Abstracts

Symposium: Climate Change and the Ecology of Sierra Nevada Forests
September 20-21 2019
UC Merced, California room

Session 1: Fire

"Bottom-up vs top-down drivers of Sierra Nevada wildfires"

Jon Keeley (U.S. Geological Survey)

Since the beginning of the twenty-first century California, USA, has experienced a substantial increase in the frequency of large wildfires, often with extreme impacts on people and property. Due to the size of the state, it is not surprising that the factors driving these changes differ across this region. Although there are always multiple factors driving wildfire behavior, we believe a helpful model for understanding fires in the state is to frame the discussion in terms of bottom-up vs. top-down controls on fire behavior; that is, fires that are clearly dominated by anomalously high fuel loads from those dominated by extreme wind events. Recent fires illustrating these patterns are presented

"A physiological approach to assess the resilience of forest communities following wildfire"

Ryan Salladay (UC Santa Cruz)

Global wildfire has recently increased in size and frequency and is expected to escalate into the future. Consequently, forest health and resilience are major concerns, especially under fire regimes of low and mixed severity in which dominant trees are surviving. To identify the cause of fire-induced tree mortality we must understand which vital functions suffer most due to high temperatures. Recent studies have shown that water transport through xylem is critically impaired following exposure to searing temperatures. The xylem dysfunction hypothesis suggests that trees exposed to non-lethal fire experience xylem damage, reducing the plant's ability to transport water from their roots to their leaves resulting in tree mortality. My proposed research will employ both lab and field-based approaches to study the physiological effects of wildfire on numerous California native tree species, thus creating a better understanding of resilient forest ecosystems. My study will include, but is not limited to, ponderosa pine, Douglas fir, valley oak, and black oak in prescribed burn sites across an elevational gradient. In the lab portion of my research I will place branch samples in a drying oven at increasing intensity to measure the anatomical and physiological effects of heat on xylem tissue. Similarly, I will collect branch samples from before and after prescribed burns to measure the effect of fire on xylem anatomy and physiology. Lastly, I will use my findings from lab and field experiments to assess long-term recovery of tree communities following fire and evaluate the risk of subsequent drought.

"How much do forest fuels changes affect giant sequoia resilience to wildfire?"

Kristen Shive (Save the Redwoods League)

Over a century of fire suppression has dramatically increased fuel loads in much of the Sierra Nevada. Coupled with the warming climate, fire severity and extent has increased in recent decades, and this trend is expected to continue. Moreover, hotter droughts may increase tree stress, which could influence their ability to recover from fire-related injuries. Although the iconic and long-lived giant sequoia are the quintessential fire dependent species, it is unclear how they will fare in wildfires under conditions of increased fuel loads and hotter droughts. In 2017, the Pier Fire burned into Black Mountain Grove, including patches of high severity. In 2018, we surveyed all monarchs (>1m diameter) in roughly 560 acres of high and moderate severity fire. Of 218 measured trees, 52 were dead, five of them with completely torched crowns. Dead monarchs were more associated with southwesterly aspects, and had prior damage including past fire scars (cat faces) and broken tops. Slope steepness was not related to the probability of mortality, but did help predict crown torching. To assess how pre-fire forest structure and tree vigor influenced monarch mortality, we are re-surveying these trees in 2019. We will document any delayed mortality, record surrounding forest structure characteristics and core a subsample of trees to assess tree vigor via recent growth rates. Preliminary analyses of the 2019 data on forest structure will be presented.

"Hydrological impacts of restoring natural wildfire regime in the Sierra Nevada within climate change context"

Ekaterina Rakhmatulina (UC Berkeley)

More than 60% of California's water supply originates in the Sierra Nevada, which is a fire prone landscape. With contemporary drought in California, forest health and water supply are already being severely compromised. Future climate trajectory is likely to exacerbate the problem. The current state of the Sierra Nevada forests is a product of 100+ years of fire suppression policies resulting in homogeneous forests with dense fuel accumulation. Predicted future increases in temperature and more frequent droughts will lead to smaller snowpack, longer drying season, and additional tree mortality. If no action is taken by forest managers today, these conditions can lead to large high severity fires. Given more public attention to wildfires, forest managers are already starting to implement wildfire management, which is a strategy of allowing lightning-ignited fires to burn if there is no risk to structures and people. Yet the uncertainty associated with future climate and the time period required to transition a currently suppressed forests to adapt to a natural wildfire regime is poorly studied. Here we examine Illilouette Creek Basin (ICB), one of few large watersheds that has adopted a wildfire management strategy for over 45 years. We use this watershed to first model the effects of an observed natural wildfire regime on snowpack and streamflow timing and volumes, evapotranspiration, and soil storage. Then an ensemble of downscaled future climate predictions is used to assess the effects of climate change in combination with a natural wildfire regime on hydrology of ICB. Modeling results show that soil storage and streamflow increase with introduction of fires. More frequent fire return interval decreases the amount of time it takes for the forest to reach significant hydrological changes caused by wildfires.

"Wildfire Impacts on Water and Carbon Cycles in California's Sierra Nevada"

Qin Ma (UC Merced), *Michael Goulden, & Roger Bales*

Wildfires in the Western U.S. are having substantial disturbance to forest ecosystems, with the spatial patterns of disturbance and recovery varying widely. We explored wildfire impacts on water and carbon cycles in the Sierra Nevada, the main headwaters for California's Central Valley, over the past three decades. We quantified wildfire effects on evapotranspiration and aboveground live biomass using remote sensing (Landsat) observations and in situ measurements. Results show that wildfires mainly reduced evapotranspiration in the first 15 years post-fire, which added up to 2.2 billion m^3 yr^{-1} during the 1st year and 16.3 billion m^3

(15 yr^{-1}) cumulatively during 15 years after the fire, over the 109,343 km^2 Sierra Nevada. Spatially, evapotranspiration reduction was greatest from high-severity fires at mid-elevation (900-1500 m) in dense forests. Wildfire disturbance on aboveground live biomass took longer to return to pre-fire levels than did evapotranspiration. Forest biomass recovery from fire mainly varied by forest species, fire intensity, and hydro-climate conditions. This study illustrates the great potential of reducing risks of drought and extreme fire by strategically restoring over-stocked forests, and predicting water and carbon benefits from management actions conducted at different locations and times.

Session 2: Wetlands

"The noise is the signal: spatio-temporal analysis of indices of high elevation meadow condition in the Sierra Nevada"

Robert Klinger (U.S. Geological Survey Western Ecological Research Center)

There are general expectations that increasing temperatures will lead to significant changes in structure and/or function of montane meadows, including lower production and greater water stress on vegetation. We evaluated these expectations by: (1) compiling Landsat satellite data on the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI), across a 30-year period (1989 - 2018) for 8,168 meadows > 2700 m elevation; then, (2) used a combination of state-space time series and spatial analyses to assess the spatio-temporal patterns of meadows with decreasing, increasing or no trends for NDVI and NDMI. Meadows with either no long-term change or an increasing trend in NDVI occurred with similar frequency (51%) as those with a decreasing trend (49%). Density of meadows with a decreasing trend in NDVI was greatest in the southern part of the range, while density of those with either an increasing trend or no long-term change were greatest in the central and eastern part of the range. Despite the different geographic patterns, several spatial statistics indicated an extremely heterogeneous mixing of meadows with different temporal dynamics, with meadow pairs 200 meters from one another often having temporal dynamics as different as those 200 km apart. The patterns indicate spatio-temporal dynamics in meadow condition are shaped as much or more by local (e.g. soil moisture, soil depth) and regional (topography) factors than simply broad climatic shifts, thus scale-dependent variability rather than broad trends will likely be a more appropriate framework to evaluate ongoing dynamics in meadow condition.

"High elevation meadow condition monitoring results over 5 years of climate variability "

Joy Baccei (Yosemite National Park)

On public lands, mountain meadows are popular destinations for recreational users due to their scenic beauty, iconic mountains vistas, close proximity to water, and availability of summer forage. In the Sierra Nevada, meadows occupy less than 1% of the landscape, and at Yosemite National Park, they occupy only 3% of the landscape. Despite their relatively small size on landscape, they provide broad-scale ecosystem services and important societal benefits. Many Sierran meadows are now highly degraded, and resource management guidance is needed. Ecological condition monitoring can inform science-based management. At Yosemite, meadows have been identified as outstandingly remarkable values (ORVs) in two Wild and Scenic River Plans. The Visitor Use & Impacts Monitoring Program (VUIMP) was developed to ecologically monitor the condition of ORVs, where monitoring of bare soil extent serves as an indicator of meadow ecological condition. This indicator was developed in collaboration with rangeland experts from two universities, based on a Tahoe National Forest Service multi-year meadow bare soil monitoring dataset, which used condition classes for bare soil cover values (low, medium, high). Yosemite now has a 5-year bare soil dataset that can be used to evaluate meadow condition in response to visitor use and climatic variability. Preliminary results from meadow condition monitoring of bare soil extent over a 5-year period (from 2014-2018) show that data collection efforts spanned a variety of environmental extremes. The severity of the 2012-2015 California drought was beyond that of any seen before in the state. The winter of 2016 brought near record spring snow pack, and the winters of 2017-2018 brought above average snowpack, based on April 1st 2017 snow water equivalent (SWE) for the central Sierra. These environmental extremes are important to keep in perspective because meadows are highly dependent on water availability, which influences vegetation cover. Monitoring over a 5-year period of climate variability has now provided us with sufficient data to re-assess the assumptions made in developing this indicator and its standards, triggers, and monitoring strategy, where we can also now compare these data with visitor use and climatic data.

"Restoring Sierra Nevada wet meadows in the context of climate change: A framework for climate-smart meadow restoration"

Marian Vernon (Point Blue Conservation Science)

Sierra Nevada meadows are a rare and critically important component of the Sierra Nevada ecosystem, the value of which far outweighs the 2% of the system they occupy. Meadows provide vital ecological functions, including carbon storage, groundwater recharge, flood attenuation, water quality improvement, and habitat for numerous species. However, 40-60% of meadows are degraded as a result of past and current land uses and are in urgent need of conservation action to restore their important ecological services. Efforts to restore Sierra meadows are being implemented in the context of a rapidly changing climate, which poses a new set of challenges. Traditional restoration approaches use a baseline of historic conditions and the historic range of variability as a reference for restoration outcomes. However, restoring Sierra meadows in reference to a historic baseline is unlikely to ensure that the restored meadow will be resilient. In this presentation, we provide an overview of climate-smart ecological restoration in the context of Sierra meadows. We define climate-smart restoration as the process of enhancing ecological function of degraded, damaged, or destroyed areas in a manner that makes them resilient to the consequences of climate change. We demonstrate how climate change considerations can be integrated into planning and design for meadow restoration projects, highlight climate vulnerabilities, and provide recommendations of best management practices to ensure restored meadows are resilient to climate change.

"Seasonal variation of methane in high-elevation lakes in Yosemite National Park"

Elisabet Perez Coronel (UC Merced)

Freshwater lakes are important natural sources of methane to the atmosphere. Mountain regions are home of over thousands of lakes but there is a significant underrepresentation of these ecosystems in previous lake methane budgets. High elevation regions are expected to experience faster warming than other ecosystems in the coming years. Understanding the dynamics involved in the methane cycle and how environmental changes in these regions affect emissions of this gas is necessary to accurately represent and quantify global methane budgets. Over a 2-year study, we followed the environmental changes in methane (CH_4), temperature, inorganic nutrients and organic matter in 5 mountain lakes located at different elevations in Yosemite National Park to understand what environmental variables correlate with higher CH_4 emissions. We found that seasonality strongly relates to CH_4 concentrations in surface lake water: higher concentrations were found on the warmest months and the lower ones at the end of the season right before winter. CH_4 concentration in lakes at mid-elevation (<3000 m) could be predicted by temperature, nitrite concentrations and elevation r^2= 0.9, p<0.0005) whereas in lakes at higher elevation (>3000 m) CH_4 concentrations could be predicted by N:P ratio and elevation (r^2 = 0.48, <0.005). When considering all the lakes sampled, elevation was the only parameter that significantly predicted CH_4 in lake water (r^2 = 0.39, p<0.005). Our results suggest that predicted increases in temperature and nutrient loading may contribute to higher CH_4 emissions from mountain regions around the world in the coming decades.

Session 3: Fauna

"Phenology and productivity in a montane bird assemblage: Trends and responses to elevation and climate variation in Yosemite"

Rodney Siegel (The Institute for Bird Populations)

Climate variation has been linked to historical and predicted future distributions anddynamics of wildlife populations. However, demographic mechanisms underlying these changes remain poorly understood. Here, we assessed variation and trends in climate (annual snowfall and spring temperature anomalies) and avian demographic variables from mist-netting data (breeding phenology and productivity) at six sites along an elevation gradient spanning the montane zone of Yosemite National Park between 1993 and 2017. We implemented multi-species hierarchical models to relate demographic responses to elevation and climate covariates. Annual variation in climate and avian demographic variables was high. Snowfall declined (10 mm/year at the highest site, 2 mm at the lowest site), while spring temperature increased (0.045°C/year) over the study period. Breeding phenology (mean first capture date of juvenile birds) advanced by 0.2 day/year (5 days); and productivity (probability of capturing a juvenile bird) increased by 0.8%/year. Breeding phenology was 12 days earlier at the lowest compared to highest site, 18 days earlier in years with lowest compared to highest snowfall anomalies, and 6 d earlier in relatively warm springs (after controlling for snowfall effects). Productivity was positively related to elevation. However, elevation–productivity responses varied among species; species with higher productivity at higher compared to lower elevations tended to be species with documented range retractions during the past century. Productivity tended to be negatively related to snowfall and was positively related to spring temperature. Overall, our results suggest that birds have tracked the variable climatic conditions in this system and have benefited from a trend toward warmer, drier springs. However, we caution that continued warming and multi-year drought or extreme weather years may alter these relationships in the future. Multi-species demographic modeling, such as implemented here, can provide an important tool for guiding conservation of species assemblages under global change.

"Drought and bark beetle mortality had opposing effects on many avian species in the southern Sierra Nevada"

Lance Jay Roberts (Point Blue Conservation Science)

Birds respond rapidly to changes in both habitat and climate conditions and thus are good indicators of the ecological effects of a changing climate, which may include warmer temperatures, changing habitat conditions, and increased frequency and magnitude of extreme events like drought. We investigated how a widespread tree mortality event concurrent with a severe drought influenced the avian community of the southern Sierra Nevada from 2010 to 2016, and used what we learned to forecast the changes that are likely to occur in the near future (through 2050). A large portion (47%) of the 45 species we included in analyses had a positive relationship with increased temperature. A similar number of species (36%) declined with drier conditions compared to the number that increased (29%). More species declined in response to high tree mortality (36%) than increased (9%). A few general patterns were evident from our results, but there is still much uncertainty as to the future composition of the avian community. Even though we projected the highest total bird abundances in the future under the warmest climate scenario that we considered, habitat modification (e.g., tree mortality) and water deficit could offset the positive influence of temperature for many species. Future climate conditions may not have a universally negative effect on biodiversity in the Sierra Nevada, but the probable vegetation changes and increased likelihood of extreme events such as drought should be incorporated into climate-smart forest and wildlife management decisions.

"Current and time-lagged effects of climate on innate immunity in two sympatric snake species"

Amanda Sparkman (Westmont College)

Rising global temperatures and changing environmental conditions, such as the record-breaking 2012-2015 drought in California, place strain on the interactions between organisms and their environment. In order to cope with limited resources, organisms may alter both their behavior and their physiological investments. Immune function in particular can be costly to develop and maintain, and therefore immunocompetence may decrease when available resources are scarce. To test for evidence of reduced immunocompetence in response to drought, two species of garter snakes (*Thamnophis sirtalis* and *T. elegans*) were sampled from four populations in the Sierra Nevada mountains of northern California from 2012-2018. Plasma samples were obtained and analyzed for three indices of innate immunity: bactericidal competence (BC), natural antibodies (NABs), and complement mediated lysis (CL). All immune indices were tested for relationships with standard climate variables, including temperature, precipitation, and two standard drought indices, Palmer Z and PHDI. Analyses revealed that spring precipitation of the current year was correlated positively to *T. sirtalis* BC , NABs, and CL whereas spring precipitation of the former year correlated positively to *T. elegans* BC and NABs, indicating that *T. elegans* immunity may experience a time-lagged response to climate. Furthermore, *T. elegans* CL and *T. sirtalis* BC and CL were significantly correlated to PHDI, which is a long-term term drought index. These results support our prediction of decreased immunocompetence in response to drought and suggest that this response varies by species and with respect to the index of immune function and climate variable under consideration.

"Resilience and vulnerability of an ephemeral water breeding amphibian, the Yosemite toad, to climate change"

Cathy Brown (US Forest Service & UC Davis)**,** *Katie Wilkinson, Lucas Wilkinson, Stephanie Barnes, Carolyn Hunsaker, and Marc Mazerolle*

The federally threatened Yosemite toad (*Anaxyrus canorus*) breeds in very shallow ephemeral water in wet meadows making it potentially vulnerable to climate change. On the other hand, it has evolved to persist in highly variable, stochastic environments. The recent California drought, one of the warmest and driest periods on record, provided an opportunity to investigate life history characteristics that may contribute to vulnerability or resiliency to climate change. Using long-term monitoring data, we compared habitat and demographic trends of Yosemite toads across pre-drought, during, and post-drought years. Both water table depths and surface water extent in breeding meadows were much reduced during the drought. Although all breeding habitats dried considerably, pothole habitats retained some water whereas many flooded vegetation habitats were completely desiccated, even at snowmelt. The timing of spring breeding coincided relatively well with snowmelt in normal and high water years, but there may be a minimum threshold for emergence. In flooded vegetation habitats, Yosemite toads did not breed during several drought years but resumed breeding the first year after the drought. In pothole habitats, breeding was normal during the drought. Abundance of adults increased in one pothole habitat whereas numbers decreased or remained small in flooded vegetation habitats. These results suggest that Yosemite toads are vulnerable to breeding habitat loss during drought conditions but that certain types of habitats may confer some resiliency for reproduction, the long-lived adults may survive periods unsuitable for breeding, and breeding phenology may be adaptive to avoid risks of early and late reproduction.

"Dragons of Pangaea: the fen-dwelling dragonflies of the Sierra Nevada"
Christopher Beatty (Cornell University)
The Petaltail dragonflies (Odonata: Petaluridae) are a small group—the family contains only eleven extant species—with a broad distribution, including Australia, New Zealand, Chile, North America, and Japan. These dragonflies have a unique life history, with larvae that dwell in mountain fens; most species dig a burrow that they live in for multiple years before emerging as adults. The Sierra Nevada are home to the Black Petaltail (*Tanypteryx hageni*), a species that lives in mountain fens throughout the range, and are also found in the Klamaths, Siskiyous, Cascades, Coast Range and Olympics, from California to British Columbia. I will present data showing that the petaltails are extremely old; the family is approximately 160 million years old, originating along the coast of the supercontinent Pangaea. Biogeographical and molecular-clock analysis suggest that diversity in this group was driven by continental drift, with most species originating in the Mesozoic. I will also explore the influence of their extended larval development times on genetic diversity among populations. *T. hageni* spends five years in the larval stage, but only four to six weeks as adults. This life history pattern could lead to allochronic diversification, with multiple cohorts living together in the same habitat. I will show preliminary population genetic data indicating that this species has a high level of genetic diversity within individual sites. I will also address the potential influences of climate change on this species, through changing availability of fen habitats. Petaltails are amongst the oldest species on Earth, deserving our attention.

Session 4: Conservation and management

"Potential consequences of a warming climate on protected area conservation capacity, vegetation, and fire regimes in the Sierra"
Sean Parks (Aldo Leopold Wilderness Research Institute)

Protected areas play a critical role in the provision of ecosystem services, particularly in a time of rapid global change and in highly human dominated regions such as that of California. Yet, even the most remote protected areas are not safeguarded from human pressures or from climate change. For example, climate change is expected to trigger major changes in the distribution of terrestrial ecosystems, and is most certainly expected to alter natural fire regimes. We have conducted a collection of studies at continental and sub-continental scales to explore how warming climate could affect protected area conservation capacity, vegetation, and fire regimes; we synthesize findings to anticipate a range of potential consequences for forests in protected areas in the Sierra Nevada. Relative to other regions, the conservation capacity of protected areas in the Sierra Nevada may be less impacted by shifting climates due to their geographic connectedness with one another. However, based on climate change projections, we anticipate shifts in forest type with transitions away from some cold montane conifer to drier forest types. As for fire regimes, long-term projections suggest that many forest types of the Sierra Nevada could experience more frequent but less severe fires, which is a reflection of increasingly fire-conducive climate and shifts in tree species distributions. Lower elevations, however, may see more stand-replacing fire as forest is replaced by shrubland systems. Fire will play an important role in catalyzing the changes to vegetation pattern that are expected in the Sierra Nevada over the next several decades.

"Transdisciplinary modeling of forest dynamics under alternative forest management strategies and climate change in the Lake Tahoe"
Patricia Manley (US Forest Service Pacific Southwest Research Station)
Forest restoration presents a plethora of challenges as a function of ecological uncertainties and social and economic limitations. A team of scientists representing a broad array of disciplines worked with a management agency technical team to evaluate the merits of alternative management strategies in promoting the resilience of terrestrial forests and community wellbeing as part of the Lake Tahoe West Restoration Partnership. We took a transdisciplinary approach by integrating our modeling across scales and resource areas, including vegetation growth and mortality, air and water quality, wildfire, wildlife habitat, and economics. We evaluated four, diverse strategies (wildfire suppression only, thinning in the wildland-urban interface, extensive thinning, and thinning combined with prescribed burning) and two climate futures to understand if and how they promoted values important to managers and stakeholders. Our modeling indicated that, in this montane landscape, climate change enhanced forest growth despite increases in wildfire activity, such that old-forest areas and associated wildlife increased under all four strategies. Higher levels of mechanical treatment enhanced most values, including reducing the risk of high-severity wildfires and associated social and environmental impacts. Less favorable outcomes included declines in the distribution of some species, increased risk of environmental impacts to air and water quality from extensive use of prescribed fire, and the possibility of long-term impacts on habitat quality for old forest associated species. The strong temporal influence of initial forest conditions as reflected in outcomes taking many decades to manifest highlighted the value of transdisciplinary modeling over many decades to inform management.

Poster session 1

"Effects of repeated prescribed fire and thinning on understory diversity in Sierra Nevada mixed conifer forests"
Maxwell Odland (UC Davis)

Climate change and fire suppression have dramatically altered the fire regimes that drive forest structure and biodiversity in the Sierra Nevada. This study compares understory plant diversity and resource heterogeneity under a full-factorial of thinning and burning treatments in a mixed conifer forest at the Teakettle Experimental Forest (TEF), as well as mixed conifer plots with active fire regimes (3-5 low-intensity fires within the last 60 years). We address two primary questions: 1) How do understory plant diversity and fine-scale environmental heterogeneity respond after prescribed burns and thinning treatments? 2) How do diversity and heterogeneity at TEF compare to reference plots in active-fire forests? Percent cover for all plant species and environmental variables (soil moisture, slope, aspect, and woody debris) were measured for all treatments and active-fire plots. Preliminary results show understory plant richness and environmental heterogeneity in active fire forests are highly variable within and across plots, similar to observed patterns in burn treatments at TEF. Burn plots at TEF without thinning showed high understory diversity and low shrub cover compared to burn plots with initial thinning treatments after the second burn treatment, where burning did not substantially remove shrub cover. This unexpected result may reflect the importance of heterogeneous patches within burns for maintaining understory diversity. Next steps include measuring understory diversity for an additional year to capture inter-annual variability, and analyzing soil nutrients, hemispherical photographs, and overstory structure to see how other important plant resources (nutrient and light availability) impact understory diversity.

"Community based fire management practices in wildland urban interface"
Samrajya Thapa (UC Merced)
California has had an increasing number of wildfires in the wildland urban interface (WUI), resulting in loss of lives, property, and habitat. As population continues to grow, development footprints expand, and climate change affects the amount and flammability of fuel, WUI areas exposed to severe fires continue to increase. It is imperative that residents be engaged with wildfire management practices and conservation efforts for them to be sustainable and comprehensive. Community-based fire management (CBFiM) consequently attracts widespread attention; however, its practical implementation frequently falls short of expectations. The CBFiM approach to wildfire management in the US has the potential to address persistent socioeconomic issues while accomplishing fuels and fire management objectives in a cost-effective manner. Fire-prone landscapes are not well studied from coupled human and natural systems perspectives and present many challenges for understanding and promoting behaviors and institutions. This paper examines factors affecting the community in decision making process around fire management, across three different dimensions i.e., biophysical, sociodemographic, and sociocultural. This study explores community perceptions of wildfire and its management practices, the variables that might explain them, and whether perceptions regarding different management practices are affected by community collaborations. Specifically, this paper determines community members' perceptions of wildfire risk; knowledge and support for the use of wildfire management practices; and opinions about the role of the community members in wildfire management planning in wildland-urban interface.

"Wildfire emissions in Sierra Nevada forests during 1984-2016"
Qingqing Xu (UC Merced)
Sierra Nevada forests contributed more than a third of total area burned in large wildfires

(>1000 acres) in California during 1984-2016. Wildfire emissions from vegetation burning in forests are a major source of greenhouse gases, trace gases, and particulate matter, affecting forest biota, human health, and visibility. Accurate and reliable information about how much emissions are produced during wildfires is the most important criteria for assessing the impacts. Here we calculated emissions of CO_2, CO, CH_4, NMOC, SO_2, NH_3, NO, NO_2, NOx, and PM2.5 from each large fire event during 1984-2016 using the Fire Inventory from NCAR (FINN) model on a 1/16° latitude/longitude grid. Our results show there have been upward trends in emissions due to increasing total area burned and area burned in moderate and high severity; most of the wildfires emitted relatively small amounts of emissions while the largest 10 wildfires contributed around 29% of total emissions; most of the emissions came from vegetation burning at low and moderate elevations; the means of annual emissions in drought and non-drought were significantly different (Mann-Whitney U Test, $p < 0.05$); emissions during drought periods 1987-1992, 2001-2003, 2007-2009, 2012-2016 were generally much larger than in non-drought year.

"Modeling fire severity in the Sierra Nevada forests"
Jonathan Sam (UC Merced)
Current wildfire modeling done in California's 4th Climate Assessment has modeled fire size as a total area burned. This research will contribute to the current statistical framework set by the 4th assessment, by adding the projection of severity classes within a given total area burned. The statistical dependence of fire severity classes is defined in Monitoring Trends in Burn Severity (MTBS), a United States Geological Survey product. The classes defined are unburned to low, low, moderate, high, increased greenness, and non-counted pixel. Fire severity, not to be confused with fire intensity, is a post-fire quantification of the vegetation changes. There are two approaches being tested to model for fire severity classes in the Westerling Lab. The first is a multinomial logistic regression that will be dependent on what the current models in the 4th assessment have modeled for fire size. The second is a conditional dependence extreme value model that will model each of the severity classes individually and we can then sum them and complete the fire projection model. Preliminary results show that there is a relationship between the fire severity classes (low, moderate, and high) and this relationship needs to be further investigated. By incorporating fire severity projections, this work could lead to more in-depth modeling projections for California's 5th climate assessment, which would ultimately aid other areas of post-fire research regarding emissions, runoff, and microbial growth.

"Threats for carbon storage in high elevation forests of the Sierra Nevada"
Sara Winsemius (UC Davis)
Recent changes in high elevation forests worldwide indicate that forest structure and long-term ecosystem stability are threatened, with implications for carbon sequestration and ecosystem refugia. Biomass and disturbance models have high uncertainty in high elevations where landscapes are more heterogeneous and data is more limited than in lower elevations. These challenges, combined with increasing disturbance area and frequency, lead to the open questions of how biomass has changed due to climate and disturbance as well as what the spatiotemporal dynamics and interactions are of change drivers. I aim to improve metrics of AGB and mortality in order to analyze drivers of change across time and space, with AGB as a surrogate for changing forest structure and other ecosystem services. To achieve these goals, I will first use Landsat in combination with airborne LiDAR and plot data to estimate AGB in

high elevation forests of the Sierra Nevada and quantify AGB change. Preliminary results for a region in the southern Sierra will be presented along with the workflow and plan for the final project.

"A multi-scale approach to restoring an aquatic reptile"
Laura Van Vranken (UC Merced)
Recent advances in genetic and genomic tools have improved our ability to detect patterns of population structure and differentiation across multiple spatial scales, particularly for non-model organisms. We aim to leverage these tools to characterize population and landscape genetic patterns for the Western pond turtle (*Emys [Actinemys] marmorata*) in an understudied portion of their range: the central Sierra Nevada and foothill region within and surrounding Yosemite National Park. Uncovering patterns of demography and structure within and between populations will allow us to guide pond turtle management in this region, primarily with the goal to direct reintroduction efforts of an extirpated population in Yosemite Valley. Preliminary results through mitochondrial DNA analyses present two distinct clades in the central Sierra, with the Merced River corridor acting as a barrier to the distribution of the southern clade. Future work will further identify population dynamics, including effective population sizes, genetic diversity, and gene flow, as well as determine if populations are adapted to their respective environmental conditions. These efforts will reveal patterns at the population and local landscape level, previously undocumented in this species, as well as inform conservation and management efforts for pond turtles in this region.

Session 5: Climate and tree mortality

"Tree mortality following drought in the central and southern Sierra"
Leif Mortenson (USDA Forest Service)
Much of California experienced a severe drought in 2012–2015 inciting a large tree mortality event in the central and southern Sierra Nevada. We assessed causal agents and rates of tree mortality, and short-term impacts to forest structure and composition based on a network of 180 11.3-m fixed-radius plots installed within three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests. About 48.9% of trees died between 2014 and 2017. Significantly higher levels of tree mortality occurred in the low elevation band (60.4%) compared to the high elevation band (46.1%). Ponderosa pine exhibited the highest levels of tree mortality (89.6%), with 39.4% of plots losing all ponderosa pine. Tree mortality (numbers of trees killed) was positively correlated with tree density and slope. A time lag was observed between the occurrence of drought and the majority of tree mortality. The implications of these and other results to recovery and management of drought-impacted forests in the central and southern Sierra Nevada will be discussed. Our work highlights increased mortality risks for trees during severe droughts, particularly under warmer temperatures attributed to climate change. In the future, it is likely that more frequent extreme weather events will increase the frequency and magnitude of severe ecological disturbances in many forests, driving rapid and often persistent changes in forest structure, composition and function across large landscapes.

"Sierra Nevada forest recovery following extreme drought and how it relates to pre-drought stand structure and forest management"
Amarina Wuenschel (U.S. Forest Service)

In the Sierra Nevada of California, we can expect future frequent and severe droughts similar to the unprecedented drought of 2012-2016 given climate change projections. The path of forest recovery following such droughts and related tree mortality is poorly understood. Further, common forest restoration in fire-suppressed Sierra Nevada forests involves reverse densification treatments designed to restore forest structure and composition, but it is unclear how such management affects post-mortality recovery. We studied the influence of common forest management practices on forest recovery within the context of severe drought along a gradient of overstory mortality using paired treated (mechanically thinned or prescribed-burned) and untreated sites. Additionally, we compared treated and untreated post-mortality forests to historic forests using natural range of variation (NRV) to evaluate how forest composition and structure is diverging because of drought. Areas that were treated had far fewer trees, but even in treated areas with severe tree mortality, trees and saplings still frequently exceeded the NRV suggesting little need for reforestation. Untreated forest stands had even higher densities with 96% of plots exceeding historic stand conditions. During treatment, more shade-tolerant trees (*Abies concolor* and *Calocedrus decurrens*) were selectively removed whereas during the drought, the shade-intolerant species (*Pinus* species) died at the highest rates. Consequentially, the majority of remaining trees of all ages in high mortality areas were oak species (*Quercus kelloggii* and *Q. chrysolepis*). Fuel loads and snag basal area were significantly reduced in treated areas indicating increased future wildfire resilience and therefor higher chance of forest recovery.

"The role of Carbon depletion in conifer resistance to drought"
Jeffrey L. Lauder (UC Merced) *& E.V. Moran*
Current understanding of which traits confer drought resilience versus susceptibility in trees is still limited. During drought, theory predicts that trees with high hydraulic safety (physiological resistance to cavitation under drought stress) will survive. We leveraged the California "hot drought" of 2012-2016—more severe than any observed in the previous 1200 years—to assess how living and dead trees differed in growth and wood anatomy relative to climate. We sampled living and dead *Pinus ponderosa* and *P. jeffreyi* in multiple stands that experienced extensive drought-induced mortality in the Sierra Nevada and found that trees that died had cellular traits normally expected to confer drought resistance, while living trees grew wood with low hydraulic safety. Annual growth in living trees increased slightly or stayed constant during and following the drought, while dead trees rapidly decreased growth prior to mortality and were more sensitive to climatic extremes. We then tested the hypothesis that high hydraulic safety comes at a carbon (C) expense due to the cost of cell wall lignification. We measured total lignin and carbon concentrations in annual rings. Dead trees were found to have higher average lignin concentrations than living trees at higher elevations but not at lower elevations, and varied annually in lignin and C concentration more than living trees. Results demonstrate the C budget implications of drought defense and may have cascading effects on tree natural history by limiting C pools for other resource-intensive processes such reproduction and growth under climate change.

"Influence of snow accumulation and ephemerality on recent tree mortality in the Sierra Nevada"
Stefano Casirati (UC Merced)
Higher global temperatures and intensification of extreme hydrologic events such as droughts can lead to a premature mortality of healthy trees that are important to forest ecosystem

functioning. In a Mediterranean climate like California with two distinct seasons, timing of precipitation (mostly in winter) is out of sync with the peak summer growing season. As a result, forest ecosystems relay heavily on seasonal water storage to meet evapotranspiration. However, plant accessible soil moisture storage alone is not enough for sustaining the ecosystem productivity. In mountain ecosystems snow plays a critical role in storing the winter precipitation and slowly releasing it to the root zone during the spring and early summer. The degree to which snow can modulate the desynchrony between precipitation and evapotranspiration depends not only on amount of precipitation but also temperature that determines the phase of precipitation and rate of snowmelt.
In this work, using Generalized Additive Models (GAM) we show how variations in the amount of snow and the snowline elevation influence and relate to the patterns of recent (2004-2017) tree mortality in the Sierra Nevada Region. We have used remote sensing based indices as a proxy for tree mortality along with a classification of snow persistence and ephemerality. Initial results indicate a strong correspondence between the extent of tree mortality and snow. Even though the magnitude of snowfall at lower and mid-elevations of the Sierra Nevada is small, proportionally it plays a bigger role due to overall lower precipitation when compared upper elevations.

"Insects and pathogens are key mediators of climate change effects on tree mortality in the Sierra Nevada"
Adrian Das (U.S. Geological Survey)
Tree mortality in the Sierra Nevada has shown the effects of climatic change in two different yet related ways: (1) background mortality rates have more than doubled in recent decades (a long-term, chronic increase in mortality), and (2) Sierra Nevada forests recently additionally experienced a massive, drought-induced tree mortality event (acute mortality). While these changes were of dramatically different intensities and at far different temporal scales, they appear to share a common thread: being significantly mediated by biotic agents of tree mortality (insects and pathogens) and having outcomes that are not necessarily consistent with the mechanisms of tree mortality that commonly dominate forest model outputs (such as competition). Our research has shown that background mortality in old-growth, mixed-aged forests is often driven by biotic agents and that background mortality processes lead to changes in spatial patterns and mortality risk that can only be understood by taking into account non-competitive processes. Additionally, we found that acute, drought-related mortality can be driven in large part by the host-tree preferences of the bark beetles that ultimately cause tree death. Furthermore, some biotic agents that are generally considered 'secondary' or unimportant can begin to play an unexpectedly large role during drought. In short, understanding how forests will change in response to climatic changes will require a more nuanced understanding of the interactions between more easily quantified factors, such as competition and drought intensity, and the response of biotic mortality agents, which are frequently the proximate cause of tree death.

Session 6: Seedlings and herbaceous plants

"Climate and seed availability drive postfire conifer regeneration: scenario planning for the 21st century"
Joseph A. Stewart (UC Davis)
Large, severe fires are becoming more frequent in the Southwest, which can kill all trees over thousands of acres. Forest regeneration in these areas may be limited because seeds must

travel long distances to recolonize burned areas and may face increasingly hotter, drier conditions when they do arrive. In low elevation forests of California, previous work shows that post-fire regeneration success is highly dependent on seed availability, long-term microsite moisture conditions, and, potentially, short-term climatic conditions during the post-fire recovery interval. Here, we extend a spatially-explicit model of post-fire seedling establishment for low elevation forests in California to incorporate variability in post-fire climate and seed inputs. Our specific objectives were to: (1) explore the utility of post-fire climate and seed availability in predicting conifer regeneration, (2) produce spatially explicit models for predicting conifer regeneration across burned landscapes of California, and (3) characterize variability in seed production and availability. We produced spatially explicit models of recruitment for three taxonomic categories: pines (*Pinus*), and firs (*Abies*), and all conifers. Preliminary results suggest a strong effect of post-fire precipitation in pines with a more modest effect for firs and all conifers. Recruitment of firs appeared to be strongly dependent on seed availability. Pines appeared to be more limited by competition than by seed availability. Seed production varied markedly between years, with partial synchrony between pines and firs and between stands located ca. 150 km apart.

"Climate effects on growth and survival of Sierra Nevada seedlings"
Emily Moran (UC Merced)
Seedling establishment and growth is a prerequisite for local population persistence and adaptation as well as for range expansion. While adult trees can often persist through extensive climatic variation, the conditions allowing seedlings to survive and grow are often more restrictive. Here I discuss two analyses of climate effects on growth and survival of Sierra Nevada seedlings. The first made use of natural seedling growth and survival data collected by the USGS in Sequoia and Yosemite between 1999 and 2009. We found that higher July maximum temperature, either directly or as a deviation from the long-term plot mean, tended to be associated with lower survival and growth across species. Precipitation and snow effects were weaker and more variable. While this suggests that increased temperatures might have negative effects on many tree populations, local adaptation to different climate regimes is a common feature across many widespread tree species. The second, ongoing analysis examines performance across elevation gradients of 13-14 populations of three pine species: low-elevation ponderosa pine, mid-elevation Jeffrey pine, and high-elevation western white pine. The first batch of seedlings was planted in Sequoia National Park in spring 2017. The highest survival relative to site mean survival has been observed in seedlings planted in sites with average conditions 1980-2010 that are slightly cooler and wetter than their home sites, suggesting maladaptation to recent local climate conditions. Growth, however, tended to be higher at warmer sites. Understanding these responses may help forest managers make decisions when choosing seed sources for restoration plantings that will have to cope with altered future conditions.

"A newly established operational provenance test sheds light on seed transfer under a changing climate"
Jessica Wright (USDA Forest Service)
Seed transfer in California is guided by the Seed Zone map, which was published in 1970, before climate change was part of the conversation. When trees are planted after stand-replacing wildfire, Forest Silviculturists need to decide what source location they will get their

seeds from. With a changing climate, questions are being asked whether or not seedlot selection should be based on climate matching, or even projections of future climate. Tools have been developed to help facilitate this process, for example, the seedlot selection tool (https://seedlotselectiontool.org/sst/). The best way to test whether this approach is effective is to use provenance test data. Provenance tests are common gardens of trees, grown from seeds collected across the species range. Here I describe a new provenance test that is advancing this approach by incorporating experimental tests plots within the context of an operational post-fire tree planting project. The Eldorado National Forest is currently conducting an extensive ecological restoration project after the King Fire burned 97,000 acres in 2014. Three, twelve acre test plots were planted between 2017 and 2019 with 12 different sources of ponderosa and sugar pine in each plot. Early results suggest differences between the species in both growth and survival across seed sources. Data such as these will help to inform seed sourcing decisions by shedding light on how seedlings from across the Sierras do in an operational planting environment.

"Survival in a drier world: A study of rapid adaptation in response to drought in the Sierra Nevada endemic monkeyflower"
Lillie K Pennington (UC Merced)
Increased climate variability is a looming threat to plant populations—plants must respond with plasticity, adaptive evolution, or face extinction. The drought in California from 2012-2016 was historic and exceptional—the driest event in roughly 1,200 years—and gives an unprecedented opportunity to examine whether plants can rapidly adapt to changing climatic conditions. Seed collections of *Erythranthe laciniata* dating back a decade provided the material for a resurrection study: by breeding seeds from before and during the drought, we can determine if plants experienced a rapid adaptive response to drought. In an initial breeding generation, it was found that time to seedling emergence differed between drought and pre-drought generations, and days to first flower differed significantly by elevation, suggesting local adaptation to climate across the range. In a second breeding generation, I grew descendants from the initial growout in common conditions. I measured the same traits to verify differences between drought and pre-drought generations. Drought plants again emerged earlier than pre-drought, and days to first flower differed across the species' range. These results provide evidence of a rapid, genetic response to drought, and provide insight into the ability of natural populations to respond to rapid climate change.

<u>Session 7: Climate variation and nutrient cycling</u>

"Fossilized drip-water from a Sierra Nevada Cave reveals stadial vs. interstadial variability in precipitation stable isotopes"
Barbara Elaine Wortham (UC Davis)
Speleothem calcite stable isotope values (δ18Occ and δ13Ccc) are considered reliable proxies of regional climate. Previous studies have shown that δ18Occ can be used to interpret changing continental temperatures and precipitation dynamics. However, the δ18O of speleothem calcite is not a direct measurement of the δ18O of drip water or precipitation given that temperature effects the water-calcite isotopic fractionation. Fluid inclusion stable isotope values (δ18O and δ2H) are considered to be more representative of precipitation as fluid inclusions are the fossilized drip-water that promoted the growth of a given stalagmite. In turn, inclusion waters have great potential as proxies of paleo-precipitation δ2H and δ18O if a clear relationship between drip-water stable isotopic composition and local precipitation

can be established and as proxies of paleo-temperature when compared to the host calcite δ18O. We analyzed fluid-filled inclusion in a stalagmite from the western Sierra Nevada to reconstruct conditions over the Pacific, the precipitation source for California. Fluid δ18O and δ2H values indicate that for colder periods such as the Last Glacial Maximum, precipitation was more negative, indicating a North Pacific source. Furthermore, fluid inclusion δ18O and δ2H values are consistent with the modern local meteoric water line (δ2H = 7.8 x δ18O + 9.2) in warm periods but cluster around a δ18O average of -13.1 ‰ during the Last Glacial Maximum (LGM; >17.5 ka) and an average of -11.8 ‰ during the Older Dryas (OD; 13.5 to 14.5 ka). The shift in fluid δ18O and δ2H values from the LGM through OD along with the difference in values of stadial and interstadial populations may record a 'stadial precipitation regime' governed by continental ice dynamics in North America. This record improves our understanding of the proxy δ18Occ record for this Sierran stalagmite and provides new insight into the variability in atmospheric organization during the waning of the Laurentide ice sheet and warming of the last deglaciation.

"Nighttime relief from hot spells within a mountain river corridor - probing the record of cold air pooling in Devil's Postpile"
Monica Buhler (Devil's Postpile National Monument)
A high density array of temperature records collected within and adjacent to Devils Postpile National Monument (DEPO) in the Middle Fork of the San Joaquin River provide a detailed account of the occurrence of cold air pooling (CAP) over the last decade. The observations contribute to DEPO's long-standing multi-disciplinary environmental monitoring program to support science-based adaptation in managing resources, and provide the public with relevant state-of-the-art environmental information. The DEPO temperature records were initiated across and along the San Joaquin River valley in 2008 and are maintained through present by DEPO staff, in collaboration with university support. More complete understanding of CAP occurrence has important implications for diverse mountain ecosystems, since nocturnal cooling may create microclimate zones that help sustain specific habitats such as wet meadows and riparian corridors. The DEPO temperature sensor array spans a range of about 1000 meters of elevation from the river bottom to bordering mountain ridges, allowing us to track CAP development and variation. Several CAP characteristics are revealed including spatial structure, regular temporal variability on diurnal and seasonal time scales, and anomalous behavior from synoptic to interannual time scales. The extent to which cold air pools develop in summer, even during heat waves, will be addressed since their function as a refugium from unfavorable warmth depends on whether they operate during extreme conditions.

"Soil organic phosphorus speciation changes with climate"
Morgan Barnes (UC Merced)
Soil organic phosphorus (P) has been identified as a critical component of bioavailable P, especially in late stages of ecosystem development. Organic P turnover rate is affected by the stabilization ability of the soil (i.e. organic matter, minerals, microbial activity) and also abiotic factors (i.e. temperature, precipitation, light). However, our understanding of P transformations in the soil, especially with ecosystem development and global climate change, is complicated due to the complexity of P species. Organic P is found in a variety of forms including monoesters, diesters, and phosphonates which vary in bioavailability. We used novel approaches including 31P nuclear magnetic resonance spectroscopy (NMR), Fourier-

transformed ion cyclotron resonance mass spectrometry (FTICR MS), and X-ray absorption near edge structure (XANES) to identify and quantify organic P stock and speciation along two elevational gradients in contrasting climates. Preliminary findings demonstrate differences between gradients, where the arid White Mountains (WM) is in the beginning stages of soil development compared to the Mediterranean Southern Sierra (SS). Overall, the SS has a greater organic P stock and it persists with depth into the mineral soil compared to the WM. Organic P is dominated by monoesters at all sites, however the most productive (mid-elevation; not limited by temperature or precipitation) sites at the SS have the largest proportion of diesters. Although these sites are the most developed, vegetation is not utilizing all of this readily bioavailable organic P species. Foliar N:P ratios increase with weathering intensity, indicating P does become more limiting relative to N.

Poster session 2

"Evaluating the effects of drought and mortality on soil moisture recovery and drying patterns in the central Sierra Nevada"

Megan Pinkus (UC Merced, Sierra Nevada Research Institute) *& Erin Stacy*

In California's Sierra Nevada, soil water storage of winter precipitation supplies more than 95% of year-round moisture, in turn providing water for vegetation growth during the warm and dry summer growing season. Water stress was a contributing factor for a massive tree mortality event in the southern Sierra Nevada. To evaluate the effects of soil moisture timing on vegetation growth, we monitored soil moisture and ET of mid-elevation forests at two sites (1160 m and 2000 m in elevation). Between 2011 and 2018, we measured volumetric water content using a combination of soil moisture sensors and remote monitoring (from a COsmic-ray Soil Moisture Observing Systems, or COSMOS) to monitor soil moisture, and eddy-covariance flux towers to monitor evapotranspiration (ET). At the 2000 m site (mixed conifer forests), annual ET was mostly consistent through the years, with a 10-20% reduction during the drought years. At the 1160 m site (ponderosa pine-oak forests), annual ET was reduced as much as 50% in the later drought years when compared to 2010 and 2011; annual ET remained low in 2016, the first year after the drought. Summer drying rates are similar amongst years, but the timing of rapid drawdown varies by more than 100 d between years due to incoming precipitation. Near the end of the drought, in 2014 and 2015, volumetric soil water content peaked at 30% (compared with 38-58% in other years), and high soil moisture periods were especially short. This research is part of the NSF-supported Southern Sierra Critical Zone Observatory.

"Tracking a tree killer: White pine blister rust in the southern Sierras from 1995-2017"

Jennifer Cribbs (USGS & National Park Service Sierra Nevada Network Inventory and Monitoring Program, & UC Berkeley), *Joan Dudney, Matt Cahill, Jonathan Nesmith, Adrian Das, Nathan Stephenson & John Battles*

White pine blister rust (WPBR) is an exotic fungal pathogen (*Cronartium ribicola*) first introduced into western North America around 1910. It has caused dramatic population declines in several species of 5-needled pines ("white pines"). White pines typically act as critical foundation species, and their loss can have complex cascading effects throughout forest ecosystems.

WPBR was first discovered in the southern Sierra Nevada Mountains in 1969. In the late 1990's, researchers established 154 long-term monitoring plots throughout Sequoia and Kings Canyon National Parks (SEKI) using a stratified random sampling design to create a formal baseline assessment of the extent and severity of WPBR infection. From 2013-2017, a collaboration between the National Park Service, US Forest Service, US Geological Survey and UC Berkeley allowed for a thorough resurvey of the plots. Crews travelled to remote wilderness to find permanent markers, reconstruct the original plots and assess the white pines for overall health and WPBR.

The incidence of blister rust in SEKI has increased overall, particularly in the western white pine (*Pinus monticola*) and whitebark pine populations. Interestingly, blister rust remains unconfirmed in foxtail pine (*Pinus balfouriana*). WPBR has decreased for sugar pine (*Pinus lambertiana*), though this may be due in part to high mortality for sugar pines. Unlike initial assessments predicted, our results suggest that blister rust will continue to threaten high elevation white pines in the Sierra Nevada and may become an increasing threat for the highly vulnerable whitebark pine.

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"Incorporating evolutionary potential into forest modeling under projected future climates"

Dean Wu (UC Merced)

Climate change will increase temperatures and alter precipitation patterns, resulting in changes in forest composition and species ranges. Sierra Nevada forests have already suffered extensive tree mortality due to drought conditions in the early 21st century, and it is unclear how they will be impacted under increasingly extreme future climate regimes. Trees exhibit heritable variation in growth and survival traits which may impact species distribution and forest dynamics under altered selection pressures expected to occur under climate change conditions. Here, demographic responses in Sierra Nevada tree species are modeled under different potential future climates using a modification of the SORTIE-ND forest simulator incorporating heritability in climate responses to assess possible effects of evolutionary potential on climate adaptation in Sierra forest trees. SORTIE-ND is an individual-based simulator originally developed for deciduous forests in the eastern US, but which has been parameterized for simulation of various forest types. This project is the first to parameterize SORTIE-ND for the summer-dry forests of the Sierra Nevada, as well as the first in which both interspecies interactions and the potential for intraspecific evolution have been incorporated into a forest simulation model.

"The giant sequoia genome project and genetic resource management of California forests"

Alison Scott (UC Davis)

The California endemic giant sequoia (*Sequoiadendron giganteum*) grows in fragmented groves that lie on the western slopes of the Sierra Nevada. About a third of these iconic trees

were logged historically, and in some groves natural regeneration was impacted by fire suppression policies. While the remaining giant sequoias are largely protected, they now face climate change related threats including intense drought and bark beetle infestations.
We can use genomic tools to aid in the preservation and conservation of giant sequoias in in a changing climate, for example by identifying trees that may be more robust in drier environments and selecting candidate groves for ex situ genetic conservation. Developing these genomic tools is one aim of the Redwood Genome Project.
We began by sequencing and assembling the entire genome of giant sequoia. We used a combination of short Illumina reads and long Oxford Nanopore reads, bolstered with Dovetail chromosome conformation capture libraries, for a total of 8.125Gbp of assembled sequence. The assembly contains eleven chromosome-scale scaffolds, including the longest scaffolds assembled to date in any organism.
To identify genetic variation and local adaptation, we are genotyping a greenhouse collection of 100 giant sequoia clones representing their range in the Sierra Nevada. This greenhouse collection will also be phenotyped for a host of physiological traits which may play a role in surviving drought conditions. Combining these data we will curate genetic markers for an expanded genotyping project, including thousands of individual trees from across the range for an environmental association study.

"Applying adaptive genetic variation in giant sequoia to climate related forest management questions."

Brian Allen (UC Davis)

Giant sequoias (*Sequoiadendron giganteum*) grow in a restricted range on the western slope of the Sierra Nevada Mountains. During the 2014 extreme drought, many old-growth sequoias within Sequoia and Kings Canyon National Parks displayed drought-induced canopy die-back, indicating vulnerability to dry climates. California climate models predict drought frequency and severity to rise in the coming decades. Since sequoias are wind pollinated and lack a long-range seed dispersal mechanism, an accelerated warming climate will likely shift the preferred habitat faster than the species can naturally adapt to it. Therefore, assisted migration of individuals genetically adapted to arid climate conditions may prove necessary to help the species persist, but current genotype validation practices are time and cost intensive. To address this, we will use the recently sequenced giant sequoia reference genome to determine genetic variation across thousands of genes by genotyping 1,152 range-wide georeferenced old-growth sequoias. These data will describe both the broad scale genetic diversity within groves and distinct differences between individual trees. Adaptive genetic variation will be identified by comparing allele frequencies to a suite of critical range determining climate variables including annual precipitation and temperature. Trees with alleles significantly correlated with arid environmental conditions are ideal cloning and seed stock resources for numerous climate-related sequoia management efforts. For instance, specific individuals can be selected to bolster genetically deficient existing groves and matched to range expanding ex-situ plantations. Last, this genotyping dataset will be publicly accessible to facilitate future research into other genetic inquiries at a fraction of the cost.