrate Zoology[15,16] have successfully amplified genetic material extracted from museum rodent skins from the early 1900s. We have already optimized 18 polymorphic microsatellite markers for Belding's and California ground squirrels and are currently extracting tissue samples from historical skins. This project will help fund a previously trained undergraduate to complete the genotyping and a postdoctoral researcher to oversee the genotyping and conduct landscape genetic analyses to quantify genetic diversity. Our hypothesis is that samples from areas with high connectivity will display less population structure (differentiation) than areas with less connectivity. Several competing statistical methods have been developed for the analysis of population structure, so best practices involve analysis with more than one method to allow cross-corroboration[17]. Specifically, we will examine population structure using the program Structure[18], the R package Geneland[19], which takes account of geographic location of samples, and the Isolation by Resistance approach used by the program Circuitscape[20] which is specifically designed to identify barriers to gene flow in a heterogeneous landscape. We expect there to be less population differentiation in connected areas compared to unconnected areas. Temporal comparisons (historical to modern and modern to future) will allow us to better identify whether genetic change is associated with landscape features or range dynamics, and this will provide further information on the effects of connectivity on gene flow and population structure. Similar work has been recently conducted on chipmunks in the Sierra Nevada by a GRP member.[16]

After establishing predictions for habitat connectivity from in-depth ground squirrel analysis, we will use a graph-theoretical modeling approach, in collaboration with Bob Westfall and Connie Millar at USFS, to test these predictions for the additional 25 Sierra Nevada mammal species for which we have comprehensive trapping data. Connectivity will be estimated from the output from our current project testing the efficacy of SDMs with the Grinnell Resurvey Project data, including as predictor variables historical and modern climate data (bioclim variables) and detailed historical vegetation maps (made available by our collaborator Jim Thorne at U.C. Davis). We will also incorporate potential evapotranspiration (PET) and actual evapotranspiration (AET) as measures of habitat quality as they may be more relevant to population persistence. We will define landscape connectivity as a function of distance and habitat suitability in occupied sites, as well as corridor width and topographic barriers. We will assess how the probability of persistence of the different mammal species (sites occupied in historical and modern

eras), probability of colonization (sites with increasing probability of occupancy across the eras), or probability of extinction (sites with decreasing probability of occupancy) is a function of landscape connectivity. Analyses will be performed on all variables jointly using spatial eigenvector mapping, which accounts for spatial autocorrelation and indicates scale-specific influences of predictor variables[21]. The importance of each connectivity metric will be assessed using hierarchical partitioning, which divides explained variance between each predictor variable[22]. A visual example of the analysis for one species is given in Figure 1.

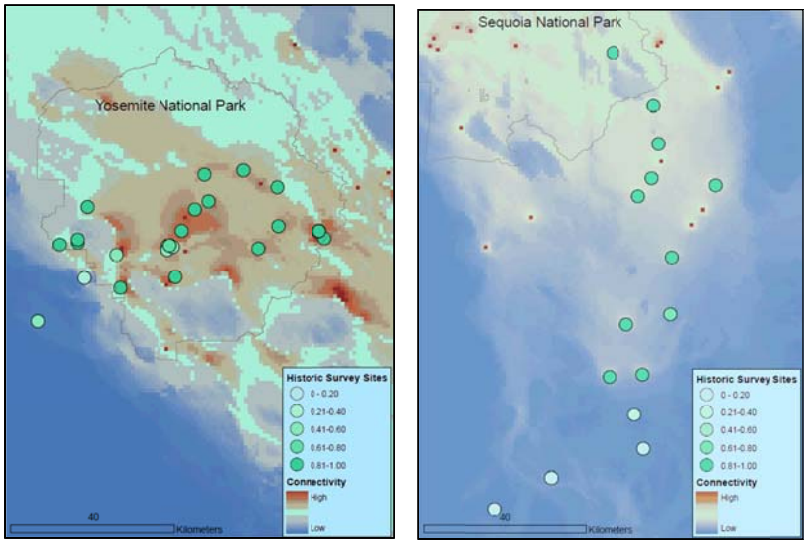

Figure 1. Examples of landscapes with high connectivity (left) and low connectivity (right). Connectivity is calculated using IBR using the output from MAXENT SDM[23] as an index of conductivity. Survey sites are color-coded by the probability of occupancy (output from occupancy analysis). Though both regions have a similar number of sites with similar probabilities of occupancy, the low-connectivity landscape should be expected to suffer higher population turnover when resurveyed in the present era. Isolated red dots indicate sites known to be occupied used by IBR but not included in the occupancy analysis.

We will also examine the effect of species-specific differences on connectivity by incorporating species life history traits (e.g., body mass, generation time, litter size, etc.; Pantheria database) into the models. We will also test and control for effects of phylogenetic relatedness using independent contrasts. Preliminary GRP results of the resurveys near Yosemite National Park indicate idiosyncratic species responses to climate change, even among closely related species. This analysis will seek to expand these results across the California LCC.

Products/Data Sharing

Project Timeline:
July-September 2011: Collect remaining field data, focusing specifically on Sierra Nevada ground squirrels and landscape characteristics
October 2011-June 2012: Genetic analysis
January-August 2012: Geographic analysis & species distribution modeling
September-November 2012: Write-up and dissemination of results:
-Develop accessible & user-friendly webpage on cal-adapt.org
-Publish 2 peer-reviewed journal articles
-Present results to USFS, NPS & DFG staff
-Present results at state/national conferences (e.g., The Wildlife Society, Society of Conservation Biology)

Measuring results

Our outputs can be quantitatively assessed at both tiers of analysis. The historical to modern analysis allows for a proof of concept on our ability to a.) identify climate change refugia from available climate layers, b.) estimate connectivity at the population (genetics analysis) and landscape (IBR) level, and c.) assess if and how connectivity across climate change refugia is important. For this part of the project we expect the following deliverables: 1. Spatially interpolated maps of genetic diversity for California and Belding's ground squirrels; 2. Mapped climate

change refugia across the Sierra Nevada; 3. Mapped population and landscape connectivity estimates across the Sierra Nevada.

All of these deliverables will be available to the partnering agencies, and made available to the other LCC participants. Further, the data will be distributed in concert with Cal-adapt. The modern to future analysis will allow land managers to incorporate connectivity information in climate change adaptation strategies. This will include a similar assessment of future climate change refugia and estimates of connectivity from the first phase of the project for assessing how to maintain connectedness into the future, both from a population genetics and a landscape level perspective. The anticipated deliverables are: 1. Mapped future climate change refugia under two climate change models and two scenarios (four outputs); 2. Mapped structure of connectivity among climate change refugia for the same scenarios. These maps will be made available to the partners in this proposal and extended to the LCC participants, as well as distributed at Cal-adapt website. These results can be used for a suite of analysis on the identification of climate change refugia for these and other vertebrate species and to inform climate change adaptation strategies that include connectivity.

References

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Budget Categories	CA LCC Request	Partner(s) Contribution(s) (monetary)	Partner(s) Contribution(s) (non-monetary value/in-kind)	Total	Details	JUSTIFICATION
Salaries	$ 78,351.69	$ -	$ 15,515.20	**$ 93,866.89**		
	$ 39,272.00				11*3538 with 2% increase	11 month salary for postdoctoral fellow Toni Lyn Morelli for genetics and other analysis
	$ 6,676.00				11*(3538*17%)	11 month benefits for Toni Lyn Morelli
	$ 14,152.00				4*3538	4 month salary for postdoctoral fellow Maria Santos for geospatial analysis
	$ 2,405.84				4*(3538*17%)	4 month benefits for Maria Santos
	$ 3,534.00				$11.78/hour * 15 hours *20 weeks	Pay for part-time genetics technician (U.C. Berkeley Undergraduate)
	$ 81.28				3534*2.3%	Benefits for part-time genetics technician (U.C. Berkeley Undergraduate)
	$ 7,068.00				2*($11.78/hour * 30 hours * 10 weeks)	Pay for 2 summer field technicians
	$ 162.56				7068*2.3%	Benefits for 2 summer field technician
	$ 5,000.00					Services from Lorraine and Alan Flint, USGS, for climate analysis
Supplies	$ 4,526.53	$ -	$ 9,030.00	**$ 13,556.53**		
	$ 724.00				Genetics	PCR kit
	$ 472.50				Genetics	Genotyping run
	$ 76.20				Genetics	Gloves
	$ 83.55				Genetics	Tubes
	$ 230.05				Genetics	Tips
	$ 1,625.85				Genetics	Reagents
	$ 320.63				3 trips * (($3.75/gallon*570 mi roundtrip)/20mpg)	Gas for travel to/from Yosemite National Park
	$ 468.75				5 trips * (($3.75/gallon*500 m	Travel for presenting results to federal and state agencies
	$ 375.00				(5 cars * (($3.75/gallon*avera	Travel costs for one-time meeting with collaborators
	$ 150.00					Food costs for one-time meeting with collaborators
Overhead	$ 14,503.69			**$ 14,503.69**		17.5% for CESU agreement
Equipment				**$ -**		
Other (specify)						
TOTAL	$ 97,381.90	$ -	$ 24,545.20	**$ 121,927.10**		

United States Department of the Interior

NATIONAL PARK SERVICE
Yosemite National Park
P.O. Box 577
Yosemite, California 95389

IN REPLY REFER TO:
N22 (RMS-YOSE)

APR 5 2011

California Landscape Conservative Cooperative
TSuchanek@usgs.gov

RE: Toni Lyn Morelli

To Whom it may Concern:

This letter is to express the strong support of the National Park Service for Dr. Morelli and Dr. Moritz's California Landscape Conservation Cooperative proposal "Determining Habitat Connectivity and Climate Change Refugia Across the Sierra Nevada". We know that changes in temperature and snowpack have been occurring in the subalpine zone of the Sierra Nevada for a number of years. This makes it very difficult to plan appropriate management alternatives for an ecosystem that is likely to be severely altered by changes in climate. The proposed study would fill major gaps in our understanding of how climate may affect species distributions and habitat connectivity. Further, it would identify climate change refugia where populations may be less likely to go extinct and may contain higher genetic diversity than populations outside of refugia. Such comprehensive information would have direct, immediate, and important relevance to management of Yosemite National Park, as well as other land management agencies throughout the Sierra Nevada.

This proposed study has all of the critical elements the National Park Service hopes to see in research proposals. It is an excellent combination of basic and applied research, and it is technically rigorous. In particular, the integration of modeling, field surveys, and genetic analysis is generally regarded to be one of the most powerful approaches for understanding ecological patterns and gaining an understanding of the mechanisms that produce those patterns. Another appealing aspect of the study is the collaboration among scientists from University of California, Berkeley, U.S. Forest Service, and the National Park Service. The research team has outstanding credentials, a track record of successful partnerships, and they bring a wide-ranging set of skills to the project. This ensures that the information will be of the highest quality and relevant to land managers and scientists alike.

In summary, Dr. Morelli and Dr. Moritz's proposal would contribute greatly to our knowledge of how climate will affect species distributions and connectivity; and it would provide the National Park Service and other resource managers with a tool for designing effective climate change adaptation strategies that are at the heart of our policy on managing climate change.

Sincerely,

s/s Joe Meyer (original signature on file)

Joe Meyer
Acting Division Chief
Resources Management and Science

Cc: Toni Lyn Morelli, Morelli@berkeley.edu

California Natural Resources Agency
DEPARTMENT OF FISH AND GAME
[Insert Your Division/Region/Branch or Program]
[Insert Your Full Mailing Address]
www.dfg.ca.gov

***JERRY BROWN**, Governor*
***JOHN McCAMMAN,** Acting Director*

April 12, 2011

Subject: Support for Morelli and Moritz LCC Proposal

To Whom It May Concern,

I am writing to convey our enthusiastic support of Dr. Toni Lyn Morelli and Dr. Craig Moritz's California Landscape Conservation Cooperative (LCC) proposal, titled *Determining Landscape Connectivity and Climate Change Refugia Across the Sierra Nevada*. I am delighted and greatly looking forward to working with them in furthering this research.

With the Department of Fish and Game's Resource Assessment Program in the northern Sierra Nevada, I have been conducting species and community studies aimed at assessing change in sensitive mountain areas. For example, we are pursuing surveys for American pika (*Ochotona princeps schisticeps*) across its elevation range – notably at historically documented sites – and we have a large-scale multispecies project to detect effects on species' distributions associated with climate or land use changes.

I believe the work Morelli and Moritz are proposing will complement and build beyond our current studies, creating synergies of information regarding the impacts and implications of climate change for montane species and ecosystems. In particular, their work will address explicitly the complex heterogeneity of temperature and other climate conditions over the landscape, which simple elevation does not capture. Their relating of these special conditions to population refugia and genetic connectivity are important next steps in understanding biotic effects of climate change in montane ecosystems. Furthermore, understanding and identifying montane refugia will be useful to land managers and species stewards in planning and implementing management responses to climate change. I am confident that this will include managers of the Department's mountain lands and Department personnel who implement our mission as stewards of the state's wildlife species, like myself.

Sincerely,

(signed)

David H. Wright, Ph.D.
Lead Scientist, Resource Assessment Program
Department of Fish and Game, North Central Region
916 358 2945
dwright@dfg.ca.gov

United States Department of Agriculture
Forest Service
Pacific Southwest Research Station
P.O. Box 245
Berkeley, CA 94701-0245
(510) 559-6300

April 6, 2011

Dr. Rebecca Fris
Science Coordinator
California Landscape Conservation Cooperative

Dear Dr. Fris,

I am writing in support of the proposal, “Determining Landscape Connectivity and Climate Change Refugia Across the Sierra Nevada", with lead investigators Drs. Toni Lyn Morelli and Craig Moritz of the University of California, Berkeley (UCB). The study as described has great opportunity to improve resource-management practices in California and to advance the sciences on which they rest. Mounting pressures from landscape fragmentation, uncharacteristically severe disturbance regimes, and challenges from interactions with changing climates, continue to impact health and persistence of California’s vertebrate species. In light of novel effects brought by climate change, resource managers in the public land agencies are desperate for science-based and landscape-wide approaches to assessing vulnerabilities, evaluating priorities, and planning adaptation actions for the state’s most important faunal species. The proposed project should fill important gaps.

The focus in this proposal on Belding ground squirrel leverages the significant knowledge accumulated already for this species (much as a result of the proposal authors’ research), banks on the diverse information and skill-sets brought forward by the UCB Grinnell Resurvey project, and serves as a model for subsequent assessments proposed for many other vertebrates in California. Whereas a large suite of species over significant landscape areas will be addressed by this project, the value of this project explicitly to an apparently declining species, Belding ground squirrel, is in itself very important.

A unique aspect of this project is its integrative nature, involving analyses based on repeat surveys, geographic assessments, and genetic interpretations. Any one of these elements would make a worthy project; together they will complement and corroborate each other in compound fashion. This comprehensive approach will provide information sorely needed by our national-forest resource managers to project potential responses of species to climate change and to develop efficient climate adaptation plans. The decision-support implications from this proposal feed logically to the existing operational programs of our land managers, especially as we begin a new round of revisions of Land and Resource Management Plans for the California national forests. Interest in locating and managing

species in multi-species refugia is of great interest to our managers, given the efficacy and utility of such an approach. A problem has been lack of data to assess these and lack of comprehensive scientific understanding to delineate locations. The proposed study here would fill that gap importantly.

I urge funding of this proposal as well based on the experience, knowledge, and networking capacity of the lead scientists. Dr. Morelli has extensive technical skills in all the project areas of the proposal and competence to manage a project of this scale. Importantly she also has intensive experience on-the-ground working with national forest and national park service units and staff in California. In that capacity she pioneered pilot climate-adaptation tools and strategies that are providing templates for application across the West. Dr. Moreli knows and understands the needs of local land managers in depth, and has an excellent ability to communicate with them effectively in written and oral contexts. Dr. Mortiz is a leading senior scientist of international renown whose work on climate impacts in California and application to conservation solutions are highly regarded.

Results from the proposed project will provide urgently needed information at a time when little guidance is available. Our land managers will be able to put this new knowledge to use directly, setting in motion plans and actions to protect California vertebrates across broad landscapes in the face of increasingly severe impacts.

Sincerely,

/s/ *Constance I. Millar*

CONSTANCE I. MILLAR, Ph.D.
Senior Scientist
USDA Forest Service
Pacific Southwest Research Station
Ph: 510-559-6435
Email: cmillar@fs.fed.us

CRAIG C. MORITZ (P.I.)

Museum of Vertebrate Zoology & Department of Integrative Biology
University of California, Berkeley, CA 94720-3160
Telephone (510) 643-7711, Fax (510) 643-8277, Email: craigm@berkeley.edu

PROFESSIONAL PREPARATION

University of Melbourne	Zoology & Genetics	B.Sc. (Honors), 1979
Australian National University	Evolutionary Biology	Ph.D., 1985
The University of Michigan	Post-doctoral Fellow	1985-1988

Honors: Whitley Award, Royal Zoological Society NSW (1997); Special Investigator Award from the Australian Research Council (1998 – 2003); Fellow of the California Academy of Science (2002); Honorary Professor at University of Queensland (2002); Virginia & Walter Gill Chair of Natural History (2002-05); President, Society for the Study of Evolution (2009).

APPOINTMENTS

From 2001	Director, Museum of Vertebrate Zoology and Professor of Integrative Biology, University of California, Berkeley.
2001 -	Honorary Professor, University of Queensland
1999 - 2001	Professor (Personal chair) University of Queensland.
1999 - 2001	Head, Department of Zoology & Entomology, University of Queensland.
1999 - 2001	Head, School of Botany, Zoology & Entomology, University of Queensland.
1995 - 1998	Reader, Dept. of Zoology, University of Queensland.
1991 - 1994	Senior Lecturer (Tenured), Dept. Zoology, University of Queensland.
1988 - 1991	Lecturer (Tenurable), Dept. Zoology, University of Queensland.
1984 - 1988	Research Fellow, Museum of Zoology, University of Michigan.

PUBLICATIONS

Carnaval, A. C., Hickerson, C.F. B. Hadadd, M.T. Rodrigues & **C. Moritz**. 2009. Stability predicts genetic diversity in the Brazilian Atlantic Forest hotspot. *Science* 323: 785-789.

Davis, E.B., M. S. Koo, C. Conroy, J.L. Patton & **C. Moritz** (2008). The California Hotspots Project: Identifying regions of rapid diversification of mammals. *Molecular Ecology* 17: 120-138.

Moritz, Craig, J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White & S. R. Beissinger (2008). Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. *Science* 322: 261-64.

Elith, Jane, Catherine H. Graham, *et al.* {**Craig Moritz**} (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29(2): 129-151.

Rissler, Leslie J., Robert J. Hijmans, Catherine H. Graham, **Craig Moritz** & David B. Wake (2006). Phylogeographic lineages & species comparisons in conservation analyses: A case study of California herpetofauna. *The American Naturalist* 167(5): 655-666.

Hoskin, C.J., M. Higgie, K.R. McDonald & **C. Moritz**. 2005. Reinforcement drives rapid allopatric speciation. *Nature* 437: 1353-1356.

Graham, Catherine H., Simon Ferrier, Falk Huettman, **Craig Moritz** & A. Townsend Peterson (2004). New developments in museum-based informatics & applications in biodiversity analysis. *Trends in Ecology & Evolution* 19(9): 497-503.

Moritz, C. 1983. Natural parthenogenesis in the endemic Australian lizard, *Heteronotia binoei* (Gekkonidae). *Science* 220: 735-737.

Toni Lyn Morelli

www.cnr.berkeley.edu/~beis/BeissingerLab/Morelli.html

Current Position

- National Science Foundation (NSF) Postdoctoral Fellow in Biology
  Department of Environmental Science, Policy & Management, U.C. Berkeley
- Volunteer co-chair and co-founder of California Pika Consortium (www.dfg.ca.gov/wildlife/nongame/CPC/)

Education

August 2008 Ph.D. Ecology and Evolution, Stony Brook University, Stony Brook, NY
May 2001 B.S. Zoology, Michigan State University, East Lansing, MI

Recent Grants, Awards, and Fellowships

- NSF Postdoctoral Research Fellowship in Biology, 2010-2012
- U.S. Department of Agriculture, Certificate of Merit, 2009
- U.S. Presidential Management Fellowship Finalist, 2008
- George C. Williams Research Award, 2008
- NSF Doctoral Dissertation Improvement Grant, 2006-2007
- Louis Leakey Foundation Research grant, 2006
- Idea Wild equipment grant, 2006
- NSF Graduate Research Fellowship, 2003-2006

Recent Research Experience

2010-2011	Conducting species distribution modeling, occupancy modeling, GIS analysis, and field research to determine the impact of climate change on California mammals
2009	Research Ecologist, Pacific Southwest Research Station, U.S. Forest Service Developing climate change adaptation options for land managers
2004-2009	Study of behavior and conservation genetics of lemurs in Ranomafana National Park In collaboration with Dr. Edward Louis, Henry Doorly Zoo, Nebraska
2003-2004	Field behavioral study of kin selection in *Propithecus edwardsi* Ranomafana National Park, Madagascar

Selected Publications

Morelli, T. L., P. C. Wright, R. A. Brenneman, & E. E. Louis, Jr. *In prep*. The effect of roads and rivers as barriers to gene flow in Madagascar: lemurs as a case study. To be submitted to *Molecular Ecology*.

Morelli, T. L. and S. Carr. *In press*. A review of the potential effects of climate change on quaking aspen (*Populus tremuloides*) in the western United States and a new tool for surveying sudden aspen decline. Res. Pap. Albany, CA: U.S.D.A., Forest Service.

Morelli, T. L., M. C. McGlinchy, and R. P. Neilson. *In press*. A climate change primer for land managers from the Sierra Nevada. Gen. Tech. Rep. Albany, CA: U.S.D.A., Forest Service.

Morelli, T. L., S. Yeh, N. Smith, and C. I. Millar. *In press*. Climate Project Screening Tool: An aid for climate change adaptation. Gen. Tech. Rep. Albany, CA: U.S.D.A., Forest Service.

Morelli, T. L., S. J. King, S. T. Pochron, & P. C. Wright. 2009. The rules of disengagement: takeovers, infanticide, and dispersal in a rainforest lemur, *Propithecus edwardsi*. *Behaviour* 146: 499-523.

Andriantompohavana, R., **T. L. Morelli,** S. M. Behncke, S. E. Engberg, R. A. Brenneman & E. E. Louis Jr. 2007. Characterization of 20 microsatellite marker loci in the red-bellied brown lemur (*Eulemur rubriventer*). *Molec. Ecol. Notes* 7: 1162-65.

Hayes, R. A., **T. L. Morelli**, & P. C. Wright. 2006. Volatile components of lemur scent secretions vary throughout the year. *Amer. J. of Primat.* 68: 1202-1207.

Pochron, S. T., **T. L. Morelli**, J. Scirbona, & P. C. Wright. 2005. Sex differences in scent marking in *Propithecus edwardsi* of Ranomafana National Park, Madagascar. *Amer. J. of Primat.* 66: 97-110.

MARIA J. F. SANTOS

Museum of Vertebrate Zoology, University of California Berkeley, 3010 Valley Life Sciences Building, CA 94720-3160, mjsantos@berkeley.edu

EDUCATION AND TRAINING

2011-present: **Post doctoral Education**, *University of California Berkeley*.
2005-2010: **Ph.D. in Ecology**, *University of California Davis*.
2008-2010: **Conservation Management Graduate Academic Certificate**, *University of California Davis*.
2001-2003: **M.Sc. Environmental Sciences and Policy**, *Northern Arizona University*.
1992-1998: ***Licenciatura* Biology Applied to Animal Resources**, *University of Lisbon, Portugal.*

SELECTED PEER REVIEWED PUBLICATIONS

Santos, M.J., H.M. Matos, F. Palomares & M. Santos-Reis. *Accepted.* Factors affecting mammalian carnivore use of riparian ecosystems in Mediterranean climates: plant composition and structure or water availability? *Journal of Mammalogy.*

Rosalino, L.M., **M.J. Santos**, C. Fernandes & M. Santos-Reis. 2011. Biogeographical region and host trophic level determine carnivore endoparasite richness in the Iberian Peninsula. *Parasitology* 138:1-8.

Santos, M.J. 2010. Encroachment of upland Mediterranean plant species in riparian ecosystems of southern Portugal. *Biodiversity and Conservation* 19: 2667-2684.

Santos, M.J. & J.H. Thorne. 2010. Comparing culture and ecology: conservation planning of oak woodlands in Mediterranean landscapes of Portugal and California. *Environmental Conservation* 37(2): 155-168.

Santos, M.J., J.A. Greenberg & S.L. Ustin. 2010. Using hyperspectral remote sensing to detect and quantify southeastern pine senescence effects in Red-cockaded woodpecker (*Picoides borealis*) habitat. *Remote Sensing of Environment* 114(6):1242-1250.

Santos, M.J. & T.G. Whitham. 2010. Predictors of *Ips confusus* Outbreaks During a Record Drought in Southwestern USA: Implications for Monitoring and Management. *Environmental Management* 45:239-249.

Santos, M.J., H.M. Matos, C. Baltazar, C. Grilo & M. Santos-Reis. 2009. Is Polecat (*Mustela putorius*) diet affected by "mediterraneity"? *Mammalian Biology* 74: 448-455.

Santos, M.J. & M. Santos-Reis. 2009. Stone marten (*Martes foina*) habitat selection in a Mediterranean ecosystem: effects of scale, sex, and interspecific interactions. *European Journal of Wildlife Research* 56(3): 275-286.

Pinto, B., **M.J. Santos** & F. Rosell. 2009. Habitat selection of the Eurasian beaver (*Castor fiber*) near its carrying capacity: an example from Norway. *Canadian Journal of Zoology* 87:317-325.

Matos, H.M., **M.J. Santos**, F. Palomares & M. Santos-Reis. 2009. Does riparian habitat condition influence mammalian carnivore abundance in Mediterranean ecosystems? *Biodiversity and Conservation* 18(2): 373-386.

Santos, M.J. & P. Beier. 2008. Habitat selection by European badgers at multiple spatial scales in Portuguese Mediterranean ecosystems. *Wildlife Research* 35(8): 835-843.

Santos, M.J., N.M. Pedroso, J.P. Ferreira, H.M. Matos, T. Sales-Luís, I. Pereira, C. Baltazar, C.B. Grilo, A.-T. Cândido & M. Santos-Reis. 2007. Assessing dam implementation impact on threatened carnivores: the case of Alqueva in SE Portugal. *Environmental Monitoring and Assessment* 142(1-3): 47-64.

AWARDS, FELLOWSHIPS AND GRANTS

CHANS - Coupled Human and Natural Systems Fellowship; Calouste Gulbenkian Foundation; United States Army Corps of Engineers; Fulbright; NASA-MSU

LORRAINE E. FLINT
U.S. Geological Survey, California Water Science Center, Sacramento, CA 95819-6129; Phone (916) 278-3223, email: lflint@usgs.gov

Education: PhD 2002, Oregon State University (Soil Physics), MS 1985, Oregon State University (Forest Soils), BS 1979, Humboldt State University (Wildlife Biology)

Positions: 2001-present: Research Hydrologist, U.S. Geological Survey, California Water Science Center, Sacramento, CA.; 1986-2001: Hydrologist, Project Chief, Yucca Mountain Project, Matrix-Hydrologic Properties; 1982-1985: Research Assistant, Dept. of Soil Science, Oregon State University

Scientific Presentations: Authored/coauthored over 100 national and international presentations, including about 15 in the last 2 years on downscaling climate change scenarios to fine-scale spatial resolution and using them in regional hydrologic models for analyses on historical and future environmental and ecological conditions.

Publications: Published over 65 peer-reviewed journal articles, book chapters, and USGS reports.

Research Direction: Current research involves downscaling future climate projections to ecologically relevant scales (1-km to 30-m) and using that as input to a regional scale hydrologic model with the same scale output. The research provides precipitation, min and max air temperature, soil moisture, potential and actual evapotranspiration, solar radiation, climatic water deficit, snow accumulation, snow melt, sublimation, recharge, and runoff. Projects are being conducted throughout the western US for analyses of water availability, flow and transport, snowmelt processes, and ecosystem change, with particular attention to the California, the Sierra Nevada, and the SF Bay Area.

Relevant Publications:

Flint, L.E. and Flint, A.L., Downscaling climate change scenarios for ecologic applications: USGS approved, in journal review.

Flint, A.L., Flint, L.E., Curtis, J.A., and Buesch, D.C., 2010, A Preliminary Water Balance Model for the Tigris and Euphrates River System: USGS Open-File Report.

Flint, L.E., and Flint, A.L., 2008, Regional analysis of ground-water recharge, in Stonestrom, D.A., Constantz, J., Ferré, T.P.A., and Leake, S.A., eds., Ground-water recharge in the arid and semiarid southwestern United States: US Geological Survey Professional Paper 1703, p. 29-59.

Flint, L.E and Flint, A.L., 2008, A basin-scale approach to estimating stream temperatures of tributaries to the Lower Klamath River, California, J. of Environmental Quality 37:57-68.

Flint, A.L. and Flint, L.E., 2008, Modeling soil moisture processes and recharge under a melting snowpack: 7:350-357 Vadose Zone J.

Flint, A.L., and Flint, L.E., 2007, Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: USGS SIR 2007-5099, 20 p.

Flint, A.L., Flint, L.E., Hevesi, J.A., and Blainey, J.M., 2004, Fundamental concepts of recharge in the Desert Southwest: a regional modeling perspective, in *Groundwater Recharge in a Desert Environment: The Southwestern United States,* edited by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, Water Science and Applications Series, vol. 9, AGU, Washington, D.C., 159-184.

Robert D. Westfall
USDA Forest Service
Sierra Nevada Research Center
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(510) 559-6438

Degrees

Ph.D., 1972. Michigan State University, East Lansing, MI.
Major - Tree physiology and forest genetics.
B.S., 1967. Michigan State University, East Lansing, MI.
Major - Forestry.

Publications

(1) Millar, C. I., J. C. King, R. D. Westfall, H. A. Alden, and D. L. Delany. 2006. Late Holocene forest dynamics, volcanism, and climate change at Whitewing Mountain and San Joaquin Ridge, Mono County, Sierra Nevada, CA, USA. Quaternary Research 66:273-287.

(2) Millar, C. I., R. D. Westfall, D. L. Delany. 2007. Response of high-elevation limber pine (*Pinus flexilis*) to multi-year droughts and 20th-century warming; Sierra Nevada, California, USA. Can. J. For. Res.: 19:3806-3823.

(3) Grivet, D., V.L. Sork, R.D. Westfall, F.W. Davis. 2007. Conserving the evolutionary potential of valley oak (*Quercus lobata* Née) in California. Molecular Ecology 17:139-156.

(4) Millar, C. I., R. D. Westfall. 2007. Rock glaciers and related periglacial landforms in the Sierra Nevada, CA, USA; Inventory, distribution, and climatic relationships. Quaternary International 188:90-104.

(5) DeWoody, J., L. Arguello, D. Imper, R. Westfall, V. D. Hipkins. 2008. Genetic evidence of hybridization between *Oenothera wolfii* (Wolf's evening primrose) and *O. glaziovana*, a garden escape. Madroño 55:132-142.

(6) Millar, C.I. and R.D. Westfall. 2010. Distribution and climatic relationships of the American Pika (*Ochotona princeps*) in the Sierra Nevada and Western Great Basin, U.S.A.; periglacial landforms as refugia in warming climates. Arctic, Antarctic, and Alpine Research 42(1):76-88.

(7) Sork V., F. Davis, R. Westfall, A. Flint, M. Ikegami, H. Wang, and D. Grivet. 2010. Gene movement and genetic association with regional climate gradients in California valley oak (*Quercus lobata* Nee) in the face of climate change Molecular Ecology 19:3806-3823.