2012 NPS George Melendez Wright Climate Change Youth Initiative Fellowship and Internship Program

FELLOWS' FINAL RESEARCH REPORTS

DECEMBER 31, 2013

Submitted by the University of Washington
Principal Investigator: Lisa J. Graumlich

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2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Rachael Bay
University: Stanford University
Start date: 05/31/2012
End date:12/31/2013

Brief project summary:

Coral reefs ecosystems are extremely valuable, providing food and coastal protection as well as sheltering millions of marine species. Corals, which form the foundation of this ecosystem, are particularly sensitive to changes in their environment. For this reason increasing ocean temperatures associated with climate change threaten coral reefs worldwide. Variance in thermal tolerance does exist within species, however. For example, in the National Park of American Samoa on Ofu Island, corals from adjacent backreef pools with very different temperature regimes exhibit differences in their ability to tolerate heat stress. This suggests that thermal history may impact heat tolerance – a physiological process known as acclimation. However, the rate and mechanism of this process is not fully understood. I conducted a controlled experiment to test the rate and mechanism of acclimation in the finger coral, *Acropora nana*. I used flow-through seawater tanks capable of temperature manipulation to acclimate corals to three different temperature regimes. At different time points during this acclimation, I tested their thermal tolerance using an acute heat stress assay. I also used high-throughput sequencing to examine changes in gene expression throughout acclimation. Understanding the process by which corals can increase their thermal tolerance will help to best conserve them in the future.

Research Approach:

Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

From previous status report:

Although the general approach is as proposed, the question I am addressing has slightly changed due to some logistical difficulties. Originally, I proposed to compare acclimation in capabilities in individuals of *Acropora hyacinthus* from two adjacent backreef lagoons in the National Park of American Samoa on Ofu Island. One change is that I have decided to instead use the species *Acropora nana*, which forms small colonies that are extremely abundant and therefore easier to sample. This will result in the publication of a new coral transcriptome which can act as a genetic resource for future studies. In addition to switching species, I have decided to simplify the question, simply examining acclimation as a process with no comparison of individuals from different lagoons. Rather than using individuals from the backreef, I used individuals from the reef crest, which are unlikely to have experienced high temperatures. This will allow me to characterize the acclimation process without the confounding factor of long-term thermal history. In the long run, I think these results will be more general that previously planned and could help predict the response of corals in different environments to climate change.

Location(s) of Research:
National Park of American Samoa (Ofu Island)

Key Findings:

1) Corals subjected to sub-lethal increased temperatures – either higher stable temperatures or a variable temperature regime – increase their heat tolerance within one week.
2) Acclimated corals increase their chlorophyll concentrations, suggesting the mechanism for acclimation may be an increase of symbiotic algae.
3) Preliminary gene expression results show approximately 30 genes – mostly involved in metabolism – that are upregulated during acclimation to higher temperatures.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

- Presentation at National Park office in American Samoa – 9/24/2012
- Presentation and touch tank presentation at local school on Ofu – 9/18/12
- Science project with local school on Ofu – 8/27/13
- Presentation at GMW biennial meeting – 03/13
- Presentation at Oceans Colloquium, Monterey, CA – 04/13

Additional Funding:
Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

Dr. Earl H. Myers & Ethel M. Myers Oceanographic and Marine Biology Trust Award - $1500
Women Divers Hall of Fame Graduate Conservation Scholarship- $1000

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*


Ocean Clear
Red Sea


Read to Learn
Discipline Chart
Writing Process
Homework

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Brian Harvey
University: University of Wisconsin – Madison
Start date: June 2012
End date: May 2014

Brief project summary:

The potential ecological consequences of climate change will fundamentally challenge National Park Service (NPS) managers to think differently about the future of park ecosystems. For western park regions, the combination of warmer climate and altered fire regimes (fire frequency, size, and severity patterns) could lead to rapid and widespread changes in vegetation and wildlife habitat. The recent increase in fire size and frequency on NPS land and surrounding wilderness areas of the west offers a timely opportunity for testing whether the spatial patterns of fire severity are changing in a period of warming climate and whether these changes are impacting postfire forest reestablishment.

My project addresses this research need by examining recent (1984-2010) temporal trends in spatial patterns of burn severity in all large wildfires (> 200 ha) across the national parks of the N. Rockies (Grand Teton NP, Yellowstone NP, and Glacier NP) and adjacent wilderness areas using remote sensing, extensive field data, and spatial analysis. Further, I am developing develop statistical relationships between downscaled climate variables and measures of spatial heterogeneity of burn severity for each fire in different topographic contexts and forest types and identify areas where changes are most rapidly occurring. Additionally, I am comparing tree regeneration patterns in high-severity (stand-replacing) patches from recent fires in common forest types of the N. Rockies to test for species-specific responses to different spatial burn pattern configurations in contrasting post-fire climate conditions.

The proposed research is progressing on schedule per the protocols in the original proposal. In summer 2012, I sampled 185 burn severity plots distributed throughout the northern Rocky Mountains that have been used to generate field-validated burn severity maps for the national parks of the northern Rockies (YELL, GRTE, GLAC) and surrounding wilderness areas. Field-validated burn severity maps were used to direct field sampling in summer 2013, during which I sampled 184 tree regeneration plots in stand-replacing fire patches (106 in the Greater Yellowstone Ecosystem; 78 in Glacier National Park). Plots were stratified by post-fire climate, with approximately half of the plots located in fires that were followed by cool/wet post-fire climate years and half of the plots occurring in fires that were followed by warm/dry post-fire climate years. Early trends indicate steady patterns of heterogeneity in wildfires occurring between 1984 and 2010. Post-fire tree regeneration in stand-replacing fire patches was surprisingly high, but decreased with distance to the edge of stand-replacing patches and in fires followed by warmer/drier conditions. Further analyses are underway for both fire severity patterns and post-fire tree regeneration patterns, and manuscript preparation is planned for spring 2014.

Research Approach:

Data acquisition

Fire perimeters and Landsat TM-derived burn severity layers for all fires in the study area (1984-2010) were downloaded from the Monitoring Trends in Burn Severity website (mtbs.gov). Fires occurring in non-forest areas (< 50% of area within burn perimeter was covered by forest pre-fire) were excluded. Fire severity was mapped using the relative differenced normalized burn ratio (RdNBR) provided in MTBS data for each fire. This RdNBR metric has been shown to be preferable to absolute measures of burn severity when comparing multiple fires across a wide region (Miller and Thode 2007, Miller et al. 2009). Preliminary analysis comparing RdNBR maps computed from Landsat images using top-of-atmosphere reflectance (i.e., images available on the MTBS website) vs. those calibrated to surface reflectance using the LEDAPS processing system (Masek et al. 2006) indicated no significant difference; therefore the RdNBR maps from MTBS were used for all analyses. The RdNBR raster grid for each fire was re-projected and clipped to the fire perimeter prior to analysis.

Burn severity field measurements

During summer 2012, 186 fire-severity plots were sampled in seven fires that burned in 2011 throughout the study area (Fig. 1). Plots in each fire were located within 100-1000 m from roads and trails for accessibility, and separated by a minimum distance of 400 m to reduce spatial autocorrelation. Each fire contained between 16 and 43 plots, depending on accessible area, and plots within a fire were equally distributed among 4 categorical fire severity classes (unburned, light surface fire, severe surface fire, and crown) (Turner et al. 1997).

Fire-caused tree mortality was recorded by classifying every fire-damaged tree > 1.4 m in the plot that was alive at the time of fire but dead at the time of sampling as killed by fire. The percentage of post-outbreak live trees and basal area that were killed by fire was used to measure fire severity on the residual canopy after the outbreak.

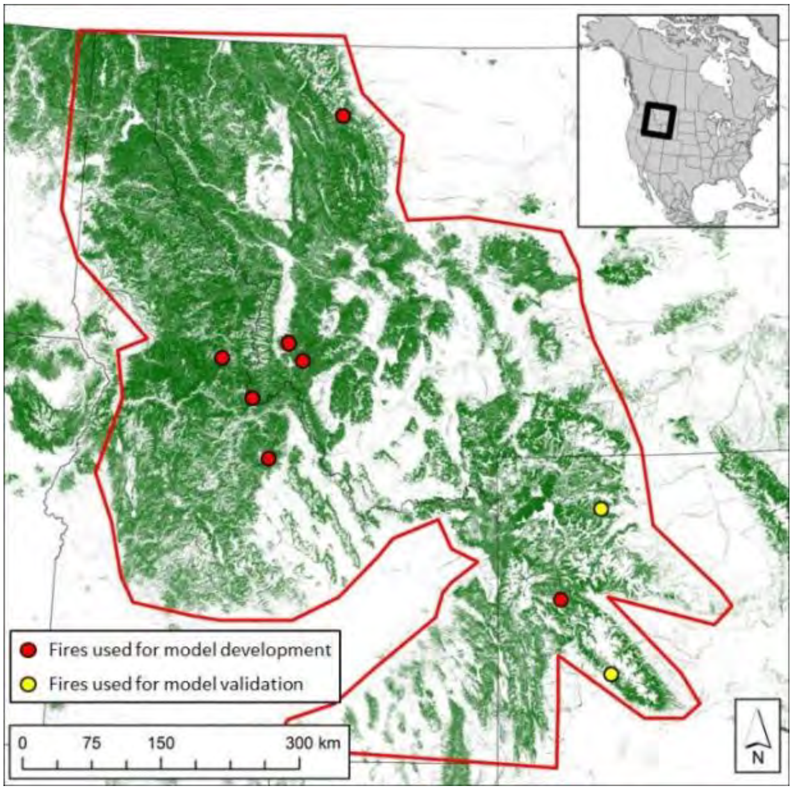

Figure 1. Location of study fires (n = 7) where field data were collected for model development (n = 186 plots in seven fires) and model validation (n = 185 plots in two fires). Green cells represent forested area (data source: NLCD).

Using field data to calibrate and validate burn severity maps

To calibrate RdNBR burn-severity maps to and ecologically meaningful value of stand-replacing fire, we developed statistical relationships between field measures of canopy-tree fire mortality and RdNBR values for our field data. We define stand-replacing fire to mean 90% of the pre-fire live basal area was killed by fire. Using the 186 field plots from fires that burned in 2011, we built linear and logistic models to test the relationship between RdNBR values and basal area killed by fire to find the best estimate of an RdNBR threshold for stand-replacing fire (> 90% of pre-fire live basal area was killed by fire). To validate the best model for predicting stand-replacing fire we used 185 independent burn severity plots from fires that burned in 2008 in the GYE. Burn severity (stand replacement or not) was predicted for each of these 185 plots based on their RdNBR value, and model performance was evaluated using predictive accuracy (user's, producer's, and overall) and the Kappa statistic.

Generating maps of stand-replacing fire

Using the RdNBR threshold for stand-replacing fire (90% basal area killed by fire), we converted each burn severity map to a binary fire severity map where each cell within the fire perimeter was assigned a 0 (RdNBR < stand replacement threshold) or 1 (RdNBR > stand replacement threshold). This was performed for each forest fire in the Northern Rockies (1984-2010).

Calculating landscape metrics of burn severity patterns

Landscape metrics were calculated initially on categorized burn-severity maps (stand replacing, less than stand-replacing) for each fire in the study period and combined in a mosaic raster for each year. Patches of stand-replacing fire were defined using a smoothing filter window (3x3 grid cells) and using an 8-neighbor rule for patch delineation prior to computing landscape metrics using Patch Analyst 5 for ArcGIS 10.0 (http://www.cnfer.on.ca/SEP/patchanalyst/).

Tracking patterns in spatial heterogeneity of burn severity among forest types, with topographic position or levels of complexity, and with climate

This component of the project is currently underway. Completion is anticipated in December 2013. Gridded topographic information has been acquired from the USGS National Elevation Dataset (NED) at ~30 m resolution to generate topographic variables (elevation, slope, aspect, topographic complexity) for each grid cell in a fire. Forest cover-type data has been acquired from LANDFIRE (landfire.gov) at 30-m resolution. Fires are being categorized by forest type and topographic context. I am using ANOVA to assess how changes in spatial heterogeneity of burn severity vary among categories. Climate data have been acquired from existing downscaled (12 km x 12 km) monthly temperature and precipitation data generated for the N. Rockies by my collaborators (Westerling et al. 2011). Each cell in the study is being assigned monthly average temperature and precipitation values. Each fire will be assigned the temperature, precipitation, and burn index (Collins et al. 2009) values (mean and 95th percentiles) from the underlying cell for a one-year time period preceding the fire, and for the duration of the fire. General linear models (with terms for spatial autocorrelation among fires) will be used to assess the relationship between climate variables and metrics of spatial heterogeneity of burn severity. Completion of this project component is anticipated by December 2013.

Post-fire tree regeneration in stand-replacing fire under contrasting post-fire climate

Using the burn severity maps generated above, fires were selected that occurred in each of the three National Parks and were followed by either anomalously warm/dry or cool/wet post-fire years (Figure 2). Fires that occurred in 1994 and 2003 were followed by at least three out of four post-fire years with relatively cool/wet climate conditions (yearly moisture deficit lower than the 1984-2012 average). Fires that occurred in 1999 and 2000 were followed by at least three out of four post-fire years with relatively warm/dry climate conditions (yearly moisture deficit higher than the 1984-2012 average).

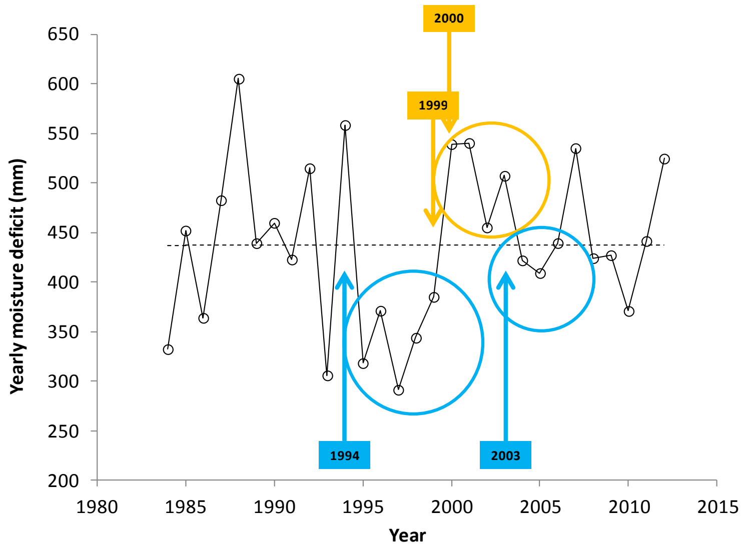

Figure 2. Yearly moisture deficit (mm) from 1984-2012 in the Northern Rockies. Fire years followed by three out of four warm/dry years are in gold; fire years with three out of four cool/wet years are in blue. Climate data are 12 x 12 km downscaled data from the entire study region (Westerling et al. 2011).

Within each fire (2 fires followed by warm/dry conditions and 2 fires followed by cool/wet conditions in YELL/GRTE; 2 fires followed by warm/dry conditions and 5 fires followed by cool/wet conditions in GLAC), post-fire tree regeneration was sampled in patches of stand-replacing fire along transects oriented perpendicular to the edge of the patch (Figure 3). Plots were located 15, 45, 90, 150, 350, 550, 750, and 1000 m from the edge of the patch, with an additional plot located 15 m outside of the patch to measure the potential seed source (Figure 4). A total of 106 plots (52 cool/wet; 54 warm/dry) were sampled in YELL/GRTE and a total of 78 plots (42 cool/wet, 36 warm dry) were sampled in GLAC. In each plot, post-fire seedlings (all trees established post-fire) were recorded in a 30-m diameter circle plot (707 m^2). Stems were recorded in 0.5-m or 2-m belts along the main axis (n-s, e-w) of the plot or in the entire plot, depending on density. If less than 100 stems were captured in the 0.5-m belts, we used the 2-m belts. If less than 10 stems were captured in the 2-m belts, the entire 707 m^2 plot was sampled. We recorded the species, age, and height (estimated by counting bud scars) for each seedling in the sample area.

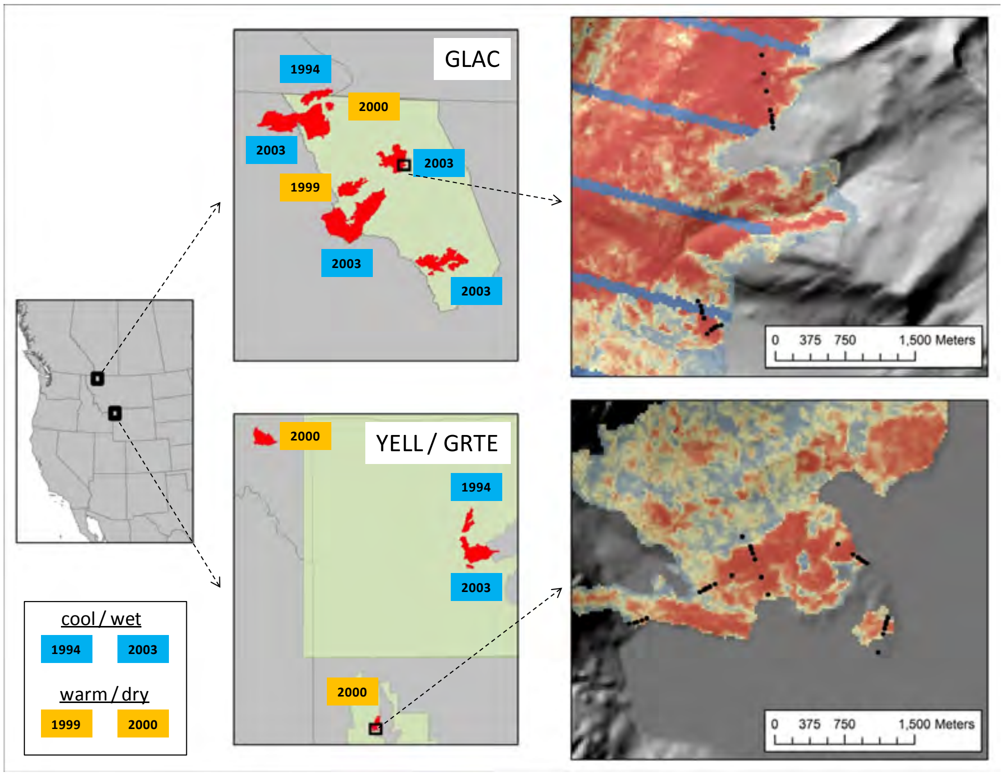

Figure 3. Study area locations (left), fire perimeters (center) and plot sample layout (right).

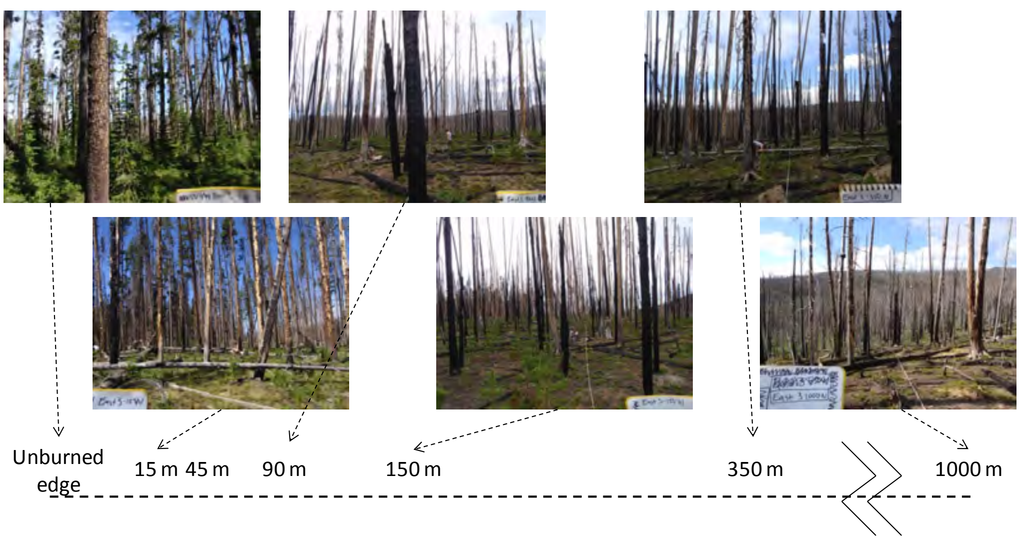

Figure 4. Schematic of plot locations along transects heading into stand-replacing burn patches.

Location(s) of Research:

Yellowstone, Grand Teton, and Glacier National Parks as well as surrounding federally designated wilderness areas. Due to the relatively small sample size of fires within each park, fire severity analyses include all forest fires in the Northern Rockies (future analyses will be conducted for fires specific to each park). All post-fire tree regeneration is limited to the national parks and adjacent wilderness areas.

Key Findings:

Fire activity in the Northern Rockies (1984-2010)

Between 1984 and 2008, a total of 733 named forest fires larger than 200 ha occurred in the N. Rockies forests, burning 3,872,568 ha in total (Figure 5). We do not present descriptive statistics of the named fires, as each named fire in the MTBS database can represent either a single fire event or multiple fire events that were managed as a fire complex. Rather, our analysis focuses on objective delineations of severely burned area within these 733 fires.

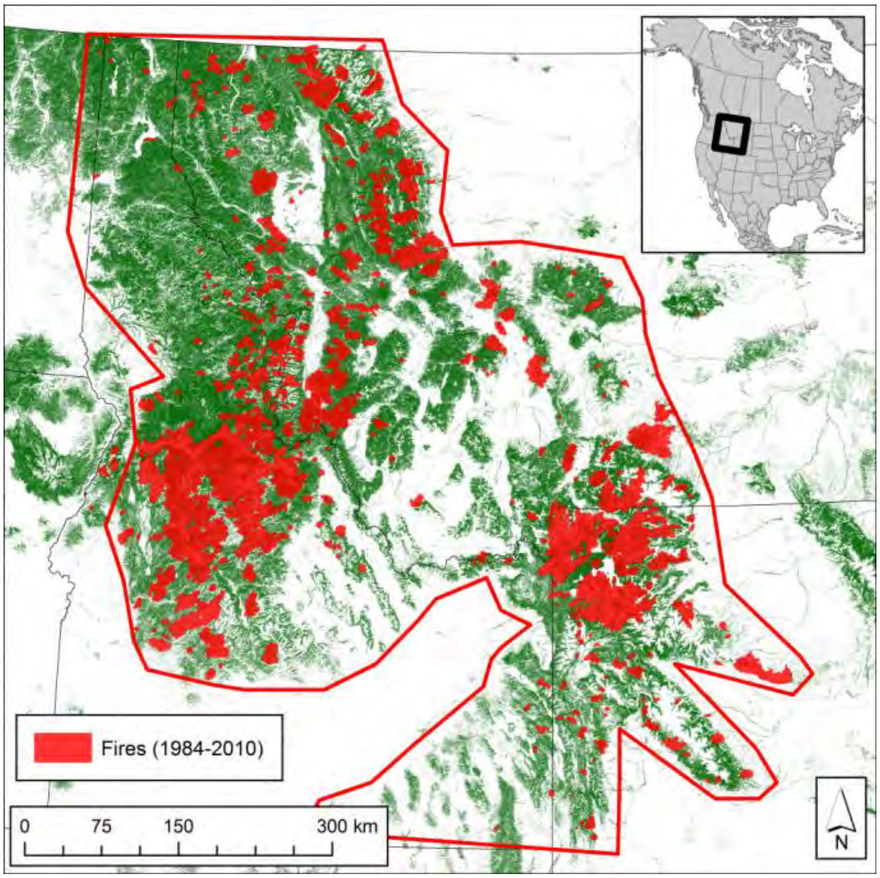

Figure 5. Northern Rockies with all forest fire perimeters (1984-2010) shaded in red.

Developing the RdNBR threshold for stand-replacing fire

Comparisons among different models used to test the relationship between pre-fire live basal area that was killed by fire and RdNBR resulted in a logistic model as the best fit (Fig. 6). The logistic model predicted that 90% of the pre-fire live basal area was killed by fire at an RdNBR value of 702. When tested against the 185 validation plots, this model performed well (71% overall accuracy, Kappa = 0.35, Table 1). User's and producer's accuracy was > 67% for all categories except the User's accuracy of non-stand replacing fire (34%). This means that our model, if anything, slightly under-predicts stand-replacing fire. Nonetheless, accuracy values are within the range of other studies (Cansler and McKenzie 2012).

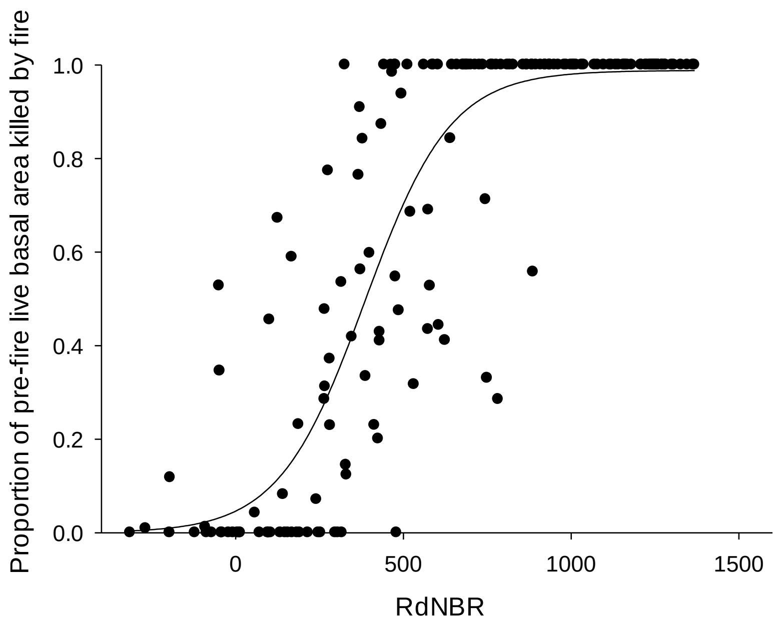

Figure 6. Final logistic model used in determining threshold of stand replacing fire (> 90% pre-fire live basal area killed by fire) from RdNBR.

Table 1. Confusion matrix and model performance for the logistic model used to map stand-replacing fire across the study area.

	Observed		
Predicted	Non stand-replacing	Stand-replacing	User's accuracy
Non stand-replacing	26	50	34%
Stand-replacing	3	106	97%
Producer's accuracy	90%	68%	

Overall accuracy = 71%, Kappa = 0.35

Amount and proportion of stand-replacing fire (1984-2010)

Of the nearly 4 million ha of forest that burned in the Northern Rockies between 1984 and 2010, 33% (1,292,587 ha) burned as stand-replacing fire (Fig. 7). The total area burned and the total area burned as stand-replacing fire fluctuate annually (Fig. 8A, B), with notable spikes in 1988, 2000, and 2007. The proportion of fires that burned as stand-replacing fire also varied annually, and ranged from 1% (1995) to 49% (2004). From 1984 to 1999, more than 30% of the burned area was stand replacing in only 6 out of 15 years; this increased to 9 out of 10 years in the last decade (2000-2010) (Fig. 8C).

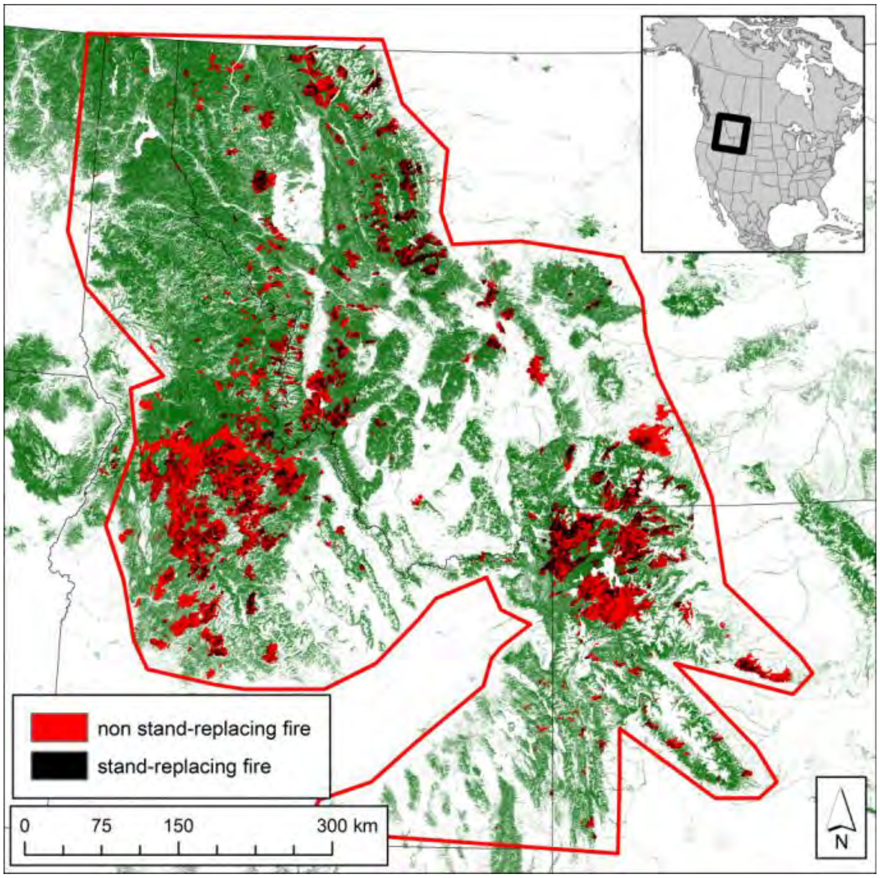

Figure 7. Study area with all forest fires for all years. Areas burned at less than stand-replacing are shown in red and areas that burned at stand-replacing are shown in black.

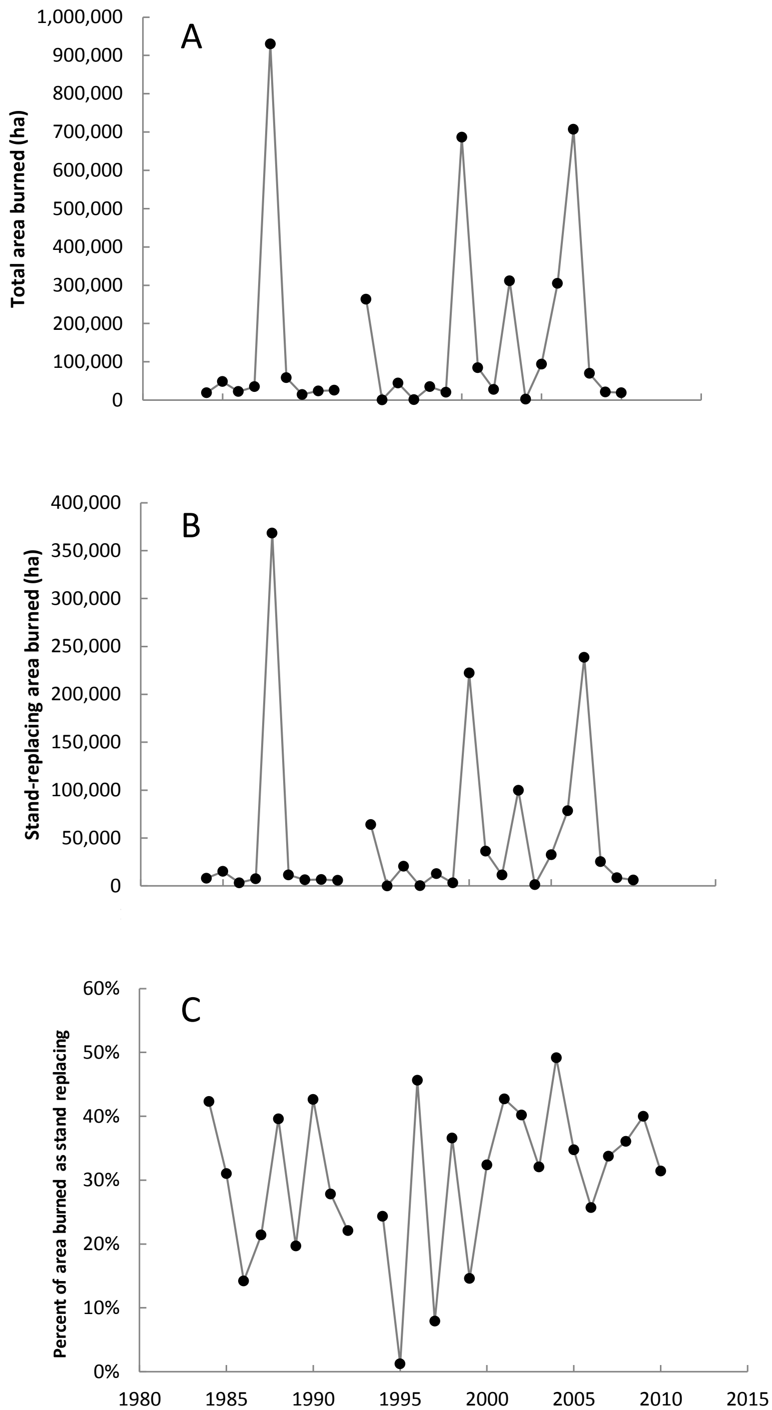

Figure 8. Total area burned overall (A) and as stand-replacing fire (B), and percentage of burned area as stand-replacing fire (C) for all forest fires (1984-2010) in the Northern Rockies, by year.

Configuration of stand-replacing fire (1984-2010)

The 1,292,587 ha that burned as stand-replacing fire between 1984 and 2010 was distributed among 173,183 individual patches. Patch size ranged from 0.09 ha (one Landsat TM pixel) to 25,584 ha, with 75% of patches smaller than 1 ha (Fig. 9). Maximum patch size did not exceed ~2,500 ha in most years; the large fire years of 1988, 2000, and 2007 being exceptions (Fig. 10).

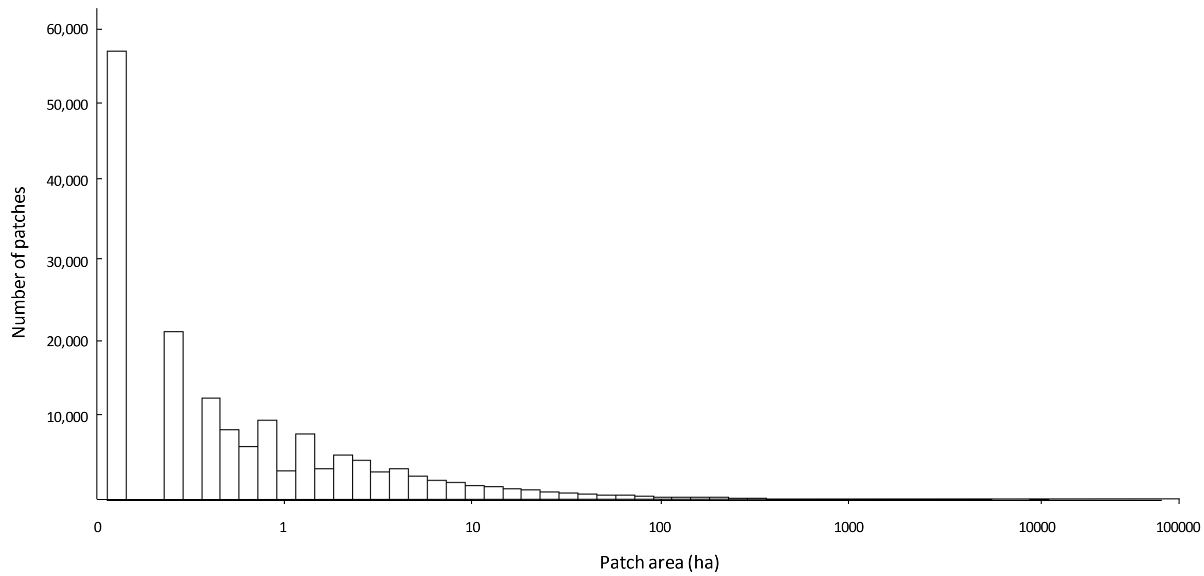

Figure 9. Frequency distribution of all patches of stand-replacing fire (*n* = 173,184) in Northern Rockies forests (1984-2010) by patch size. X-axis is log-scale.

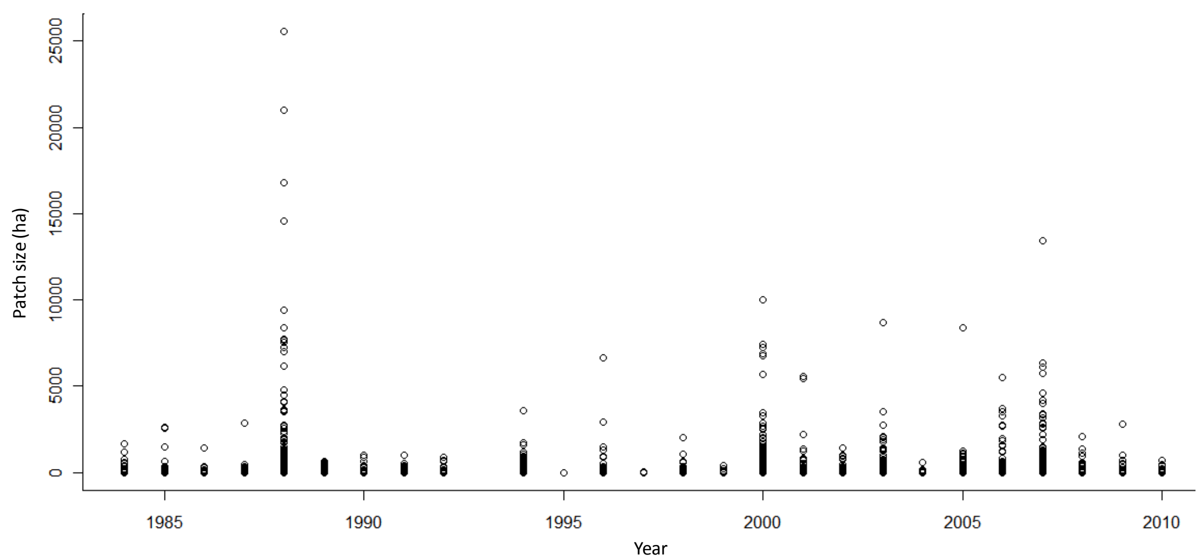

Figure 10. Patch sizes (ha) for stand-replacing fire (*n* = 173,184 patches) in Northern Rockies forests (1984-2010).

The cumulative frequency distribution for all fires across all years indicates that 50% of the total burned area occurred in patches larger/smaller than ~1,000 ha (Fig. 11A). Separate cumulative frequency distributions for each year indicated year-to-year variability in the proportion of stand-replacing fire in small or large patches (Fig. 11B). No significant ($P > 0.05$) trend over time was apparent, as the patch size representing the 50th

percentile of the total stand-replacing area burned did not change over time (Fig. 12). Mean patch size was 7.5 ha (se = 0.35), and was annually variable (Fig. 13), but showed no significant trend over time ($P > 0.05$). Yearly edge density for stand-replacing fire (m of edge per ha^{-1} of area) also showed no significant ($P > 0.05$) trend over time (Fig. 14). Further analyses are underway to asses other metrics of the configuration of stand-replacing fire (e.g., area-weighted measures of patch size and shape), and examine fires individually.

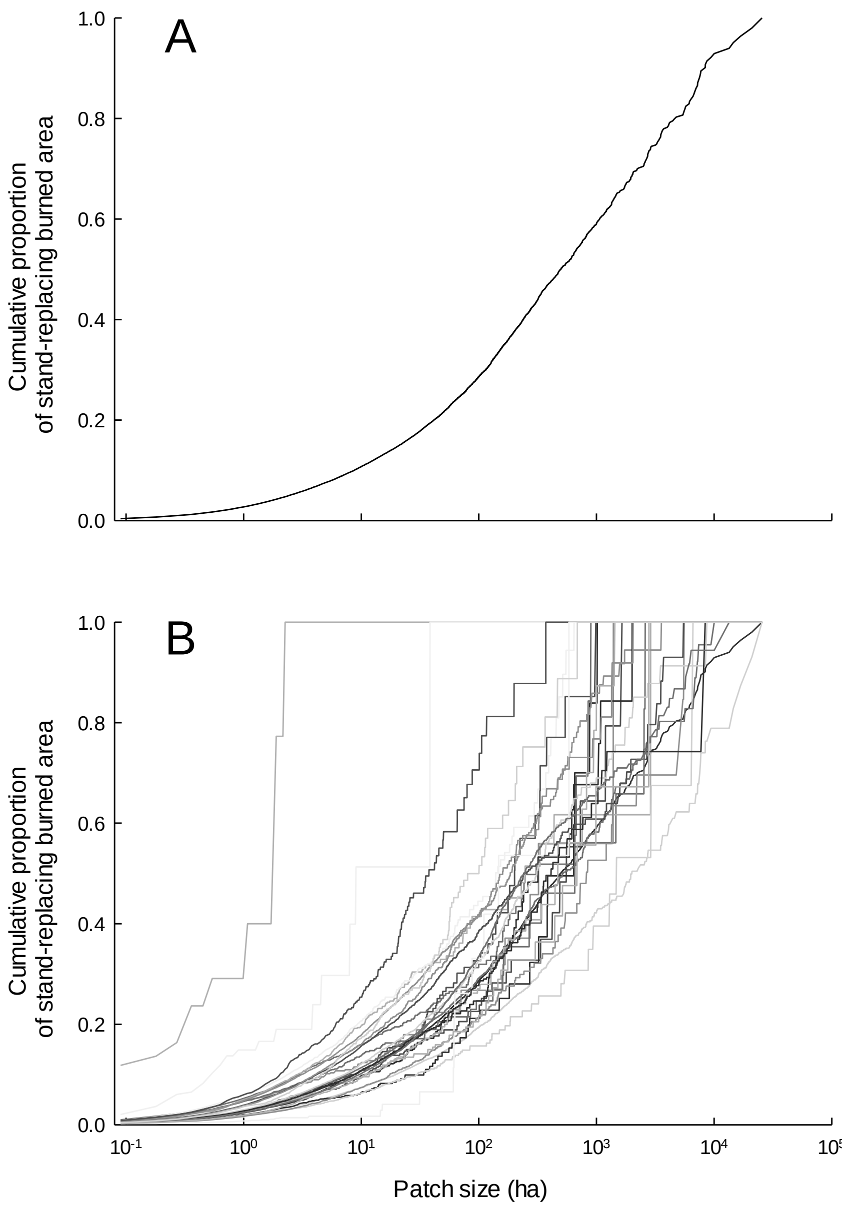

Figure 11. Cumulative frequency distribution of stand-replacing burned area (y-axis) with increasing patch size (x-axis) in all years combined (A) and in each year separately (B). Colors in (B) grade from light (1984) to dark (2010). X-axis is log-scale.

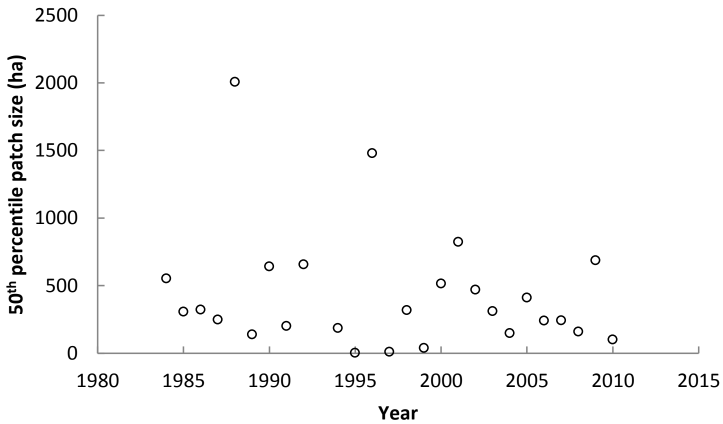

Figure 12. The 50th percentile patch size (patch size from cumulative frequency distribution at which 50% of stand-replacing area was burned, in ha) in each year. There was no significant trend over time ($P > 0.05$).

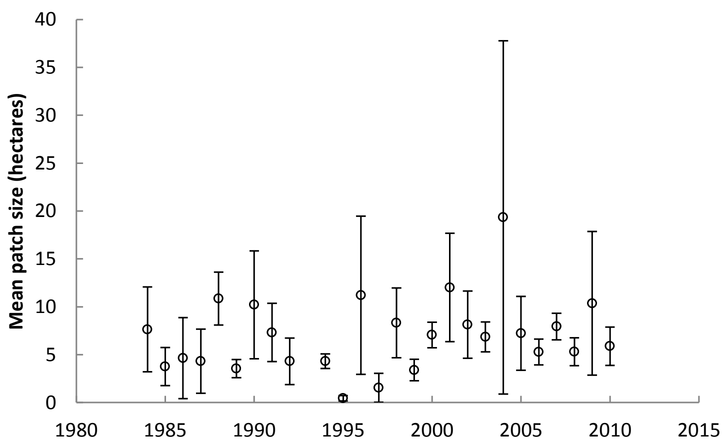

Figure 13. Mean patch size (ha) of stand-replacing fire by year. Error bars are 95% confidence intervals. No significant change over time ($P > 0.05$).

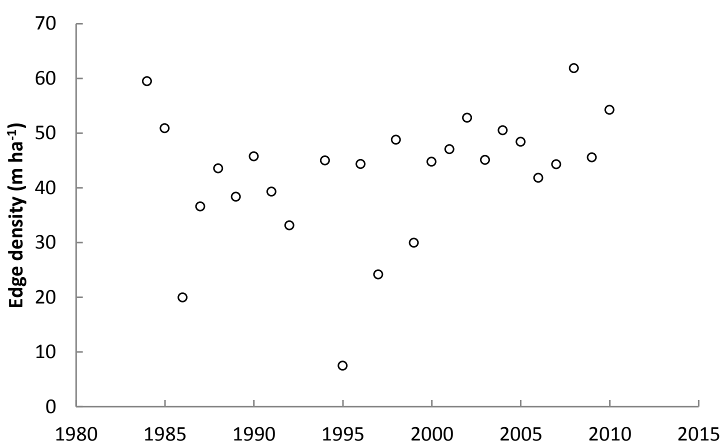

Figure 14. Edge density (m ha^{-1}) for stand-replacing fire. Edge density showed no change over time ($P > 0.05$).

Post-fire tree regeneration in stand-replacing fire patches followed by contrasting climate

Ongoing analyses are accounting for the age of post-fire seedlings; therefore seedling data have been normalized by year (e.g., tree seedlings per hectare per year) to make comparisons across fires and plots. Post-fire tree regeneration was significantly affected by distance to the edge of the stand-replacing burn patch in YELL/GRTE (Fig. 15A) and GLAC (Fig. 15B); however the effect of distance was weaker and the overall seedling density was higher in GLAC. Seedling density was significantly ($P < 0.05$) higher in fires that were followed by cool/wet post-fire climate years. Further analyses are underway to test for species-specific responses and account for distance-to-edge and climate in the same model.

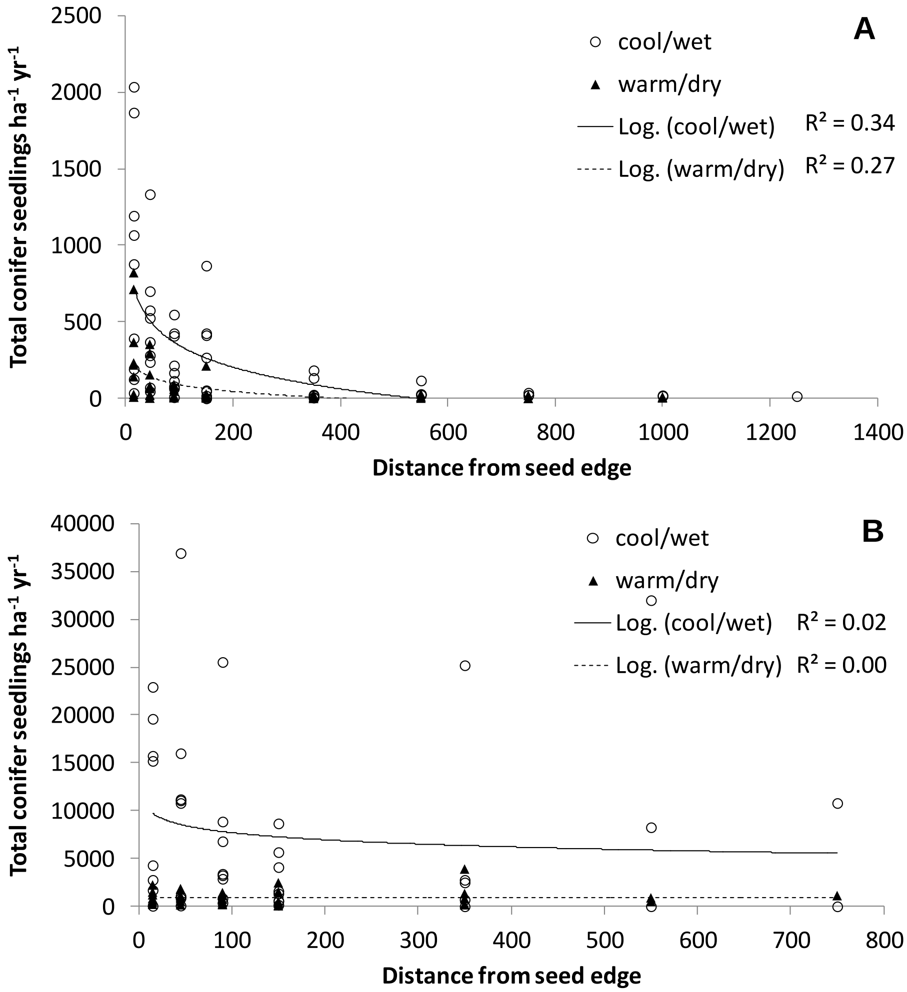

Figure 15. Post-fire seedling density (normalized by year) at different distances from the edge of stand-replacing burn patches in the GYE (A) and GLAC (B).

References:

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Deliverables/Research Products:

Research Product:	**Delivery/completion date:**
Invited presentation at the 2012 Association for Fire Ecology: International Fire Ecology and Management Congress, Portland, OR	December 2012
Invited presentation to the "Climate Change in America's National Parks" webinar series	November 2013
Spatial dataset: Regional maps of rates of change in burn severity patterns across national parks in the N. Rockies	December 2013 (planned)
Refereed publication: Trends in spatial heterogeneity of burn severity (1984-2010) in national parks of the Northern Rocky Mountains, USA	December 2013 (planned)
Refereed publication: Differential postfire tree regeneration responses to spatial heterogeneity of burn severity in conifers of the Northern Rocky Mountains	May 2014 (planned)
Presentation to park managers / public: Presentation of findings at the 12th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, Yellowstone NP	October 2014 (planned)

Additional Funding:
The GMW Fellowship will be augmented by a separate award from the Joint Fire Sciences Program (Graduate Research Innovation Award) and a graduate teaching assistantship from the University of Wisconsin - Madison.

Other:

- Fieldwork and subsequent data entry, processing, and analysis have involved the training of 8 undergraduate students at the University of Wisconsin (4 paid and 4 student interns). Continued involvement of undergraduate students is anticipated for future academic semesters.

- Due to the high public concern about wildfire, I had numerous opportunities to share information about my research with interested park and wilderness area visitors. Many people who I spoke with were very eager to learn about my research and other projects that are being undertaken in the park to examine the effects of climate change on park resources.

Photographs:

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Margot Higgins
University: University of California at Berkeley
Start date: 05/31/2012
End date:12/31/2013 (because she experienced a serious health crisis, Margot submitted her final report in December 2014)

Inventorying Local Knowledge In Wrangell-St.Elias National Park and Preserve as a Way to Better Understand a Dynamic Social and Ecological System

By Margot Higgins
PhD Candidate, UC Berkeley

INTRODUCTION

On the tattered calendar that lives among jars of canned salmon, moose salami, cranberry relish and pickled garlic, Wrangell-St. Elias National Park and Preserve resident Bill Rickard[1], has been marking daily natural history based observations on and near his land since he purchased his property in 1983. For a 10-year period Bill only left the park two times, and through almost thirty years of concentrated time on park land, he has gained a unique perspective on the changes that have occurred in that landscape. Bill knows that his subsistence lifestyle in the bush, depends on his knowledge of the environment as a whole. It is not enough to understand the behavior of moose or bears. He must understand what they eat, how they think during big snow year or after a forest fire, and how they interact with one another.

Like Bill, people living on or near Alaska national park land, and dependent on its resources for part of their livelihoods, are, in most cases, very well aware of the biophysical changes occurring around them because they generally spend extensive time on the land and are directly affected by the changes that have occurred there. In addition, people with a long association with the park and preserve are informed by journal entries, photos and oral histories, such as those offered by old timers or tribal elders, who provide accounts of how things used to be. The local knowledge and experience of people like Bill, who choose to live in such close proximity to the land, may offer a special opportunity for monitoring of the impacts of dynamic changes in the land, particularly those created by climate change.

Learning about the knowledge and experience of people who live in communities in or near Wrangell-St. Elias helps further the mission of the park, which is to preserve and protect ecological integrity and *heritage resources* of a vast ecosystem. I wanted to conduct research in the

[1] A fictional name has been used to protect the identity of the individual I am referring to.

communities near the park, in order to help document this local knowledge and experience. In this way, with this research, I could expand the current interdisciplinary studies and the area that NPS monitors by including more private lands in this effort, including the long term observations of local residents.

The late Nobel Prize winning social theorist Elinor Ostrom (2009) called for the need to establish a common framework between local knowledge and the various discourses of western science for explaining complex social-ecological systems. Without such an integrated framework she wrote, “isolated knowledge does not cumulate.” This report aims to begin to link these efforts.

METHODS

My field work, for which I was awarded a research fellowship, was conducted near Wrangell-St. Elias National Park and Preserve for approximately three months in the summer of 2012, following two previous summers of preliminary field work in the same area. There are 23 resident zone communities in this park where approximately 5,200 residents are eligible for subsistence. One must live in a resident zone community to claim subsistence on park lands.

In June-August 2012, based primarily out of the resident zone communities of McCarthy and Kennicott, I also traveled to more remote and less tourist driven communities of the park by plane and vehicle. I interviewed (~52 people – still compiling) in 15 communities, including McCarthy, Kennicott, The Chitina River, Glenallen, Copper Center, Slana, Nabesna, Chistochina, Gakona, Chisana and Tok, Chitina, Valdez, and Kenny Lake. A few additional interviews were conducted with part time park residents in Anchorage. Being interviewed was voluntary and individual data and locations are confidential.

I drew on the practices of ethnographic research, and used more than one research method: my methods included (1) in-depth unstructured interviews through a snowball sampling technique, (2) ongoing informal participant observation, and (3) archival research.

<u>In-depth unstructured interviews</u>

For the interviews, which were the dominant method of inquiry for this research, I queried park residents about their phenological observations, and more general observations about changes in the land. Specifically, I solicited personal record, photographic and shoebox data sets, using different questions each time. I made a specific effort with my line of questions to understand how likely it would be that they would share their observations in an online database such as the National Phenology Network. When it was logistically possible, I also took the time to walk them through the NPN website and explain the various features of the network. When speaking with people, I needed to keep a number of sensitivities in mind, in particular, that subsistence users tend to be very private about the ecological patterns they have observed and many do not agree with a number of policies implemented by the National Park Service.

My sampling technique is most closely described by the snowball sampling approach. This method entails collecting data from a few members of the target population of park residents who are closely observing changes in the land, and using the content of that interview to help identify additional members of that population that might provide useful information. Data or knowledge grows from extended associations through previous acquaintances, thus, the sample group can appear to grow like a rolling snowball through this approach. For example, there were several occasions when one interview would raise questions that would prompt me to approach a particular individual. Sometimes these follow up interviews were also used to fact check or confirm a previous statement or explore a particular theme in greater depth. Due to the remote locations of most park residents, and the fact that many people, (especially those with cell phones) are not listed in an official directory like a phone book, this technique was especially appropriate. For these interviews, I prioritized full-time residents, but also included some seasonal residents, especially those who have spent several decades in and around the park.

I conducted several formal sit down interviews, but I also found it was useful to talk with people while they were engaged in their usual daily activity, such as fixing a roof, putting up a bear fence, or preparing strips of local salmon for the brining and smoking process. In a sense, this helped me meet people more on their terms and adjust to local ideas of productive work and learning: by watching and learning rather than pestering them with a list of prescribed questions. Several interviews extended into a number of subsequent informal conversations as I ran into a number of my interviewees over and over again throughout the summer, particularly in the communities of McCarthy and Kenneott where I was renting a cabin, but also in places like Glenallen, Kenny Lake, Chitina, and Slana where I passed through more than one time.

Informal participant observation

Because snowball sampling is hardly representative of the larger study population, however, I primarily used this technique to explore different populations within the park and match this information with several years of participant observation and archival work. I participated in many social events in various park communities, including public lectures, storytelling events, a barbeque hosted by the governor, potluck dinners, community softball, dances, and other windows into community social relations and experience. This gave me a better sense of local values and how people in these physically isolated communities see themselves in relation to the rest of the world, to other communities in the park and to the government.

When selecting which communities I would prioritize for interviews, I considered an array of logistical considerations, including travel time, travel mode, expense, whether or not I would have a place to stay, local events, and weather. I tried to cover a wide range of park communities and visit those communities where people were most likely to access Park lands for subsistence. For instance, for this project, I chose not to visit the coastal community of Yakatat[2], which requires an expensive plane ticket, and because most subsistence resource use takes place on National Forest land instead of on national park land, or through fishing practices in Prince William Sound.

As I gained more experience in Park communities, I developed a better understanding of the different interest groups in the park, how communities differed from one another and how to approach individuals on their terms and through their particular level of familiarity with park issues and ecological observations. This approach added a layer of detail that extended beyond our

[2] I did visit Yakatat as part of my larger dissertation research in 2013.

informal conversations and interviews. Being up front about the fact that we come from different perspectives (for example, me a part time visitor, from an academic background funded by the federal government) in some ways allowed us to identify and discuss the space between our experiences and also acknowledge the areas where our experience overlaps.

Most of the interviews were recorded with permission by audio and transcribed by my research assistants and me. For this report, I subsequently analyzed these transcripts and notes for common themes related to observations of biological signs of seasonal change. (see tables 1, 2, and 3). On the rare occasion that someone was not comfortable being recorded, I listened and took notes instead of using the audio recorder.

Archival research

Archival research for this report included research through personal collections, NPS offices in Anchorage and Copper Center, the Wrangell Mountains Center Library, Friends of Kennicott and the McCarthy Area Council, among others.

STUDY SITE

Scientists expect climate change to register first in northern climates; moreover, arctic and subarctic environments may be especially vulnerable to even slight shifts in temperature (National Assessment Synthesis Team 2010). Wrangell-St. Elias is home to one of the largest resident zone populations of any national park, with roughly 5,200 residents that are eligible for subsistence rights. Living in remote rural areas, and relying more on the direct consumptive use of natural resources, these residents tend to have a different relationship with park resources than those who live in and around parks in the lower 48. Humans have long played a role in influencing the natural resources in the area, through dependence on plants and animals for subsistence. (Drazkowski and Simeone and Valentine 2005, Kofinas 2002).

According to a recent Natural Resource Condition Assessment, considerable data gaps persist for many of the park's natural resources (Drazkowski 2011). While an inventory of the vascular plant flora of Wrangell-St. Elias National Park and Preserve, Alaska, was conducted from 1994 to 1997 and in 2003, there are still large areas in the park that have not been surveyed and park managers lack sufficient knowledge about most rare species. Currently there is one ecologist who is responsible for the 13.2 million acre Park and Preserve and the park budget offers only about one cent per acre. Given the enormous area that Wrangell-St. Elias encompasses, incorporating local knowledge into exiting monitoring efforts may be especially important.

Established through the ANILCA legislation in 1980, Wrangell-St. Elias represents subarctic and coastal ecosystems in south-central Alaska, and it is part of one of the largest protected contiguous areas of land in the world. At 13.2 million acres, eight of which are designated wilderness, Wrangell-St. Elias is our nation's largest national park, comprising 16 percent of all national park lands. In addition to being part of the National Park System, the United Nations recognized Wrangell-St. Elias as part of a 24 million acre UNESCO World Heritage Site. Encompassing four mountain ranges and three climate zones (Drazkowski 2011), the area contains a wide diversity of habitats, including glaciers, recently deglaciated primary successional ground, river bars, taiga forest, and alpine tundra, many of which may be disproportionally susceptible to the impacts of climate change.

Change has been noticeably evident to scientists and local residents over the past 100 years in the park and preserve, and future years will likely see significant changes at the intersecting levels of the climate, hydrology and vegetation. Ice-covered valleys will become covered with vegetation. Glacial streams may become deglaciated rivers that flow through Alaska's interior. Lakes may cease to freeze entirely and new patterns of vegetation will emerge and evolve. Given the physical characteristics of this park, tied with its long human history and anticipated changes and fluctuations, this region presents one of North America's best opportunities for understanding, and managing, climate-induced shifts in physical habitats, ecological and social communities.

Figure 1. Resident Zone Communities of Wrangell-St. Elias National Park and Preserve.

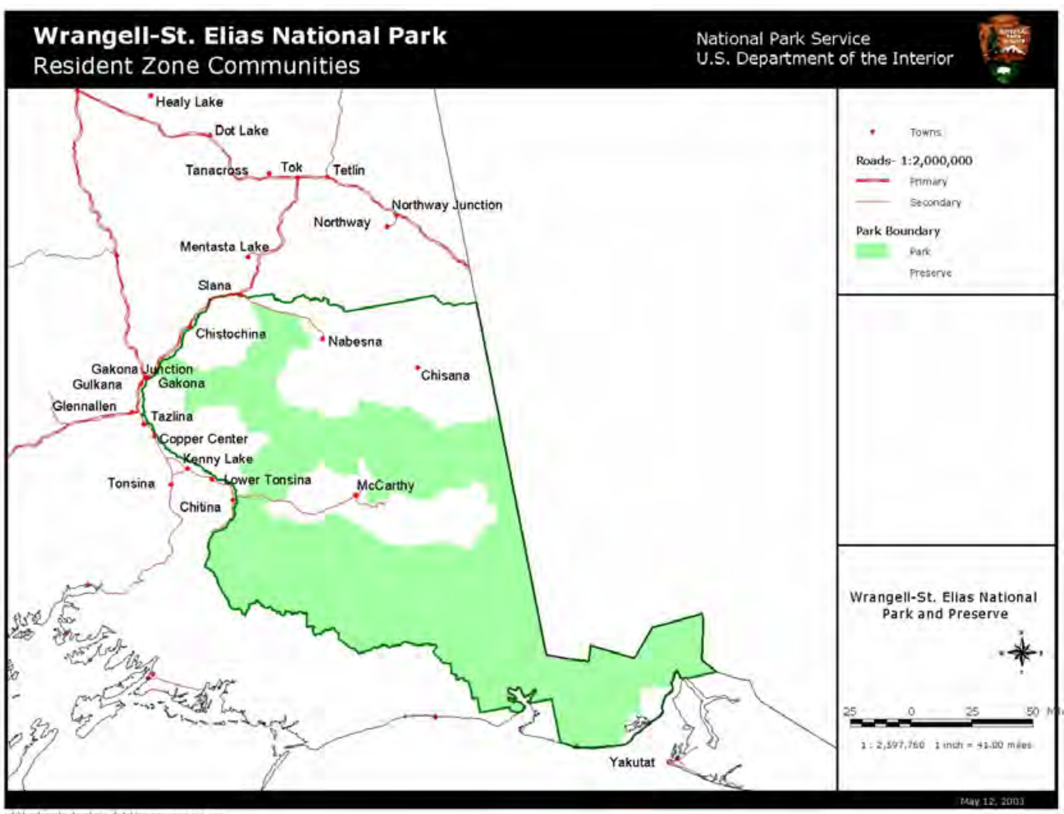

Table 1. Overview of Community Data Sets

Park Community	Number of	Kinds of Records Found

	People Interviewed For this Report (N =59)	
Kennecott	8	Journals that go back to the 1950s Photos that go back to the 1950s
McCarthy	12	Journals that date back to the 1950s Photos that date back to the 1950s Swallow boxes that date back to 2011
Long Lake	2	Swallow boxes that date back to the 1950s, photos
Chitina	1	Journal of 18 years
Glenallen	6	Journals
Kenny Lake	5	Willow Creek Watershed Monitoring Project, school projects, photos, journals
Chistochina	2	Journals going back to the 1950s
Slana	4	Trap line records
Nabesna	4	Ellis journals and photos pilot logs
Tok	3	Bird journals, entries on National Phenology Network website
Banks of the Chitina River	3 plus1 part time long time seasonal	Most journals were lost in a fire, pilot records
Chisana	4	Many records lost in a fire, Personal journals, essays and photos
Mentasta	1	Photos
Gakona	1	Oral histories, personal essays
Copper Center	2	Photos, NPS Aspen phenology (entered on the National Phenology Network website)

Table 2. Summary of local observations of ecological change in Wrangell-St. Elias Park and Preserve from 59 interviews in 15/23 resident zone communities.

Observations related to glacial retreat	• [There has been an] increase of glacial dust • "There are increased respiratory issues in the region and I suspect that has to do with glacial dust." • The (Kennicott) Glacier was a lot taller [in the early 80s]. • The Kennicott Glacier almost reached McCarthy when I arrived here [in the 1970s]

	• The first time we came out there was one little pond at the face of the glacier or the foot or the toe. . . a little pond. . . [it is] maybe three times the size of this lawn and now it basically runs all the way around on the other side. • I had no clue that lake was over there [pointing to the glacier] until I want to say two years ago when I took a hike over there. I was astounded. I had never seen it before,” “that pool at the base of the Chisana Glacier did not exist before.
Observations related to wildlife	• I can only remember what it was like in the 60’s and there was an awful lot more game here compared to what there is now. And the decline in the game from the 60’s till now had nothing to do in the hunting -- it has to do with range that is weather oriented that we can do nothing about now. • There have been recent sightings of caribou feeding in lakes. I haven’t seen that before. • I am seeing moose that have traveled a long distance. They have different body types. • There are more moose • I spent 11 years on that [unnamed river] I have an intimate knowledge 40 miles of that river. When you spend decade you watch how salmon runs change year to year. You see their spawning areas. You know hunt camps. There are places we hunt caribou that I’m sure are pre-history. • There are migration bottlenecks where caribou need to cross. • Three individuals reported cougar sightings (though others dismissed these as more probably lynx)
Observations related to weather change	• We have west wind now. There is no word for west wind in Athabascan culture, but the predominant wind pattern is now westerly. • winter temperatures do not dip as low. • [We are] Not seeing same kinds of temp patterns. No it hasn’t happened again. My comment o that winter was if it ever hits 65 below again I will move so fast you will never know I was here. . . beeper goes off. It has not hit 65 below since [the early 1980s]. I’m still here. • Certainly I’m noticing warmer winters. Absolutely warmer winters. You can probably get the data for that. When my girls were little it was soooo cold every winter for long periods of time. We just don’t get that anymore. You might get 40 below for maybe a week, piece of cake, you know. There was two winters ago when I don’t think I pulled out my heavy parka. Wow. It just wasn’t cold. If it was cold it was short term. It was twenty below the whole time. It just didn’t drop down. It seems like our falls are longer. I do not think it is frosting as early. This is unscientific observation, just day to day to day to day. • I remember when my girls were little in the mid eighties. Once school started mid-August there was frost every morning. Last year I do not know when the first frost was? End of September? October? • It seems like in the last few years the falls have been certainly nicer. And maybe you get a first frost but it is certainly not, you know, we have done moose and caribou and it has been just fine to process it outside. I remember doing it and

	being so cold that your fingers are going to fall off. I don't know maybe I have gotten tougher over the years. That could be part of it too. You have been doing it for so long, maybe that has been part of it. • Well the first winter I stayed here it got down to 54 below then it was 18 days it never got above a minus 40 and I was house sitting Kenyon's house and they were in Florida. And anything you put in the woodstove burned I mean fast. It's like a dog eating raw meat. And you I would have to go out and take the [rotor] reports but at the same time if I had to do any physical work it was done about noon or 1 o'clock because that was the warmest part.
Observations related to hydrology	• We have more precipitation. • There is more sedimentation, river erosion. • I spent time on the Nabesna River in the 60s and 70s. It would fill with silt when the ice went out. Now rivers and streams run by rain instead of the glacier. • I never thought I'd see the day when the Nabesna River would be clear in November. And we do not know what the impact may be on fisheries. • One of the things that has been noticeable from my view shed, and talking to park people, talking to pilots, talking to guides and people who do subsistence activities is sluffing of the bluffs. Hill movements, erosion, you know, is this melting of ice lenses. What is causing this? Not that I'm looking to what is causing it. I just want to document what is happening. We do see these bluffs changing, moving sluffing, melting out, you know. What is it? Maybe not permafrost. Maybe it is just ground water changing. • Definitely I've seen the river erode. It is all erosion and deposition. I do not know that. It is such an extreme river. What is normal? What is not? I would never really say something is normal or abnormal just because it is so dynamic and unpredictable. Water level can go up 3-4 feet in a few hours, it can drop it can erode 20 feet of bank in a couple of hours. Definitely I've seen lots of changes in the Copper River through this whole area. Places where roads accessed the river then they are gone, erode away and [in] 2-3 years it has eaten up hold bank and then it stops it pushes over. • Water temps [on local rivers] has consistently been warmer for over a decade.
Observations related to insects	• Beetles. There are not many around. The interesting question is why did they quit? They look more like ants than beetles. Beetles stopped east of the copper river. • Bark beetles are coming up north. They are at my house in Gakona. They were south, you know in that whole lower Tonsina area, Valdez, and of course the Glen Highway out toward Anchorage. Klutina. All of these forests were mega impacted years and years ago. They are still here and I see them up our way where when these forests were devastated and died we did not have them up north. They are up there now. They are absolutely responsible for more fires.
Observations related to birds	• The swallows were here pretty early this year. They were all around our house and then they just disappeared. And it was weeks later the mosquitoes showed up in force and the swallows have not been back to my house.

	• Swallow arrival coincides with daughter's birthday May 10 and swallows usually fledge by July 4. This year they were 2 days early.
Observations related to fisheries	• I've seen lots of things. One thing is that king salmon are on the decline right now. Geez there was a few years we got as many kings as we did reds. Now they are very very scarce. Is that a change in the river? I do not know. Is that part of its natural cycle that this happens every 20 years. But definitely king salmon are different • We are seeing fish in streams in late august. [They] used to stop around July 25. These are critical decision points [for subsistence fishing. The best fishing is in late July when it used to be June. Late runs are good when they didn't used to be. They are in good shape at the end of August. • There was extensive drought from the 60's until 1997. Lakes half emptied out. Creeks just trickled. We went decades with no rain in summer. Then we had extensive rains from 2006 on. Salmon were waiting by the weirs. As soon as sediment revealed water coming up, there was gathering force. (could be placed in hydrology section too)
Observations related to vegetation	• A proliferation of plant food is changing animal migration. • When I moved here in those early years, there was no vegetation on these bluffs, on Simpson Hill out here. They were just bare sediments" • I think precipitation is different. I think we have a lot more precipitation and vegetation is changing. The lushness the thickness, places you used to walk through are now just grown up. The willows are growing so incredibly fast. . . • I think we have a lot more precipitation and the vegetation is changing. The lushness the thickness, places you used to walk through are now just grown up. The willows are growing so incredibly fast. • My driveway when we moved in was just gravel and it was wide and now . . . thick vegetation is to the other side in just nine years. It is just amazing -- the undergrowth-- how lush it is. • Certainly fireweed were late this year. And cotton seeding from cotton trees was late late late and much much less. It didn't snow [cotton seeds]! That is usually mid June to the 24th or 25th. This year it didn't do it. The fireweed was super late but it still went quick. There are flowers at the top now and we are in august so probably a week late or so from peaking out to the top but they were two or three weeks late to bloom.

Results

Through interviews with local community members in 15 resident zone communities (see Figure 1, Table 1), I gathered a wide array of local knowledge about changes in ecosystems that have occurred and are occurring near and in Wrangell-St. Elias National Park and Preserve.

How residents document changes in ecosystems

The ways are varied in which people document their observed changes, or record information that can later be reviewed to be able to note changes. The most common ways are through oral histories, photographs, personal journal recordings, gardening journals, hunting journals, trap line records, piloting logs, daily entries on a calendar, and targeted monitoring projects, such as the Willow Creek Monitoring Project. The types of recordings people made did not vary a great deal with various geographic settings in the park but had more to do with specific practices such as hunting or trapping. Some residents offered site-specific information about changing conditions related to glacier retreat, wildlife, weather change, hydrology, insects, bird migration, fisheries and vegetation.

During most interviews, I discussed the possibility of submitting information to the National phenology Network or a similar online database. Just over a third of the people I interviewed (37%)[3] seemed willing to enter their observations online with about 24% additional maybes. Many people expressed great interest in better understanding how to use the website and make better sense of the existing database. This enthusiasm existed in most of the resident zone communities I visited, with the exception of Chisana, Mentasta, and Chistochina, where people were less willing to share their observations with government officials – or academics, though I was offered a number of comments about changes in the land, in spite of that. A number of individuals also expressed support in inspiring others in the community to enter observations on NPN, especially through the existing education systems and programs in Glenallen, McCarthy, Kennicott, and Kenny Lake.

Contrary to what I expected most people living in the resident zone communities of Wrangell Saint Elias National Park and Preserve had access to the Internet and this access seems to be growing. Even in remote communities like Chisana and along the Chitina River, having Internet access was key for tourism related businesses. Several people did comment, however, that they do not check e-mail very often, or try to stay away from Internet as much as they can, so they may not be likely to make entries on the National Phenology Network Database.

About 20% of the people I interviewed did not offer substantial comments on changes in the land.

DISCUSSION

My research suggests that the existing amount of local ecological knowledge about Wrangell-St. Elias National Park and Preserve is diverse and extensive. The park residents I interviewed are proud of their observations and take great pride in the variety of interactions and observations they have with the land. This connection forms a strong part of their identity and connection to others. One of the biggest obstacles for submitting data seemed be influenced by past experience with government officials, (particularly NPS) and a general feeling that is deeply historically

[3] Calculations are made from interview data which are confidential and cannot be shared

embedded in this region that local data or observations would not be valued or adequately incorporated in natural resource management plans without adversely impacting local needs. Many people did not want to share knowledge about changes in the land out of fear that it might create further restrictions around subsistence use.

A number of my interviewees commented on the lack of good scientific data and sound consistent monitoring by NPS. In some cases, people were well aware of the larger structural and financial causes for this gap within the agency, but among others, there was a fair amount of distrust and blame placed toward the agency. Many individuals made fun of the seasonal or three or four-year field biologists that they encountered in the field. As one of my informants told me "you can get observational data and habitat data if you speak to people [in the park] or learn to talk [to them]. NPS has lots of statistical data on salmon, but no inference data [from park residents]. There is no observational data about water temps which has consistently been warmer for over a decade."

Tensions also arose between what is perceived as an NPS prioritization for key stone conservation species like grizzly bears and dahl sheep instead of paying more attention to the species that are used by locals for subsistence. As one Ahtna resident commented "the Chistochina subsistence report is complete, but they (NPS and Alaska Fish and Game) missed a few valid points. No one asked about king salmon in the 60's and 70's in specific locations like Atele Creek (need to check spelling) Indian River, Sinona creek, the inlet by Mentasta Lake. These are all places people visit [for subsistence]." Another person commented, "My issue with data is not about being better or worse. [It is the] perfect fit for NPS that doesn't do much good for the rest of us. This is the NPS mindset. Data is conveniently not recorded, overlooked, and [not] subject to an interpretive stance."

With several other similar instances noted among those I interviewed, people within the non-profit community and local natural resource agencies nevertheless, expressed great excitement about recording their observations, particularly phonological observations about plants and animals. But they also expressed that do not yet know how to incorporate it so they can use it within increasingly financially constrained agency management decisions. And people seemed constrained by the time involved in entering data. One person more familiar with the National Phenology Network (NPN) (Betancourt 2005), for example, mentioned that his biggest challenge in submitting to NPN is coordinating data sets so they do not need enter data twice.

Local and traditional knowledge in Wrangell-St. Elias National Park and Preserve includes many of the same components as conventional western science, including distinct observations of change, premises about causality, and general theories underpinned with a paradigm of knowledge. Observations of change by local knowledge are not confined to ecological dimensions but also include social components and as well as intricate observations of social and ecological interaction. Yet the park is also a primary example of where management regimes that are attractive to one segment of a society or local community may be deemed less desirable by another. It is a place where there are different sets of stakeholders who possess different levels of power in relation to national park management. Scholars have suggested that normative values such as uneven power relations, history culture do not fit easily into management models (Nightingale 2011.) My research also revealed that there are a number of local observations and related approaches to natural resource management that do not get captured in current management attempts, despite the best efforts on behalf of NPS.

Data from my interviews [see Table 1] suggests that while local observations can't be exported directly into existing scientific data sets, they are far from anecdotal. While such local knowledge does not often fit very precisely within a tight and traditional western science box or approach, it may still be extremely valuable and there should be a way to keep track of (and honor) these observations in a way that might be complementary to the existing data base of NPN and other similar efforts which are more rooted in traditional western science. Sight based nuance and intellectual property politics also shape the ways that such knowledge can be shared and integrated and this must be carefully considered in the context of building trust between NPS and local park residents.

There is a great deal of room for NPS to recruit local residents in current park monitoring efforts such as weed monitoring, and many park residents expressed interest in such activities. Nevertheless, park residents and particularly members of Alaska indigenous communities, need to be involved in monitoring efforts and creating natural resource management agreements related to shifting climate conditions from the ground up or they are bound to stir social tensions. For example, as I observed in one case, when a long time local resident stumbled upon a team of brand new NPS hires (mostly from out of state) to do a weed monitoring effort that he had not been invited to provide input toward, future relations between him and agency managers may be easily soured. He inquired if the team was aware of all of the coastal plants he had recently noticed that were showing up in the Alaska interior and they were not. This information suggested to him that NPS has very little idea of what is actually going on beyond a particular resource management plot or single isolated monitoring effort.

An important take home question is to think about is how natural history observations can be shared between local park residents and natural resource managers in a way that respects local communities for a lifetime of observation that often exceeds that of individual natural resource managers. Park managers may need to think about the limits of scientific knowledge and embrace more uncertainty and unpredictability. Another central challenge is to keep such information updated and relevant in a high-turn over work environment, such as NPS, when the next group of natural resource managers steps in to the job.

There is growing momentum to on a national level to begin keeping track of such local, non-western science observations, especially in the context of climate change. This sentiment is especially strong in the region that encompasses Wrangell St-Elias National Park and Preserve. But at the same time that Alaskans take pride in their ability to engage in such observation and knowledge collecting, the area also bears the scars of colonialism, uneven power relations and recognition of whose knowledge counts (Kofinas 2007)As scholars of local knowledge, citizen science and participatory action research have noted (Fortmann 2008, Berkes 2008, Kofinas 2002, 2007), integrating local knowledge into current scientific monitoring programs will not be a simple cut and paste approach (Cote and Nightingale 2012). Instead there needs to be a more a critical examination of the role of knowledge at the intersections of social and ecological systems to capture how power plays out through natural resource management models and how competing values come up against one another.

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ACKNOWLEDGEMENTS

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2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Kerry L. Howard
University: University of Nevada, Reno
Start date: 6/2012
End date: 9/2013

Brief project summary:

The primary objective of this research project is to use modern and fossil diatom assemblages, modern limnological data, and paleolimnological records to investigate the effects of environmental change on phytoplankton communities in alpine lakes of Lassen Volcanic National Park (LAVO). Changes in diatom community structure in sub-alpine lakes may be attributed to increasing temperatures (climate change), modifications in landscape, increases in atmospheric nutrient deposition, or a complex interaction of these forcing factors, particularly where multiple forcing factors effect the region. Diatom-based paleolimnological syntheses from LAVO lake cores will provide information on past ecological states. Modern data will help characterize seasonal variability in diatom blooms and the physical forcings associated with the floras to help evaluate how existing sources of environmental change relate to modern diatom community composition in LAVO alpine lakes. The ecological and scientific significance of the results of this study can be merged with current and future monitoring data from alpine lakes in LAVO and used to interpret ecological response to environmental change.

Work reported on in fall 2012 continued into last spring (2013). Multiple analyses were conducted on sediment cores recovered from several lakes in Lassen Volcanic National Park in August 2012. Stable isotope analyses of carbon and nitrogen were conducted on gravity core samples from Manzanita Lake and Widow Lake. An XRF scan for major elements was also conducted on each core. Analyses of chlorophyll a were conducted for all water samples taken from LAVO lakes in June and August 2012. Diatoms were identified in Manzanita Lake sediment core samples and counted percent relative abundance of species present. A stratigraphically constrained cluster analysis will be preformed using diatom count data (relative abundance of species present).

Research efforts during the 2013 summer field season included recovering two 1.0-1.2m-long push cores (Livingstone corer) from Manzanita Lake and continuing with seasonal limnological sampling in select lakes within Lassen Volcanic National Park. Coring Butte Lake with a push coring device (such as a Livingstone corer) instead of a gravity coring device was planned for early October 2013. Unfortunately coring operations planned for Butte Lake were inhibited by the government shutdown. Water samples collected during limnological sampling were submitted for nutrient and major ion analysis. Samples from plankton tows were prepared on slides and imaged for diatom identification. Plans are currently in place to conduct a variety of analyses on the Manzanita Lake sediment cores collected in August 2013. Work on these cores

will include: analyses to obtain an age model (^{210}Pb or ^{14}C), stable isotope analysis, diatom analysis, loss-on-ignition, and elemental analysis by scanning XRF.

Research Approach:
Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

Obtaining a good age model for sediment cores recovered from lakes in Lassen Volcanic National Park is instrumental in quantifying any environmental changes recorded by geochemical (i.e., stable isotopes) and paleoecological (i.e., diatom) proxies in these cores. Thus far, it has proved difficult, if not impossible, to date the gravity sediment cores recovered last year (2012 field season) using ^{210}Pb. This is mainly because confidence is lacking that these cores have a sediment record extending beyond about 200 years into sediments that have background levels of ^{210}Pb. Samples of core sediments with background ^{210}Pb samples are required to construct an age model using the ^{210}Pb method.

To counter this problem, a different coring technique was employed during the 2013 field season. In August 2013, a push coring (modified Livingstone) device became available for use in LAVO, and two cores 1.0-1.2m long were recovered from Manzanita Lake. A push coring device can be used to recover longer lengths of sediment cores, but requires lots of heavy or unwieldy equipment not easy to bring in to lakes accessible only by foot. For this reason, a push core was only attempted at Manzanita Lake, which accessible by road.

Unfortunately, even though longer sediment cores were recovered for Manzanita Lake, another problem remains. The main lake of interest, Manzanita Lake, was affected by the eruption in 1915. A large volume of mud entered the lake at this time, creating a thick, relatively instantaneous layer of sediment on which organic sediments from the last ~100 years sit. The layer of more organic sediments is of interest, but obtaining an age model for these sediments using 210Pb may be difficult since the volcanic layer is obscuring access to sediments with background levels of ^{210}Pb. To rectify the issue of obtaining an age model for these sediments, another dating approach, ^{14}C, is under investigation. The ^{14}C method can be used to date recent sediments because of atmospheric fallout of radionuclides from atomic bomb testing occurring in the 1950's-1960's. This method, however, will require gathering samples of appropriate organic matter in Manzanita Lake core sediments, which may or may not be present.

Location(s) of Research:

Research during the 2013 field season was conducted in Lassen Volcanic National Park, specifically samples were collected and measurements were taken from six different subalpine lakes in the park. The lakes sampled were: Manzanita Lake, Butte Lake, Snag Lake, Widow Lake, Silver Lake, and Cluster Lake.

Key Findings:

Currently, most research activities are still underway for this project, and it is expected that the entirety of the project will not be concluded until December 2014. Conversely, proposed deliverables will be completed as soon as possible, and it is expected that the electronic resource of diatom flora will be available in early 2014. A number of analyses on samples collected during the 2013 field season have yet to be completed. Furthermore, a synthesis of all data collected for the project is still in development, and data analysis has been started, but not yet completed. Robust data analysis and synthesis relies on an age model for recovered sediment cores, which hopefully will be forthcoming over the next 6-8 months. Obtaining an age model using either the ^{14}C *or* ^{210}Pb *methods is expected to take awhile—turnaround depends on the sample queue at the labs where samples are sent for processing.*

Key findings so far pertain to modern diatom taxa data collected during seasonal limnological monitoring of LAVO lakes selected for study. Araphid diatom taxa sensitive to nitrogen loading in subalpine-alpine lakes (as suggested in relevant literature) are present in certain LAVO lakes and dominate spring phytoplankton blooms (see AGU meeting abstract, below). For example, Manzanita Lake is dominated by blooms of Asterionella formosa and Fragilaria crotonensis. Additionally, the Fragilaria tenera-nanana group is present in Widow Lake. Butte Lake is also dominated by colonial araphid species during the spring phytoplankton bloom, including A. formosa and F. crotonesis, as well as other araphids including: Distrionella species, Staurosira species, and Psuedostaurosira species.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

- ***AGU Meeting Abstract*** *(12-3-2012)--Session Title: GC11A. Climate Change in Mountain Environments Posters—Presentation Title: Diatom Community Changes in Five Sub-alpine Mountain Lakes in Northern California.* *http://fallmeeting.agu.org/2012/eposters/eposter/gc11a-0974/*

- ***Diatoms of Lassen Volcanic National Park****: This is an electronic resource of diatom flora found in lakes sampled as part of GMW fellowship research. This product is in the form of PDF plates that will be linked as a project page to the Diatoms of the United States webpage (http://westerndiatoms.colorado.edu/). This product is not available yet, as discussions regarding the formatting of the product are still underway with the review board for Diatoms of the United States. Once finished, the product will also undergo review by the review board (see website) before publication. When the product is available to the public, Lassen Volcanic National Park and the GMWCCFP will be notified.*

- ***Professional Paper**: A professional paper is in development detailing the results of the limnological monitoring conducted on lakes sampled in Lassen Volcanic National Park. This paper will include information on diatom taxa indentified in plankton tows during limnological sampling of the studied lakes. A main component of this paper or perhaps an additional paper is that of data from the sediment cores. Inclusion of this information is dependent on obtaining a good age model for core sediments. Data from core records without an age model is unlikely to be published. Lassen Volcanic National Park and the GMWCCFP will be notified when a paper is submitted for publication.*
- ***Interpretive Talk:** An interpretive talk is under construction regarding the results of the limnological monitoring conducted on lakes sampled in Lassen Volcanic National Park as well as the diatom taxa identified in the park. Hopefully, results from sediment core records can also be included. Efforts are underway to work with park educational staff to develop this interpretive talk. This talk should be available by summer 2014.*

Additional Funding:
Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

N/A

Other:
- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

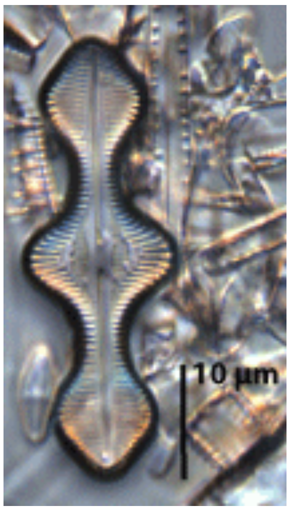
I attended a workshop on freshwater diatomite, held at Iowa Lakeside Lab (Lake Okoboji, IA) in June 2013. The workshop was comprised of researchers—geologists, biologists, geochemists, and limnologists interested in studying freshwater diatomite formation in the western United States. As part of the workshop, I spoke about my GMW fellowship and my research regarding lakes in Lassen Volcanic National Park. There was a lot of interest among the researchers regarding large blooms of diatoms in the modern lake systems in LAVO simply because of the volcanic context. It is possible conditions in some LAVO lakes may provide some answers regarding the formation of thick diatomite deposits in the western United States during the Miocene-Pliocene epochs. This outcome was surprising, since I never intended my research in LAVO to be related to diatomite deposits in the western United States. In any case, the outcome of this workshop may end up being a component of research for my dissertation.

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

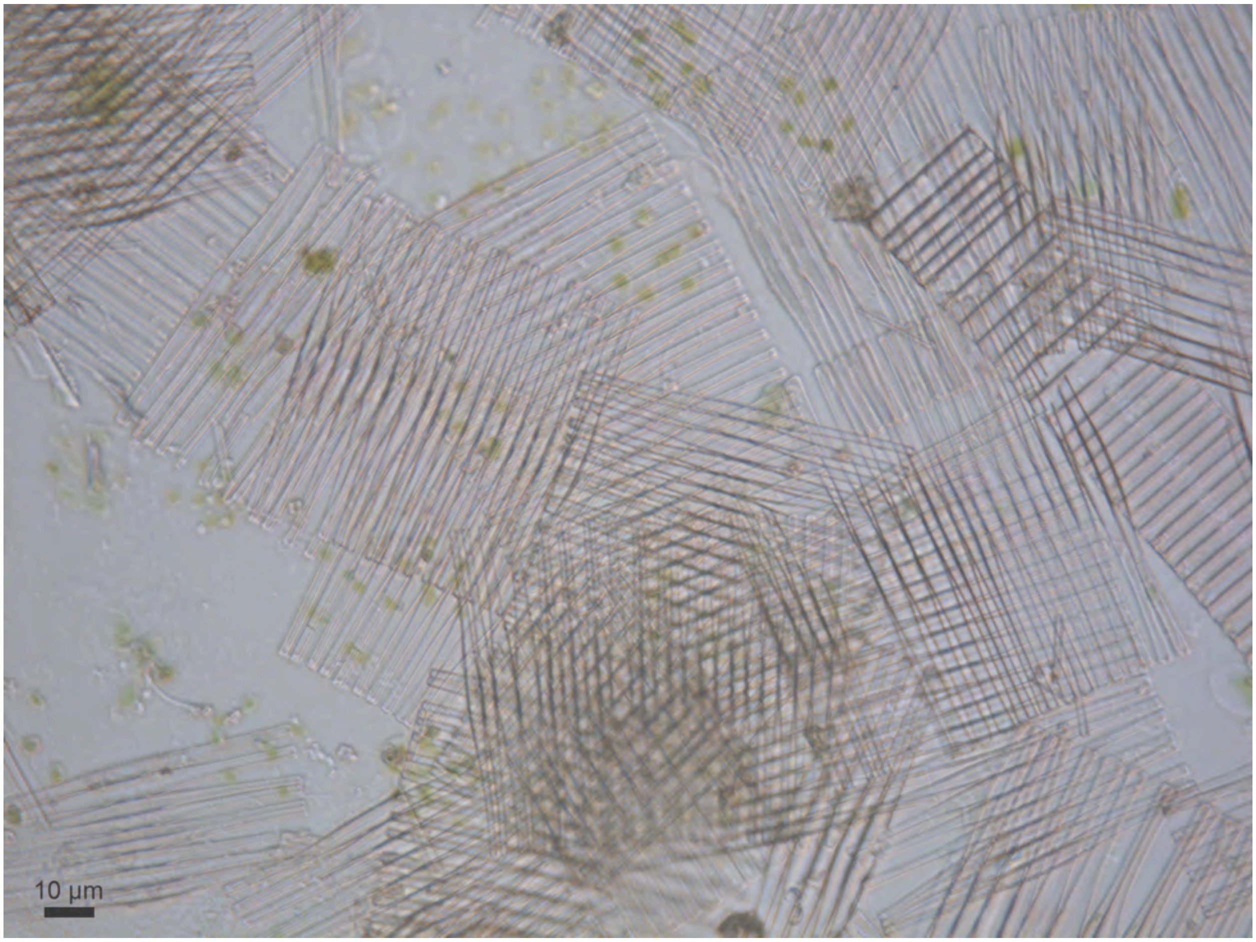
I was able to revisit and sample a lake in a region that underwent moderate-high intensity burning in the Reading Fire that occurred last August in Lassen Volcanic National Park. The *differences in the landscape and local ecosystems in the burned areas are astounding, but also breathtaking, in their own way. I have attached the picture below:*

Silver Lake (Lassen Volcanic National Park), after the Reading Fire, imaged in August 2013

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*



Picture of a diatom species, *Caloneis lewisii* from a prepared slide of sediment sample 16cm deep in Manzanita Lake (LAVO) gravity core. Imaged at the MacBride Lab, Iowa Lakeside Lab, June 2013.



Lake surface plankton tow sample from Manzanita Lake (8.8.12) showing massive bloom of colonial diatom species *Fragilaria crotonensis.* Imaged at the University of Nevada, Reno.

Lake Helen: taking water column measurements of temperature, conductivity, and dissolved oxygen

Preparing a sediment grab sampler (Ekman sampler) for use in Manzanita Lake


1.2m push core recovered from Manzanita Lake in August 2013

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Amanda Koltz
University: Duke University
Start date: 06/01/2012
End date: 08/31/2013

Brief project summary:

With the current and forecasted changes in climate, it is necessary to understand how organismal adaptations to climatic drivers fit into a broader ecological context. My dissertation bridges basic questions in community ecology, global change ecology, and ecosystem ecology to relate changes in community structure to ecosystem functioning. Changes in ecosystem functioning are of particular significance in the Arctic, and numerous studies have stressed the importance of arctic microbial communities in driving ecosystem processes. However, the composition and activity of the microbial community can be modified by soil invertebrates, and soil invertebrates themselves are regulated by generalist predators such as spiders. Due to their generalist feeding behavior, spiders have persisted through millions of years of climatic changes and mass extinctions, and therefore understanding the influence of spiders on decomposer food webs, especially in the context of global change, is relevant in countless different types of ecosystems. If spiders indirectly inhibit decomposition in the Arctic as documented elsewhere, they could be providing an important ecosystem service by slowing the release of carbon from permafrost soils.

The goal of this project is to improve the understanding of how warmer temperatures in the Arctic may alter community dynamics and ecosystem functioning. To accomplish this goal, my research is exploring how the structure of decomposer food webs and the rates of decomposition of organic matter in the Arctic are affected by wolf spider predation and how these predation effects differ under warmer temperatures. By comparing spider feeding ecology in different Arctic sites and performing a fully factorial mesocosm experiment (factors: spider density x temperature) this work is testing the hypotheses that 1) predation by spiders alters the biomass distribution of key functional groups in arctic decomposer communities; 2) predation effects of spiders influence microbial community composition; 3) spider predation indirectly changes the rates at which carbon is lost from the system; 4) warming alters predation effects on community structure and function.

By detailing the response of the decomposer food web to changes in temperature and predation by generalist predators, this research will ultimately provide insight into the relationship between aboveground and belowground systems and into the effects of global climate change on community structure and function.

Research Approach:
Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

There have been no major changes to the original questions, hypotheses, or basic approach in this research. The only minor change was to the experimental warming treatments in my plots during the third year of field work. While the experimental treatments (spider density manipulations and warming) were successful each year, the research plots were not warmed as much as I anticipated in 2011 and 2012. During the 2013 field season, I implemented a more extreme warming treatment by covering the research plots with plastic greenhouse sheeting. It's my hope that this new warming treatment will help me see the community effects of warming more clearly. In addition, before breaking down the experimental plots at the conclusion of the 2013 field season, I also did some additional sampling of the arthropod communities using a wider variety of techniques (e.g. open pitfalls, sticky traps). This snapshot of the broader community should provide better information on the presence and abundances of other arthropod predators that may mediate the effects of wolf spiders on the microarthropod community.

Furthermore, I currently hold a Doctoral Dissertation Improvement Grant from the National Science Foundation to characterize the bacterial and fungal communities in my experimental research plots. Over the last three years, I have collected samples from my plots for this purpose; I plan to visit Dr. Matthew Wallenstein's lab at Colorado State University in the spring to receive training and carry out the associated laboratory work for this extra side project.

Location(s) of Research:

The main experiment of my dissertation research was carried out on the North Slope of Alaska near Toolik Lake. Toolik Lake is located 21 km north of the boundary of the Gates of the Arctic National Park and Preserve in the northern foothills of the Brooks Range (68°38'N and 149°43'W, elevation 760 m) and is approximately 240 km north of the Arctic Circle.

Key Findings:

Progress and plans to completion:

Over the last year and a half, I successfully completed the second and third field seasons in the Alaskan arctic. I have also now processed the majority of the collected samples in the laboratory, and the rest of the lab work to be completed by December 2013. I expect to complete and submit a manuscript on this research by February 2014. By April, I plan to have a second manuscript prepared for publication submission, after which I will be visiting M. Wallenstein's lab at CSU to do the laboratory work on the soil microbial communities (as mentioned above). My goal is to finish and submit all the papers that will comprise my dissertation by July 2014 in order to graduate by the early fall.

Key findings:

The data from 2011 and 2012 indicate that wolf spider densities do affect microarthropod communities and decomposition rates in the Arctic. Higher wolf spider densities led to faster rates of decomposition of both grass and deciduous shrub litter. While deciduous shrub litter showed this pattern after one summer season, it took two years for wolf spiders to indirectly affect decomposition rates of grass litter. With the grass litter, experimental warming buffered the effect of the spiders such that there was no change to decomposition rates (Fig.1).

Additionally and surprisingly with the grass litter, the effects of higher wolf spider densities were much larger belowground than at the soil surface.

A difference in soil surface vs. belowground decomposition effects of wolf spiders appears to be mediated by the microarthropod community. While soil microarthropod densities were not *directly* affected by wolf spiders, in plots with more spiders, the microarthropods shifted from further belowground to closer to the soil surface (Fig.2). Microarthropod densities were negatively associated soil fungal biomass, which was, in turn, negatively related to decomposition. This makes sense, because the fungal communities responsible for decomposition are also prey for the microarthropods. Thus the vertical movement by the microarthropods in response to changing wolf spider densities could cause less predation on fungi belowground and facilitate faster decomposition. The mechanism for more rapid decomposition at the soil surface in plots with higher wolf spider densities does not follow this rationale (given the higher densities of microarthropods at the surface). One possibility is that microarthropod behavior at the soil surface may be partly dictated by other soil surface predators like beetles and other types of spiders. Anti-predator avoidance often leads to reduced feeding rates, which would allow the fungal community to thrive despite high abundances of microarthropods at the surface. Alternatively, in the face of high grazing pressure, fungal communities have been shown to change their morphology and exhibit compensatory and stimulatory growth. In this case, unnaturally high densities of microarthropods at the soil surface could have sparked fungal growth and accelerated litter decomposition.

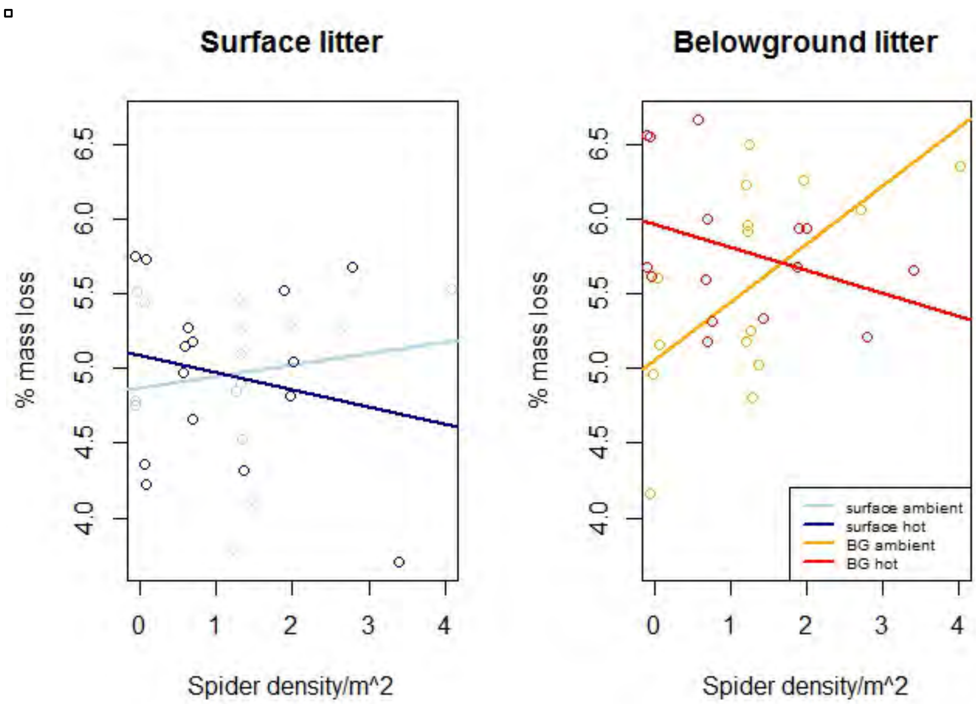


Fig. 1. Interaction between spider density and warming treatment on the percent of graminoid litter mass lost in the second year of the experiment. Mixed effects model using sqrt(percent mass loss) and random intercepts by block (location: t= -5.26, *df=51, p<0.01; spider density: t=* 2.26, *df=51, p=0.03; temp treatment: t=* 2.42, *df=51, p=0.02;* temp:spider density*: t=-* 2.44, *df=51, p=0.02).*

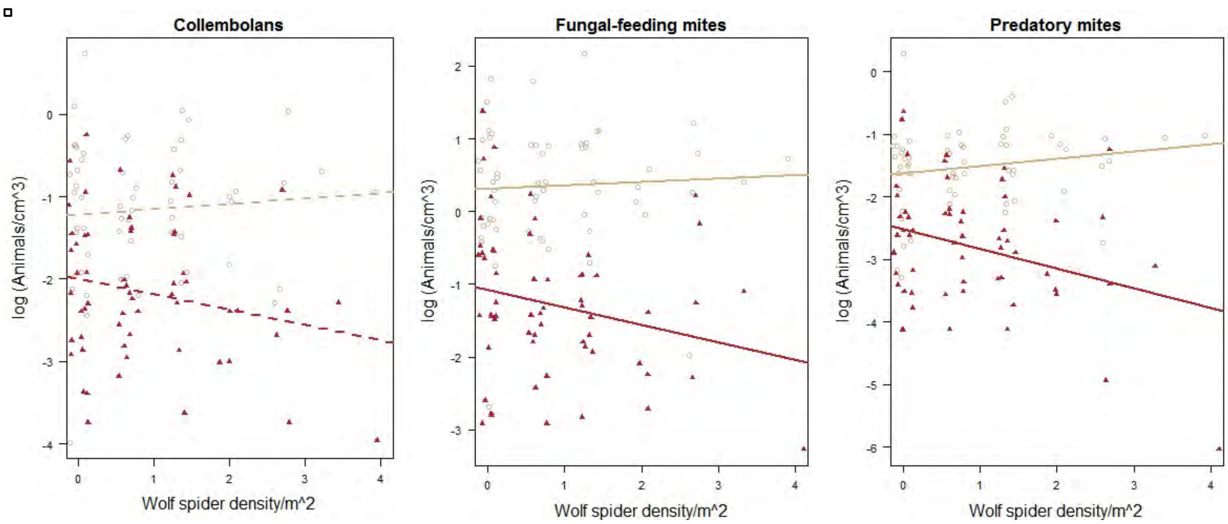


*Fig. 2. Densities of fungal-feeding and predatory mites at soil surface and belowground in response to altered wolf spider densities. Tan points are surface measures; brown points are from belowground samples. Mixed effects models using log(microarthropod density) and random intercepts by block. Dotted lines indicate non-significant interaction (Collembola model: location: t=*4.15*, df=111, p<0.01; spider density: t=-1.77, df=111, p=0.079; spider:location: t=*1.74*, df=111, p=0.085. Fungal feeding mite model: location: t=*7.13*, df=111, p<0.001; spider density: t=-*2.29*, df=111, p=0.024; spider:location: t=*1.94*, df=111, p=0.054. Predatory mite model: location: t=* 4.55*, df=111, p<0.001; spider density: t=* -2.95*, df=111, p=0.004; spider:location: t=*2.87*, df=111, p=0.005.*

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

Conferences attended:

- Entomological Society of America Annual Meeting, Austin, TX (invited symposium speaker) (11/2013)
- Ecological Society of America Annual Meeting, Minneapolis, MN (8/2013)
- Conference on long-term changes in tundra ecosystems, Aarhus, Denmark (11/2012)
- Ecological Society of America Annual Meeting, Portland, OR (8/2012)

Presentations to academic audiences:

Koltz, A. and J. Wright. *Warming alters ecosystem effects of wolf spider in the Arctic.* National Science Foundation Review of the Arctic Long-Term Ecological Research Site, Toolik Lake, AK (6/2013).

Koltz, A. *Wolf spiders: the true arctic predators*. Duke University Nicholas School of the

Environment Graduate Afternoon Seminar, Durham NC (4/2013).

Koltz, A., Hoye, T. and J. Wright. *Warming over the last 15 years has altered the functional composition of high arctic arthropod communities*. Arctic Long-Term Ecological Research Meeting. Woods Hole, MA (3/2013).

Koltz, A. *Changes in arthropod community structure and function.* Conference on long-term changes in tundra ecosystems. Aarhus, Denmark (11/2012).

Koltz, A. and J. Wright. *Effects of wolf spider density on decomposer community structure and function in the Arctic.* Ecological Society of America Annual Meeting, Portland, OR (8/2012).

Koltz, A. and J. Wright. *Effects of wolf spider density on decomposer community structure and function in the Arctic.*International Polar Year Conference. Montreal, Canada (4/2012).

Koltz, A. and J. Wright. *Effects of wolf spider density on decomposer community structure and function in the Arctic.* Arctic Long-Term Ecological Research Meeting. Woods Hole, MA (3/2012).

Educational deliverables:

- Blog post for National Geographic Explorers Journal: *Searching for Wolf Spiders in the Land of Frozen Summers.* (6/4/2013)

  http://newswatch.nationalgeographic.com/2013/06/04/searching-for-wolf-spiders-in-the-land-of-frozen-summers/

- Contributed to National Geographic Education Blog: *Bringing Arctic Field Work to Students.* (7/23/2013)

  http://blog.education.nationalgeographic.com/2013/07/23/wolf-spiders-bringing-arctic-field-work-back-to-students/

- Hosted K-12 teachers in the field for 4-6 weeks each in 2012 and 2013 through the PolarTREC Program (see below under *other* for additional information on PolarTREC educational outreach activities)
- Gave a virtual presentation to the entire 7th grade class of Kenwood Academy (Chicago, IL) on climate change in the Arctic and the role of soil food webs and spiders. This presentation was in collaboration with my 2013 PolarTREC teacher, Nell Kemp (May 2013).
- Assisted in journal posts from the field and creation of arctic and climate change-related educational materials with PolarTREC teachers.
- Co-hosted three educational webinars to K-12 students, teachers, and general public audiences from the field with PolarTREC teachers (archived at PolarTREC websites below).

Additional Funding:

Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

- Duke University – Summer Research Fellowship (standard graduate stipend for two months during summer 2013)

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

Additional to my work in Alaska, I spent two months visiting Dr. Toke Hoye at the University of Aarhus, Denmark in the fall of 2012. The U. of Aarhus houses annually collected monitoring data and samples over the past 15 years from NE Greenland. This unparalleled resource provided an opportunity to explore the long-term effects of climate change on arthropod communities from High Arctic Greenland. Analyses for this project are almost completed; I plan to start writing up our findings upon this fall.

I also spent time during my fellowship to further opportunities in science for a variety of students and educators. In the last year, I worked with and trained two female undergraduate students, one of whom is of Hispanic American descent. I also hosted a K-12 science instructor as part of my research team during the 2012 and 2013 field seasons through the PolarTREC program (PolarTREC: Teachers and Researchers Exploring and Collaborating, NSF funded). PolarTREC is meant to connect research scientists to teachers in order to bring Arctic Science to the classroom. Teachers participate in hands-on field research, which helps to increase students' understanding of and engagement in science and the Polar Regions. In turn, the experience helps researchers engage in K-12 education and enriches their outreach and research dissemination. In 2012, Nick LaFave, a high school environmental science teacher from Clover, SC, joined me in the field for six weeks, and in 2013, Nell Kemp, a middle school environmental science teacher was a member of my team for four weeks. I worked extensively with Nick and Nell on a variety of different topics relating to arctic science, climate change, ecosystem ecology, and of course arctic wolf spiders. Both teachers blogged regularly from the field and have developed classroom materials related to my project and broader topics in arctic science. With Nick, I hosted two educational webinars from the field: one for the general public and another for a teacher development workshop. Nick's expedition and my project have been featured on a number of different websites, and recently Nick was awarded District Teacher of the Year, in part because of his work bringing research science back to the classroom. Nell and I also hosted a webinar in the field and developed course materials for a teacher development workshop at the Field Museum of Natural History in Chicago. I am continuing to work with Nick and Nell this year. Nick and I plan to give several public outreach talks together about arctic science and for one of his advanced classes to visit Duke this spring. In addition, I will be visiting Nell's 7th grade classes in late November to do hands-on field and laboratory activities related to my research on arctic spiders.

Here are the PolarTREC sites and blogs related to Nick and Nell's arctic expeditions and a few related examples of press releases on their experiences:

Nick’s 2012 expedition project page:
http://www.polartrec.com/expeditions/predatory-spiders-in-the-arctic-food-web

Nell’s 2013 expedition project page:
http://www.polartrec.com/expeditions/predatory-spiders-in-the-arctic-food-web-2013

Press releases
http://www.gastongazette.com/articles/lafave-71583-teacher-nick.html
http://www.charlotteobserver.com/2012/05/25/3262408/school-news.html
http://www.heraldonline.com/2012/05/24/3998707/ultimate-science-lesson.html
http://www.winthrop.edu/news-events/article.aspx?id=24471
http://www.ogd.com/article/20120603/ADV01/706039921/0/ogd
http://www.enquirerherald.com/2012/05/24/v-all_comments/1919736_ultimate-science-lesson.html
http://blog.education.nationalgeographic.com/2013/07/23/wolf-spiders-bringing-arctic-field-work-back-to-students/

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*


Arctic Circle
ALASKA
Ithaca is
GORGES

Amanda- Antigun

Digging pitfall trap at burnsite

Tundra soil sample

Burn-vacuuming with Ashley

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
October 1, 2013

Fellow Name: Michael Lukens
University: Central Washington University
Start date: 5/2012
End date: 10/2013

Brief project summary:

With the creation of Mount Rainier National Park (MORA) in 1899 came the active management of the park's landscapes and a heavy emphasis on fire suppression. Today managers at MORA have made understanding past fire activity and potential drivers of fire activity a high priority in hopes of making more informed decisions in regard to the application of fire. In addition, the potential impact of climate on future fire activity is also of great concern. To address these questions and concerns, analysis of macroscopic charcoal preserved in lake sediments was used to reconstruct the fire history for Mount Rainier.

Research Approach:

The purpose of this research was to use fossil charcoal preserved in lake sediments to reconstruct the Holocene (past ~11,000 years) fire history for MORA. From these records, shifts in fire frequency, mean fire intervals (MFI), charcoal accumulation rates (CHAR), significant fire events and fire event magnitude were determined. Once reconstructed, these fire histories were used to address the following research questions:

1) How did fire activity change during the Holocene on the Sunrise Ridge of MORA?

2) What factors influenced this past fire activity (e.g., climate variability, human land use, etc)?

Location(s) of Research:

Mount Rainier National Park (MORA)

Key Findings:

Reconstructions for sites across Mt Rainier show that during the late Pleistocene fire activity was low. Transitioning into the early Holocene, fire activity increased and remained high from the start of the mid-Holocene through ca. 6,000 cal yr BP and then declined through ca. 4,500 cal yr BP. From the start of the late Holocene, fire activity increased substantially through ca. 2,000 cal yr BP, decreased through ca. 1,000 cal yr BP, and then increased to present. The similarity between the records for MORA and other sites in the Pacific Northwest suggests that broad-scale climatic variability, such as changes in annual insolation and the El Niño–Southern Oscillation, were likely the primary driver of fire activity on Mount Rainier during the Holocene. While it is possible that human-set fires also influenced the fire reconstructions, results from the lakes along the Sunrise Ridge do not show clear evidence of anthropogenic burning. In terms of future fire activity, projected increases in summer temperature and decreases in summer precipitation will most likely lead to a higher occurrence of drought and subsequent fire at MORA.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

- 2013 Master's Thesis
- Presentations at several academic conferences. NWSC 2012, MTNCLIM 2012, AAG 2013
- Two formal presentations of results and findings to the staff at MORA.
- Several upcoming publications.

Additional Funding:

I was able to secure funding from CWU through the Master's Research Fellowship ($700), the CWU Grant Program ($400) and through Mount Rainier National Park ($3000).
In addition the funding that allowed for this research provided the opportunity to host a field school for undergraduate students to assist in research in the field.

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

  At this time, several articles are in the process of being written by myself and my advisor (Dr. Megan Walsh) and will be submitted to various academic journals for publication on the long term fire history of Mt Rainer. In addition, this information will be presented at future conferences focused on mountain environments, fire, and climate change.

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

  Several unidentified Tephra layers were discovered in lake sediment cores taken from around Mt Rainier; these layers were transferred to Dr. Jim Vallance at the USGS Cascade Volcano Observatory and are in the process of being identified. Dr. Vallance believes that the cores from my research will greatly aid in better understanding the volcanic history of Mount Rainier and past eruptive periods in the Cascades.

Photographs:

Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.

** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*

See attached report: See Appendix A

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Lisa Marrack
University: University of California at Berkeley
Start date: June 15, 2012
End date: To be extended to Sept. 2014

Brief project summary:

Various climate change scenarios predict that sea levels will rise between 0.75 to 1.9m by 2100 (Vermeer and Rahmstorf, 2009). Sea level rise and changes in storm run-up during large surf events will affect nearshore habitats, cultural resources, water resources, and infra-structure. Current efforts to model sea level rise inundation scenarios within the five national parks on the Big Island of Hawaii (ALKA, KAHO, PUHO, PUHE, HAVO) indicate that while some coastal resources will be flooded, others will be created (Marrack, in review). Anchialine pool habitats, which are significant natural and cultural features within four of the park units, will be impacted. These brackish pools are fed by upslope groundwater and support candidate endangered invertebrates. Accurate predictions for future anchialine habitats and the endemic species that depend on them are severely limited because spatial data on pool location is insufficient and current pool condition is not known along most of the ALKA trail. To improve the predictions of sea level rise impacts on anchialine habitats, I have been collecting location and habitat condition data for pools within ALKA, KAHO, PUHO, and HAVO. This data is being used to predict: 1) resources that will be lost due to inundation; 2) resources that will be threatened by invasive fish dispersal as sea levels rise; 3) future locations of high quality habitat. To assist with climate change risk assessment and scenario planning, I have been sharing my results with NPS resource staff and affiliated land managers through maps, reports, and presentations. The results will be extremely helpful for future trail routing, visitor accommodation, disaster planning, and resource prioritization actions such as invasive species removal. The information will also be useful for informing the public about the impacts of climate change on island coastal resources

Current Status: My work is on target to answer the questions put forth in my original proposal.

1. *How does pool condition and endemic species distribution relate to invasive fish distribution, water quality, and land-use?*

2. *What are the locations of anchialine pools within ALKA, KAHO, PUHO, and HAVO, and what pools will be inundated under various sea level rise scenarios?*

3. *Under various sea level rise scenarios, what are the dispersal pathways of introduced fishes from current locations to future pool habitats?*

4. *Which pools and future pool locations are the highest priority for protection? Which are the highest priority for introduced species removal?*

Research Approach:
My work is based on field surveys and GIS modeling. The basic approaches put forth in the original proposal are the same. Several modifications have been incorporated into the methods due to results acquired over the course of the study. First of all, I used National Geodetic survey semi-permanent benchmark elevations in my study area to ground-truth the FEMA LiDAR data used for the Digital Elevation Maps and sea level rise models. Results indicated that the LiDAR was vertically offset in its projection by an average of + 0.25 m meaning that it is representing elevations 0.25 m higher than reality. I have been working with the NGS staff who re-surveyed the same benchmarks in September of 2013 to confirm this observation. The NGS results should be available by the end of October and will be incorporated into the models of invasive fish dispersal with sea level rise. Both the GMW fellowship and an extension of a CCESU contract between the NPS and UC Berkeley will fund this continued work in 2013.

Additionally, to improve detection of anchialine pools, I tested incorporating groundwater levels into sea level heights. This work proved successful and was used to write a paper that was just accepted by the Journal of Coastal Research in September 2013.

Location(s) of Research:
This research is being conducted within the Ala Kahakai National Historic Trail (ALKA) corridor. Established in 2000 for the preservation, protection and interpretation of traditional Native Hawaiian culture and natural resources, ALKA is a 175-mile trail corridor that wraps around the coastline of the Big Island of Hawaii. The ALKA corridor encompasses private land, State conservation areas, and the four other Big Island National Parks (KAHO, PUHO, PUHE, HAVO). Because I am mapping as many pools as possible within the ALKA corridor, I am visiting sites on private, state, and NPS lands. Private lands include those held by The Nature Conservancy, Kamehameha Land Trust, various resort developments, and individuals. All of my permits and permissions are up to date and have allowed access onto a large portion of the ALKA corridor.

Key Findings:

- Survey data from 340 pools mapped between 2012 to 2013 along with data from an additional 100 pools surveyed by the NPS between 2007 -2009, show that the dominant pool grazer, the endemic shrimp *Halocaridina rubra*, as well as the candidate endangered shrimp *Metabateaus lohena* live throughout the ALKA trail in pools representing a wide range of salinities (1.8 – 25 practical salinity units), substrate types (0-100% rock), and pool morphologies. Surveys confirm findings of previous small scale studies showing that some rare pool fauna (endemic shrimp and gastropods) have very limited distributions that may be less than 1km area.

- Invasive species distribution: Tilapia occurred in 3.5% (n=14) pools and Poeciliids (guppies, misquito fish) occurred in 23.9% (n=95) of pools surveyed. The Tahitian prawn *Macrobrachium lar* occurred in 3.8% (n=15) of pools. Tilapia, Poeciliids, and *M. lar* were found at sites on the western and southern coastlines in a variety of land-use areas including residential, resort, National Parks, and Hawaii State Conservation lands.

- During daylight surveys *Halocaridina rubra* was present throughout the study area in 45% of pools. Shrimp were observed in pools that become dry at low tide but fill with water at higher tides. Non-parametric regressions (generalized additive models) indicate that the presence of introduced fishes (Tilapia, guppies, mosquito fish) and a high % of silt on the pool bottom are the most significant factors negatively affecting the probability of *H. rubra* presence in pools.

- *M. lohena* occurred in 13% of pools surveyed during daylight hours and co-occurred with *H. rubra* in all but 1 pool. Non-parametric regression analysis indicates that pools with higher canopy cover and those with *H. rubra* have a higher probability of *M. lohena* presence.

- Incorporating groundwater levels into sea level rise models improves detection of current anchialine pools by up to 37%.

- Sea level rise scenario maps confirm that sea level rise will inundate some current pools, and that new pools will emerge on the landscape.

- Preliminary tests of cost-distance and circuit theory have been used to model invasive fish dispersal within KAHO pools. Sea level rise will provide connectivity between pools, especially at higher tides, allowing introduced fishes to disperse into previously uninfected areas. Once the NGS benchmark resurvey data arrives, I can proceed with this analysis more fully. This will allow us to prioritize fish removals.

- Diel surveys (night/day) of pools show that pools with fishes (Tilapia and Poeciliids) have different temporal patterns of *H. rubra* densities compared to pools without introduced fish. During the day, shrimp are at low densities or are not present in pools with fish, but at night when fish are inactive, shrimp densities are as high or higher than in pools without introduced predators.

- Stable isotope analysis (pilot study) confirms assumed food web structures showing that the introduced predators are eating the dominant grazer in the system but may shift to other prey once these grazing shrimp are absent. This may have important implications for the grazing control that *H. rubra* have on macro-algae which is usually absent in healthy pool ecosystems.

Deliverables/Research Products:

PAPERS

Marrack, L.(accepted 9/2013). Incorporating Groundwater Height into Sea Level Detection Models for Hawaiian Anchialine Pool Ecosystems. Journal of Coastal Research.

Marrack, L.(in peer review, 2013). Predicting Impacts of Sea Level Rise for Cultural and Natural Resources in Five National Park Units on the Big Island of Hawaii. Technical Report. CCESU University of California at Berkeley and National Park Service. 23 pgs.

NOTE: I am working on other papers as well as my dissertation. I will have these available when they are finished.

GIS PRODUCTS

ArcGIS maps, raster files, and vector geodatabases of anchialine pool habitats along the ALKA corridor in relation to various sea level rise scenarios. Available 2012. These will be updated with results from the NGS 2013 benchmark survey and sent to each park on an external hard drive.

PRESENTATIONS

Marrack, L., September, 2013. Predicting the Effects of Sea Level Rise & Introduced Species on Hawaiian Anchialine Pools. POET – NPS Webinar.

Marrack, L. July, 2013. Predicting the Effects of Sea Level Rise & Introduced Species on Hawaiian Anchialine Pools. Sea Grant – REEF talk – Pu'u Kohola National Historical Park.

Marrack, L. July, 2013. Sea Level Rise Effects: Anchailine Pools and Wetlands. Peter Vitousek Ecology Symposium. University of Hawaii, Hilo

Marrack, L. June, 2013. (**Poster**). Modeling the Effects of Sea Level Rise and Introduced Species on Hawaiian Anchialine Pools. Evolution Meeting , Snowbird, Utah.

Marrack, L. March 2013. Predicting the Effects of Sea Level Rise and Introduced Fishes on Hawaiian Anchialine Pool Ecosystems. Abstract and presentation. George Wright Society Meeting, Denver, Colorado.

Marrack, L. March 2013. Modeling the Effects of Sea Level Rise on Anchialine Pool Ecosystems. Big Island Water Resources Group Symposium II. Hilo, Hawaii.

Marrack, L. August 2012. Predicting the Effects of Sea Level Rise and Introduced Species on Hawaiian Anchialine Pool Ecosystems. Hawaii Conservation Conference. Honolulu, Hawaii.

Other: Along with my ALKA partners, we have tried to get the word out on my research and the available GIS products that I have created to as many people as possible. To that end I have given power point talks to :

- Kamehameha Schools Resource Management Groups (Oahu and Big Island)
- Hawaii County Planning Department (Hilo and Kona)
- National Parks staff –PUHO, PUHE, KAHO, ALKA, HAVO, PICCC (Pacific Island Climate Change Center)
- Resource manager for State Conservation Land
- Private land owners along the trail including The Nature Conservancy

Additional Funding:
The Fellowship has been extremely valuable for securing other research funding. Because I have receive other, less flexible awards, I have been able to stretch the fellowship award for over a longer time period allowing additional field work.

-Edward A. **Coleman Fellowship** in Water Management, **UC Berkeley:** Fall 2013
-California Cooperative Studies Unit - UC Berkeley and NPS: 2011- 2013. Recently modified to September 2014.

Other
It has been a fantastic experience to walk so much of the ALKA corridor where I often encounter more goats and mongoose than people. It is terribly exciting to be walking (and sweating) through the black, arid lava fields and to come across cold groundwater fed anchialine pools full of beautiful red shrimp that are found nowhere else in the world. I have also been able to meet some amazing folks who are working to protect the land and restore anchialine pools. At this time I know of eight groups working to protect pools outside of NPS boundaries that are in various stages of planning or wanting to plan for invasive fish removal along the ALKA trail corridor. One community group (Hui Aloha Kiholo) has received a grant from the Hawaii Tourism board to do so. The difficult part is that rotenone, a previously successful fish removal chemical, is now banned in Hawaii. A partner with the USGS-BRD is now trying out CO^2 and electroshock techniques for removals. This grass roots community interest is exciting and makes me hopeful for ecosystem protection into the future. I try to share the results of my work if it is helpful and try to connect people that may be able to help each other. The ALKA staff (Rick Gmirkin, Ida Hanohano, Nahaku Kalei, Mandy Johnson) and superintendant (Aric Arakaki) have been incredibly supportive. Because much of the ALKA trail is undeveloped, there is a chance for us to protect areas that will become the anchialine pool habitats of the future as sea levels rise. Even the county planners have been receptive to this idea, so I am hopeful that we can protect this special ecosystem moving forward.

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.

Three anchialine pools on the Ala Kahakai National Historic Trail. YSI instrument for collecting water data is shown.


Endemic anchialine pool shrimp a) *Halocaridina rubra*, (0.5 to 1 cm) the dominant grazer in the system, b) *Calliasmata pholidota*,(3 cm) rare shrimp found in one site on the south coast of the Island of Hawaii and one location in Maui.

All photos taken by Lisa Marrack In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Carly Muletz
University: University of Maryland
Start date: May 1, 2012
End date: June 30, 2014

Brief project summary:

The purpose of my project was to determine the distribution and functionality of salamanders' resident skin bacteria and the distribution of the amphibian skin fungal pathogen *Batrachochytrium dendrobatidis* (*Bd*; implemented in worldwide amphibian die-offs (Olson et al. 2013)) along an elevational gradient in two salamander species in Shenandoah National Park. I used an elevational gradient (700 – 1000 m; sampled at 100 m intervals) as a proxy for variation in climate (Rahbek 2005) to predict distributional changes in resident bacteria and *Bd* with changes in climate. I sampled red-backed salamanders, *Plethodon cinereus*, and white-spotted slimy salamanders, *P. cylindraceus*, because red-backed salamander populations in the Northern US are relatively stable, while there is indication of population declines of several slimy salamander species (Highton 2005, Caruso & Lips 2013). I hypothesized that (i) salamander species would have distinct bacterial communities, (ii) salamander populations of the same species would have distinct bacterial communities that would have predictable structure along an elevational gradient, and (iii) *Bd* presence would be correlated to low diversity of bacteria. I used traditional culturing methods to identify protective bacteria that inhibit *Bd* growth (anti-*Bd* bacteria) to assign functionality of certain resident bacteria. I used new high-throughput sequencing methods to characterize the entire bacterial community to determine the taxonomic distribution (including anti-*Bd* bacteria) of salamander-associated bacteria along the elevational gradient. I used quantitative PCR to detect the presence of *Bd* on salamanders. Taken together, the overarching objective of the research was to identify the affect of climate on salamander skin microbial composition and host-pathogen disease dynamics of two species of salamanders in Shenandoah National Park.

Research Approach:

Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

My hypotheses are the same as I originally proposed (as noted above), but I made a few changes in the methods. Specifically, I conducted the high-throughput sequencing preparation and reaction at the National Zoological Park-Center for Evolutionary and Conservation Genetics as opposed to outsourcing the job as originally proposed. Due to money saved by conducting the high-throughput sequencing in house, I was able to sample more salamanders than originally proposed. However, I sampled less of one species, *P. cylindraceus*, due to their rarity in the park. Furthermore, I sampled more sites than originally proposed so to increase replication of the elevations. Specifically, I proposed to sample 10 salamanders of each species at four sites (total n = 40). Instead, I surveyed 11 sites (at least two sites per elevation) and ultimately sampled 7 *P. cylindraceus* and 50 *P. cinereus* (total n = 57); only *P. cinereus* was used to address how bacteria and *Bd* were distributed across the elevational gradient, due to low sample size of *P. cylindraceus*.

Finally, the timeline of research completion was extended given the need for more time to complete the study. Specifically, because I conducted the high-throughput sequencing in house the time needed to complete these runs were more than if the work was outsourced. Also, Sanger Sequencing of the culturable anti-*Bd* bacterial isolates to identify taxonomic identity of these bacteria has not been as straightforward as originally thought. I have had to do trouble shooting in DNA extraction, PCR conditions and sequencing protocols to get high quality PCR products for sequencing. This has taken additional time that I originally did not allow for.

Location(s) of Research: <u>Shenandoah National Park, VA</u>. The fellowship was awarded for me to conduct research in Shenandoah NP, but I also collected and analyzed similar data from two other protected areas: Catoctin Mountain Park, MD and Mt. Rogers National Recreation Area, VA (Figure 1). I am including them here for a broader scale understanding of my fellowship topic.

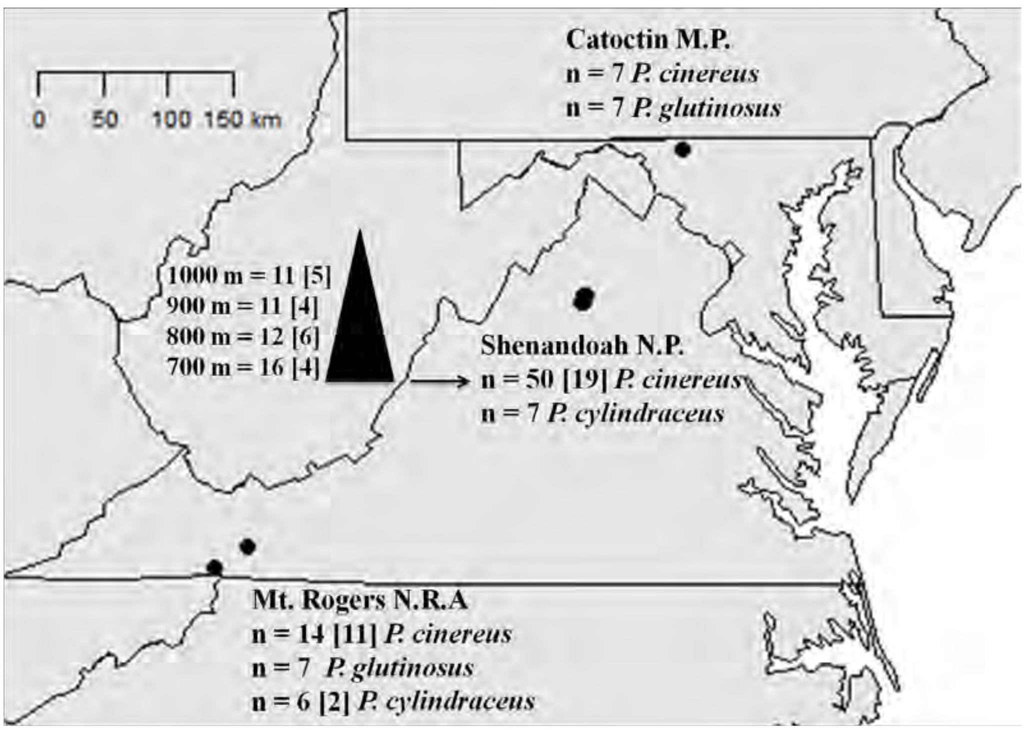


Figure 1: Field sampling locations with *Plethodon* species and samples sizes specified for each location. All salamanders had their entire bacterial community sampled (first number indicated for sample size). In some instances, a subset of salamanders was sampled for identification of anti-*Bd* bacteria (number in brackets). If no brackets are present, sample size for entire bacterial community and anti-*Bd* bacterial identification are the same. Black triangle indicates that sampling occurred along an elevational gradient at Shenandoah National Park.

Definition of important terms pertaining to study results:

Protected areas: Shenandoah NP, Catoctin Mountain Park, Mt. Rogers NRA

Bd: The amphibian skin fungal pathogen *Batrachochytrium dendrobatidis* that has been implemented in mass mortality events, declines and extirpations of amphibians globally.

Bacterial OTUs: operational taxonomic units which are defined as sequences that are >97% similar in nucleotide bases; given the nature of identifying bacteria based on DNA sequences molecular microbiologists use the OTU term to avoid debate associated with species concepts in biology. An OTU can be thought of as being similar to a species.

Bacterial community structure: I am referring to β-diversity when I use this term; β-diversity indicates the amount of shared bacterial OTUs between salamanders. Specifically, this looks at the number of bacterial OTUs, the identity of these OTUs, and how the OTUs change between salamanders, i.e., turnover between local populations.

Unifrac distances: A measure of β-diversity that incorporates the phylogenetic relatedness of bacterial OTUs. This is a commonly used metric to examine bacterial community structure.

Anti-Bd bacterial morphospecies: A culturable bacteria isolate that inhibited the growth of *Bd*. I am in the process of sequencing these anti-*Bd* bacteria to determine taxonomic identity. At the moment, each anti-*Bd* bacterial morphospecies is standardized per salamander; for each salamander I isolated unique morphospecies using common microbiology techniques.

Chao1 estimate: An estimate of α-diversity (number of species) that is suited for communities with many low abundance organisms, which is typically the case in microbial communities.

Key Findings:

- *Bd* was not detected on any salamander surveyed at all the protected areas. On a separate project, colleagues and I tested almost 1500 *Plethodon* samples representing 14 taxa (museum specimens and present-day salamanders) over ~500 km geographic distance from 1957-2011 and found less than 1% prevalence on these individuals (Muletz et al., manuscript in prep). This indicates that *Bd* is not likely associated with the observed declines of certain *Plethodon* taxa. My advisor and colleagues are now examining the potential link of climate change to the observed declines of *Plethodon* species.

- There was no difference in the number of bacteria (total bacterial OTUs: Figure 2 and anti-*Bd* bacterial morphospecies: Figure 3) between salamander species sampled at the same protected area (T-test, ANOVA: $p > 0.05$). However, there were significantly more bacteria (total bacterial OTUs and anti-*Bd* bacterial species) present on salamanders, species pooled together, at Shenandoah NP than salamanders found at the other two protected areas (ANOVA, $p = 0.008$). Salamanders, on average, had: 37 bacterial OTUs and 1 anti-*Bd* bacterial species at Catoctin, 32 bacterial OTUs and 1 anti-*Bd* bacterial species at Mt. Rogers, and 52 bacterial OTUs and 4 anti-*Bd* bacterial species at Shenandoah.

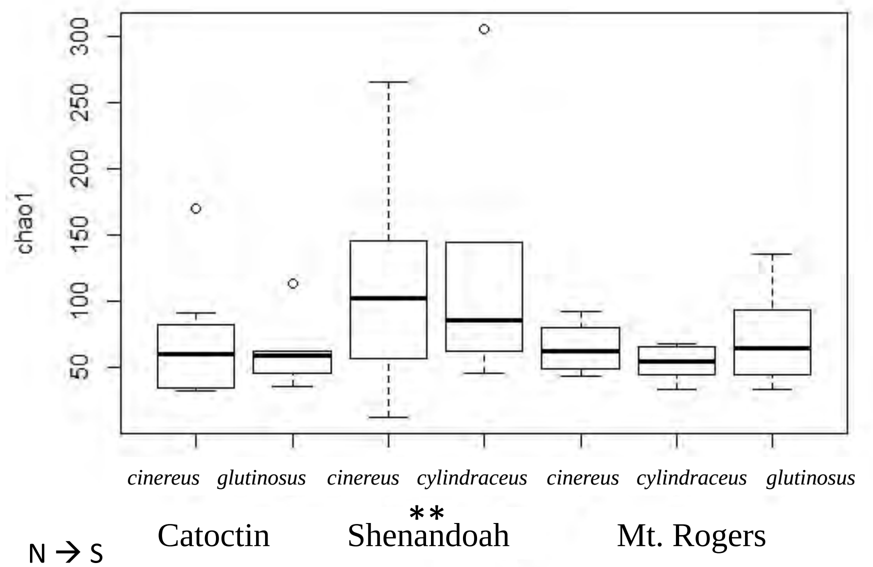


Figure 2: The Chao1 estimate of the number of bacterial OTUs (α-diversity) per salamander across a 497 km latitudinal gradient for three *Plethodon* species. Salamanders at Shenandoah NP, regardless of species, had significantly higher α-diversity (ANOVA: $p = 0.008$) indicating that environmental factors may be more influential in shaping bacterial community structure than evolutionary processes.

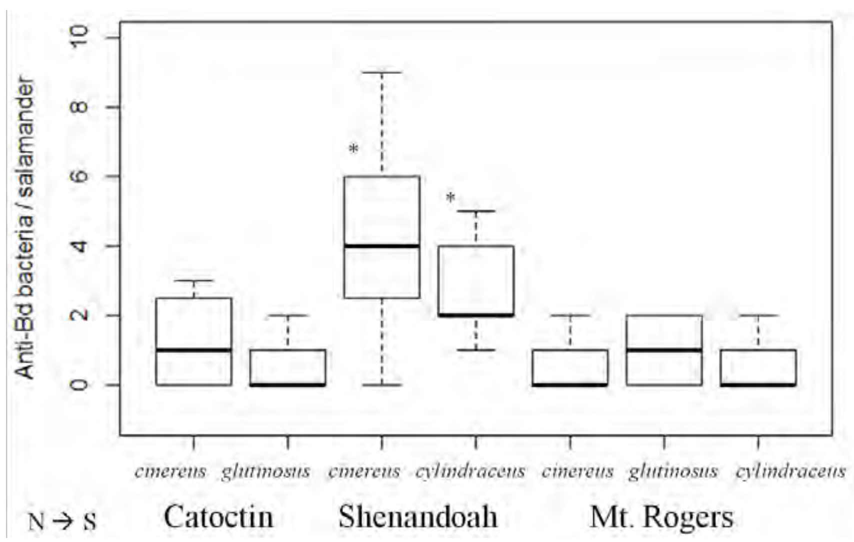


Figure 3: The number of anti-*Bd* bacterial morphospecies per salamander across a 497 km latitudinal gradient for three *Plethodon* species. Salamanders at Shenandoah N.P. had significantly more anti-*Bd* bacteria per salamander, regardless of species, than at the other parks sampled (ANOVA: $p < 0.001$), and had a higher number of salamanders with at least one anti-*Bd* bacteria (X^2: $p = 0.047$).

- Salamanders at Shenandoah NP have a more dissimilar bacterial community structure from the salamanders at Catoctin and Mt. Rogers (Figure 4; PERMDISP: p = 0.001). While along the elevational gradient at Shenandoah NP *P. cinereus* populations exhibited similar bacterial community structure (Figure 5; PERMISP: p > 0.05)

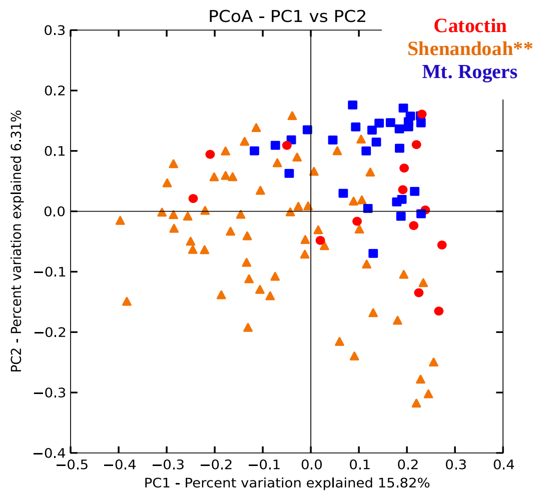


Figure 4: Representation of UniFrac distances (a measure of phylogenetic β-diversity) across all sites, with species combined. This indicates how the bacterial community structure varies among parks. Salamanders at Shenandoah NP had significantly dissimilar structure in their bacterial community than salamanders at the other parks (PERMDISP: p = 0.001). This indicates that there is more variability in the bacterial community present on salamanders in Shenandoah NP.

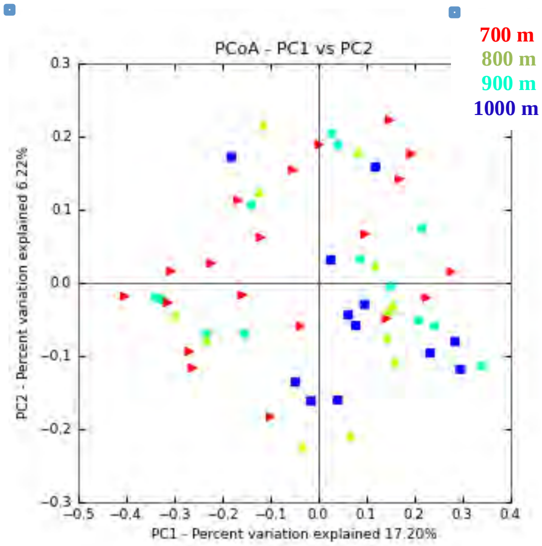


Figure 5: Representation of UniFrac distances across *P. cinereus* populations along an elevational gradient in Shenandoah NP. This indicates how the bacterial community structure varies among salamander species. Regardless of elevation, *P. cinereus* individuals had significantly similar structure in their bacterial community (PERMDISP: p > 0.05).

- At Shenandoah NP, *P. cinereus* populations sampled along an elevational gradient exhibited similar numbers of bacterial OTUs (Figure 6) and anti-*Bd* bacterial morphospecies (Figure 7), as well as similar bacterial community structure along the elevational gradient. In other words, there was no predictable pattern in bacterial community composition along an elevational gradient in Shenandoah NP.

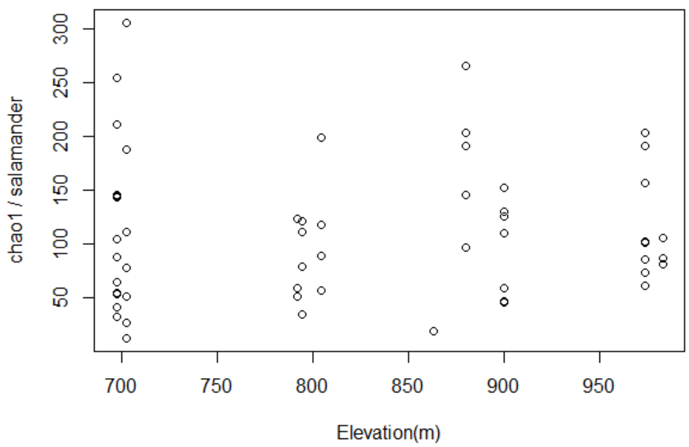


Figure 6: Chao1 estimate of α-diversity per salamander along an elevational gradient in Shenandoah N.P. There was no elevational pattern in α-diversity (Regression: $p > 0.05$) on *P. cinereus* indicating that elevation could not predict bacterial community structure in Shenandoah NP.

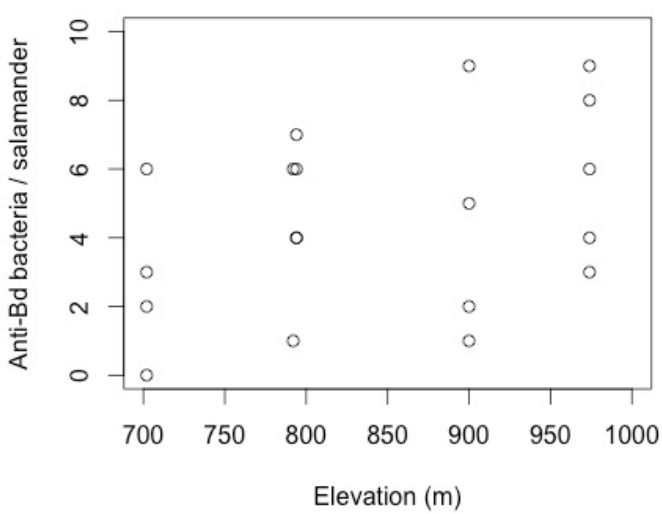


Figure 7: The number of anti-*Bd* bacteria per salamander along an elevation gradient (700 – 1000 m). Elevation did not predict the number of anti-*Bd* bacteria per salamander in Shenandoah N.P. (Regression: $p = 0.11$) or the number of salamanders with at least one anti-*Bd* bacteria as 18/19 had anti-*Bd* bacteria.

- I identified 131 anti-*Bd* bacterial isolates from all the salamanders sampled at all the protected areas. To date, I have sequenced 39 of these anti-*Bd* bacterial isolates from salamanders from Shenandoah NP to determine taxonomic identity. So far, I have found 17 anti-*Bd* bacterial species that have been identified in previous studies on amphibians sampled in Virginia, California, Panama and Columbia and 10 new anti-*Bd* bacterial species. The most common anti-*Bd* bacteria (on 3+ salamanders) are *Acinetobacter calcoaceticus*, *Burkholderia phytofirmans*, *Curtobacterium flaccumfaciens*, *Pseudomonas trivialis*.

- The three most abundant bacterial OTU genera in the entire bacterial community (80% of all the bacterial OTUs) on salamanders in Shenandoah NP are *Pseudomonas*, *Acinetobacter* and *Stenotrophomonas*. These are all genera that also contain anti-*Bd* bacteria indicating that there may be selection for bacteria that have anti-fungal (or anti-microbial) properties.

- Taken together, these results indicate that salamanders in certain protected areas (in this case Shenandoah NP) are likely more protected from microbial pathogens than in other regions. Also, results suggest that regional processes have a stronger influence on bacterial community composition than local processes. This conclusion is drawn from the results that there are no differences between species at protected areas, or populations at the same protected area, but there are differences between protected areas. Also, there is indication that there is selection either at the microbial or salamander level for antimicrobial bacterial species.

- Further speculation on the differences of bacterial OTUs and anti-*Bd* bacteria between parks:

    - I likely observed more anti-*Bd* bacteria at Shenandoah because the salamanders have higher bacterial richness. This indicates the importance of high bacterial diversity; the more bacteria the salamander possess the more likely the salamander is to have bacteria with defenses against *Bd* (or potentially other pathogens). A side note here is that I cultured a similar number of bacteria per salamander from salamanders at Catoctin and Shenandoah, but more bacteria were anti-*Bd* at Shenandoah, so I do not think it is a sampling issue here. Also these numbers OTUs/salamander and anti-*Bd* bacteria/salamander were consistent across all of the sites sampled at Shenandoah, so even if had only sampled one site in Shenandoah I still would have seen this trend.

    - The differences in protected areas suggest that selection has occurred at Shenandoah or at both Catoctin and Mt. Rogers. Due to little published research to date indicating what influences bacterial diversity on wildlife hosts it is difficult to determine what forces may be influencing this observed differences. However, I hypothesize that it does not relate to environmental factors, as these parks are relatively similar to one another. Catoctin may be the most 'urban', but Mt. Rogers is very similar based on observations to Shenandoah. I have salamander and site metadata (e.g., salamander body temperature, canopy cover, etc.) that I do, nonetheless, plan to analyze to see if there are environmental correlates for these observed differences.

- There is one thing that I will suggest that may explain this observed difference based on empirical work. Based on findings from Matilla et al. (2012) that found more genetically diverse bee hosts had higher gut bacterial diversity and more putatively helpful bacteria, I would speculate that salamanders at Shenandoah are more genetically diverse than those at Catoctin and Mt. Rogers. However, it could also be possible that the presence of another pathogen could be causing this difference in bacterial community structure, but I have no data or literature to cite on this speculation.

Literature Cited:

Caruso NM, Lips KR (2013) Truly enigmatic declines in terrestrial salamander populations in Great Smoky Mountains National Park. *Diversity and Distributions* **19**, 38-48.

Highton, R. 2005. Declines of eastern North American woodland salamanders (*Plethodon*). In: M.J. Lannoo (Ed.), Status and conservation of U.S. amphibians. University of California Press, Berkeley. pp 34–46.

Mattila HR, Rios D, Walker-Sperling VE, Roeselers G, Newton ILG (2012) Characterization of the Active Microbiotas Associated with Honey Bees Reveals Healthier and Broader Communities when Colonies are Genetically Diverse. *Plos One* **7**.

Olson DH, Aanensen DM, Ronnenberg KL, *et al.* (2013) Mapping the Global Emergence of Batrachochytrium dendrobatidis, the Amphibian Chytrid Fungus. *PLoS One* **8**, e56802.

Rahbek C (1995) The elevational gradient of species richness – a uniform pattern. *Ecography* **18**, 200-205.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

Presentations:
Muletz, C., Fleischer R., Yarwood S., Grant E., Lips, K., 2013. *Plethodon* salamanders' skin microbiome in disease protection. *Oral Presentation*, Ecological Society of America, Minneapolis, MN.

Muletz, C., Fleischer R., Yarwood S., Grant E., Lips, K., 2013. It's a small world: geographic and taxonomic variation in *Plethodon* salamanders' microbiome. *Oral presentation*, George Wright Society, Denver, CO.

Muletz, C., 2013. Microbial ecology of amphibian skin. *Oral presentation*, Non-Invasive Genetic Techniques Course in Wildlife Conservation, Smithsonian Conservation Biology Institute, Washington, D.C.

Muletz, C., Caruso, N., Fleischer R., Yarwood S., Lips, K., 2012. It's a small world: geographic, taxonomic and temporal variation in *Plethodon* salamanders' microbiome. *Oral presentation*, World Congress of Herpetology, University of British Columbia.

Muletz, C., Caruso, N., McDiarmid, R., Fleischer R., Yarwood S., Lips, K., 2012. Latitudinal and elevation variation of *Plethodon* salamanders' skin bacteria. *Oral presentation*, Amphibian Disease Conference, Arizona State University.

Media:
Virginia Gewin, October 2013. Salamanders wield microbial shield. Frontiers in Ecology and the Environment, Volume 11, Issue 8. Link.

Investigating Salamander Skin in Shenandoah National Park, Sept/Oct 2012, National Park Service Climate Change Response Program Newsletter, Pg. 2. Link.

Outreach:
Public presentation at Reptile Discovery Center, Smithsonian National Zoo, Washington, DC, "Woodland Salamanders: where they are, what they do, and why they are awesome." Fundraiser for Appalachian Salamander Exhibit, September 2013.

Additional Funding:
Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

N/A

Other:

- All salamander and site data that I collected in Shenandoah NP was shared with the USGS Northeast Amphibian Reptile Monitoring Initiative. The data is being used to understand salamander occupancy in Shenandoah NP.

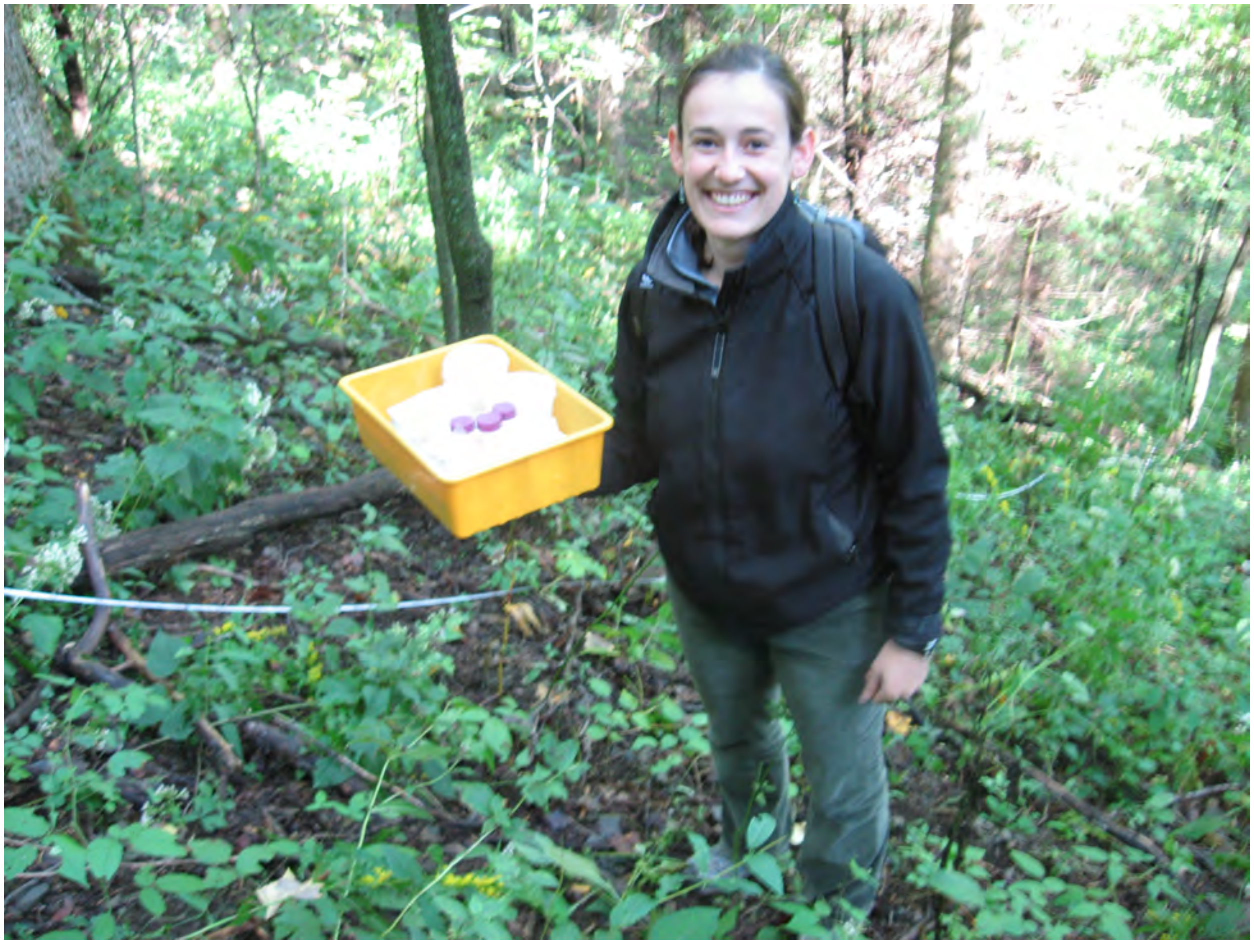
Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

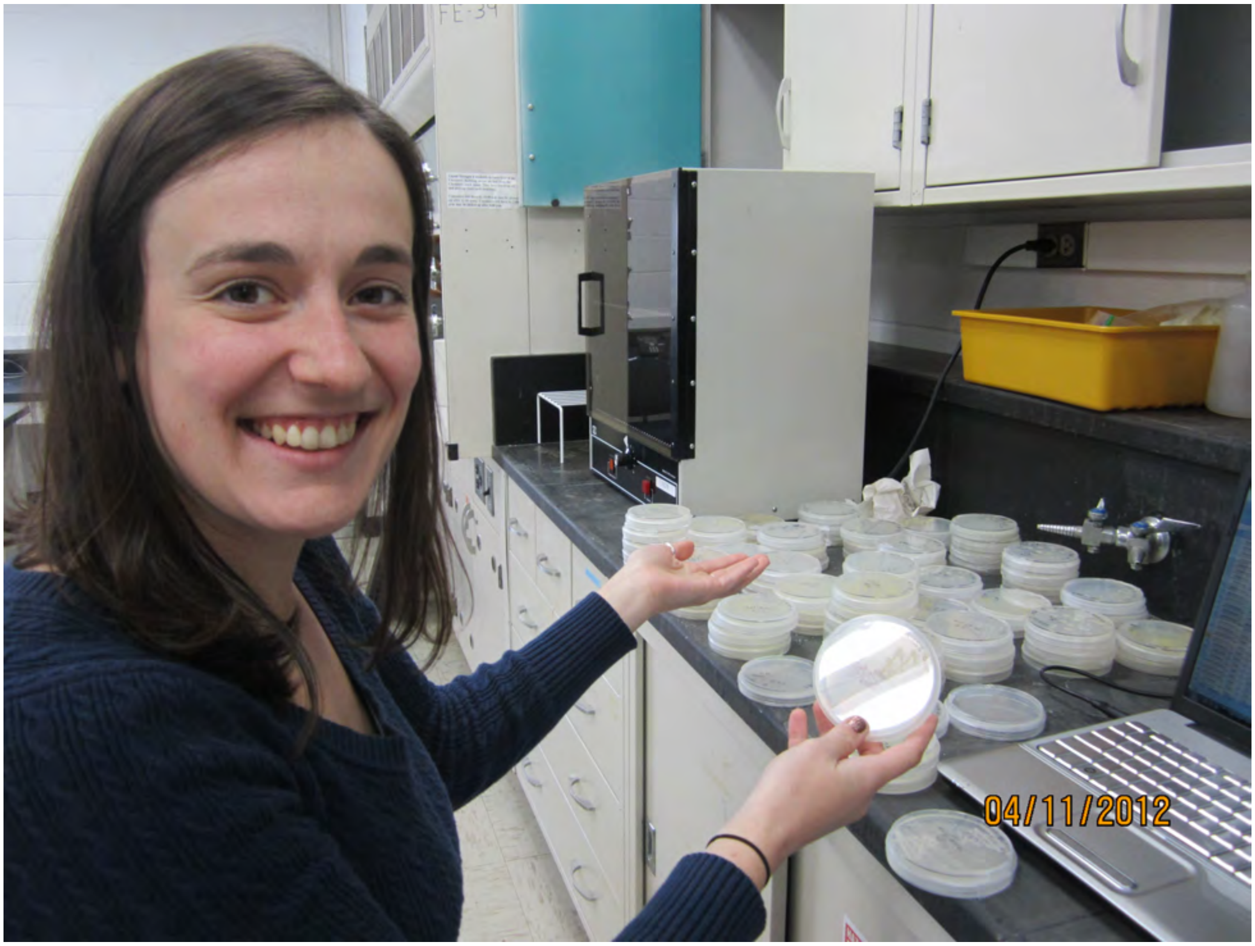
Catching salamanders can be a tricky endeavor. One species of salamander, the slimy salamander, is rare in Shenandoah National Park. Adults can be the length of a human hand, and are black with white spots, so they are not hard to miss if you see one; it's just being quick enough to catch them that are the tricky part. We had sampled a total of four slimy salamanders (we had found one per day) at the start of our last day in the field. After bushwhacking down the side of Stony Man Mountain, our team was lucky enough to randomly pick a locality that slimy salamanders had an affinity for. We found four slimy salamanders! Sadly though I was not quick enough to catch the third one we encountered. I flipped the rock, said "Got one!" went to grab it and it was down in a burrow before I could catch it. I was quite disappointed in myself, but luckily a few meters up I found another one that made me forget about my previous disappointing miss. There is something about this species that is captivating to me and makes me smile every time I hold one in my hand. Sadly, this group of salamanders is experiencing declines across most of the Eastern US, and there is some suggestion that climate change may be driving these declines. I have included a picture of me holding the fourth and final slimy salamander we found that day ☺

Photographs:

Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.

** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*




04/11/2012

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Guadalupe Ruiz-Jones
University: Stanford University
Start date: May 21, 2012 (award date)
End date: December 2013 (I have requested a no cost extension to cover cost that will be charged after January 1st, 2014)

Brief project summary:

The central goal of my GMWCCFP-funded project is to study short-term growth in corals exposed to highly variable environmental conditions (e.g., pH and temperature) versus nearby conspecifics that experience more moderate conditions. My field site for this project is the US National Park on Ofu Island, American Samoa. To investigate the influence of natural environmental variability on coral calcification, the fluorescent dye Caclein was used to mark the skeleton of *Acropora surculosa* at specific intervals, allowing me to measure linear extension growth rates in sequential periods of times. The tide causes the environmental variability to change through time, allowing me to compare growth during a period with moderate variability followed by a period with increase variability. The coral fragments were stained in temperature controlled tanks with water circulation (designed by the National Park Service staff on Ofu Island). I have repeated this experiment twice. In September 2012 I stained coral samples from two locations three times, marking two growth periods of six full days each. In August 2013 I stained coral samples from the same two locations four times, marking three growth periods of five full days each. All coral samples are petrographically thin sectioned and mounted on microscope slides. Measurements of linear extension are made from photographs taken of the thin sections using a fluorescence microscope set to excite Calcein and detect the correct wavelength emitted. I will then compare the amount of linear extension growth that occurred during a period with moderate environmental variability to growth that occurred during a period with pH and temperature extremes.

Research Approach:
Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

There have not been any significant changes to my research question or hypothesis since I submitted my status report in October, 2012. The trial project I did attempting to measure linear extension growth rates of corals growing on glass slides has not proved to be a feasible way to measure growth. The slides are very fragile and due to the mechanism by which the skeleton is laid down on the glass slide to form the "skirt of skeleton", staining the corals with Calcein does not mark the skeleton with a distinct stain line the way it does in coral branches. Therefore, we have currently decided not to pursue using corals affixed to glass slides as a method to measure short-term linear extension growth rates under different environmental conditions.

Location(s) of Research:
Ofu Island, American Samoa. We work in the coral reef located within the US National Park on Ofu.

Key Findings:

I have examined the coral samples that were stained in September 2012 and I am currently waiting on the August 2013 samples to be petrographically thin sectioned. In the preliminary results from September 2012 we found that during a week with slightly higher environmental variability coral branches of *Acropora surculosa* grew between 0-40% (mean = 20%) more than the previous week, which had slightly less environmental variability. The results from this set of linear grow measurements show a pattern of slightly higher growth rates during a period of slightly higher environmental variability; however, the conditions during this growth period were not ideal because a swell rolled in and dampened the environmental variability. The samples collected in August 2013 were in the reef growing during a period of moderate variability followed by an extreme low tide that resulted in large environmental variability. I am very excited to measure linear extension growth rates in these samples to see if the pattern we detected with the September 2012 samples holds up.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

(I am including all since the start of my fellowship)

- Presentation of my research project to 7th and 8th grade students of Olosega School, American Samoa (9/18/2012)
- Presentation at the NPS office in Pago Pago, American Samoa (9/24/2012)
- Poster presentation at the Third International Symposium on the Ocean in a High-CO_2 World, Monterey CA (September 2012)
- Poster presentation at the Reverse Science Fair at North Salinas High School, CA (10/16/2012)
- Oral presentation at the 2013 George Wright Society Conference, Denver CO (March 2013)

Additional Funding:

Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

NA

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

My field work in American Samoa has given me the incredible opportunity to work with Samoans that work for the National Park Service. Through my interactions with locals I have come to learn about the Samoan culture, like how to catch a coconut crab. I have been fortunate enough to have several NPS staff members assist me in the field, especially Carlo Caruso and Ricky Misaalefua. Often there are times when I am stressed out or worried about how my coral samples will survive in the reef or the safety of a particular thing in the reef and the locals are great at calming my worries. I have also had the pleasure of personally showing some members of the NPS staff experiments we have set up in the reef. It is a wonderful feeling to be swimming in a beautiful, bountiful coral reef thinking about the scientific questions we are asking and realizing how much more there is to learn about the coral reef and the organisms living there.

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*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NPS


Class Corner
Announcements

2012 NPS George M. Wright Climate Change Fellowship Program

Fellowship Research Final Report
October 31, 2013

Fellow Name: Patrick D. Shirey
University: University of Notre Dame
Start date: June 1, 2012
End date: September 30, 2013

Brief project summary:
The goal of our research is to identify brook trout habitat that could serve as year-round thermal refuge under climate change in the wild and scenic Namekagon River of the St. Croix National Scenic Riverway. Brook trout are indicators of ecosystem health in cold-water systems experiencing population declines due to factors including land-use change, groundwater withdrawal, and introduced species. Under climate change, we can expect brook trout populations to continue to decline. Results of our study will guide National Park Service resource managers in 1) protecting habitat that is thermally suitable for brook trout and 2) implementing future restoration projects for habitat that is thermally suitable but not of sufficient quality to sustain brook trout populations and habitat that is not thermally suitable but contains spring seeps that could be reconnected to the river. This project will help the resource managers of the Saint Croix National Scenic Riverway mitigate for the projected effects of climate change by identifying brook trout habitat to be protected and restored. We would like to see the Namekagon River restored to a unique recreational destination fishery for trophy-size brook trout in the upper Midwest.

Current Status:
Based on recommendations from the local NPS personnel, we decided to remove temperature loggers from the river before the 2012 winter because of risk of ice damage. Other parts of the project have remained the same as proposed. Temperature loggers were deployed in June 2012 and retrieved in September 2012. Fish in Namekagon River tributaries were surveyed in July and August 2012. Temperature loggers were deployed again in June 2013 and retrieved in September 2013. We redeployed temperature loggers in September 2013 to record temperatures at some locations through 2014. By the end of 2013 we will finalize a manuscript for publication in the open-access journal *Land*.

Motivation for Research:
Serious historical (e.g., introduced species, land use) and future (e.g., climate change) challenges threaten the integrity of aquatic ecosystems of the upper Mississippi River and Laurentian Great Lakes region. Under the threat of introduced species, and changing land use and climate, protection and restoration of stream fish habitat to an ecosystem resembling minimally-impacted historical conditions almost certainly will be necessary to perpetuate native brook trout (*Salvelinus fontinalis*) and other biota that depend upon cold water (EBTJV 2006). Brook trout are an indicator species for functioning aquatic ecosystems throughout their native range. Brook trout require cool to cold-water

temperatures, high water quality, clean gravels, a plentiful invertebrate food supply, and natural flow regimes (Baird and Krueger 2003). In small streams, brook trout are generally the top predators in the food web and can therefore structure lower trophic levels. During the past century, the distribution of brook trout has decreased and populations have become fragmented in their native range of eastern North America (EBTJV 2006; Hudy et al. 2008). Brook trout populations have declined due to timber harvest and mining, land-use change, overfishing (Huckins et al. 2008), and nonnative species introductions (EBTJV 2006). Future threats, including a changing climate, could further fragment and reduce remaining populations (Meisner 1990a; Ries and Perry 1995; Flebbe et al. 2006). If society wants to protect brook trout populations, action is needed to identify, protect, restore, and monitor brook trout habitat to provide populations with the resilience to withstand current and future disturbance.

In this fellowship project, we evaluate management options for brook trout using a case study in the Namekagon River that focuses on resource management decisions for brook trout under the threat of habitat changed by past and current land use, introduced species, and potentially warmer temperatures. The framework and methods used to review the history of the river, its ecology, the ecological requirements for sustaining brook trout populations, and legal requirements for managing the river can be applied to resource management challenges in other river systems. Given the historical change, ecological knowledge, and legal requirements, we suggest management options for resource agencies involved in managing this wild and scenic river and its tributaries.

Location(s) of Research:

The Namekagon River, located in northwest Wisconsin, is part of the St. Croix National Scenic Riverway. Congress established the riverway in 1968 under the Wild and Scenic Rivers Act (WSRA) to protect and enhance the outstanding natural, scenic, and recreational values of the St. Croix and Namekagon Rivers. Although the scenic Namekagon River is a relatively pristine tributary in the Mississippi River drainage, major logging in the late 1800's changed the land-use of northern Wisconsin (Anderson et al. 1996; Rhemtulla et al. 2009) and log drives altered river systems and their aquatic habitats in the Mississippi and Laurentian Great Lakes Basins (Rector 1953). Following log drives and landscape change, non-native species including brown trout and rainbow trout were introduced into river systems throughout Wisconsin, including the Namekagon River. Since these habitat changes, brook trout have declined in the Namekagon River and are rarely observed in the mainstem.

We reviewed the history of the Namekagon River and its watershed land-use in relation to the fish habitat of the cold-water zone from pre-logging through present-day. Using the historical information as a baseline to guide additional research, we determined a need to (1) monitor water temperatures of the Namekagon River its tributaries, (2) review ecological requirements for sustaining brook trout populations, and (3) place ecological knowledge in the context of managing the Namekagon River fishery. Our goal was to address the hypothesis that warm summer temperatures are the primary factor restricting the current range of brook trout to tributaries and to mainstem locations downstream of tributary outflows in the Namekagon River.

Key Findings:

Figure 1. Mean temperatures (°C) for July 2012 in the upper Namekagon River and its tributaries

In the absence of the exotic brown trout would the river support native brook trout given summer temperature and available habitat? Over a five-year period from 2008 through 2012 the temperature of the mainstem of the Namekagon River exceeded the *upper tolerance limit* for brook trout (24.9°C) 1% of the time and brown trout (25.0°C) 0.9% of the time (temperatures that exceed the upper tolerance limits typically occur in early- to mid-July). Over these five years, river temperatures fall within +/- 2°C of the *optimal growth temperature* for brook trout (14.2°C) 23.5% of the year and for brown trout (12.6°C) 12.2% of the year at Leonard's School Road, while *final temperature preferrendum* was 28.0% for brook trout (14.8°C) and 35.9 for brown trout (15.7°C) (USGS gage station 05331833, analyzed using ThermoStat Version 3.0 by Jones and Schmidt 2012). Simple linear regressions of daily temperature measurements at this location from 1996 to 2013 indicate that annual daily temperatures are not increasing. However, July daily temperatures from 1997 to 2013 significantly increased at a rate of 0.003°C per year (p-value <0.01). In 2012, mean temperatures in the mainstem ranged from form a high of 26.1°C below the outflow of Lake Namekagon to a low of 20.3°C below the outflow of Big Brook (Figure – temperature). Other notable cool-water areas in the mainstem include the river downstream of Cap Creek (20.9°C in July 2012; 20.0°C in July 2013) and the river at Cable Wayside Landing (20.9°C in July 2012).

Timeline of:

1. **Accomplishments to-date:**

- Deployed temperature loggers from June 15 through September 29, 2012
- Scouted sites for current and future surveys
- Surveyed fish communities and stream habitat at 12 sites in 8 different tributaries of the Namekagon River
- Notre Dame field crew also participated in Namekagon River fisheries surveys with the Wisconsin Department of Natural Resources in 2012
- Presented research at the St. Croix Research Rendezvous on October 16, 2012
- Deployed temperature loggers from June 20 through September 15, 2013
- Deployed temperature loggers September 2013 to record temperatures in 2014

2. **Anticipated completion date for each task of the project: (insert rows as needed)**

Research Project Tasks:	**Completion Date:**
Fish community surveys of Namekagon River tributaries	August 20, 2012
Summer 2012 temperature monitoring	September 29, 2012
Completing data analysis from summer 2012	March 1, 2013
Summer 2013 temperature monitoring	September 21, 2013

3. **Expected Deliverables/Research Products:** Please include any conferences or meetings you attended and information about abstracts submitted and presentations made. (insert rows as needed)

Research Product:	**Delivery/completion date:**
St. Croix Research Rendezvous, Marine on St. Croix, MN ("brings together scientists, resource managers, agency staff and the interested public to hear presentations about research plans, projects and findings in the St. Croix watershed")	**October 16, 2012**
George Wright Society Conference abstract submitted on October 1, 2012; abstract presented in March, 2013	**March 2013**
Public outreach via kayak: *Where are the brookies?* Led public outreach via kayak river paddle to discuss research on temperature, brook trout, and potential impacts of climate change on the Namekagon River.	**June 20, 2013**
Public Radio, WOJB live broadcast: Where are the Brookies? A discussion about monitoring and restoring brook trout habitat. National Public Radio station on Lac Courte Oreilles Tribal Lands.	**June 21, 2013**

Podcast on personal website: http://www3.nd.edu/~pshirey	
Public Presentation: Merging ecology, history, & law to find solutions for protecting and restoring habitat for native brook trout in the Namekagon River. Public presentation offered in conjunction with "*Legacies and Paradise Lost? Climate Change in the Northwoods and Beyond*", St. Croix National Scenic Riverway, park headquarters & visitor center. St. Croix Falls, WI http://www.nps.gov/sacn/parknews/program-on-climate-change-and-brook-trout.htm	**August 1, 2013**
Ecological Society of America Annual Meeting, Minneapolis, MN. Merging ecology, history, and law to inform environmental policy at the federal level: Challenges and rewards of interdisciplinary research. Special symposium: The Ecology-Policy Interface: Perspectives on Student Engagement. *30-minute oral presentation*.	**August 5, 2013**
Manuscript: Namekagon River history and environmental monitoring of cold water zone to report temperature and fish survey data (for the Open Access journal *Land*, special issue "*Landscape Perspectives on Environmental Conservation*" http://www.mdpi.com/journal/land/special_issues/environmental-conservation); inclusion in dissertation as a chapter; dissertation to be defended on November 26, 2013	**Fall 2013**
Final Report	**September 2013**

Additional Funding:
Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

Yes, we submitted an internal NPS proposal in collaboration with the NPS St. Croix Falls office that received funding for a project to restore habitat and monitor response of brook trout and other fish species for FY2016-FY2018 ($302,766).

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

In September 2013, we collected and filtered water in the field to sample for environmental DNA (eDNA) of brook trout and brown trout in 56 locations throughout the upper Namekagon River watershed to determine distribution of each species in the watershed. Another graduate student at Notre Dame, Nathan Evans, is using this eDNA survey in his dissertation research. An outdoors writer, Greg Seitz, joined us for fieldwork on September 20, 2013 and covered this work in an article that was also published by a local newspaper in Wisconsin (http://www.stcroix360.com/2013/09/taking-the-brook-trouts-temperature/)

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

Because we work in a wild and scenic river that is very accessible, we have the opportunity to engage with the public to talk about our research and the importance of our work to the future of the resources of the St. Croix National Scenic Riverway. For example, while collecting temperature loggers, I met some fisherman who travel every year to fish for brook trout in Big Brook, a tributary of the Namekagon River, but haven't fished the mainstem in over 10 years because of the lack of brook trout; they were very excited to hear about the research and what it could mean for restoring brook trout to the mainstem. I included some pictures that they were kind enough to share with me. Their enthusiasm for fishing for brook trout is a main reason why I have committed time and effort to researching the Namekagon River so that we can restore the brook trout fishery for others to travel and enjoy.

We also had the opportunity to demonstrate our research to people attending a cross-country competition at a park in Hayward, WI where we sampled brook trout in Hatchery Creek. A picnic pavilion sits just 50 feet from a brook trout stream, so I hope to incorporate public education and outreach events at this park in the future.



Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*

Patrick deploying a temperature logger in the Namekagon River near the USGS gauge at Leonards School Road, Cable, WI.

Ph.D. student Nathan Evans deploying a temperature logger while GMW Fellow Patrick Shirey records coordinates.

University of Notre Dame field crew working with National Park Service personnel to electrofish Cap Creek at its confluence with the Namekagon River (left) and process fish species length and weight (right)

University of Notre Dame field crew led by Patrick Shirey (2nd from left) working with National Park Service personnel and volunteers to electrofish Big Brook, a tributary of the Namekagon River.

Photo of an adult brook trout from Big Brook, a tributary of the Namekagon River, in Cable, WI

Notre Dame graduate student Haley Pack holding an adult brook trout from Big Brook, a tributary of the Namekagon River, in Cable, WI

University of Notre Dame field crew led by Patrick Shirey working with a volunteer from the non-profit Namekagon River Partnership to electrofish Big Brook near its confluence with the Namekagon River.

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Emlia Sogin
University: University of Hawaii at Manoa
Start date: May 31, 2012
End date: December 2013

Brief project summary:
Our research seeks to investigate metabolite production in reef building corals across sea surface temperature anomaly gradients inside and outside the Kalaupapa National Historical Park (KALA) boundary. We will be able to measure differences in metabolite composition as it relates to past thermal history of the major reef building corals in Hawaii. Furthermore, we are interested in characterizing metabolite production inside and outside the park, between corals collected at the start and end of summer season, and between the north shores of Molokai and Oahu. Finally, we have conducted a manipulative experiment to determine differences in response of corals to global climate change stressors and measured metabolite production as a function of increasing temperature regimes. Our research will help to characterize the responses of corals across local environments in terms of metabolite composition. The end goal is to eventually develop biomarkers for stress that can expand upon current monitoring techniques that will enable park managers to initiate management action in a proactive time frame (e.g. act in <1 year).

Research Approach:
We proposed two separate projects to investigate the impacts of temperature stress on Hawaiian reef building corals. Specifically, we sought to measure differences in metabolite composition by employing metabolite-profiling tools using proton-nuclear magnetic resonance spectrometry (^{1}H-NMR) and mass spectrometry (MS) techniques.

1. *Field collections across thermal stress anomaly (TSA) gradients.* Initially, we proposed to sample corals on the windward (cooler sea surface temperature [SST]) and leeward (warmer SST) shores of Molokai and Oahu, and inside and outside KALA, to determine how SST may influence metabolite production in corals. As an added value to our initial sampling design, we sampled across a thermal stress anomaly gradient (TSA), which is a measure of the frequency and severity of thermal stress events over the past 30 years. At each sampling location, we collected replicate samples of both *Pocillopora meandrina* and *Montipora capitata*, two of the major reef building corals in Hawaii. To compare changes over a summer field season, we also sampled *M. capitata* at the start and end of the summer. Sampling sites were randomly chosen within 4 km X 4 km grid to allow for the following comparisons:

1. Along a TSA gradient within Kaluapapa National Historical Park
2. Between sites inside and outside the Park on the north side of Molokai
3. Between selected sites on Molokai and Oahu

In addition to metabolite profiles, we also collected samples for the analysis of *Symbiodinium* communities. *Symbiodinium* are single celled dinoflagellate partners that live within the coral's tissues and are fundamental to the survival of corals. Corals are known to regularly associate with 4 major clades (A-D) of *Symbiodinium*, each of which are hypothesized to be functionally distinct in their nutritional roles for the host. *Symbiodinium* diversity was assessed by employing 454 next-generation sequencing, which has allowed us to capture in-depth analysis in the taxonomic composition of *Symbiodinum* communities. By analyzing *Symbiodinium* communities over these gradients, and in correlation with metabolite profiles, we will have a better understanding of how changes in thermal regimes may influence coral physiology and ultimately coral health.

2. *Experimental manipulation*. In order to directly test the effect of increased temperature regimes on metabolite production in reef building corals in Hawaii, we originally proposed to conduct a manipulative experiment using the Hawaii Institute of Marine Biology's (HIMB) 24-tank exposure facility. However, to conserve our coral resources in Hawaii, we have teamed up with Dr. Hollie Putnam at HIMB, who recently conducted a manipulative experiment to investigate the impacts of elevated carbon dioxide (pCO_2), which is the leading cause of ocean acidification (OA), and temperature on the corals *Pocillopora damicornis* and *M. capitata.* Replicate colonies were exposed to ambient or elevated levels of OA and SST conditions for 1.5 months. Each colony was characterized for reproductive output, calcification, growth rates, and metabolic parameters (e.g. photosynthesis and respiration) that define coral health and sensitivity to stress. Metabolite production was characterized and compared between treatments using ^{1}H-NMR and gas chromatography (GC)-MS analysis. The GC-MS analysis was submitted to UC Davis Metabolomics core facility to obtain exact mass measurements for metabolites involved in primary metabolism and lipid production pathways. Our parallel measurements in metabolite data will also be integrated with transcriptomics and proteomics datasets, which will enable us to take a systems biology approach to describe coral response to global climate change stressors.

Location(s) of Research:
The field research was conducted at Kalaupapa National Historical Park on the north shore of Molokai and on the north shore of Oahu adjacent to the Pupukea Marine Life Conservation District. All laboratory work was conducted at the Hawaii Institute of Marine Biology on the island of Oahu.

Key Findings:

1. *Experimental*:
   - We see differences between treatments in both ^{1}H-NMR profiles and primary metabolism analysis (GC-MS), indicating that differences in metabolite production can be detected between treatments. This trend is stronger for *P. damicornis* then it is for *M. capitata.*

Current Status:
Due to time and weather constraints in sampling, our project is not yet complete. Here is a look at our accomplishments to date:

1. Field Collections

- Methods for NMR analysis have been developed and successfully implemented with corals on Oahu
- Permits from the National Park Service and Department of Land and Natural Resources obtained (September 28th, 2012)
- Sampling plan developed and executed for collection of corals on Molokai and Oahu, currently all samples are stored at -80°C at HIMB
- Concurrent data on temperature regimes at each of the sites were collected
- *M. capitata* samples from June 2013 have been extracted and analyzed for metabolite composition

2. Experimental

- High temperature and pCO_2experiments were conducted at HIMB
- ^{1}H-NMR profiles from a manipulative high $pCO_2$and temperature experiment obtained and analyzed
- Samples from a manipulative high pCO_2 and temperature experiment were profiled using GC-MS techniques for both primary metabolism and lipid profiles

Timeline for Completion:

Research Project Tasks:	**Delivery/completion date:**
Acquisition of lipid profiles from UC Davis Core Facility	November 2013
Extraction and analysis of remaining samples collected at Kalaupapa and North Shore, Oahu	December 2013
Extraction and data acquisition for DNA sequencing of *Symbiodinium* partners	January 2014
Complete NMR dataset analyzed	February 2014
Submission of Manuscript 1: Metabolomic assessment of the impact of $pCO_2$and temperature on corals	Spring 2014
Submission of Manuscript 2: Metabolomic assessment of metabolite profiles from corals collected across a thermal gradient within and outside the Kalaupapa National Historical Park	Summer 2014

Deliverables/Research Products: (Please list.)

Research Product:	**Delivery/completion date:**
International Coral Reef Symposium- *Oral Presentation* Metabolomic profiling methods for corals	July 13, 2012
Hawaii EPSCoR Annual Statewide Meeting- *Oral Presentation* NMR-based analyses looking at the manipulative experiment (pCO2 X Temperature experiment)	September 14, 2012
Western Society of Naturalists Meeting- *Oral Presentation* *Is exposure to global climate change stressors reflected in metabolite profiles of the coral Pocillopora damicornis?*	November 8, 2012
Testers Annual Symposium - *Oral Presentation* *Is exposure to global climate change stressors reflected in metabolite profiles of the coral Pocillopora damicornis?*	April 17, 2013
ALSO Ocean Sciences Meeting- *Oral Presentation* *Variation in coral metabolite production after exposure to Global Climate change stressors is species specific*	February 2014

Other:

- *Personal progress in degree program:* In addition to my work being completed in Kalaupapa, I am also working on projects investigating coral metabolite production in Moorea, French Polynesia and Taiwan. One of our recent discoveries through our data drive approach is that coral species differ in expression of varying classes of metabolites. Of particular interest, we found that betaine compounds, which are important osmoprotectants and antioxidants, are differentially expressed between coral species. This work is currently in preparation for publication. Betaines are one class of compounds that we plan to target in our analyses for the work funded by this fellowship program.
- *Antidotal Sampling Information:* Because metabolites can change on the order of seconds to minutes, we developed a very unique sampling plan for our fieldwork in KALA. Divers collected samples n the benthos at 30+ feet using on SCUBA (fig. 2). Immediately afterwards, a snorkeler would retrieve the sample and return it to the boat where is was flash froze within 3 minutes of sampling using liquid nitrogen. This allowed the entire KALA dive time to be involved in the sampling process and preserved the samples in the best state possible. Coral sample hand offs between the diver and snorkeler were always exciting!

  Antidotal Site Information: It was very refreshing diving off of the coast of Kalaupapa, because unlike many sites in the Main Hawaiian Islands, Kalaupapa is relatively untouched by people. This has allowed reefs to remain healthy and vibrant. While sampling, we saw turtles, eagle rays, and large fishes. Furthermore during our time transiting between sites, we encountered sharks, dolphins and flying fish. It was rewarding to be able to interact with a healthy reef system in Hawaii.

Photographs:

Figure 1. *Montipora capitata*

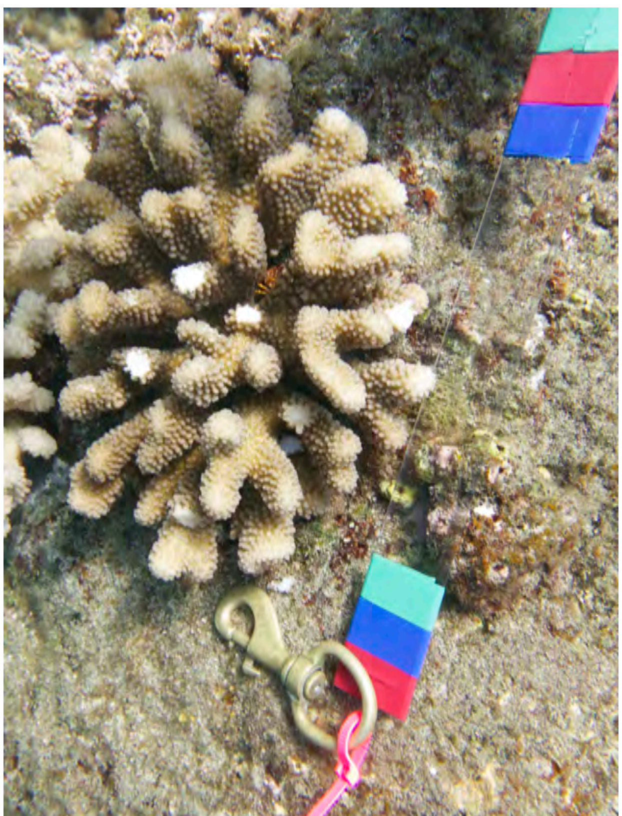

Figure 2. *P. meandrina* colony

Figure 3. Emilia Sogin sampling a colony of *P. meandrina*

Figure 4. Emilia Sogin handing off a sample to Sly Lee at depth

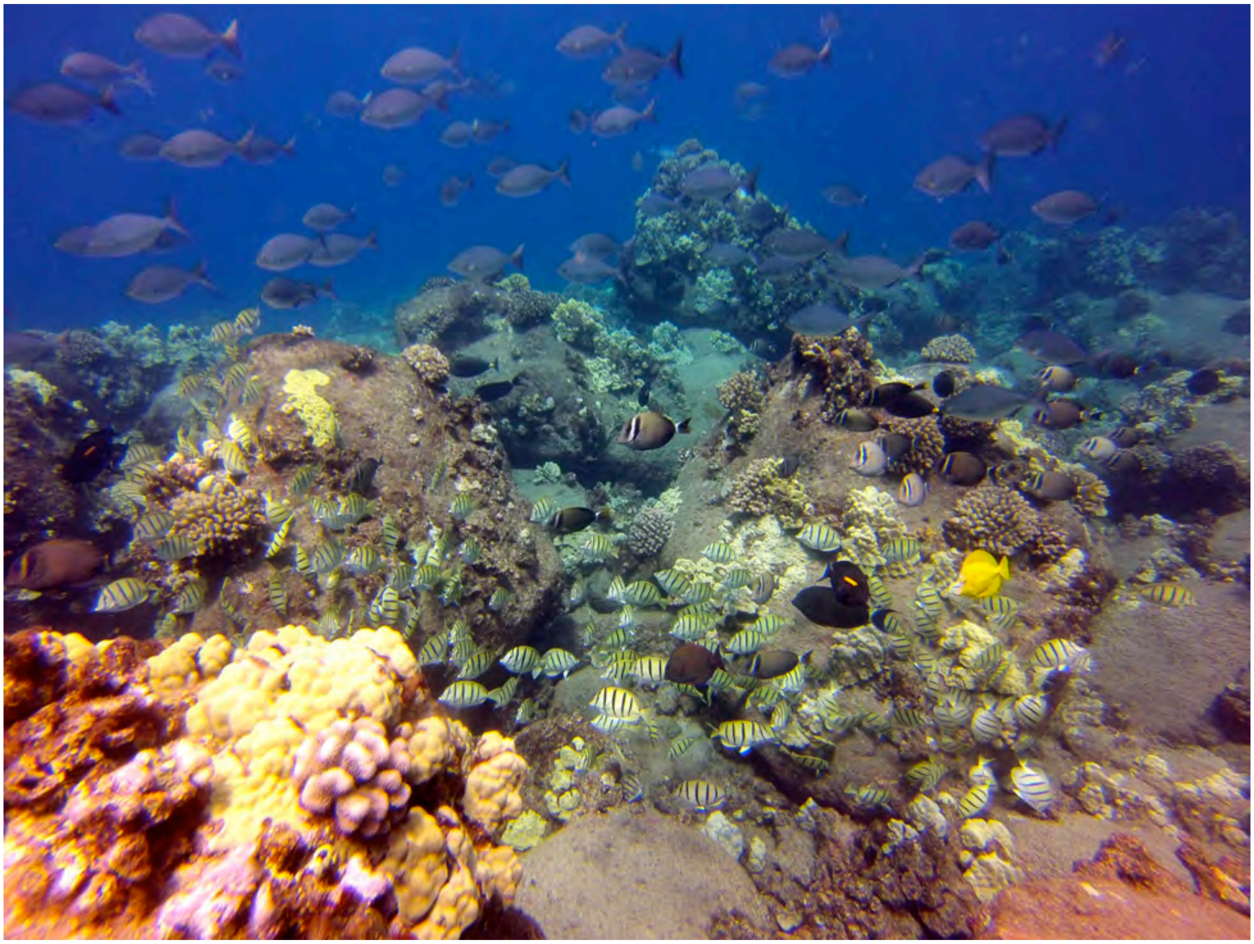
Figure 5. Kalaupapa Reefs

2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Joseph A. E. Stewart, jaes@ucsc.edu (302)299-2758
University: Univ. California Santa Cruz, (formerly University of Nevada Reno)
Start date: March 1, 2012
End date: December 31, 2012

Distribution and Abundance of Pikas in Yosemite

Brief project summary:

I collected baseline occupancy data on a climate-sensitive saxicolous species, the American pika (*Ochotona princeps*), in the Greater Yosemite Region.

Research Approach:

Following an occupancy analysis approach (Mackenzie *et al.* 2006), I conducted 89 surveys (89 sites, 1 visit to each site) for saxicolous small mammals in the greater Yosemite transect (Moritz *et al.* 2008) during the summer of 2012 (7/8/2012 – 9/8/2012). Tim Watkins requested that I follow the National Park Service (NPS) pika survey protocol (Jeffress *et al.* 2011), a significant alteration of the methods I proposed in my George Melendez Wright Climate Change Fellow grant application. Following this protocol, each site consisted of a 12-m radius circle, meant to represent the approximate territory size of an American pika. Surveys were conducted for 30 minutes or until pikas were detected. Sites were randomly selected within 8 stratum (e.g. stratified by elevation and talus area) following the Generalized Random Tessellation Stratification (GRTS; Kincaid & Olsen 2013). In addition to the sites I surveyed, an additional 124 sites were discovered, upon visitation, to be either inaccessible (to dangerous to access) or not suitable habitat (no talus).

In addition to NPS protocol surveys, I conducted 13 surveys (11 sites, 2 sites visited repeatedly) following the California Department of Fish and Wildlife (CDFW) pika survey protocol (Stewart *et al.* In Review). The CDFW pika survey protocol is similar to the NPS protocol except that each plot is defined as an entire talus field, with survey effort commensurate with the size of the talus field. In contrast to the NPS protocol, which was designed to measure fine scale occupancy (e.g. population density), the CDFW protocol was designed to measure larger scale occupancy (e.g. range shifts). A key difference between the two protocols is that the vast majority (~90%) of current pika detections with the NPS protocol are based on detection of fresh scat only (Jeffress *et al.* 2013). In contrast, when pikas are present, CDFW protocol surveys generally result in more robust evidence of current occupancy—visual, aural, or green hay pile detections (Stewart & Wright 2012).

I evaluated the performance of logistic models of pika occupancy in the NPS protocol plots using the Akaika Information Criterion and an information theoretic approach (Burnham & Anderson 2002). Predictor variables were measured on the ground (during surveys), and derived from GIS layers. Predictor variables included measures of:

vegetation, rock size, precipitation, temperature, climate water deficit, actual evapotranspiration, snow, talus, and elevation. I evaluated all possible combinations of 43 predictor variables, using up to three non-interacting predictor variables per model.

Location of Research:

Surveys were conducted in the Greater Yosemite Region (Figure 1; Moritz *et al.* 2008). Sites were randomly selected, following a Generalized Random Tessellation Stratification, within mapped areas of pika habitat (i.e. talus). I used the boundaries of a 1997 Yosemite vegetation map (in which talus is delineated as its own distinct category) as the boundary for the study. This study boundary had the important advantage of depicting the pika's lower elevational margin on both the eastern and western slopes of the Sierra Nevada.

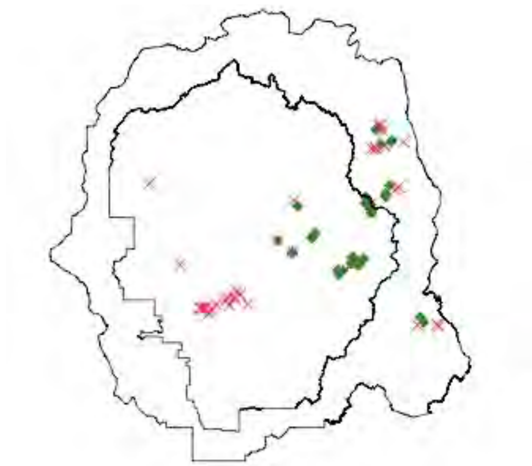

Figure 1. Location of NPS protocol pika surveys. Green diamonds—occupied sites; red crosses—unoccupied sites; inner polygon—Yosemite National Park boundary; outer polygon—study area boundary.

Key Findings:

I found that summer temperature was the most important predictor of which sites had pikas and which did not. Sites with low average summer temperature (June, July, August) were more likely to be occupied by pikas. Additionally, I found that site position on the talus and rock size distribution were two of the most important predictors. Sites closer to the periphery of their talus field, and sites with a greater proportion of 0.5 – 1 m diameter rocks were most likely to be occupied. Across the Yosemite transect, the best performing logistic model estimates that approximately 50.6 % (95 % C.I. = [34.9 %, 66.1 %]) of potential habitat was currently occupied by pikas, perhaps representing a total population of approximately 6,400 pikas in the region.

The finding that summer temperature is the most important predictor of occupancy is consistent with other studies (Beever *et al.* 2011; Calkins *et al.* 2012; Stewart *et al.* In Review). This result has important implications—because summer temperature is projected to increase more than annual temperature in the study region and throughout the south western US (Hayhoe *et al.* 2004; Taylor *et al.* 2012), pikas here will have higher exposure to climate change than if their biology was tied to annual temperature. Looking into the future, the logistic model predicts continuous population decline as summer temperatures continue to warm (Figure 2). Under a business as usual greenhouse gas emissions scenario (e.g. RCP 8.5; Hijmans *et al.* 2005; Rogelj *et al.* 2012) and taking into account the full range of 17 global circulation models (i.e. increase in mean summer temperature between 3.5 and 7.7 °C), the model predicts that pika occupancy in the greater Yosemite Region will drop to between ~ 0.25% and 8.9% by the year 2070.

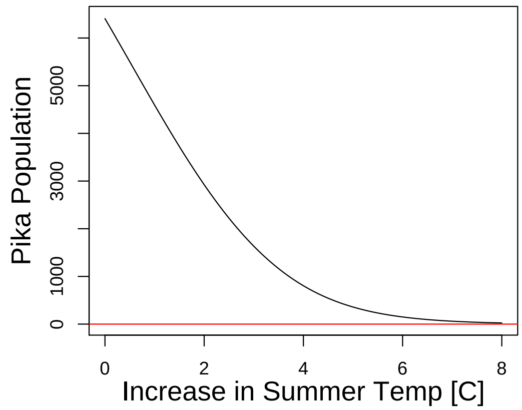

Figure 2. Modeled decline of the Yosemite pika population with increasing summer temperature.

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Deliverables/Research Products:

***Presentation at a National Scientific Conference:**

I presented results from this study at the George Wright Society Conference in August 2013.

Stewart, J.A.E. 2013. Pikas in Yosemite: surveys at two spatial scales. *George Wright Society Conference on Parks, Protected Areas, and Cultural Sites,* Denver, CO. <PPT or PDF available upon request>

***Data for Park Managers**

Data from this project has been delivered to Sarah Stock, park liaison for this study.

***Thesis:**

Results from this study were included in my Master's Thesis Exit Seminar and Thesis Defense. <PPT or PDF available upon request>

***Publication in Peer-Reviewed Journal:**

I am in the process of preparing a manuscript for this study. My working title is "On the distribution and abundance of American pikas in the Greater Yosemite Region."

***Presentation to Public and Park Staff at Yosemite Forum:**

I'm scheduled to present at the Yosemite Forum on January 14, 2013.

Additional Funding:

I have not received any other sources of funding directly related to this study or to the NPS pika protocol.

Other:

- Please include information about additional products, presentations, or outcomes related to this research project that are not otherwise included in this report.

I gave the following presentation, an updated version of my presentation to the George Wright Society Meeting, this fall at the California Department of Fish and Wildlife Science Symposium.

Stewart, J.A.E. & D.H. Wright. 2013. Pikas in California: surveys at two spatial scales. *California Department of Fish and Wildlife Science Symposium,* Folsom, CA. <PPT or PDF available upon request>

- Please share any anecdotes or stories from your project -- surprising discoveries, interesting happenings in the field, etc. -- that you think would be especially interesting for a general audience.

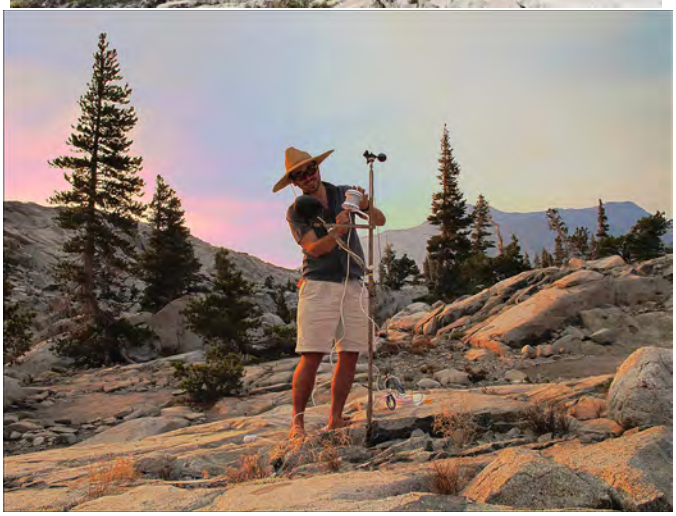
Contrary to Moritz *et al*. 2008, I found that all historically documented pika locations in Yosemite were currently occupied by pikas. Resurveys conducted in 2011 and 2012 show that the one historical site they identified as extirpated (Glen Aulin/McGee Lake) is still occupied (2011 and 2012) and that the one low elevation historical site they did not revisit (Washburn Lake) was occupied in 2011.

CDFW surveys conducted at the historical sites Soda Springs and Washburn Lake in October 2013 did not detect current pika occupancy at either site, despite easy detection during previous modern era surveys. Additional survey effort is necessary to verify if these sites are now extirpated.

Additionally, I found multiple isolated and low-elevation sites where there is abundant old pika poop, but no apparent current pika occupancy. These sites—which are located at low elevations on both the western and eastern slopes of the Sierra—are suggestive of upslope range contraction in the Yosemite Region.

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*





2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Kristin Strock
University: University of Maine
Start date: June 2012
End date: September 2014

Brief project summary:

Climate change is affecting key variables (wind speed, dissolved organic carbon (DOC) concentrations) that regulate lake thermal habitat, and recent changes raise concern over declining habitat quality. Recent research in Isle Royale National Park (ISRO) suggests that lake habitat quality in this remote park is changing rapidly. In lake ecosystems, vertical temperature gradients in the water column have a strong effect on habitat quality. Specifically, lakes undergo vertical, thermal stratification during the summer, with a warm, mixed layer developing in the surface waters and a cool, dark layer forming in the lake bottom. Changes in the depth of the surface mixed layer can alter the availability of cold water refuge required by certain fish species, influence nutrient cycling, and modify productivity and diversity of plankton. A fossil record of algae from Siskiwit Lake in ISRO reveals that the depth of the mixed layer has more than doubled over the 20th century, but it remains unclear whether these changes: 1) fall within the range of natural variability; 2) affect food quality at the base of the aquatic food web, and 3) are occurring more broadly across lakes in the park. The goal of this study was to assess variability in lake thermal habitat response to changes in climate using both high frequency monitoring and paleolimnological techniques.

Lake temperature was monitored using high frequency sensors in three lakes that ranged in size (1600, 430, and 143 ha) and average dissolved organic carbon (DOC) concentration (5, 6, and 7 mg/L). For the two larger lakes, modern sensor data were paired with paleolimnological analyses of diatom-inferred lake mixing depth over the last 200 years. Fossil algal pigments were used to study the effects of lake mixing on lake productivity and food quality. Project outcomes will aid in predicting future changes in lake water quality in response to continued climate change and the potential influences on wildlife that rely on this valuable resource. Observations suggest changes in lake thermal structure are already occurring in ISRO and in boreal ecosystems throughout the Northern Hemisphere, underscoring the urgency to evaluate modern changes in the context of past variability and develop effective management plans required to protect these freshwater resources and the biota that rely on them in a changing climate.

Research Approach:

Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.

In the original grant application, a long sediment core collected from Siskiwit Lake was going to be used to extend the record of climate-induced change throughout the Holocene; however, initial analyses revealed poor diatom preservation. These issues in preservation made it impossible to reconstruct long-term changes in lake habitat in this lake. Conversely, initial analyses of the short core from Desor Lake revealed a strong relationship between lake mixing and regional wind speed (Figure 6) and good diatom preservation. Additional funds were garnered to return to ISRO to collect a sediment record that spans millennia from Desor Lake in August, 2013. The funds from this fellowship were then reallocated to reconstruct mixing depths for Desor Lake over the last several thousand years. This time frame will capture warm periods in the past that can be used to predict potential effects of continued warming in the future.

Location(s) of Research:

ISRO is an island 2,314 km^2 in size, located in the northwest corner of Lake Superior (Figure 1). Aquatic environments cover 80 percent of the park area and support a dynamic native fish population that has long been a cultural resource for the area and supported active fisheries for lake trout, northern pike and several other species. The island also has a history of copper mining which varied in intensity over time and ended by the late 1800's (Shelton 1997). Accessible only by boat or seaplane, ISRO lake ecosystems are designated as Class I Wilderness due to relatively pristine and undisturbed landscapes. As a result, these boreal lake ecosystems are high priorities for protection and conservation.

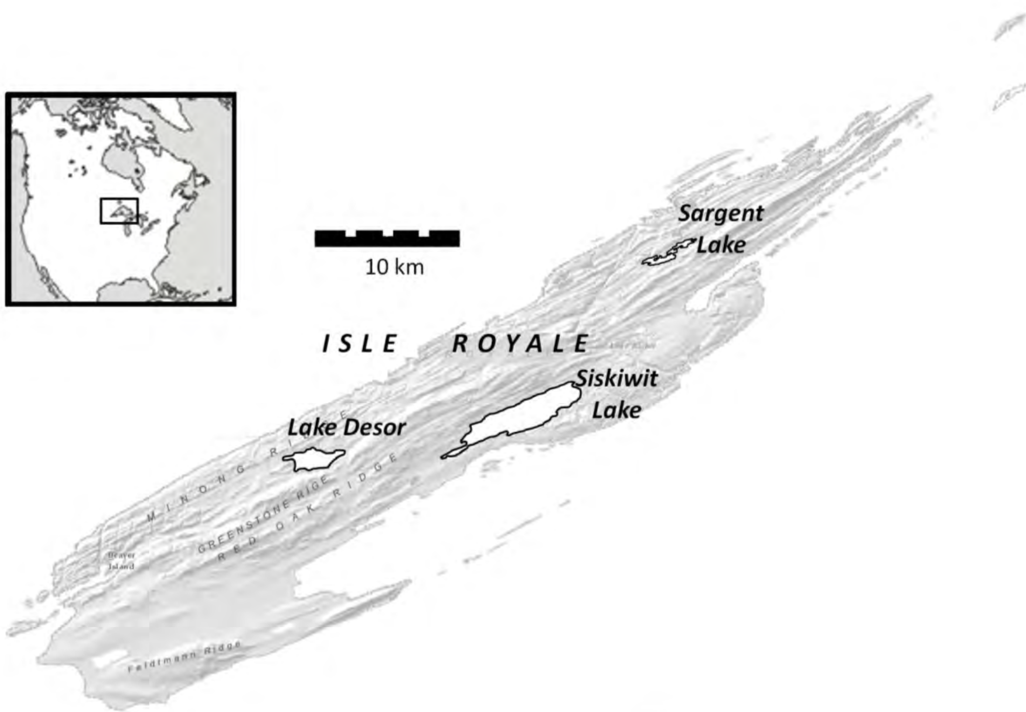


Figure 1. Map of Isle Royale National Park, an island located in the northwest corner of Lake Superior. The three lakes included in this analysis, Siskiwit, Desor, and Sargent, are outlined in black.

The bedrock geology of the island consists of a series of basaltic lava flows interlayered with sedimentary rocks (sandstones and conglomerates) (Thornberry- Ehrlich 2008). Glacial till and erratics are scattered across the island, with abundant glacial till deposits on the southwest end of the island that covers most bedrock. The terrestrial ecosystem is in a transitional zone between northern hardwood and southern boreal forests, with dominant species of white birch, quaking aspen, white spruce, balsam fir, and tag alder (Stottlemyer et al. 1998). Lakes on the island are typically mesotrophic; however, Siskiwit Lake is oligotrophic with low nutrient concentrations and algal biomass (Table 1). The lakes have alkaline pH values and DOC concentrations ranging from 4 to 7 mgL^{-1}. Siskiwit is considerably larger (1605 ha) and deeper (maximum depth of 49 m) as compared to Desor (428 ha in size and a maximum depth of 13m), both of which are larger than Sargent lake (143 ha in size and a maximum depth of 13m).

Lake	Depth (m)	Area (ha)	pH	Chl *a* (μgL^{-1})	TP (μgL^{-1})	TN (μgL^{-1})	NO_3 (μgL^{-1})	DOC (mgL^{-1})	SO_4 (mgL^{-1})
Siskiwit	49	1605	7.9	2	4	241	19	4.5	5.2
Desor	13	428	8.2	6	11	416	5	6.4	3.2
Sargent	13	143	8.0	2	13	396	3	7.4	4.6

Table 1. Morphometric and chemical data for lakes included in this study (Kraft et al. 2010).

Key Findings:

Introduction

Water temperature is one of the most ecologically important features of lakes. As the lake warms throughout the open water season, the warmer surface waters decrease in density and are unable to mix with the cooler water below, resulting in stratified thermal habitat zones (Dodds 2002) (Figure 2). The depth of the surface mixed layer has important implications for aquatic organisms, affecting the productivity and diversity of plankton and fish communities. Lake water temperature also influences many other physical and chemical characteristics of lakes, such as light, nutrient and oxygen availability (Wilhelm and Adrian 2008). Specifically, as lake water temperature increases, fish change their position in the water column and migrate to cooler waters (Matthews et al. 1985). One of the key reasons why temperature is so important for fish health is that it strongly controls the oxygen levels in water, with warmer waters holding less oxygen. When this cool, oxygen rich habitat area declines, it reduces the availability of suitable habitat for fish and in extreme cases can result in fish kills.

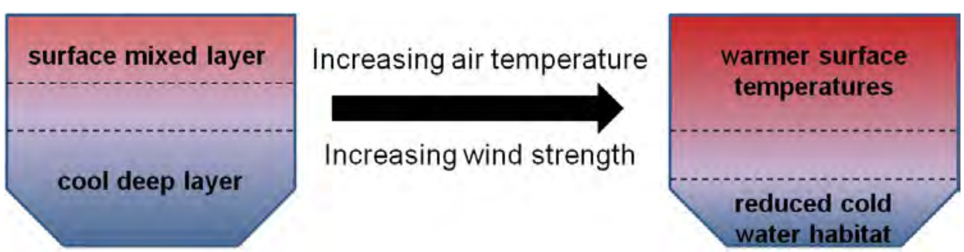


Figure 2. The effects of increased warming and wind strength on lake mixing and the corresponding changes in lake habitat quality

As surface waters warm, many fish move into deeper waters to find tolerable temperatures. However, shallow waters help to protect fish from mid-lake predators, so species forced into deeper waters may be exposed to increased predation (Lynch et al. 2010). Warmer waters may also promote the replacement of native fish species, often adapted to a more narrow range of habitat conditions, by non-natives able to thrive in disturbed environmental conditions (Stokstad 2010). Understanding changes in lake mixing is a key step towards providing sound information on habitat management in a changing climate.

A fossil diatom record from Siskiwit Lake in ISRO indicates remarkable change in lake habitat quality over the 20th century (Figure 3). Diatoms (*Bacillariophyceae*), the most numerous phytoplankton, are unicellular autotrophs with glass-like cell walls that preserve in lake sediment. Specific diatom species have known ecological preferences and as a result, can be used to reconstruct environmental variables such as pH and nutrient concentrations (Dixit et al. 1994). Saros et al. (2012) developed a mixing depth model to reconstruct the depth of the warm, mixed layer from diatom fossils. They applied the model to a sediment core from Siskiwit Lake spanning back to the year 1750, and found that mixing depths have more than doubled (from 5 meters to 12 meters) in this lake over the 20th century (Figure 3). Modern reconstructions of mixing depth are in agreement with national park monitoring of thermal stratification, where the mixing depth is often observed at approximately 10 meters.

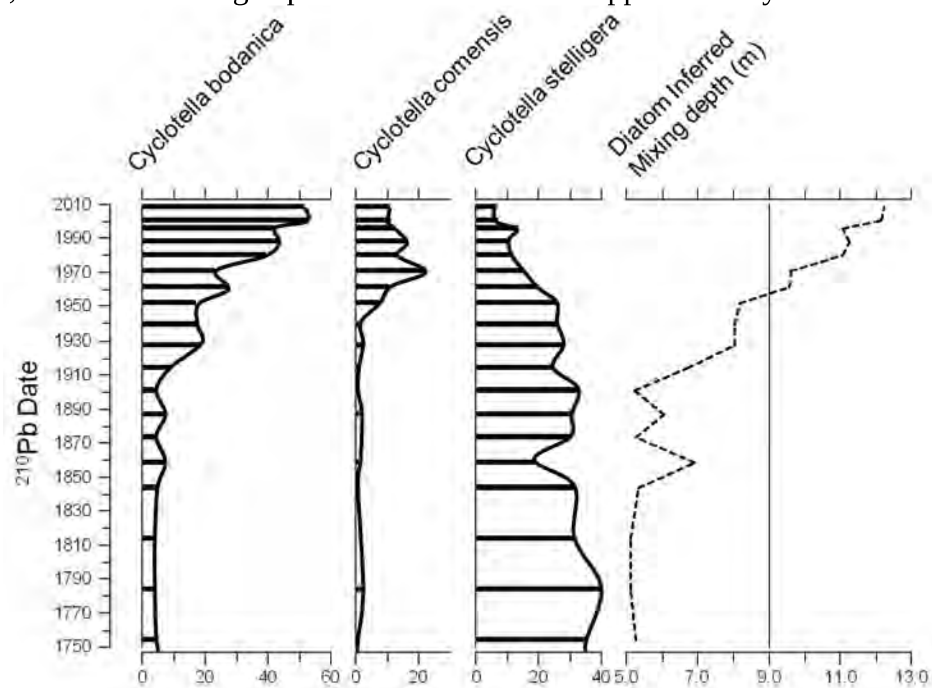


Figure 3. Relative abundance of Diatom species indicative of changes in lake mixing and the corresponding mixing depth reconstruction from Siskiwit Lake sediment core

Changes in lake mixing depths require considerable changes in lake water clarity or in wind strength, depending on the size of the lake. Thermal stratification is regulated by wind in moderately large lakes like Siskiwit in ISRO (greater than 500 hectares; Fee et al. 1996). In smaller lakes, both water clarity (Fee et al. 1996) and wind strength (von Einem and Graneli 2010) play a role, with the relative importance of these controls varying by region. Given the large surface area of Siskiwit (1,605 hectares), wind strength would have to increase over the lake to produce deeper mixing depths. Desai et al. (2009) demonstrated that wind strength has been increasing over Lake Superior (and thus over ISRO) in recent decades. They attribute this to a weakening of the air-to-lake temperature gradient that occurs as ambient temperature increases, causing an increase in wind speed over the open water of Lake Superior. It remains unclear, however, whether this increasing wind strength is also driving changes in mixing depths in the other lakes of ISRO, which are smaller than Siskiwit and therefore may be under control by both water clarity and wind strength.

The implications of these changes in lake mixing depth for lake productivity are also currently unclear. Research in other boreal lakes has suggested that deepening mixed layers can increase production by algae, with green and brown algae responding the strongest to this change

(Cantin et al. 2011). In contrast, Berger et al. (2010) found that total phytoplankton production was unaffected by deepening mixed layers, but was stimulated when the mixed depth became shallower. Changes in the amount and quality of food at the base of the food web have important implications for food web dynamics in lake ecosystems, with cascading effects predicted for fish and waterfowl production and health (Cheung et al. 2011, Wetz et al. 2011).

Project Findings

All three lakes had synchronous changes in daily epilimion thickness throughout the summer of 2012, suggesting that wind affected epilimion thickness irrespective of lake size (Figure 4). Sargent and Siskiwit the most strongly correlated (ρ = 0.85, $p < 0.001$), followed by Siskiwit and Desor (ρ = 0.71, $p < 0.001$), and Sargent and Desor (ρ = 0.50, $p < 0.001$). The width of the epilimnion in Desor Lake was significantly correlated to wind speed measured at Lake Superior weather stations (ρ = 0.29, $p = 0.04$) throughout the season. Both Siskiwit and Sargent Lakes were less strongly correlated, ρ = 0.20 and 0.19, respectively. The absolute thickness of the epilimion differed between the large lakes (Siskiwit and Desor) and the small lake (Sargent). Sargent lake (143 ha) had the greatest concentration of DOC and is in the size range where stratification is influenced by water clarity (Fee et al. 1996) in addition to wind (von Einem & Graneli 2010).

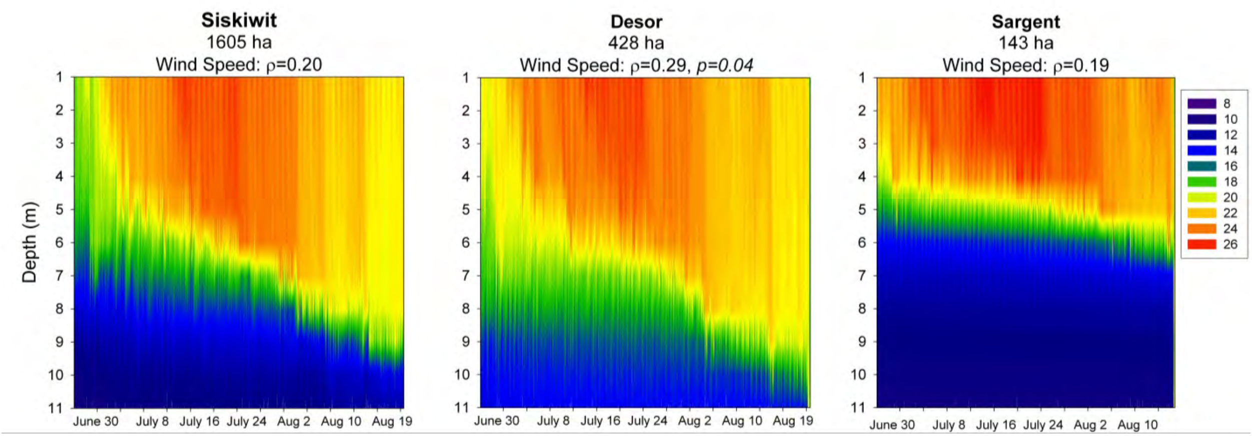


Figure 4. Hourly temperature data (˚C) collected from sensor arrays deployed at one meter intervals in Siskiwit, Desor, and Sargent lakes for July and August of 2012. The size of each lake and the Spearman's rho correlation coefficient comparing the thickness of the epilimion to daily wind speed and the p-value for significant correlations (p<0.05) are included above each plot.

The coherent changes in lake epilimion thickness across the different lakes suggests that wind affected lake physical structure similarly throughout the summer despite differences in lake size and DOC concentration. This supports the prediction that thermal stratification is regulated by wind in large lakes (Fee et al. 1996) and agrees with findings by von Einem and Graneli (2010), where wind strength can influence thermal stratification in small lakes despite increasing DOC concentration. The thickness of the epilimion was similar for Siskiwit and Desor lakes throughout the summer of 2012 (~9 m in depth), but Sargent Lake had a shallower epilimion depth (~6m epilimion depth). The shallower epilimnion depth in Sargent Lake could be related to the increased concentration of DOC and small surface area (143 ha). Keller et al. (2006) observed a strong relationship between epilimion thickness and DOC for small lakes (<100 ha), where lakes with higher DOC concentrations had shallower epilimnia.

Diatom inferences from the two larger lakes (Siskiwit and Desor) documented a coherent shift to deeper lake mixing as regional wind speed increased during the 20th century. The deepening of the diatom-inferred mixing depth began at approximately 1960 in Desor Lake when *Cylotella comensis* increased in abundance and *Discostella stelligera* declined (Figure 5). At the same time, the composition of the entire diatom community, represented by the DCA Axis 1 scores, also shifted. Lake mixing deepened synchronously in both Siskiwit and Desor lakes (*rho*=0.8, *p*=0.01) and was correlated to modeled regional wind speed in Desor Lake (*rho* = 0.6, *p*=0.05) (Figure 6). Lake mixing records from both lakes track regional wind speed in the first half of the 1900's but depart from the trends in wind during the most recent decades as diatom-inferred mixing depth continued to deepen in Siskiwit Lake.

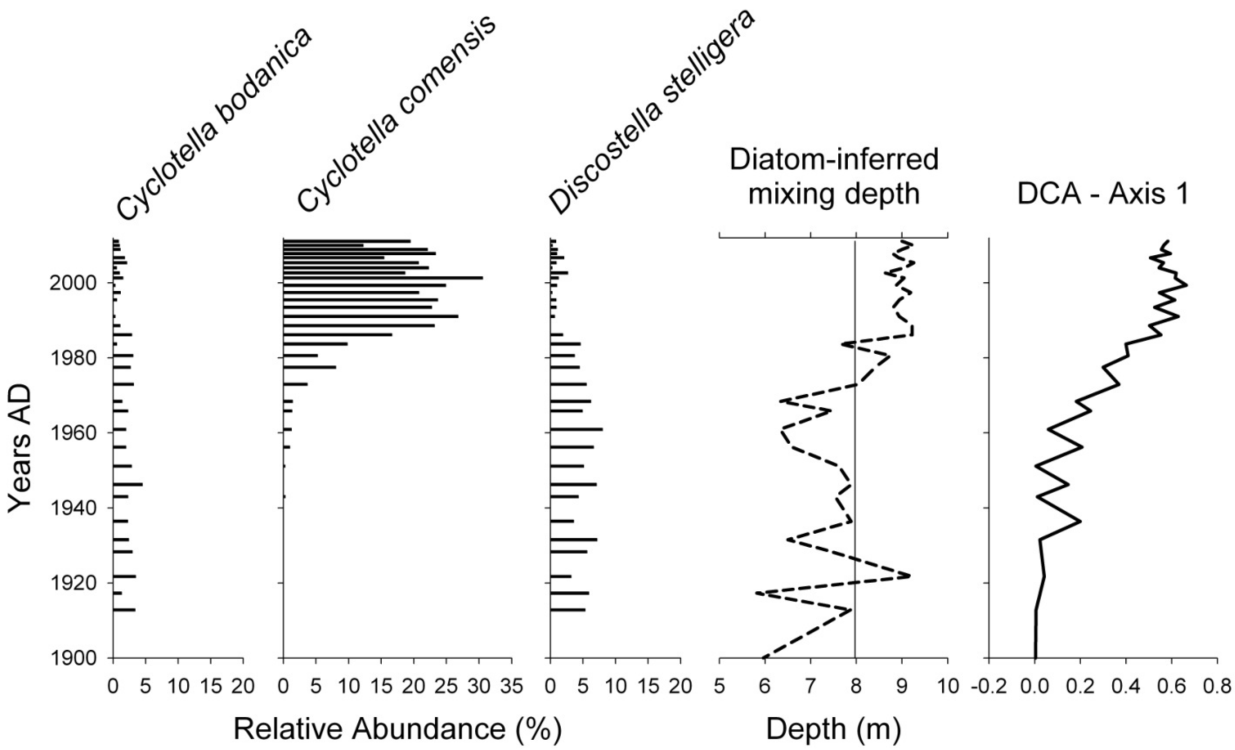


Figure 5. Sedimentary profiles of the relative abundance of the three diatom taxa used to infer lake mixing depth, reconstructed lake mixing depth, and the detrended correspondence analysis (DCA) of the entire diatom assemblage shown at right. The vertical line on the mixing depth plot is an overall average for the period of record.

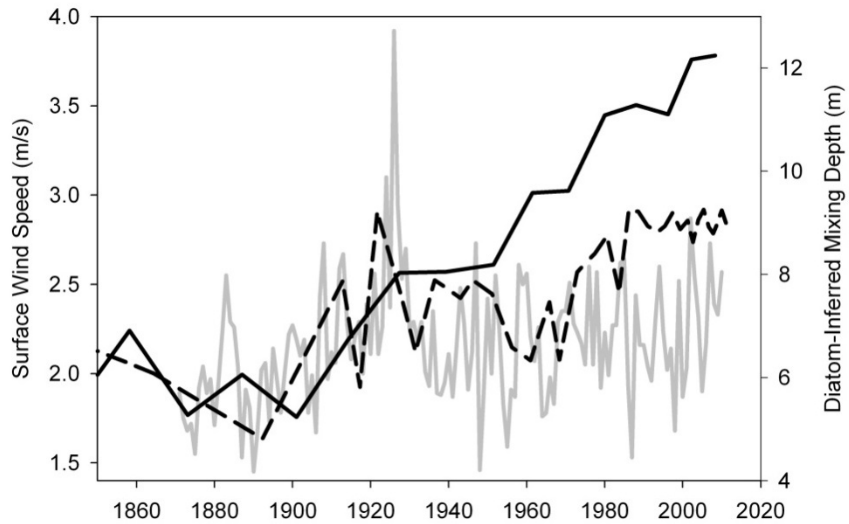


Figure 6. Diatom-inferred lake mixing depth records for Siskiwit (solid black line) and Desor (dashed black line) lakes in comparison to regional wind speed (gray) from the NOAA-CIRES 20th century climate reanalysis (Compo et al. 2011). ***Lake mixing deepened synchronously in both Siskiwit and Desor lakes (rho=0.8, p=0.01) and was correlated to modeled regional wind speed in Desor Lake (rho = 0.6, p=0.05).***

Changes in lake mixing in Desor Lake had subsequent effects on lake habitat, evidenced by changes in the algal community, that were not detected in Siskiwit Lake despite similar changes in lake mixing depth over time. Algal standing crop declined as mixing depths deepened in Desor Lake (Figure 7). If increases in wind drive the epilimion depth to extend deeper than the euphotic zone (the depth where 1% of the surface irradiance remains), phytoplankton growth will be increasingly limited by light (Jones et al. 1996) and net phytoplankton growth can be negative (Houser 2006). In Desor Lake, the secchi disk transparency (assumed to be the depth at which 10% of surface irradiance of photosynthetically active radiation (PAR) remained) is approximately 2.6 m (Elias & Damstra 2011). This is considerably shallower than the average thickness of the epilimion (9m) and would suggest that there is a large amount of area in the epilimion that is light limited. This is not the case for Siskiwit Lake, which has a secchi disk transparency of 8.5 m (Elias & Damstra 2011) and a mixing depth of 9m. This would suggest that phytoplankton in Siskiwit Lake, the larger and more oligotrophic lake, are nutrient limited. Sargent Lake has a secchi disk transparency similar to Desor (2.8 m, Elias & Damstra 2011), but has a shallower mixing depth (6m). Deeper lake mixing can alter depth optima for algal groups differently across these two lakes due to variable patterns in resource limitation. Increased light limitation may have temporarily reduced the algal standing crop in Desor Lake. In small lakes in southern Sweden, increased wind deepened lake mixing while increased DOC concentration reduced the depth of the euphotic zone leading to an increase in light limitation (Von Einem & Graneli 2010).

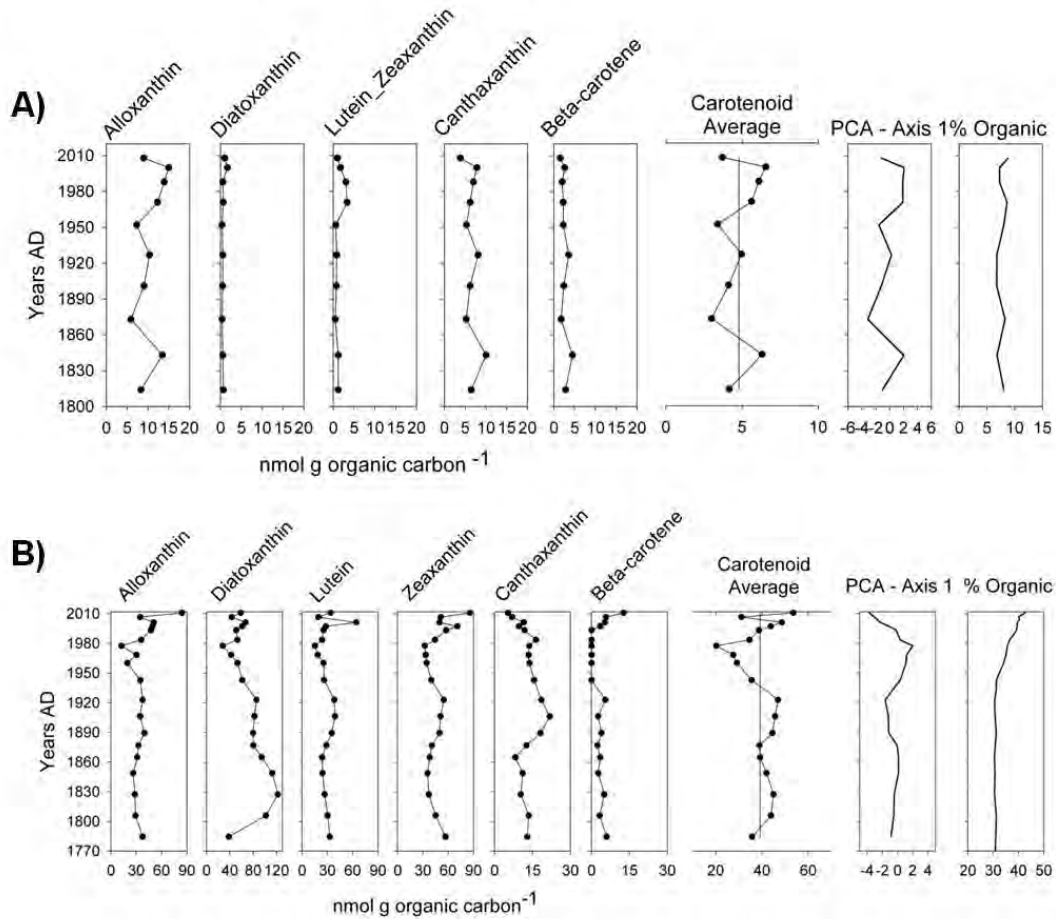


Figure 7. The sedimentary record of fossil pigments, principal component analysis axis 1 score for all pigments detected, and the percentage of organic material in A) Siskiwit Lake and B) Desor Lake. Pigment concentrations are expressed per gram organic matter and represent cryptophytes (alloxanthin), diatoms (diatoxanthin), green algae (lutein), cyanobacteria (zeaxanthin), colonial cyanobacteria (canthaxanthin), and most algae and land plants (Beta carotene). In the Siskiwit core, lutein and zeaxanthin were inseparable during detection and are presented together.

Changes in lake mixing can also alter the availability of nutrients differently across lakes. Deeper thermoclines can lead to greater oxygenation of the hypolimion and reduced anoxia at depth (Scully et al. 2000), which could reduce sediment phosphorus release. Desor Lake is shallower than Siskiwit Lake, 13 m as compared to 49 m, and experiences periodic anoxia in the hypolimnion (Kraft et al. 2011, personal communication with NPS staff). In this case, deeper mixing may have led to reduced anoxia and diminished sediment phosphorus release, resulting in decreased algal biomass while mixing deepened. Prolonged, deep mixing could subsequently increase the exposure of sediments to warm epilimnetic waters, which could increase mineralization rates and associated nutrient release (Liikanen et al. 2002). Increased vertical mixing would then make these hypolimnetic nutrients more available to epilimnetic plankton communities (Kristensen et al. 1992).

While mixing depths remained stable and deep from 1980 to present in Desor Lake, cyanobacteria and cryptophyte pigments increased in concentration. Cryptophyte species are often motile and can have mixotrophic feeding strategies. This species could benefit from deeper mixing because they have low light: nutrient needs and can capitalize on high bacterial biomass at the edge of the hypolimnion (Ptacnik et al. 2003). An increasing frequency of cyanobacteria blooms have been observed in other lakes in ISRO in recent years, with *Lyngbya birgei* G.M. Smith, *Anabaena flos-aquae*, and *Anabaena planctonica* Brunnthaler as the three most prevalent bloom species (Edlund et al. 2011). Changes in water temperature, duration of ice cover, and stratification have been suggested as possible mechanisms driving these changes, but have yet to be directly tested.

Summary

All three lakes had synchronous changes in daily epilimion thickness throughout the summer of 2012, suggesting that wind affected epilimion thickness irrespective of lake size. The absolute thickness of the epilimion differed between the small lake (epilimion depth of ~6m) and large lakes (~9m for both). The small lake had the greatest concentration of DOC and is in the size range where stratification is influenced by both water clarity and wind (< 500 ha). Diatom inferences from the two larger lakes documented a coherent shift to deeper lake mixing (an increase of 3 and 6m) as regional wind speed increased during the 20th century. Algal biomass declined in the slightly smaller (430 ha) lake as mixing deepened (from 1920 to 1980). Cyanobacteria and cryptophyte pigments increased in concentration from 1980 to present, a period of stable and deep mixing. Algal pigment concentrations in the largest lake were unchanged as mixing depth deepened over the past 100 years. Climate-mediated increases in wind altered lake physical structure; however, the way in which these changes affected lake habitat and phytoplankton were variable and may have been influenced by lake-specific differences in nutrient and light limitation.

Continuing Work

Almost 10 m of lake sediment was collected from Desor Lake in August 2013 to extend the record of physical lake habitat from 200 years (~30 cm) to several thousand years. This core will be used in place of the long core from Siskiwit Lake which had poor diatom preservation.

Deliverables/Research Products: (Please list.) This may include, but is not limited to presentations at the park(s), conferences/meetings attended, interpretive talks, published articles, electronic education products, etc.

Include the links to any of your research products that are available electronically. If they are print products, please attach them at the end of this report as appendices.

Presentations:

- 2013: **Strock, K.E.D.** Understanding climate-driven change in lake habitat structure in Isle Royale National Park. Climate Change Research from the Next Generation: George Melendez Wright Climate Change Fellowship Science in Parks. National Park Service Webinar.
- 2013: **Strock, K.E.D.**, J.E. Saros, M.B. Edlund, D.R. Engstrom. Using centric diatoms as indicators of climate-mediated changes in lake thermal structure in the great lakes region. 22nd North American Diatom Symposium. Bar Harbor, Maine.

- 2013: Saros, J.E., **K.E. Strock**, J.R. Stone, Climate-induced changes in lake thermal structure and productivity inferred from paleolimnological reconstructions. American Society of Limnology and Oceanography Meeting. New Orleans, Louisiana.
- 2012: **Strock, K.E.D.**, J.E. Saros, M.B. Edlund, D.R. Engstrom. Climate-mediated changes in boreal lakes: A diatom-based reconstruction of changes in lake thermal stratification. International Paleolimnology Symposium. Glasgow, Scotland.

Print:

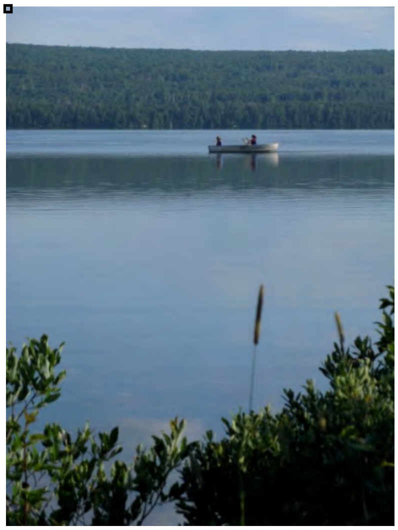
- **Strock, K.E.D.** Response of boreal lakes to changing wind strength: coherent changes in physical lake habitat across large lakes but varying effects on primary producers *in* Ph.D. dissertation entitled "Deciphering Climate-mediated changes in boreal lake ecosystems." University of Maine. Anticipated date of completion: December, 2014.
- **Strock, K.E.D.** 2012. Looking to fossils to manage lakes in Isle Royale *in* National Park Service Climate Change Response Program News. September/October 2012.
- **Strock, K.E.D.** 2013. Expedition summary for the University of Maine Climate Change Institute. www.climatechange.umaine.edu/isle_royale_national_park_2013.

Additional Funding:

Were you able to use the Fellowship as leverage for securing other research funding? If so, please list the sponsor, program, and the amount of funding.

- University of Maine Climate Change Institute Churchill Exploration Fund, *Understanding climate-driven change in the boreal lakes of Isle Royal National Park.* ($1,226)
- University of Maine Graduate Student Government, *Climate mediated changes in energy in Isle Royale National Park USA: a diatom based reconstruction of changes in thermal lake stratification.* (Travel to present) ($637)
- University of Maine Graduate Student Government, *A diatom-based reconstruction of lake thermal stratification in Isle Royale National Park.* (Travel to present) ($425)

Photographs:
Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.
** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*



2012 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2013

Fellow Name: Katherine Marie Wilkin
University: University of California at Berkeley
Start date: January 2013
End date: August 2013

Brief project summary:

A substantial portion of Yosemite, Sequoia, and Kings Canyon National Parks' floristic biodiversity occurs in refugia of various kinds. Cold refugia form at the intersection of cold-air drainages in basins and drainages from valleys up to mid-slope in relatively mesic areas and/or on north-facing slopes. In these sites, many species exist at the southern extent of their ranges and do not exist outside of refugia at this latitude. Climate change's predicted increased warmth and disturbances may cause local extirpation of some refugia species. Alternatively, these regions may become climatic refugia for other species which are currently common in the region, but could become rare as the climate changes and/or increasingly restricted to refugia. Cold refugia have distinct plant communities and may also have distinct ecological processes from surrounding areas, such as fire frequency or severity.

In the near future, Yosemite National Park plans to conduct prescribed burns to protect the residents adjacent to forests. These plans' ecological impacts on the cold-refugia plant communities found within this proposed burn sites are uncertain. Park managers need to know more about the fire ecology of cold refugia before they can take appropriate management action. Therefore, I review and synthesize geophysical and fire ecology research to enhance understanding of refugia in the Sierra Nevada mixed conifer forest.

As an NPS George Melendez Wright Climate Change Fellow, I achieved some of my goals: (1) Identify potential refugia; (2) Examine published data for insights into the refugia fire ecology; and (3) Infer the vulnerability of refugia to fire, especially prescribed burns and/or high severity fire. Most importantly, this study will create a framework as regional land managers work to mitigate climate change's impacts on biodiversity by focusing on climate refugia and their distinct ecology. This information synthesis will enhance land managers' ability to protect refugia biodiversity.

Research Approach:
My techniques to identify cold-refugia with limited field data in a Maxent model received significant critique. Therefore I deployed a climate sensor network (Fall 2012) to make the environmental model more defensible. The Rim Fire has made it impossible to retrieve the climate sensor network and incorporate the field-based data into the model for analysis at this point in time.

Location(s) of Research: Yosemite National Park

Key Findings:

- In Yosemite's mixed conifer zone**,** cold-air pools (CAPs) occupy about one-fifth of the total land area. Here**,** CAPs were less likely to burn than the surrounding area to burn from 1984 to 2010. Fires burned 20% less area when cold air pools were present, compared to the surrounding landscape.
- Fine scale variation in climate is directly tied to both canopy and understory cover which are altered by fire (*12*). Ford et al. (2013) demonstrated that fine-scale biological drivers, such as canopy and understory cover, can significantly affect soil surface temperatures at a greater magnitude than elevation (**Error! Reference source not found.**). While these results cannot strictly be transferred to Yosemite National Park, they offer insight into the magnitude at which fire alters the vegetation and thus the local climate. If any of my climate sensors survived the Rim Fire, then we will have a more nuanced understanding of how fire changes fine scale climate.

Deliverables/Research Products:

Current:

- Coordinated submission of Sierra Nevada fire history studies (5 total) to the World Data Center for Paleoclimatology fire scar database (*1*)
- Included six undergraduate students in research and took four students for their first (working) visit to Yosemite National Park
- Created refugia focused EndNote library for Yosemite National Park (Appendix A)
- Deployed climate sensor network in Yosemite National Park
- Attended Ecological Society of America's Climate Refugia Workshop in Eugene, OR 8/2013
- Presented project poster at CA-LCC's Southern Sierra Climate Change Workshop and Yosemite's Fire and Hydro-climate conference (see Kate Wilkin; Department of Environmental Science, Policy, & Management at University of California – Berkeley; Protecting forest biodiversity: understanding climate change refugia for management ---http://climate.calcommons.org/aux/sscaw/posters.htm)
- Wrote management report (see Appendix B)

In preparation:

- Novel roles of refugia, publication in preparation
- The fire ecology of Sierra Nevada cold-refugia, publication in preparation
- Cold-refugia indicator guide, in preparation

Additional Funding:

- USFS donated climate sensors and solar radiation shields: ~$4000
- UCB Environmental Science, Policy, and Management Departmental Continuing Fellowship: ~$15,000
- University of California at Berkeley's Sponsored Project for Undergraduates: $1500

Other:

- Working in an active fire landscape is exciting, but complicated and there is great uncertainty! The Rim Fire most likely consumed my climate sensor network was mostly and I am waiting for the area to open to determine the outcome. I am prepared to redeploy climate sensor network once the area affected by the Rim Fire is open for administrative use. However, if any sensors survived the fire, then I can include how fire changes the environment of cold-refugia --- I'm crossing my fingers for at least a 5% survival rate!
- Working with students from University of California at Berkeley's Sponsored Project for Undergraduates was highly enriching. These students created a field guide for cold-refugia plants (in preparation), collected biological and physical data at Yosemite National Park. Through this project I explored mentorship and am now a finalist for an undergraduate mentorship program. My fellowship essay included my GMWCCFP research experiences. An excerpt from my BerkeleyConnect Mentorship Fellowship application follows:

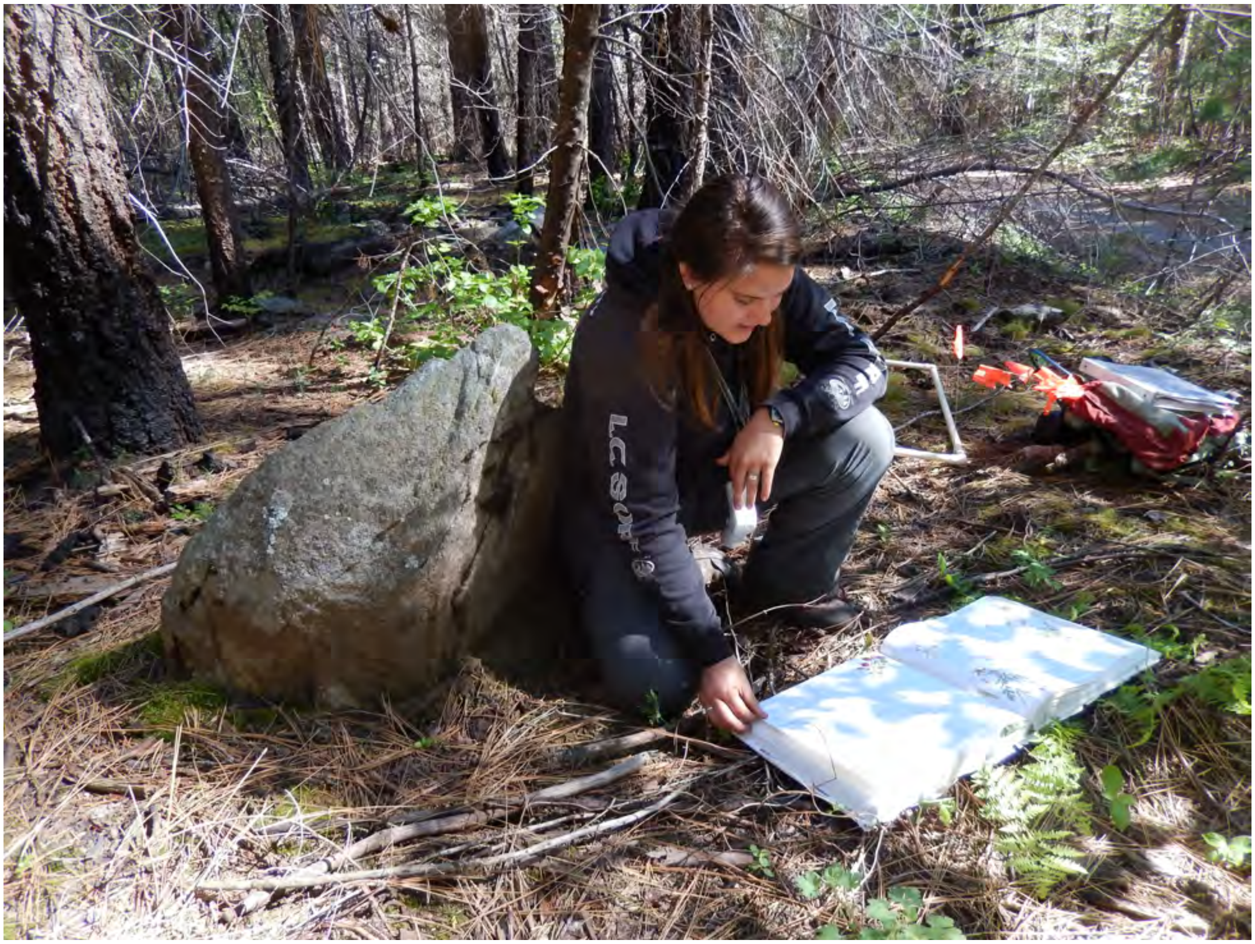
  As we sat together on Lembert Dome watching the sunset over Tuolumne Meadows with an undergraduate student said, "I had never met a real person before you."

  Maddie was explaining how her spring semester Sponsored Projects for Undergraduates (SPUR) experience had impacted her studies at Berkeley. She was part of my undergraduate team who spent the spring semester researching potential cold refugia indicator species, creating an identification guide, and searching for these plants in Yosemite National Park. Together we navigated their early professional experiences --- collaborated on research and products, taught one another plants, camped together, navigated with a compass, networked with park service staff, and discussed career options in natural resources as we hiked. As a team we accomplished more than the research goals I had outlined during the semester. One of the unexpected outcomes from the semester was that I recognized how much I was enriched by interacting with these students. Mentorship changed from something I have always enjoyed to a primary career goal.

Photographs:

Please include 3-5 photographs from your project. We are especially interested in any photos of you doing your research.

** In doing so, you are granting the University of Washington and the National Park Service permission to use your photos in publications (web, electronic, or print) related to the George M. Wright Climate Change Youth Initiative.*



Madeline Green identifying a plant during our field work at Yosemite National Park
DSCN0154.JPG

Madeline Green and Jonathon Fluornoy reading a plot during our field work at Yosemite National Park.
DSCN0226.JPG

Madeline Green and Jonathon Fluornoy after a hard day’s work in the field.
DSCN0290-001.JPG

Thomas Reyes attaches a solar radiation shield for the climate sensor network.
SDC11786.JPG

David Campbell places a LogTag climate sensor into a solar radiation shield.
SDC11790.JPG

Appendix A: Important citations for understanding and managing cold-refugia.

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Appendix A: Management report for Yosemite National Park.

Protecting forest biodiversity:
Understanding climate change refugia for management

A George Melendez Wright National Park Service Climate Change Fellowship project

Katherine Marie Wilkin
PhD Candidate
Department of Environmental Science, Policy, and Management
University of California at Berkeley
Kate.Wilkin@berkeley.edu

NPS GEORGE MELENDEZ WRIGHT
CLIMATE CHANGE
YOUTH INITIATIVE

Contents

Abstract

A substantial portion of Yosemite, Sequoia, and Kings Canyon National Parks' floristic biodiversity occurs in refugia of various kinds. Cold refugia form at the intersection of cold-air drainages in basins and drainages from valleys up to mid-slope in relatively mesic areas and/or on north-facing slopes. In these sites, many species exist at the southern extent of their ranges and do not exist outside of refugia at this latitude. Climate change's predicted increased warmth and disturbances may cause local extirpation of some refugia species. Alternatively, these regions may become climatic refugia for other species which are currently common in the region, but could become rare as the climate changes and/or increasingly restricted to refugia. Cold refugia have distinct plant communities and may also have distinct ecological processes from surrounding areas, such as fire frequency or severity.

In the near future, Yosemite National Park plans to conduct prescribed burns to protect the residents adjacent to forests. These plans' ecological impacts on the cold-refugia plant communities found within this proposed burn sites are uncertain. Park managers need to know more about the fire ecology of cold refugia before they can take appropriate management action. Therefore, I review and synthesize geophysical and fire ecology research to enhance understanding of refugia in the Sierra Nevada mixed conifer forest.

As an NPS George Melendez Wright Climate Change Fellow, I will achieve these goals: (1) Identify potential refugia; (2) Examine published data for insights into the refugia fire ecology; and (3) Infer the vulnerability of refugia to fire, especially prescribed burns and/or high severity fire. Most importantly, this study will create a framework as regional land managers work to mitigate climate change's impacts on biodiversity by focusing on climate refugia and their distinct ecology. This information synthesis will enhance land managers' ability to protect refugia biodiversity.

Fellowship products

Current:

- Coordinated submission of Sierra Nevada fire history studies to the World Data Center for Paleoclimatology fire scar database (*1*)
- Created refugia focused EndNote library for Yosemite National Park
- Deployed climate sensor network in Yosemite National Park
- Attended Ecological Society of America's Climate Refugia Workshop in Eugene, OR 8/2013
- Presented project poster at CA-LCC's Southern Sierra Climate Change Workshop and Yosemite's Fire and Hydro-climate conference
- Wrote management report

Publications in preparation:

- Novel roles of refugia
- The fire ecology of Sierra Nevada cold-refugia

Special thanks

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Special thanks to volunteers including Sponsored Project for Undergraduate participants Kate Clyatt, Madeline Green, and Jonathon Fluoroy for their help creating a cold refugia indicator plant guide; Sponsored Project for Undergraduate participants Shannon Fairchild, Kristine Grace, and Xuantong Wange for assistance with the climate sensor network collection and analysis; climate sensor solar shield construction team including Sasha Berleman, Stella Cousins, Chris Dow, Danny Fry, Anu Kramer, Katy Seto, and Eric Waller; climate sensor deployment volunteers participants Dave Campbell, Tom Reyes, Alison Colwell, and Janelle Cassiani.

Introduction

Why are refugia important?

Early climate change ideas predicted catastrophic species extinctions. As scientists investigated species response to climate change further, a more nuanced perspective emerged indicating that species may be able to persist in cold-refugia (*2, 3*). These cold-refugia are believed to play an integral part in the rapid expansion of many species when the ice sheets retreated, provided a source propagules for rapid species migration (*4-10*). This phenomenon is especially apparent in complex terrain such as the mixed conifer zone of Yosemite National Park (Yosemite) which has cold-refugia. Here, Pacific Northwest species have disjunct populations in species such as *Taxus brevifolia* (Pacific yew), *Arbutus menziesii* (Pacific madrone), and *Lithocarpus densiflorus* (tanbark-oak) (Appendix A). While cold-refugia gained dramatic interest as important conservation areas (*2*), threats to their ecology and conservation have not been fully explored .

What are refugia?

Many people have tried to define cold-refugia based on biology (*11*) or climate (*3*). Keppel et al.'s (2011) biological definition of refugia is "habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions." Dobrowski et al. (2011) defines refugia to occur where extant climates (temperature and available water) are maintained during climate change. Together they form a holistic definition, a habitat which buffers climate and allows species to persist in and to potentially expand from under changing environmental conditions.

In the Sierra Nevada, cold-refugia (refugia) form at the intersection of relatively mesic areas with cold-air pools and/or north-facing slopes. Here, many species exist at their southern range extent and do not exist outside of refugia at this latitude. Climate change's predicted increased warmth and amplified disturbances cause local extirpation of some refugia species. Concomitantly, these regions become refugia for other species which are currently common in the region but may become rare and/or restricted to refugia with climate changes. Refugia not only have distinct communities, but they also exhibit distinct ecological processes from surrounding areas, such as fire frequency or severity.

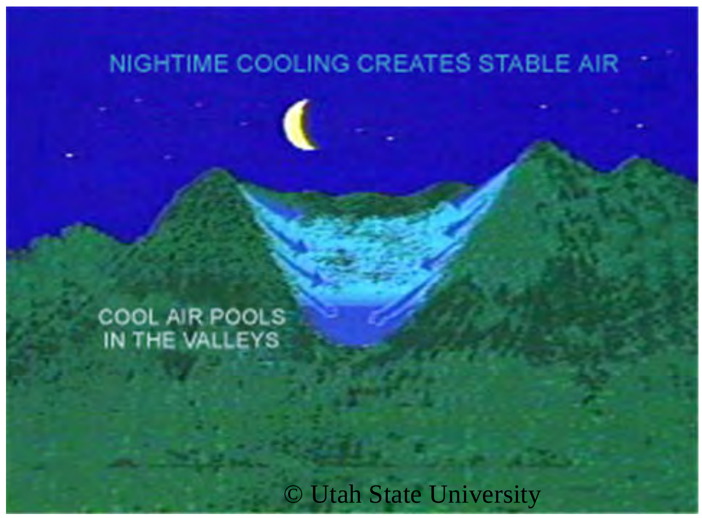


Figure 1 Cold-air pool landscape position and physics.

Project goals

Refugia are an important component of conservation management, but are poorly understood. Therefore, I review and synthesize geophysical and fire ecology research to enhance understanding of refugia in the Sierra Nevada mixed conifer forest in this management report. As an NPS George Melendez Wright Climate Change Fellow, I will achieve these additional goals: (1) Identify potential refugia; (2) Examine published data for insights into the refugia fire ecology; and (3) Infer the vulnerability of refugia to fire, especially prescribed burns and/or high severity fire. Most importantly, this study will create a framework as regional land managers work to mitigate climate change's impacts on biodiversity by focusing on climate refugia and their distinct ecology. This information synthesis will enhance land managers' ability to protect refugia biodiversity.

How will climate change alter cold-refugia?

Despite refugium's many conservation values, the conservation of an individual refugia or a network of refugium is not without reservation, especially due to limited conservation funding. Keppel and Wardell-Johnson (2012) highlight the importance of a refugia's climate buffering potential and projecting climate change and its biological effects (*2*). I expand 'climate change and its biological effects' to explicitly include species interactions (inter- and intra-specific) and ecological processes. In addition, land management needs to be addressed for refugia conservation (Figure 2).

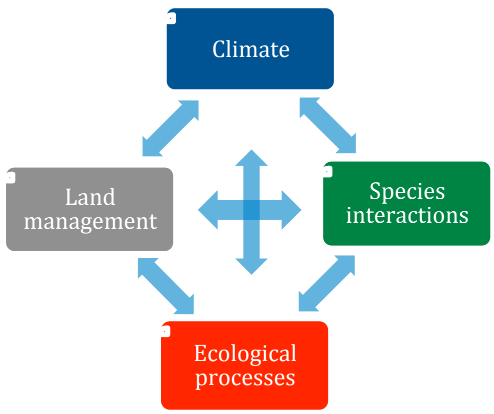


Figure 2. Cold-refugia ecology is complex and affected by climate, land management, species interactions, and ecological processes, and their interactions.

Changing climate

As Keppel and Wardell-Johnson (2012) discussed, refugium have distinct climates which change in synchrony or asynchrony with the regional climate (*2*). These climates either lag behind the surrounding climate or change at a slower rate i.e. buffer climate change (Figure 3); and these relationships are seasonally dependent (*12*). The buffered refugia are of greater conservation significance because they are more stable.

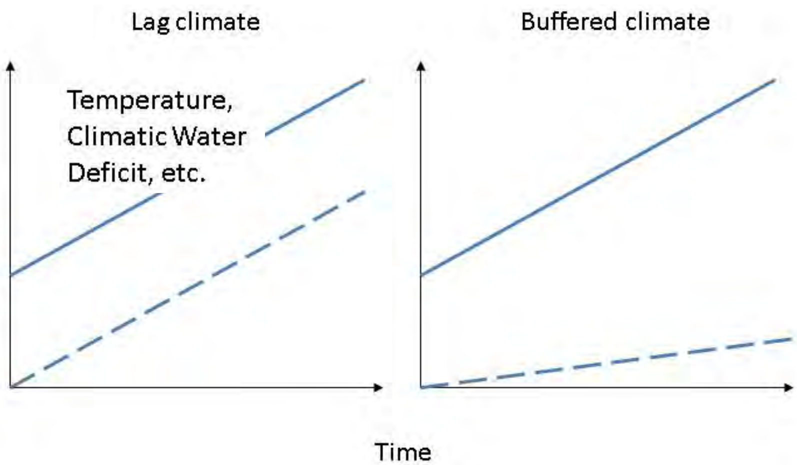


Figure 3. Refugia climates either lag behind the surrounding climate or change at a slower right i.e. buffer climate change.

Topographic drivers of climate in Yosemite, especially within cold-refugia are difficult to understand with limited published studies. Therefore, 90 LogTag temperature climate sensors were deployed in the Fall of 2012 to downscale climate and understand regional microclimate drivers. Because the majority of sensors were likely destroyed by the Rim Fire, I will retrieve and redeploy the sensors this Fall (2013) with assistance from the University of California at Berkeley's Sponsored Projects for Undergraduate students program.. The surviving sensor data will be reviewed for trends, but the small sample size will limit inference power. The unique climate and potential buffering capacity of Yosemite's cold-refugia will be evaluated by 2015 (*13-15*).

Changing fire regimes

Fire regimes, especially fire frequency and severity, are changing world wide due to land management and climate change. Refugia are at a greater risk from changing fire regimes (*16*) due to their predisposition to local extinction i.e. their small, isolated nature. Refugia also have unique fire ecology including fire frequency, fire severity, fire behavior, and fuels (*17*, *18*) (Figure 4).

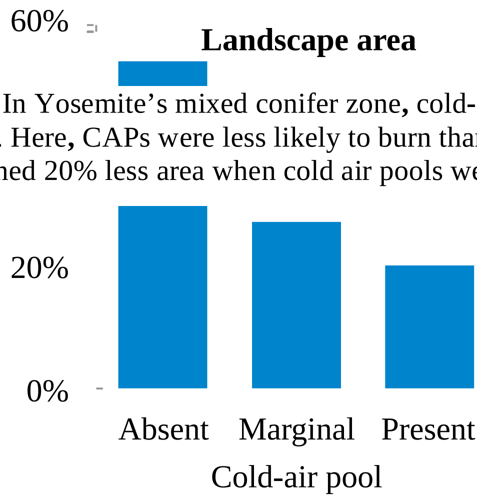
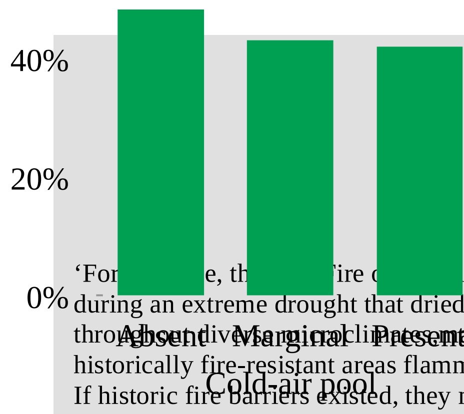
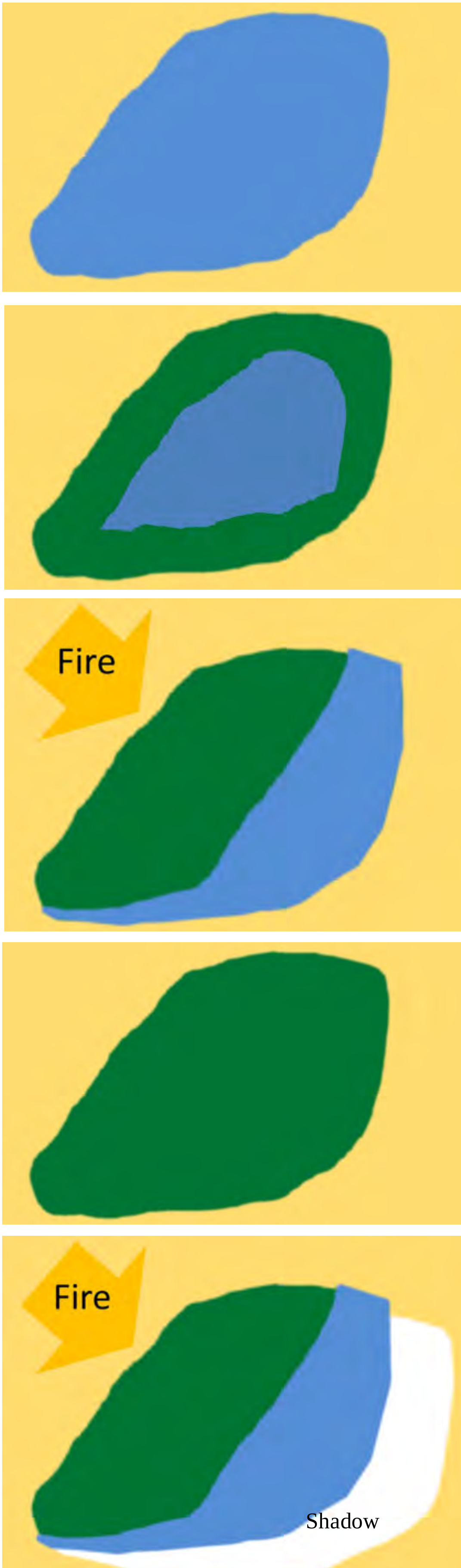


Figure 4. In Yosemite’s mixed conifer zone**,** cold-air pools (CAPs) occupy about one-fifth of the total land area. Here**,** CAPs were less likely to burn than the surrounding area to burn from 1984 to 2010. Fires burned 20% less area when cold air pools were present, compared to the surrounding landscape.



‘For e, th ire c during an extreme drought that dried fuel throughout diverse microclimates, making historically fire-resistant areas flammable. If historic fire barriers existed, they most likely did not function during this fire.’

Refugia in rugged terrain seperated by fire barriers such as rock or water are more likely to have decreased fire frequency than their surrounding terrain (*17*). However, these topographic controls diminish under climate change. If fire becomes driven by extreme events such as drought or wind storms, then refugium’s historic fire barrier will no longer function (*18*). For example, the Rim Fire occurred during an extreme drought that dried fuel throughout diverse microclimates,making historically fire-resistant areas flammable. If historic fire barriers existed, they most likely did not function during this fire. Refugia with historic fire barriers are more susceptibale to high severity fire since fuel may have built up since they last burned.



Refugia are defined by their distinct climates which moderate fire behavior (Figure 5). Fire behavior is moderated by:

1. Temperature regime:

CAPs are cooler in the evening and morning but reach similar maximum daytime temperatures as surrounding areas.

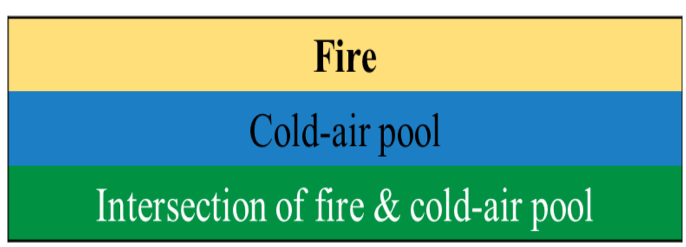
North-facing slopes are also cooler in the evening and morning but do not reach similar maximum daytime temperatures as surrounding areas.

2. Moisture regime:

CAPs have greater fuel moisture than the surrounding area because they occur in drainages and moisture loss is moderated by lower temperature.
North-facing slopes do not have additional moisture inputs, but nonetheless their moisture loss is moderated by lower temperatures. Fuel moisture differences have less fire behavior effects during late fall and/or droughts. (*19*)

Refugia, especially in arid regions like Yosemite, have greater moisture, fuel production, and an unprecedented risk from fire (*3, 20, 21*). Refugia commonly occur in riparian areas which were heavily altered by fire suppression resulting in unprecedented amounts of fuel (more than five times greater than historic levels), leaving them susceptible to high severity fire that might be quite detrimental to biodiversity (*21*). If the climate becomes drier, these fuels have reduced moisture and availble to burn for a larger portion of the year. These additional fuels contribute to more frequent or severe fires. However, refugia may not be homologs to riparian areas. Fire is significantly less likely to occur in refugia than in other areas; refugia area burnt from 1984 to 2010 is only 80% of expected area in Yosemite National Park's mixed conifer zone (*22*) (Figure 4). Additionally, if fire occurs in refugia, then it is significantly less likely to be high severity fire. The combination of published and preliminary results gives rise to

Figure 5. The interaction of fire and CAP may be dependent upon fire behavior including the fire's direction, magnitude, and intensity. (A) Fires which move slowly (low magnitude) and release little energy (low intensity) may respond quickly to a refugium's microenvironment and not penetrate the CAP, whereas (B) fires with high magnitude and intensity may respond slowly to a CAP (burn a buffer around the perimeter), (C) and/or a larger region near the flame front, or (D) even burn the entire CAP. (E) There also may be a CAP fire shadow where a reduction in fire extent or severity may persist beyond the CAP boundary.



new questions for both refugia and riparian areas: *Are they influenced by alternative disturbance regime such fungal plant pathogens? Do they have similar fire regimes?*

Prescribed fires, especially in areas with heavy fuel loads that cause higher severity fires, threaten to extirpate rare plants occurring at their southern range extent because small populations are highly susceptible to extirpation from localized events. While prescribed fire and mechanical treatments in the short-term are an immediate threat to inhabitants of refugia, the long-term lack of fire exacerbate climate change's increasing disturbance threats to biodiversity, including increased fire frequency and severity (*23*, *24*). Increased fire frequency and severity can be moderated during some fire events, but cannot be mitigated during extreme fire events (*25*, *26*). Active suppression tactics will only reduce risk in the short-term and are not likely to be deployed to protect refugia during extreme fires. (*27*)

Fire changing climate

Many studies have demonstrated that fine scale variation (vegetation, slope, aspect, soil moisture) in climate can have more variation than coarse scale variation (elevation, latitude) (*12, 13, 28, 29*) . Vegetation, slope, and aspect affect the duration and intensity of solar radiation, and heat loss. Moisture mediates the solar radiation absorption and loss.(*12*)

Some of these variables, both canopy and understory cover, are directly altered by fire (*12*). Ford et al. (2013) demonstrated that fine-scale biological drivers, such as canopy and understory cover, can significantly affect soil surface temperatures at a greater magnitude than elevation (**Error! Reference source not found.**). While these results cannot strictly be transferred to Yosemite National Park, they offer insight into the magnitude at which fire alters the vegetation and thus the local climate.

Table 1. Results from Ford et al. (2013) demonstrate that experimentally removing vegetation, much like a high severity fire, significantly alters local climates at Mt. Rainer National Park. Results include the mean and standard error.

Removing canopy cover:

- Snow disappears 19 +/-7 days earlier
- Maximum temperature increase 1.9 +/- 0.2 ℃
- Minimum temperature decrease 0.4 +/- .03 ℃

Removing understory cover:

- Snow disappears 0.6 +/-7 days earlier
- Maximum temperature increase 1.5 +/- 0.1 ℃
- Minimum temperature decrease 0.1 +/- .1 ℃

Soil moisture is also indirectly altered by fire (*30*); Fire alters vegetation and thus alters soil moisture. Specifically, vegetation has the potential to intercept precipitation with foliage, mediate soil moisture with foliage, reduce soil erosion with their fine roots, convert surface water to ground water by slowing the water's velocity, and contribute to evapotranspiration (*30-33*). No publications were located which focused on experimentally altering hydrology to change microclimate.

Changing species interactions

Species interactions will change potentially dramatically. Changes may include phenology, behavior, population age distribution, size and structure of individuals, pulse recruitment, population size, and meta-population dynamics (*34, 35*). In fact, Cahill et al. (2013) suggest changes in species interactions are the driving cause of species extinctions rather than available climate space (*36*). Species persistence in cold-refugia may occur naturally or require significant management to overcome species interactions.

The ability of refugia to persist is dependent upon maintaining environmental, fundamental, and realized niches[1] (*34, 35*) (Figure 6). The realized niche changes due to changes in intra and interspecific species interactions (*34, 36*). Refugia would not be able to maintain current species due to these changes. The pre-climate change refugia state and changes to both the environment and species interactions will uniquely affect the outcome of each refugium.

[1]Environmental niche is the climate where the species can persist.
Fundamental niche is the area where species can persist given interactions with other species.
Realized niche is where species are present i.e. where the environmental and fundamental niche overlap.

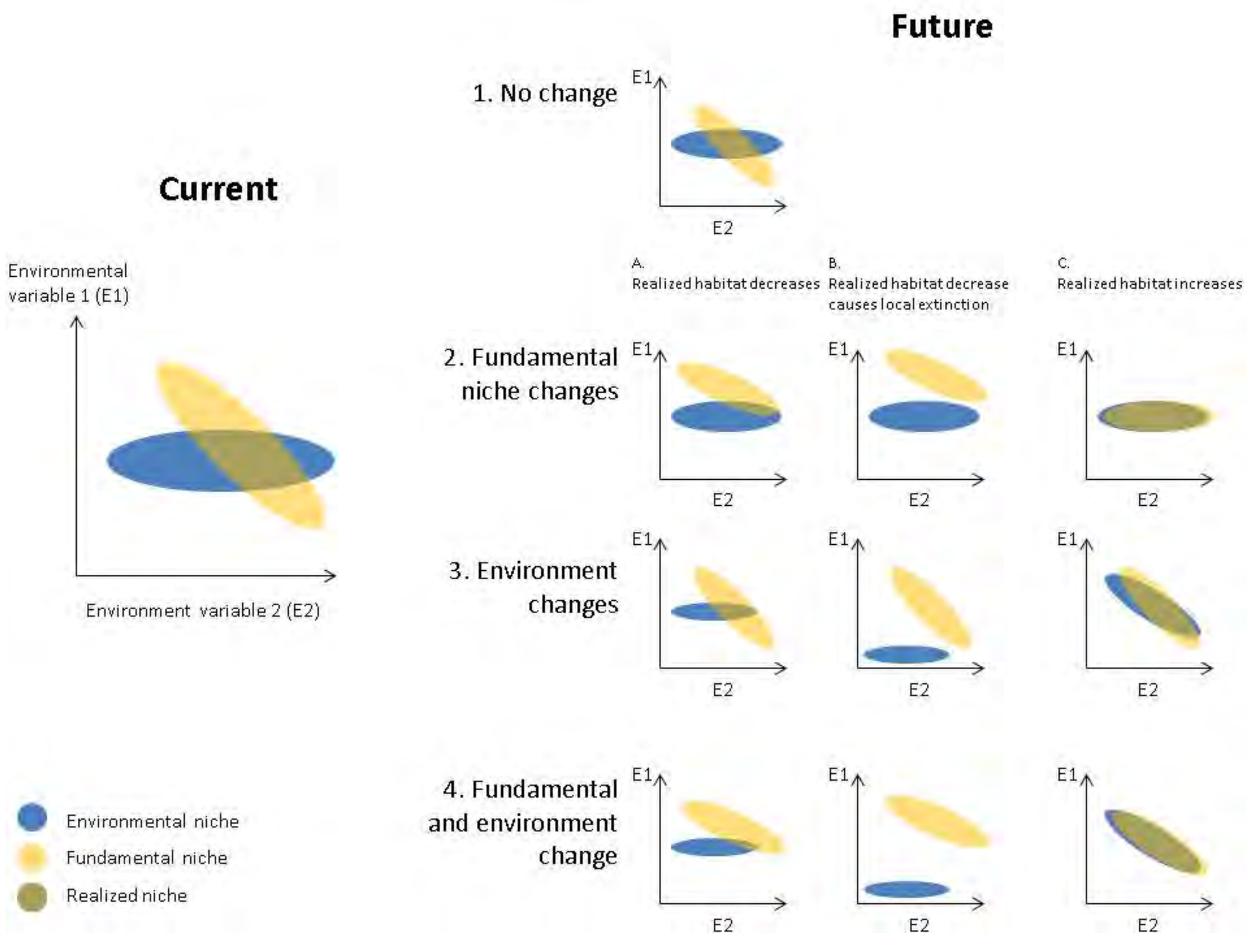


Figure 6. Adapted from Jackson and Overpeck (2000):

1. Best case scenario: Both climate and fundamental niche are maintained. The refugia will persist.
2. Climate is maintained, but the fundamental niche shifts due to changing species interactions. This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).
3. Climate is not maintained, but the fundamental niche is maintained. This will cause the realized niche to shift: This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).
4. Neither Climate nor fundamental niches are maintained. This will cause the realized niche to shift: This will cause the realized niche to shift and either: decrease in size (A), decrease in size until the population is locally extinct (B), or increase in size (C).

What are novel roles for cold-refugia under climate change?

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Despite widespread interest, refugia may be overlooked by others as a climate change mitigation strategy given their common designation as a short-term resistance strategy (*27, 37, 38*). Refugia's role in ecology may also change (*11*). Historically refugia shrunk and expanded as they did during glacial and interglacial periods. In contrast, species which currently persist in refugia may not be able to expand due to the projected magnitude and unidirectional nature of climate change (*39*). *If refugia may be the last place species exist before extinction, then can we call these areas refugia as per Keppel et al.'s (2011) definition (11)?* Nonetheless, refugia have garnered much attention and have an important role in the conservation toolbox which we describe (*2*).
Refugia may function as part of resistance, resilience, and/or response strategies (Table). Protecting refugia is commonly identified as a climate change resistance strategy, but their protection also functions in the resilience and response frameworks. Resistant strategies include fortifying areas from climate change and disturbances. Resilient strategies include managing areas to withstand climate change and disturbances. Response strategies include facilitating changes to climate change adapted species, communities, and structures. Most actions are not exclusively in one framework. A combination of these strategies is thought to best aid conservation. Resistance and resilience strategies may only delay the inevitable repercussions of climate change. (*27, 37, 38*)

Table 2. Refugia play an important and evolving role in conservation.

	Resistance	Resilience	Response
Historical role of refugia			
Place for species to exist in, retreat to, and expand from (*11*)	X	X	X
Additional strategies			
Short-term refuge during disturbances (*2*)		X	X
Gardens and source propagules for assisted migration (*37*)			X
Important role in landscape heterogeneity	X	X	X
Natural history museum	X		
Create and maintain refugia for any of the described roles			X

Refuge

Refugia have been defined by some as a place where species may persist on an evolutionary time scale (*11*), but species may be able to take short-term refuge in refugia as well (*40*). During extreme, but short-term disturbances species may be able to exist in, retreat to, and expand from refugia. Refuge will be increasingly important as disturbance events become more frequent and/or sever as predicted with climate change.

Assisted migration

Refugia may be an asset for planned or impromptu assisted migration projects (*37*). Refugia may function as gardens where propagules can be cared for before or during transplanting. They may have source propagules for impromptu assisted migration project which occur after major environmental changes. The small carrying capacity of many climate refugia imposes strict limits on population size while their geographical isolation restricts opportunities for meta-population dynamics. Survival under such conditions renders relict populations prone to evolutionary processes such as genetic drift and local adaptation (*41*). It has consequently been argued that they could harbor genotypes with greater tolerance to climatic stress (*42, 43*). Yet empirical evidence remains scant and such expectations might be overly optimistic.

Landscape heterogeneity

Diverse environmental and species niches which occur near one another may reduce the effects of climate change. Refugia may resist climate change effects by buffering climate. The nearby placement of the refugia to other areas reduces the distance a species needs to travel to maintain its climate, i.e. the velocity of climate change, which enhances refugia's role as both a refuge and refugia (*44*). For example, California's high biodiversity has been attributed to topographic buffering. This topographic buffering is believed to allow floral species to persist longer than areas without buffering. While new species arise at the same rate, species extinction rates are slowed, and greater biodiversity accumulates (*45*).

Natural history museum

Refugia may be natural history museums. As climate shifts, common species may become restricted to areas which maintain historic climate. People will be able to visit these sites, see plants they remember from their youth, and learn about how climate change has dramatically altered natural systems.

Create and maintain refugia

Refugia could be created by planting desired species in areas which buffer climate for in-situ conservation (*46*). Refugia may also need to be maintained with desired species assemblages due to the effect of climate change on species interactions and ecological processes. Possible response actions include seed bank supplements; transplantation; watering; thinning or removing undesirable species, phenotypes, or genotypes. We may be able to utilize naturally cool places, such as cold-air pools, by protecting or enhancing tree cover that protects cold-air pools from mixing into the surrounding atmosphere or by enhancing dams to allow cold air to be stored in pools desired locations.

Conclusion

Oliver et al. (2012) advise conservation planners that their "highest priority (is) to reduce negative edge effects and improve in-situ management of existing habitat patches ". Refugia do exactly this, allowing in-situ management of habitat patches (*46*). Refugia are complex habitats guided by species interactions, climate, and ecological processes that may interact with one another and change with climate. Therefore, protecting the land associated with refugia is not sufficient to protect the biological and physical properties of refugia. While managers will be asked to make decisions about refugia without understanding their full ecological complexity, they must understand that refugia are not static and are likely to have novel roles and ecology.

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Appendix A. Species at their southern range in the central Sierra Nevada

Alison Colwell and Martin Hutten compiled potential refugia indicators, vascular and non-vascular species at their southern range extent in the central Sierra Nevada.

Ahtiana pallidula

Acer glabrum

Adenocaulon bicolor

Alectoria sarmentosa

Allotrpa virgata

Arbutus menziesii

Arctostaphylos manzanita ssp. manzanita

Arctostaphylos mewukka ssp. mewukka

Arnica latifolia

Asarum lemmonii

Botrychium tunux

Carex diandra

Carex pachystachya

Carex viridula

Cephalozia lunulifera

Cerastium beeringianum (var. capillare)

Cladonia umbricola

Claopodium bolanderi

Conostomum tetragonium

Cyphelium karelicum

Cypripedium montanum

Galium mexicanum var. asperulum

Githopsis diffusa ssp. robusta

Githopsis pulchella ssp. campestris

Githopsis pulchella ssp. pulchella

Githopsis pulchella ssp. serpenticola

Gratiola neglecta

Helodium blandowii

Hypogymnia tubulosa

Japewia subaurifira

Japewia tornoense

Leptosiphon bolanderi

Leucolepis acantheneuron

Limnanthes alba ssp. versicolor

Limnanthes striata

Lithocarpus densiflorus

Marsupella sparsifolia

Mimulus inconspicuus
Mimulus kelloggii
Minuartia pusilla
Minuartia rubella
Minuartia stricta
Moerckia blyttii
Myrica hartwegii
Myurella julacea
Narthecium californicum
Nephroma helveticum
Nephroma resupinatum
Pachistima myrsinites
Parmeliella parvula
Parmeliopsis hyperopta
Perideridia howellii
Perideridia kelloggii
Phoenocaulis cheiranthoides
Placopsis lambii
Pleuricospora fimbriolata
Polytrichum sexangulare
Pseudotsuga menziesii
Riccardia latifrons
Rinodina disjuncta
Scapania gymnostomophila
Sidalcea diploscypha
Sidalcea glaucescens
Silene invisa
Stereocaulon glareosum
Stereocaulon rivulorum
Taxus brevifolia
Trientalis latifolia
Tritomaria exsectiformis
Vaccinium sp.
Veronica cusickii