2011 NPS George Melendez Wright Climate Change Fellowship Program

FELLOWS' FINAL RESEARCH REPORTS

DECEMBER 31, 2012

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

2011 NPS George M. Wright Climate Change Fellowship Program
Fellowship Research Status Reports
December 31, 2012

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2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Lukas Bell-Dereske
University: University of New Mexico
Start date: May 2011
End date: September 2012

Brief project summary:

The broad reaching effects of climate change are likely the biggest problems facing ecologists and park managers during the coming century. Climate change will likely lead to the extinction of many species of organisms (ranging from bacteria to trees) and huge changes in the ranges of many more organisms. Added to the broad reaching effects of climate change, many parks are composed of land reclaimed from other anthropogenic disturbances. Understanding how climate change could possibly affect restoration efforts of these areas is an important goal for both the National Park Service and ecologists.

My research focuses on the restoration of two sites in the Great Lakes dunes of Sleeping Bear Dune National Lakeshore. Over 21% of the freshwater dunes in the world are within the Great Lakes region. This ecosystem is critically important to the region because it acts as an attraction for tourists and buffers the inland areas from lake storm surges. In addition, the dune ecosystem is home to endangered fauna, such piping plovers, and flora, such as pitcher's thistle. Regional climate change models predict an increase of winter and summer storm events that will likely lead to increased disturbances in this fragile system. To my knowledge, no studies have examined the effects on climate change on the Great Lakes dune plant community.

Another understudied aspect of climate change is its effect on the microbial symbioses that are ubiquitous in natural systems. All plants interact with bacterial or fungal symbionts at some point within their life spans. These microbial symbionts have been shown to increase their host's drought and heat tolerance; these benefits may reduce the effects of climate change on their hosts.

My research focuses on the symbiotic interaction between fungal endophytes and American beachgrass (*Ammophila breviligulata*) and how the symbiotic interaction may reduce the effects of climate change on Great Lake dune plant communities. Fungal endophytes are symbionts that spend most of their life cycle within the aboveground tissue of plant species. Fungal endophytes have been shown to increase the drought tolerance of their hosts and can have broad reaching effects on the diversity of plant communities. This past summer I established a restoration experiment that examined the effects of the endophyte/grass symbiosis and climate change driven alterations in the precipitation regime on a dune plant community. My experiment focuses on three questions:

1) How will the combined effects of climate change and endophyte mutualism affect *A. breviligulata*?
2) How does the presence of the endophyte in *A. breviligulata* affect the plant community response to climate change?
3) How will the endophyte mutualism affect ecosystem processes under climate change?

Research Approach:

My experiment manipulates three factors: endophyte presence in *A. breviligulata*, community composition, and amount/timing of rain events. Plots either receive *A. breviligulata* individuals with the endophyte or individuals free of the endophyte. My experimental plant communities are composed of four grass species (including *A. breviligulata*), one herbaceous species, and one shrub species. For the community, treatment plots are either composed of clumps of the monocultures or all plant species mixed together. The major change in the design of my experiment is the precipitation manipulation treatment. A recent Great Lakes regional climate change study predicted an increase of 30% in precipitation during the spring and summer months with an added increase in the frequency of extreme rain events. My new design examines how increases in precipitation and change in timing of precipitation will affect plant communities. The precipitation treatments are 1) Ambient: plots only receive the ambient amount of rain, 2) Increased: plots receive a 30% increase in month precipitation applied weekly, and 3) Extreme Rain Events: plots receive a 30% increase in monthly precipitation applied once a month in simulated extreme rain events.

Location(s) of Research:

Sleeping Bear Dunes National Lakeshore, Leelanau County, Michigan

Key Findings:

I just established my experiment this summer and was not able to begin the watering treatments due to high mortality of my plant species during this summer's drought and record hot summer. I have some preliminary results on how the fungal endophyte and community treatments affected the restoration of the plant community which I will detail here.

The presence of the endophyte increased the growth of its host *A. breviligulata* across all community treatments.

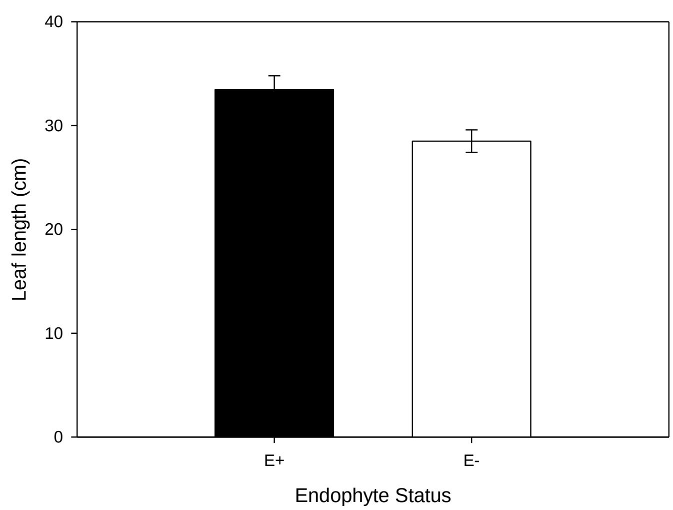


Figure 1: The effect of endophyte status on the growth of its host *A. breviligulata* (E+= Fungal Endophyte present, E- = Fungal Endophyte absent). The endophyte had a marginally significant increased the growth *of A. breviligulata* (p=0.07697, df=1)

Overall, the presence of the endophyte/*A. breviligulata* had a facilitative effect on the restoration by increasing growth of all species.

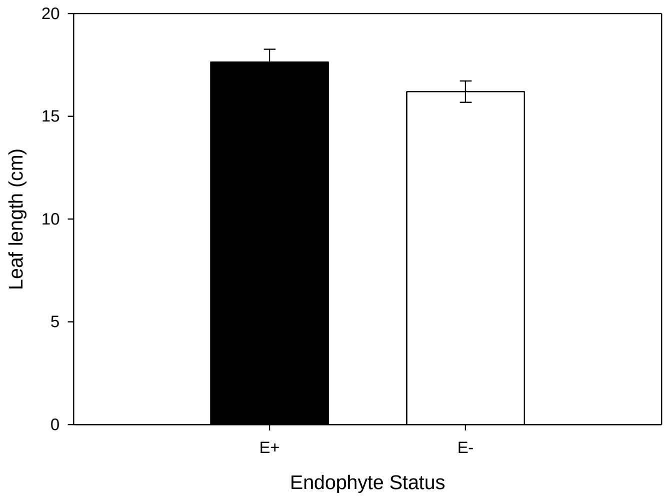


Figure 2: The effects of endophyte status on the average length of the longest leaf of random individuals from each plot across all species (E+= Fungal Endophyte present, E- = Fungal Endophyte absent). The presence of the endophyte significantly increased biomass across all species ($p<0.01$, df=1).

Deliverables/Research Products: (Please list)

Since my project has just been fully established, I do not have any deliverables from the project at this time. I have listed some deliverable from my other project examining the effects of endophytes on plant species growth in the Great Lake dunes that was indirectly funded by this grant.

- Presentation at Graduate Science Day at Rice University 2012, Title: The effect of symbionts and density on plant community interactions, File name: GSD 011 Bell-Dereske.pptx
- Presentation at University of Houston-Rice University Symposium 2012, Title: The effect of symbionts and density on plant community interactions in the Great Lakes dunes, File name: UH-Rice Bell-Dereske 012.pptx
- Poster presented at Ecological Society of America 2012, Title: Facilitative effects of dune ecosystem engineer *Ammophila breviligulata* increases with density and association with an aboveground symbiont, File name: ESA poster 012.pptx

Additional Funding:

I was not able to leverage funding with the George Wright Fellowship. However, I will be using the fellowship to leverage funding in the future. I also received a Student Grant from Society of Wetland Scientists concurrently with George Melendez Wright Fellowship ($998) and a Graduate Research Fellowship from the National Science Foundation.

Anecdotes:

My plots are in an area of Sleeping Bear Dunes that is only starting to receive traffic from tourism, so my interactions with visitors were limited. However, when visitors would happen upon my experiment while I was working, I would always strike up a conversation about climate change; I would also explain the experiment and my research goals. I had some interesting interactions with visitors, which I can relate in an interpretive component.

I used a small water pump to pump water 80 meters from Lake Michigan to my plots. Every day I laid out the hose from the lake to my plots. One day around noon, I was about to water my plots during a particularly hot day. I had my hose to the lake laid out and I was unrolling hose into my plots. All of a sudden I heard someone yell, "Who are you and what are you doing to my lake?!?" The outburst startled my and I look over see a lady stomping towards me. I stopped unrolling my hose and walk over to see what was the matter. The lady got right into my face and asked me, "What are you pumping into the lake?" This took me aback because my sites are around a two mile walk from the nearest road. I could not imagine anyone willing to haul chemicals that far to pump them through a garden hose into the lake. I chuckled and explained that I was not pumping anything thing into the lake, but using lake water for watering a restoration experiment. We had a great conversation about the dunes and how climate change may affect the fragile plant community. It turned out that she lived nearby and walked the beach most days, but had not really thought about the dune plant community before.

On another climate change related topic outside my expertise, but is a concern for wildlife biologists, is the outbreaks of diseases. During the original planting of my experiment at the end of last May, I saw a bald eagle just sitting in one of my plots. I walked near it to get a better look. It was not moving and looked very sick. I called the bird biologists at Sleeping Bear Dunes and they came out immediately to check on the eagle. They said that it was sick due to botulism. While they were taking pictures and samples, I was able to get within a few feet of the massive bird of prey. I never saw the bald eagle after that day, but this last September there were tens of large water fowl lying dead along the beach near my plots. According to the local newspapers, this summer there was massive outbreak of botulism in the Great Lakes region. Wildlife biologists believe that the outbreak was due to the warm lake temperatures and algae blooms combined with round golby fish that have invaded the lakes. Experts predict that these outbreaks will only get worse as the lake warms during the next century

Acknowledgments

I would like to thank Sleeping Bear National Lakeshore for allowing me to conduct my research in such a beautiful area; I want to specifically Amanda Brushaber, Ethan Scott, and Steve Yancho for all of their help permits and locating possible sites for me research. I also want to thank Joy Marburger for her insights on conducting research in National Parks and for agreeing to be my park sponsor on short notice. Additionally, I want to thank my graduate studies advisor Jennifer Rudgers for her help at all points of this research project. Finally, I would like to thank the George Melendez Wright Fellowship Program which made my research possible.

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.*

Late May 2012: Western Site: Planting the plots with pottipuki planter

Late May 2012: West site nearly planted.


Late May 2012: West site planting process.

September 2012. West site end of the year sampling.

September 2012. East site end of the year sampling.

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Sarah Bisbing
University: Colorado State University
Start date: May 2011
End date: September 2012

Brief project summary:

An understanding of the role of phenotypic plasticity and genetic variation in overall success and relative distribution is still poorly documented for many widespread organisms. As changes in climate impact habitat, species will be forced to adapt or migrate to accommodate their environmental requirements. This research used genetic and ecological information to examine the nature of adaptation and the drivers of variation among the subspecies of *Pinus contorta*, the most widespread pine of western North America. This species' broad distribution is divided into four geographically and morphologically distinct subspecies (ssp. *murrayana*, *latifolia, contorta,* and *bolanderi*), with each subspecies growing under and hypothesized to be locally adapted to a unique set of edaphic and climatic conditions. Climatic changes may have variable effects on populations across the distribution of the species, and conservation may require subspecies-level action.

Figure 1. Clockwise from top left: subspecies *contorta* in Petersburg, Alaska; subspecies *latifolia* in Banff National Park, Alberta; subspecies *murrayana* in Inyo National Forest, California; and subspecies *bolanderi* in Mendocino County, California. Photo credits: Sarah Bisbing, 2010.

I addressed the following questions: 1) what is the level of genetic diversity across the range of *Pinus contorta*? and 2) how may this species respond to changing climatic conditions? Molecular genetic analysis and species distribution modeling were used to assess current population structure and the response of the species to variable conditions. By using genetic and ecological information to assess variation and model potential distribution under future climate change scenarios, we aim to provide managers with the resources required to prepare them for the impacts of climate change. Such information will be crucial for land managers working to maintain species and communities in the face of a rapidly changing climate, providing them with a better understanding of the adaptive abilities of *Pinus contorta* and aiding in predictions of species' performance in novel environments. Moreover, information on population structure will enable managers to preserve unique populations across the landscape, providing species with the opportunity to persist through the maintenance of high levels of variation.

Research Approach:


Figure 2. Measuring tree height at the Juneau, Alaska, long-term common garden. Photo credit: Sarah Bisbing, 2012.

In this research, I used ten microsatellite markers to quantify gene flow and examine the genetic population structure across *Pinus contorta*, the most widespread conifer in western North America. I also used species distribution modeling to predict any future shifts in suitable habitat. Finally, I planted three long-term common garden plots across western North America. Each garden is located in the respective habitat of each subspecies, with local and foreign individuals planted in each garden. Over the next few years, these gardens will allow us to test local adaptation to specific combinations of environmental and climatic conditions.

Only one aspect of my initial research proposal has changed. Due to time constraints, I was unable to implement the proposed growth chamber experiment. After doing quite a bit of additional background research and time management calculations, I learned that this type of experiment would require over a year of time (in addition to the time required for the initial stages of germination and growth). Beyond that, analysis and writing would require an additional year or so. I plan to graduate next summer, and this timeline was not a feasible task for my dissertation work.

Location(s) of Research:

Sampling occurred across the entire range of *Pinus contorta*, from the Yukon to southern California and east to South Dakota. Genetic samples were collected from all four subspecies (ssp. *murrayana*, ssp. *latifolia*, ssp. c*ontorta*, and ssp. *bolanderi*) and from each distinct ecological region. Sampling on National Park Service land occurred within the following parks: Glacier Bay, Yosemite, and Yellowstone.

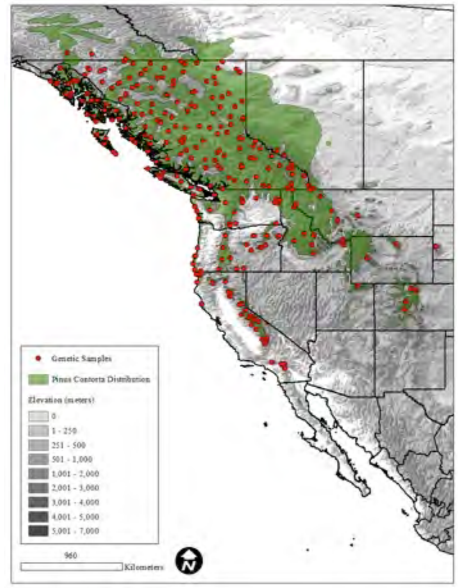


Figure 3. *Pinus contorta* genetic sampling locations.

Key Findings:

Analysis of these ten microsatellite markers resulted in a population structure of three genetic clusters (ssp. *murrayana*, ssp. *latifolia*, and ssp. c*ontorta*). Subspecies *murrayana* is the most isolated of the subspecies, possessing the greatest number of unique alleles and showing little admixture with the other subspecies. Subspecies *bolanderi* shows high admixture with subspecies c*ontorta* and subspecies *latifolia,* suggesting gene flow between these three subspecies. Overall, analysis of neutral genetic material shows historically high levels of among-subspecies gene flow. The genetic structure of subspecies *murrayana* should, however, be taken into account when developing management plans for the Sierra Nevada region. Although this subspecies does contain relatively high levels of within-subspecies genetic diversity, it is the most isolated from gene flow with the other subspecies. This is concerning for the future stability of this population. Under rapidly changing climatic conditions, high levels of genetic diversity and unimpeded gene flow between subspecies provide the genetic material necessary for acclimation and adaptation. Without these pools of genetic material, species can become more isolated over time and eventually decline following rapid environmental or climatic alteration.

Species distribution modeling was implemented on both the species-wide and subspecies levels. I used the population clustering information from genetic analyses as a basis for subspecies-level modeling, with three subspecies or genetic clusters (ssp. *murrayana*, ssp. *latifolia*, and ssp. c*ontorta*) used in this predictive analysis. Species-level modeling results were quite different from subspecies-level results, supporting our observation that the combinations of environmental and climatic conditions under which subspecies grow are quite different. This suggests that modeling should in fact be done on the subspecies-level, as species-wide modeling assumes that habitat suitable for one subspecies will be suitable for all others. Regardless, both species-wide and subspecies-level modeling predicts nearly complete loss of suitable habitat for subspecies *murrayana*. Predictive modeling also showed a dramatic shift in habitat for subspecies *contorta*, with suitable habitat moving further inland and upward in elevation. Notably, suitable habitat is predicted in many areas that may not be available for range shifts during the next century. The Juneau Icefield (southeast Alaska), for example, is classified as future habitat for a range shift. It seems unlikely, though, that this area will be ice-free and suitable for establishment. Subspecies *latifolia* habitat is predicted to shift both further northward in latitude and upward in elevation. Suitable habitat is lost from the southern extent of the range, including in areas of Utah and Colorado. Overall, however, this subspecies should remain a dominant species across the intermountain west. These results should be interpreted with caution, as they are predictive models that only utilize available environmental and locational information. Additionally, these predictions do not mean that current trees will die off and result in the loss of entire populations. They do, however, suggest that future germination and establishment will be limited. These subspecies are likely to experience significant habitat loss over the next century. Subspecies-level management and conservation should be made a priority, so as to promote persistence of both this species and its many associated ecological processes.

Results from both genetic analyses and predictive modeling suggest that this species should be managed at the subspecies level. As each subspecies grows under a unique combination of ecological and climatic conditions, each is likely to respond to rapidly changing climatic conditions in a different manner. To preserve the many beneficial processes associated with this species, including wildlife habitat and watershed stability, subspecies-level habitat protection should begin now. Managers, for instance, can work to protect areas that are predicted to be suitable for future germination and establishment. Maintenance of habitat connectivity should also be prioritized in any effort to sustain among-subspecies gene flow.

Deliverables/Research Products:

- **Bisbing, S.M.**, D.J. Cooper, and A.L. Angert. 2013. Range-wide patterns of genetic population structure and potential geographical range shifts of *Pinus contorta* (ssp. *latifolia, murrayana, contorta*, and *bolanderi). In Prep for submission to Molecular Ecology.*

- **Bisbing, S.M.**, D.J. Cooper, and A.L. Angert. 2012. Range-wide patterns of genetic population structure and potential geographical range shifts of *Pinus contorta* (ssp. *latifolia, murrayana, contorta*, and *bolanderi).* Annual Meeting of the Ecological Society of America, Portland, OR, August 2012.

Additional Funding:

- **Bisbing, S.M.** (PI) Gloria Barron Wilderness Society Fellowship: Conserving the adaptive potential of western forests: Using range-wide patterns of genetic population structure and niche modeling to predict the response of *Pinus contorta* to climatic change, $10,000. 2012 - 2013

Other:

- This funding provided a platform for my long-term research program. I used some of the funding from this fellowship to establish long-term common garden plots across western North America. These gardens will be used over the next 8-10 years to assess local adaptation across the subspecies of *Pinus contorta*.

- I have made many lasting connections as a result of this range-wide study. Because of the collaborative nature of this research, I have developed relationships with researchers and land managers at the local, state, federal, and university levels in the following states/provinces: Alaska, Alberta, Arizona, British Columbia, California, Colorado, Montana, Oregon, Utah, Washington, and the Yukon Territory. These are relationships that will span many research projects and continue for many years into the future.

- The opportunity to implement this project has truly set me up well for a long, collaborative career in forest conservation and management.

Photographs:

Figure 4. Measuring height at the Juneau, Alaska, common garden plot.

Figure 5. Molecular genetic lab work in the Angert lab at Colorado State University.

Figure 6. Planting trees at the Juneau, Alaska, common garden plot.

Figure 7. Hauling trees to the Pingree Park, Colorado, common garden plot (just outside of Rocky Mountain NP).

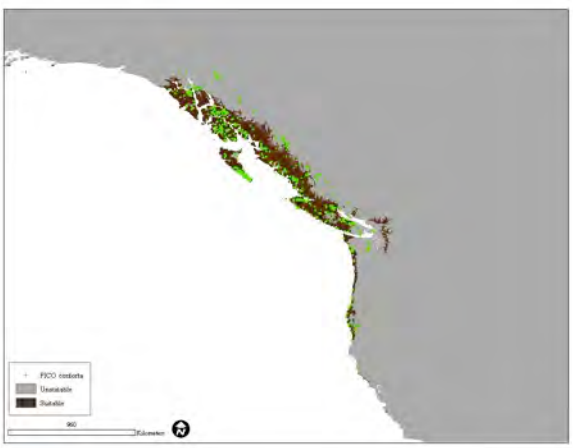


Figure 8. Current distribution of suitable habitat for *Pinus contorta* ssp. *contorta*

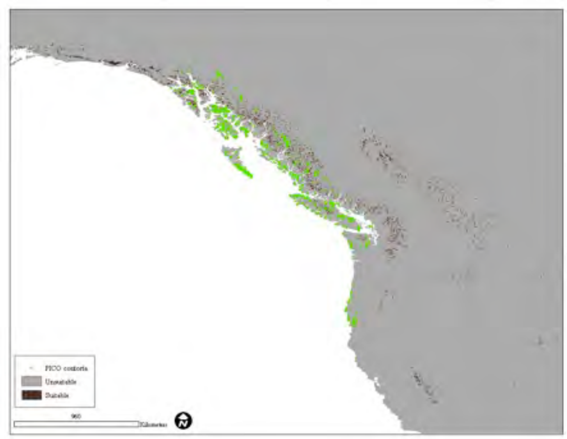


Figure 9. Predicted suitable *Pinus contorta* ssp. *contorta* habitat for 2080 (under A2 IPCC scenario)

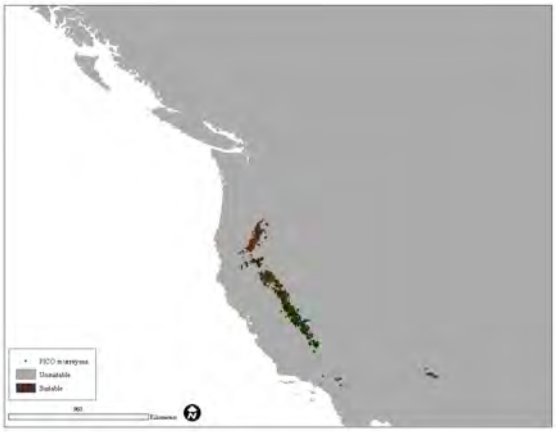


Figure 10. Current distribution of suitable habitat for *Pinus contorta* ssp. *murrayana.*

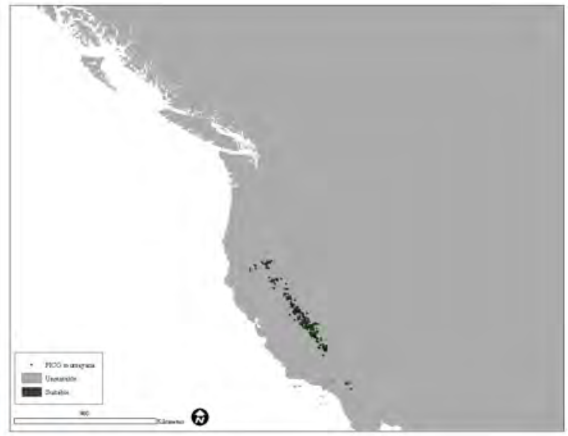


Figure 11. Predicted suitable *Pinus contorta* ssp. *murrayana* habitat for 2080 (under the A2 IPCC scenario).

- *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.*
- ***Because this work will be published, I'd really prefer if the habitat suitability maps were not used in publication (web, print, or otherwise). I am providing them here for NPS managers.***

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Kirsten Feifel
University: University of Washington
Start date: September 2011
End date: September 2012

Brief project summary:

It has been suggested that recent climate change may be a contributing factor to an increase in harmful algal bloom (HAB) outbreaks worldwide but there are few long-term records available to statistically assess relationships between environmental variability and HABs. A harmful algal bloom is generally a phytoplankton that negatively affects an ecosystem through the production of chemical toxins or damaging physical interactions. While harmful species of phytoplankton typically comprise a small component of the entire phytoplankton community, changes in HAB populations can serve as bioindicators of large-scale marine ecological disturbances such as changes in climate or eutrophication. HABs may be a harbinger of change and therefore serve as the quintessential "canary in the coalmine" for the oceans as well as having direct impacts on human and ecosystem health. Understanding the effects that large-scale climate variability and local environmental conditions have on HAB populations could indicate impending changes in oceanic ecosystems.

One common, coastal cold-water HAB forming species in the Pacific Northwest, *Alexandrium catenella*, produces a suite of paralytic shellfish toxins (PSTs). During blooms of *A. catenella*, cells containing PSTs can become concentrated in filter-feeding bivalves and ingestion of these PST-laden bivalves can cause paralytic shellfish poisoning. The most potent PST, saxitoxin, is a neurotoxin that causes disruption in the neuromuscular and respiratory systems and can be lethal to humans within a few hours of ingestion.

Olympic National Park, located along the western coast of Washington State, has jurisdiction over the natural resources found within its coastal intertidal zone. Over the past decade, Olympic National Park has had multiple HAB outbreaks that forced managers to limit recreational and tribal shellfish harvests. In 2008 and 2010, resource managers at the Olympic National Park were forced to close shellfish harvesting due to blooms of the harmful alga *A. catenella*. However, a dearth of data has precluded the ability of managers to assess if HABs of *A. catenella* are truly increasing in Olympic National Park and, if so, what the cause is.

One way to begin to examine the relationship between historical climate variability and HABs is to develop long-term records using sediment cores. Some HAB forming species in the Pacific Northwest, such as *A. catenella*, can form a dormant cyst after a bloom that can become entrained in the sedimentary record; we presume that changes in cyst abundance over time reflects historical changes in *A. catenella* populations. The research objective of this project was to better assess the historical occurrence and range of *A. catenella* along the Olympic coast by extracting sediment cores along five transect lines extending from shoreline to depths of 150 m and in one nearby inlet. It is thought that the toxins found in the shellfish along the Olympic National Park coastline originate from HABs found in the waters within the adjacent Olympic National Sanctuary but, it is unknown where the cyst beds reside and how long the cysts have been present in the region.

In a previous study based out of an inlet nearby to the Olympic National Park bounds, we found that *A. catenella* cysts had been present since the late 1800s and cyst abundances were positively correlated with sea surface temperature and local air temperature. We expected to find *A. catenella* cysts in sediment cores extracted from sediments along the Olympic National Park coast and hypothesized that the cyst records developed from sediment cores would be correlated to sea surface temperature and air temperature. We also hypothesized that the cysts would be located further offshore in the muddy sediments found in the deeper, lower wave energy, waters.

Research Approach:

Coring along the Olympic coast was done using a Smith-Mac while aboard the R/V Tatoosh. The coring device was selected based upon the R/V Tatoosh's winch and A-frame maximum weight bearing capacities. Once sediments were brought up to the boat deck, three sawed off 50 cc syringes were used to sub sample the sediment grab. Then the top 1 cm of the surface sediments was removed and transferred in to a sterile plastic bag. Two water samples were taken at each station, one using a plankton net tow the other using a Nisken bottle. Sediment samples were further processed in a laboratory at the University of Washington. Sediments were sieved and then stained to help identify cysts of *A. catenella* in the samples.

In December, 2011 follow up field work occurred while onboard the R/V Barnes in nearby Sequim Bay. Coring was done using a kasten corer, which can extract 1 m long sediment cores. Two cores were taken, partially processed onboard the ship and brought back to the lab for further analysis. Chronologies of the cores were assessed using isotopic dating with lead-210.

In the lab, sediment samples were processed to separate dinoflagellate cysts from surrounding sediments. The numbers of cysts per sediment layer were quantified through manual counts on the microscope. Some cysts were isolated by hand, imaged and placed in to growth media to assess long-term viability and potential degradation rates over time.

Location(s) of Research:

Sediment cores were extracted along five transect lines along the Olympic coast in late August, 2011 while onboard the R/V Tatoosh and from one nearby bay, Sequim Bay in December, 2011 while onboard the R/V Barnes. Sites were selected based upon areas historically prone to experiencing shellfish toxicity, proximity to oceanographic data (SST, wind stress), proximity to air temperature records, available sediment information, and relative distance to other sites. Ideally, sediment cores would be extracted from muddy bottoms to assure an intact chronological record and minimal disturbance to the sediments during the coring process.

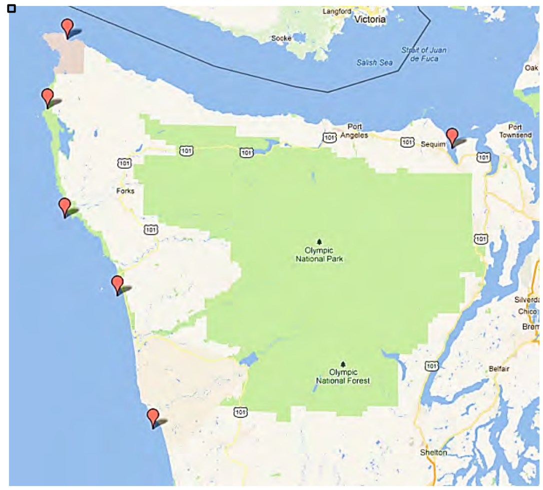


Figure 1. Map of coring sites (red markers, N-S Neah Bay, Makkaw Bay, La Push, Kalaloch Beach, MocRocks Beach. E- Sequim Bay) and ONP bounds (in green).

Along the Olympic coast, transect lines were run from the shorelines of Neah Bay, Makkaw Bay, La Push, Kalaloch beach, and MocRocks beach (Figure 1). The transect line began at the edge of the surf zone or at 15 m depth, which ever was closest to shore. Sediment cores were taken at depths of 15, 20, 50, 100, and 150 m. The ship ran perpendicular to depth contour lines based upon bathymetric maps and sonar readings.

Key Findings:

Olympic coast transects:

Sediments nearshore (0-50 m) were generally classified as "gravel" or "sand", a product of the relatively high wave energy environment found along the coastline. Muddy sediments were found far off shore, at depths of 100 and 150 m along the coast and at 5 m in the quiescent waters of Neah Bay. We first examined the sediment samples that were primarily composed of mud because we thought they would have the highest concentrations of *A. catenella* cysts. *A. catenella* cysts are non-motile and thus, will be transported like a passive particle in the ocean. Thus, the highest cyst concentrations should be found in similar grain sizes or fine sediments such as mud.

In general, very few *A. catenella* cysts were found in our samples. One cyst was found at both the 100 and 150 m depths off of Kalaloch beach. Another three cysts were found at the 150 m depth off of Makkaw Bay. No *A. catenella* cysts were found in the surface samples collected in the nearshore environment (0-50 m). Cyst beds at these concentrations are considered to have little ecological relevance when compared to the cyst beds found elsewhere in Puget Sound. For example in 2012, Bellingham Bay, located to the north, had cyst concentrations of 1070 cysts cm^{-3} and Quarter Master Harbor, located in southern Puget Sound, had cysts concentrations of 708 cysts cm^{-3} (PS-AHAB website, 2012).

One interpretation of these results is that *A. catenella* blooms along the Olympic coast originate from nearby bays and are transported by currents and tides to the Olympic coast. Another possible explanation is that we simply did not sample at the locations of the cyst beds along the Olympic coast. This was the first cyst bed mapping attempt along the Olympic coast; the sampling schematic was designed to cover a large area in the hopes we would happen upon a cyst bed. It is also possible that the cyst beds, if present off the

Olympic coast, are located even further off shore. In the Gulf of Maine, *Alexandrium* cyst beds have been found at locations more than 50 km or more offshore (Anderson et al., 2005).

Sequim Bay cores

The Sequim Bay cores indicate that *A. catenella* has been present in that bay since at least the late 1800's. From the 1950s to 2011, the numbers of *A. catenella* cysts in Sequim Bay have steadily increased. This could indicate that HABs of *A. catenella* are more common today relative to the past 100 years or, these results could also be interpreted as evidence of natural cyst degradation over time. It is unknown what the preservation potential of *A. catenella* in sediment cores is.

To better assess the long-term survival of *A. catenella* cysts in sediment cores, cysts from the Sequim Bay core were hand-picked from sediments and placed in to growth media. The cysts were monitored for a four week period and successful germination of the cyst, into a motile *Alexandrium* cell, was noted. Preliminary results indicate that cysts of *A. catenella* as old as 100 years are able to successfully germinate when introduced into growth media. These results bolster arguments that cysts of *A. catenella* do not rapidly degrade over time and that cyst records may be a useful proxy of historical algal blooms.

Deliverables/Research Products:

- Feifel, K.M., S.J. Fletcher, E. Lessard. "Relationships between cyst fullness, age and germination success of *Alexandrium catenella* and *Scrippsiella* spp. in a sediment core from Sequim Bay, WA, USA. 15th International conference on Harmful Algae. Invited poster. Changwon, South Korea. October 29- November 2, 2012.
- Feifel, K.M. "The harmful alga *Alexandrium catenella* and recent climate change: looking to the past to see the future." University of Washington Biolunch symposium. Presentation. May 15, 2011.
- Feifel, K.M., R.A. Horner. "A historical reconstruction of an *Alexandrium catenella* cyst record from Sequim Bay and its relation to climate variability." Salish Sea Ecosystem Conference. Poster. Vancouver, CA. October 25-27, 2011.
    - Received "Best Student Poster" 2nd place.

Additional Funding:

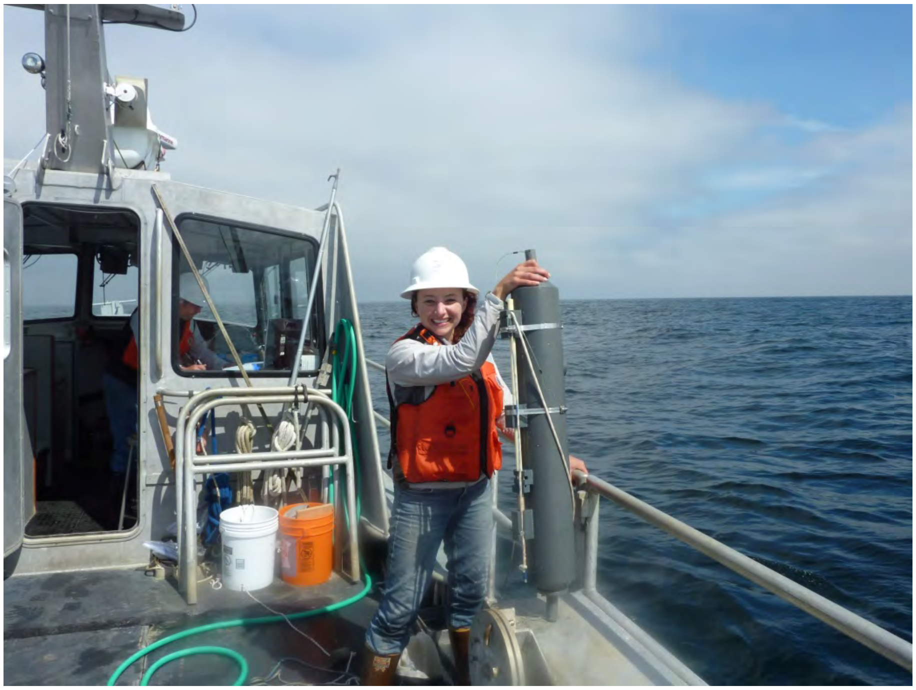
Processing of the Olympic Coast sediment cores was completed with the help of an undergraduate assistant. He was awarded a $4,000 Mary Gates Research Scholarship through the Mary Gates Endowment at the University of Washington to support his research efforts.

Support from the GMW Climate Change Fellowship provided the catalyst for my research. In 2011, I was awarded an NSF IGERT on Ocean Change, which provides me with two years of support (~$64,000) and tuition (~$30,000) to complete the research that I have started under the GMW Fellowship.

Other:

I plan to publish all of my research results in peer-reviewed science journals. I foresee completing my first manuscript in Spring, 2013. The funds from the GMW fellowship will support all of my research needs to complete my PhD dissertation at the University of Washington. I expect to complete all my requirements by Spring, 2014.

Photographs:



2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
Coral resilience and resistance in the National Parks of the Pacific Islands during times of global change
December 31, 2012

Fellow Name: Christopher P. Jury
University: University of Hawaiʻi at Mānoa
Start date: 6/1/2011
End date: 12/31/2012

Brief project summary: Coral reefs are extremely valuable to citizens of the United States and peoples abroad, providing a variety of goods and services. A recent NOAA survey found that the U.S. public values Hawaiian coral reefs alone at some $34 billion per year. Corals are the keystone group of organisms which build coral reefs. It is therefore critical to understand and potentially mitigate the factors which could negatively impact the growth of coral reefs. The release of carbon dioxide (CO_2) from human activities is leading to ocean warming (due to climate change) and ocean acidification. Ocean warming stresses corals and leads to coral bleaching. When corals become bleached they often die, though recovery is possible depending on the severity of the stress and the tolerance of the particular corals in question. Corals which recover from bleaching experience reduced growth rates and reproductive output for up to several years after bleaching. Ocean acidification reduces seawater pH. It is also stressful to corals and often chronically reduces coral growth rates.

While much is known about the individual effects of ocean warming and ocean acidification on corals, much less is known about their combined effects or about the potential for corals to adapt or acclimatize to higher temperature and lower pH over time. Adaptation occurs at the level of the population due to fixed, genetic differences among coral individuals. In contrast, acclimatization occurs at the level of the individual coral due to previous conditioning (e.g., previous high temperature exposure vs. no high temperature exposure). At regional scales corals have already adapted or acclimatized to a range of temperatures. This raises the question, could coral adaptation or acclimatization over coming decades reduce the impacts of climate change and ocean acidification on coral reefs? Further, are there areas at local scales where corals are naturally more tolerant or less tolerant of high temperature and low pH? Answers to these questions will allow us to spend limited conservation resources wisely. By protecting coral reefs which are most likely to survive under a changing climate we have the best chance to maintain the valuable goods and services they provide.

This study took advantage of natural differences in ocean temperature and ocean pH which occur in the Main Hawaiian Islands to examine the potential for corals to adapt or acclimatize to future climate change and ocean acidification. This work helps to identify areas at greater or lesser risk from climate change and ocean acidification.

Research Approach: Seawater temperatures are naturally ~0.5 °C (~1 °F) higher on the leeward sides of the larger Main Hawaiian Islands than on corresponding windward shores whereas ocean pH is likely similar on windward and leeward reefs. This temperature difference is equivalent to approximately 20-30 yrs worth of ocean warming under high CO_2 emissions. On the island of Oʻahu the inner portion of Kāneʻohe Bay reaches a summertime temperature ~1.5 °C (~3 °F) higher than offshore temperatures, or those on most Hawaiian reefs. The pH in the inner portion of Kāneʻohe Bay is also 0.1-0.15 units lower than on most reefs. These conditions are equivalent to approximately 40-50 yrs worth of ocean warming and ocean acidification under high CO_2 emissions. I took advantage of these natural differences in temperature and ocean pH to examine the potential for coral adaptation or acclimatization to future conditions. The windward vs. leeward reef comparison was funded by the George Melendez Wright Climate Change Fellowship Program (GMWCCFP). The Kāneʻohe Bay comparison was funded by University of Hawaiʻi Sea Grant College Program and the GMWCCFP. These two studies were performed concurrently, under the same conditions, so I report the results of both studies here.

For the windward vs. leeward reef comparison I collected many small pieces of three coral species (*Montipora patula*, *Pocillopora meandrina*, and *Porites lobata*) at windward and leeward reefs on the islands of Molokaʻi, Maui, and the Big Island of Hawaiʻi. For the Kāneʻohe Bay comparison I collected many small pieces of three coral species (*Montipora capitata*, *Pocillopora damicornis*, and *Porites compressa*) around the Hawaiʻi Institute of Marine Biology (HIMB), inner Kāneʻohe Bay, and at a nearby control off of Waimānalo, Oʻahu, HI site with more typical temperature and pH conditions. After collection all corals were transported to HIMB and allowed to recover from collection stress. However, after shipping many of the *Pocillopora meandrina* (collected from Molokaʻi, Maui, and Hawaiʻi) experienced tissue recession. None of the other coral species experienced recession after shipping and had a healthy, normal appearance soon after unpacking. It seems that this species is unusually sensitive to shipping stress, so it was excluded from further analysis. The remaining five species together constitute almost 90% of the coral cover across the Hawaiian Islands.

Upon arrival at HIMB the corals were initially housed in an outdoor, flow-through seawater system while the remaining corals were collected (over ~3 weeks). Once all the corals had been collected they were moved to the indoor, flow-through aquarium system used to perform the experiments discussed below. The corals were allowed to acclimate to ambient Kāneʻohe Bay seawater conditions for 11 weeks, to rule out short-term acclimatization as a factor in their responses, and then were exposed to one of three levels of temperature (26.8, 28.3, 29.8 °C; ~80, 83, 86 °F) and one of three levels of CO_2 (390, 600, 930 μatm) in a fully factorial design. These levels of temperature and CO_2 range from present-day to potential future end-of-summer conditions. The corals were held under these conditions for 5 weeks, a realistic time of exposure to seasonal maximum temperatures. After 5 weeks of exposure under these conditions temperatures in all tanks were reduced by 1.5 °C (~3 °F) while maintaining CO_2 as before and the corals were allowed the chance to recover from high temperature stress. These conditions were maintained for 9 weeks, a time period long enough to determine if the corals would most likely recover or die following high temperature stress. During the experiment coral growth, bleaching, mortality, and tissue recession were measured. At the completion of the experiment corals were preserved to allow for genetic, tissue, and skeletal analyses.

One additional change had to be made to the original research plan. Originally I intended to extend this study by performing similar experiments with corals collected in

American Samoa. However, it was not possible to secure permits necessary to allow foreign corals to be brought into the state. The funding requested to cover the costs of the work in American Samoa therefore were repurposed to cover the costs of water chemistry analyses and other disposable supplies for this project which were not requested in the original budget.

Location(s) of Research: Corals were collected at windward and leeward sites off of the islands of Molokaʻi (Kalaupapa and Hale o Lono), Maui (Kanaha Beach Park and Makena Landing Beach Park), and the Big Island of Hawaiʻi (Punaluʻu County Beach park and just north of the Kona Airport) as well as inner Kāneʻohe Bay and off Waimānlo on the island of Oʻahu.

Key Findings: As expected, corals experienced bleaching under elevated temperatures and the intensity of bleaching increased with increasing temperature and exposure time. Elevated CO_2 tended to result in higher rates of and more widespread incidence of coral bleaching as well as reduced rates of recovery after temperatures were lowered. Elevated CO_2 also tended to increase coral mortality and tissue recession substantially for some species (especially *Montipora patula*), but had little or no effect on other species (e.g., *Pocillopora damicornis*). Among the species examined, *Porites compressa* was relatively tolerant of high temperatures. It tended to bleach slowest and had among the lowest rates of mortality or recession as compared to other species. In contrast, *Montipora patula* and *Pocillopora damicornis* were much less tolerant of high temperatures and suffered heavy mortalities as a result of high temperature exposure. In contrast, *Pocillopora damicornis* appeared relatively insensitive to elevated CO_2 whereas the other species showed variable levels of tolerance (i.e., some individuals of a species were more tolerant while other individuals were much less tolerant).

There were no clear differences in temperature or CO_2 tolerances between windward and leeward corals (*Montipora patula* and *Porites lobata*). In sharp contrast, the corals from inner Kāneʻohe Bay had much higher temperature and/or CO_2 tolerances as compared to conspecifics from the control site at Waimānalo. Both *Montipora capitata* and *Pocillopora damicornis* from inner Kāneʻohe Bay experienced far less bleaching and mortality at a particular temperature level as compared to conspecifics from Waimānalo. *Porites compressa* were relatively temperature tolerant at both sites but the *Porites compressa* from Kāneʻohe Bay were much more CO_2 tolerant than those from Waimānalo. For example, at the lowest temperature and the highest level of CO_2 the *Porites compressa* from Kāneʻohe Bay experienced net growth whereas those from Waimānalo experienced net dissolution.

While the trends above emerged clearly it must be stressed that there was individual variation among different corals collected at each of these sites. At any given site, some corals of a given species were more tolerant or less tolerant to high temperature and CO_2 as compared to other individuals at the same site. These tolerances did not differ systematically between windward and leeward corals. This may be because a temperature difference of 0.5 °C is not large enough to drive local adaptation. Rather, the potential for adaptation is simply overwhelmed by gene flow occurring around each island and throughout the archipelago. In Kāneʻohe Bay the temperature difference of 1.5 °C is much larger and is accompanied by a large pH difference of 0.1-0.15 units. It appears that these much larger differences may be sufficient to overwhelm gene flow and lead to local adaptation or long-term acclimatization.

These results have important implications for the responses of Hawaiian coral reefs to climate change and ocean acidification. They will inform management decisions and help to protect the $34 billion worth of annual benefits of Hawaiian coral reefs. First, leeward reefs in the Main Hawaiian Islands will likely be impacted by climate change sooner than windward reefs, because they are naturally ~0.5 °C warmer and the corals have similar temperature tolerances. In addition to climate change and ocean acidification impacts, human population densities tend to be higher on the leeward shores of the Main Hawaiian Islands than on windward shores, suggesting the potential for greater impacts on leeward reefs from local stressors. However, the reefs of inner Kāneʻohe Bay clearly show that adaptation or long-term acclimatization to moderately higher temperature and CO_2 is possible and that larger temperature and CO_2 excursions are more likely to drive adaptation or long-term acclimatization. Therefore, leeward reefs may also serve as regions where coral genotypes with higher temperature tolerances can be generated through natural selection. The export of coral larvae from leeward reefs and from inner Kāneʻohe Bay could serve as a mechanism to enhance coral temperature and CO_2 tolerances on downstream reefs where those more tolerant larvae settle.

The coral samples from this study are preserved and I have additional genetic, tissue, and skeletal analyses planned. These additional data will provide further detail about the responses of Hawaiian corals to elevated temperature and CO_2.

Deliverables/Research Products:

- These data were presented at the 12th International Coral Reef Symposium held in Cairns, Australia; July, 2012 www.icrs2012.com.
- These data were presented to a lay audience as part of the "Evenings at Hanauma Bay" lecture series; October, 2012 www.hanaumabayeducation.org.
- A detailed scientific report of these findings will be presented to the resource managers at Hawaiʻi's National Parks, the Department of Land and Natural Resources (DLNR), and will be made available to other resources managers upon request.
- Results of this study will be published in scientific journal articles.
- Results of this study will be communicated to lay audiences through blog posts and popular articles at sites such as www.reefs.com and www.advancedaquarist.com. These publications reach tens of thousands of individuals from around the world annually.

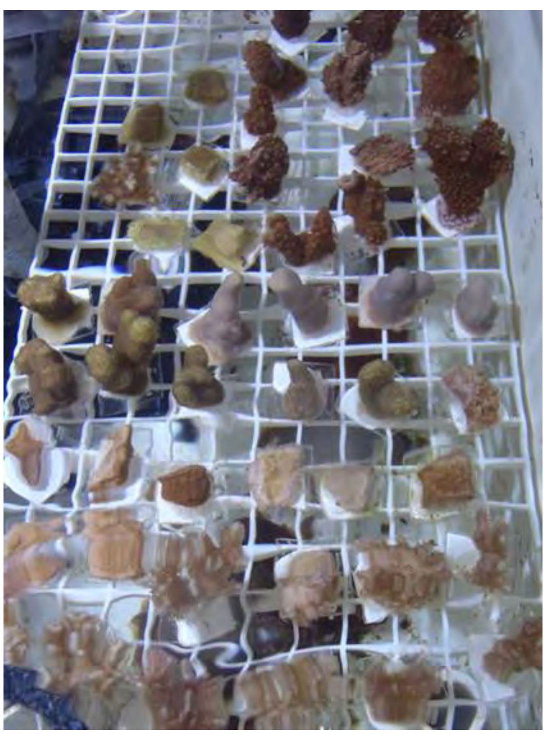
Additional Funding: Preparation and funding via the GMWCCFP was very helpful in securing additional funding through the UH Sea Grant College Program, as discussed above. UH Sea Grant is providing funding of $61,438 which is enhanced by a 50% non-federal in-kind match.

Other:

- While collecting corals for this project I encountered many individuals from the public who were curious about what I was doing. This provided me the opportunity to engage in public outreach directly with resource users who depend on these coral reefs for their livelihoods and for recreation (beachgoers, fisherman, surfers, etc.). These individuals ranged in age from young children to retirees. In all cases the people I spoke with were interested in what I had to say and thanked me for the work I was doing.

- The northern shore of Moloka'i is dominated by tall sea cliffs and therefore difficult to access due to the remoteness. As a result there is little fishing along the northern shore of Moloka'i as compared to much of the Main Hawaiian Islands. Fishing is entirely restricted at Kalaupapa National Historical park, where I did my coral collection. While in the water at Kalaupapa I regularly saw huge, mixed-species shoals of surgeonfish numbering many hundreds of individuals (see photo). These shoals were vastly larger and more numerous than what I have seen elsewhere in the Main Hawaiian Islands and demonstrates the benefit that large functionally protected areas can have on ecosystem health and services.

Collecting samples



Present time

Future - 2100

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Kristen Kaczynski
University: Colorado State University, Fort Collins, CO
Start date: January 2011
End date: December 2012

Brief project summary:

Willows are critical components of Rocky Mountain riparian ecosystems, particularly within Rocky Mountain National Park (RMNP), where they are the dominant woody vegetation. They provide food for elk, moose and beavers; habitat for resident and migratory bird populations, and amphibians; and are integral components of the structure and function of montane riparian ecosystems. However, willow stands have declined in stature, condition, and production over the past two decades. My research has shown that willow canopy volumes have decreased by an average of 65% within the Kawuneeche Valley at the headwaters of the Colorado River. Research on willow decline has focused primarily on the effects of elk browsing and altered hydrologic regimes due to the loss of beaver populations. However, other key stresses related to climate change, such as fungal infection and temperature induced late-season drought may be interacting in novel ways with these known factors. I performed controlled greenhouse experiments to test the strength of the interacting stressors, including drought and temperature stress. In addition, I investigated connections between the onset of the decline and landscape scale climate drivers, such as drought or increased/decreased maximum or minimum ambient temperatures and biological factors, such as elk and moose population estimates. I explored these linkages using the population age structure of live and dead stems to examine short spatial and temporal scale, and GIS and aerial photos to examine longer scales. Results will inform RMNP managers on the timing and causes of this decline and should form the foundation for riparian recovery and restoration efforts within RMNP and possibly throughout the West.

Research Approach:

My research had two primary objectives. First, I determined the temporal scale of the current willow decline (*Objective 1*). Using willow stem chronologies, I determined when the decline began and analyzed correlations with climate driven variables, such as annual precipitation and growing season minimum and maximum temperatures, as well as biological variables, such as elk and moose population numbers. Second, I examined the strengths of the interacting stressors contributing to the decline using a split split plot manipulative experiment. I included both warming and ambient temperature treatments, high and low water, and fungal infection (*Objective 2*). The methods used for objective 1 were not significantly different than methods in my original proposal. I did, however, drop the bi-weekly measurements of long term ground water monitoring wells due to time constraints. I minimally altered methods for objective 2. I inoculated willow stems with two isolates of *Cytospora chrysosperma*, collected from Endo Valley in RMNP. Instead of collecting data on plant xylem pressures, I measured the volumetric water content of the soils using a TDR probe. I measured pre-treatment and post-treatment aboveground primary production and dried and weighed roots for an estimate of belowground production. In addition, I measured photosynthetic capacity and stomatal conductance at two sampling periods (mid July and early August) using a LiCor 6400XT. Temperatures were recorded every hour in each treatment (n=6) using Hobo H8 units (Campbell Scientific). See photos of the warming shelters at the end of this report.

Location(s) of Research:
Rocky Mountain National Park

Key Findings:

Objective 1: Temporal scale of the willow decline

Aerial Photo Analysis

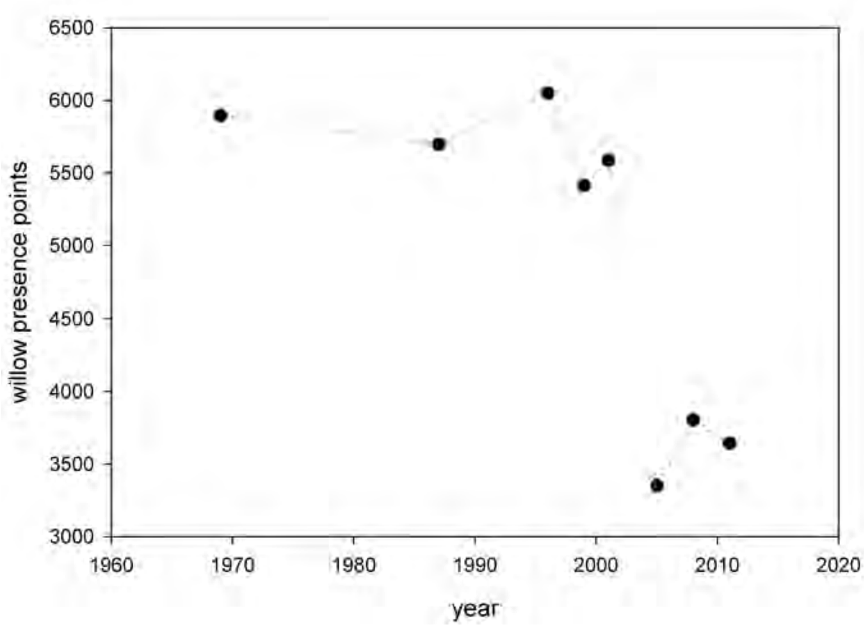


Figure 3: Willow presence points through time at the headwaters of the Colorado River in Rocky Mountain National Park. Points were randomly generated for the entire study area and sampled for each aerial photo year.

I analyzed aerial imagery for eight years 1969, 1987, 1996, 1999, 2001, 2005, 2008 and 2011. Willow cover in the Kawuneeche Valley was relatively constant between 1969 and 2001 but decreased by an average of 40% between 2001 and 2005. Bayesian Poisson regression models with a change point performed better than models not including a change point. Change points occurred between 2001 and 2005 for all models. The best model included the number of moose hunting tags issued for the region adjacent to the study area in RMNP and annual total snow accumulation and 95% of the weight of evidence favored this model over all other candidate models. As moose hunting tags increased, holding snow depth constant, the presence of willows decreased and as snow depth increased, holding moose hunting tags constant, willow presence increased. The number of moose hunting tags issued in a given year, an indicator of moose abundance, was a stronger parameter than snow depth.

Epicormic shoot analysis -- finer scale examination of the decline

Sixty nine percent of epicormic shoots sampled had initiated between 2002 and 2005. This indicates disturbance to the stem that influenced the apical meristem allowing lateral buds to expand. The timing coincided with the sharp decline in willow cover in the valley measured using aerial photographs (Figure 1). Since 2005 a decrease occurred in the number of epicormic shoots initiated because all formerly tall willow stems in the study area have died back. Thus, epicormic shoot formation is no longer possible on most willow plants in the study area. Three models were used to describe the initiation of epicormic shoots. In all models, as the length of the growing season increased, the number of epicormic shoots increased, when holding other variables constant. GDD was the strongest variable in all models. The second variable in the model was either current year elk numbers, current year moose hunting tags, or previous year elk numbers. Elk population numbers had a negative effect on epicormic shoot initiation. As elk numbers increased in the current year or previous year, the number of epicormic shoots decreased, holding GDD constant. Moose hunting tags had a positive effect. As hunting tags increased, indicating more moose, the number of epicormic shoots increased.

Objective 1 conclusion: Biotic factors, such as ungulate browsing, rather than historic and current climatic factors, explained more of the short and long term dynamics of the willow dieback in the Colorado River headwaters.

Objective 2: Manipulative greenhouse experiment simulating climate change effects

The warming shelters averaged approximately 2° warmer than the ambient temperature treatments (Figure 2; Photo 2).

Belowground production was significantly lower in the ambient temperature treatment ($p = 0.012$; effect size (ES) = 0.065) (Table 1). Belowground production was not significantly different between drought and watered treatments ($p = 0.313$). The interaction was not significant.

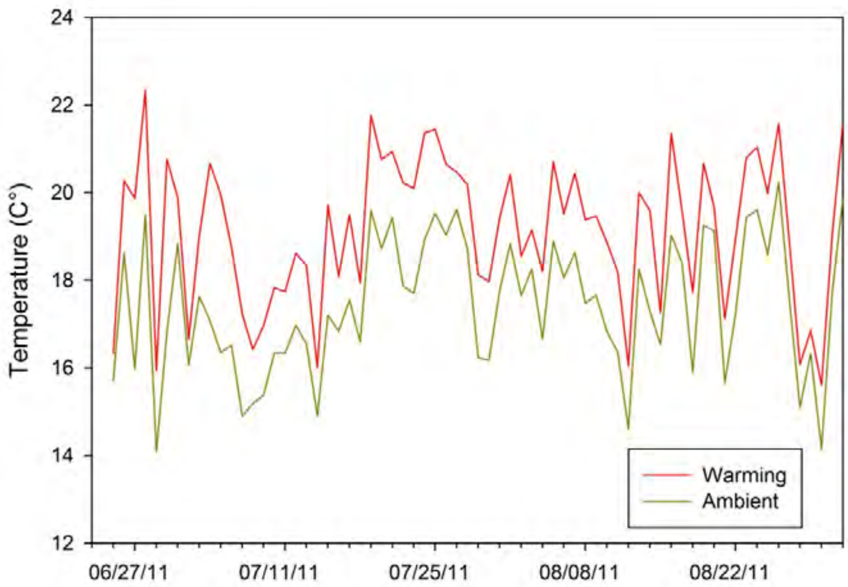


Figure 4: Daily averages of treatment temperatures between warming and ambient. Warming treatment averaged 2° C higher than ambient.

Table 1: Treatment means for plant response variables. AG diff is the difference between post treatment and pre treatment production.

	AG diff (g)	BG (g)	Photo (Aug)	Cond (Aug)	Canker length (mm)
Ambient + drought	-0.69	25.71	7.04	0.09	50
Ambient + water	-1.17	31.14	8.19	0.13	47
Warming + drought	-0.39	35.59	8.07	0.10	57
Warming + water	-1.53	35.31	8.59	0.14	49

There was a greater difference in pre and post treatment aboveground production in the watered treatment ($p = 0.0383$; ES = 0.045) (Table 1). However, this change was not significantly different between warming and ambient temperatures ($p = 0.565$). The interaction was not significant.

Photosynthetic capacity, or the amount of carbon fixed during photosynthesis, did not differ between plants in the warmed and ambient treatments ($p = 0.252$) or between plants in the drought or watered treatments ($p = 0.214$) during the sampling period in August (Table 1). Stomatal conductance was significantly lower in the drought treatment ($p = 0.0031$; ES = 0.0896), but did not differ in the temperature treatments ($p = 0.768$).

Cankers due to *C. chrysosperma* averaged 45 mm and 57 mm on wound one and wound 2 and were significantly greater than control wound sizes, which averaged 11 mm (wound 1 vs. control: $p < 0.000$; wound 2 vs. control: $p < 0.000$). There were no significant differences in canker lengths between the two isolates ($t = 0.266$, $p = 0.791$) therefore, the isolate effects were combined. There was no significant difference between canker lengths in warming and ambient ($p = 0.594$), drought and watered ($p = 0.346$) or the interaction of temperature and water ($p = 0.72$).

Objective 2 conclusion: Below ground root production was controlled by temperature, whereas aboveground leaf production was controlled by water availability. Cytospora canker growth occurred under all treatments.

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.

- Oral presentation at RMNP interpretive staff training (June 16, 2011)
- Science behind the Scenery presentation at RMNP (July 12, 2011)
- Forest and Rangeland Stewardship Departmental Seminar (October 26, 2012)
- Oral presentation at the Society of Wetland Scientists Rocky Mountain Region December meeting (December 7, 2011)
- Oral presentation at Front Range Student Ecology Symposium (Feb 22, 2012)
- Presentation/poster at biennial RMNP research conference (March 6, 2012)
- Guest speaker for National Science Foundation funded GLOBE teacher workshop, field trip to RMNP (July 8, 2012)
- Science behind the Scenery presentation at RMNP (July 10, 2012)
- Oral presentation at Ecological Society of America annual conference (August 9, 2012)
- Spatial and temporal dynamics of willow decline in the northern Colorado Rocky Mountain region. Manuscript in prep
- The role of potential future climate change on willow dieback. Manuscript in prep

Additional Funding:
No.

Other:

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

I received the 2012 Rocky Mountains Cooperative Ecosystems Studies Unit student award for my research on willow decline in RMNP (nominated by resource managers at RMNP).

- 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.

When my advisor and I were first starting to piece together the story of the willow dieback we discovered that sapsuckers [woodpeckers] were playing a large role. Sapsuckers create holes, or sapwells, in willow stems to access highly nutritious sap during their breeding season. Many stems that had evidence of old sap wells were also dead above the sap well, due to a Cytospora fungal infection. We decided to investigate if the sapsuckers were a possible vector for the fungus, so we caught individual birds, swabbed their beaks and their feet, and cultured the swabs in the lab. We were able to positively identify Cytospora (through DNA analyses) on 1/3 of the birds we caught.

Photographs:

Figure 5: Measuring stomatal conductance and photosynthetic capacity using LiCor 6400XT.

Figure 6: One replication of paired experimental treatments: Ambient temperature in front, warming shelter in plastic sheeting, behind

Figure 7: *Cytospora chrysosperma* infection on an inoculated stem

Figure 8: Venting window on warming shelter to prevent overheating

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Lydia Kapsenberg
Affiliation: University of California Santa Barbara
Start date: August 1, 2011
Projected end date: July 30, 2012

Brief project summary:
Ocean acidification (OA), the decline in surface seawater pH as a direct result of anthropogenic CO_2 dissolving into surface oceans, is expected to affect many marine species, especially calcifying organisms. The result of these biological impacts will likely alter community structure of key marine ecosystems. The Channel Islands National Park (CINP) spans a temperature gradient associated with the California Current Large Marine Ecosystem seasonal upwelling, however, there are no data regarding the local near-shore carbonate chemistry. The objectives of this project were two-fold: (1) To deploy two autonomous pH SeaFET sensors to characterize near-shore pH in the CINP and (2) to conduct laboratory based experiments testing fertilization of two sea urchin species (*Strongylocentrotus purpuratus* and *S. franciscanus)* from two locations spanning an upwelling gradient in the CINP. The environmental and biological data can be used to assess the potential for species' tolerance to the changing marine environment. This project will advance CINP resource management by initiating a pH monitoring program within the Park's waters and by documenting near-shore carbon chemistry for the first time as well as advancing the understanding of the effects of OA on local marine organisms.

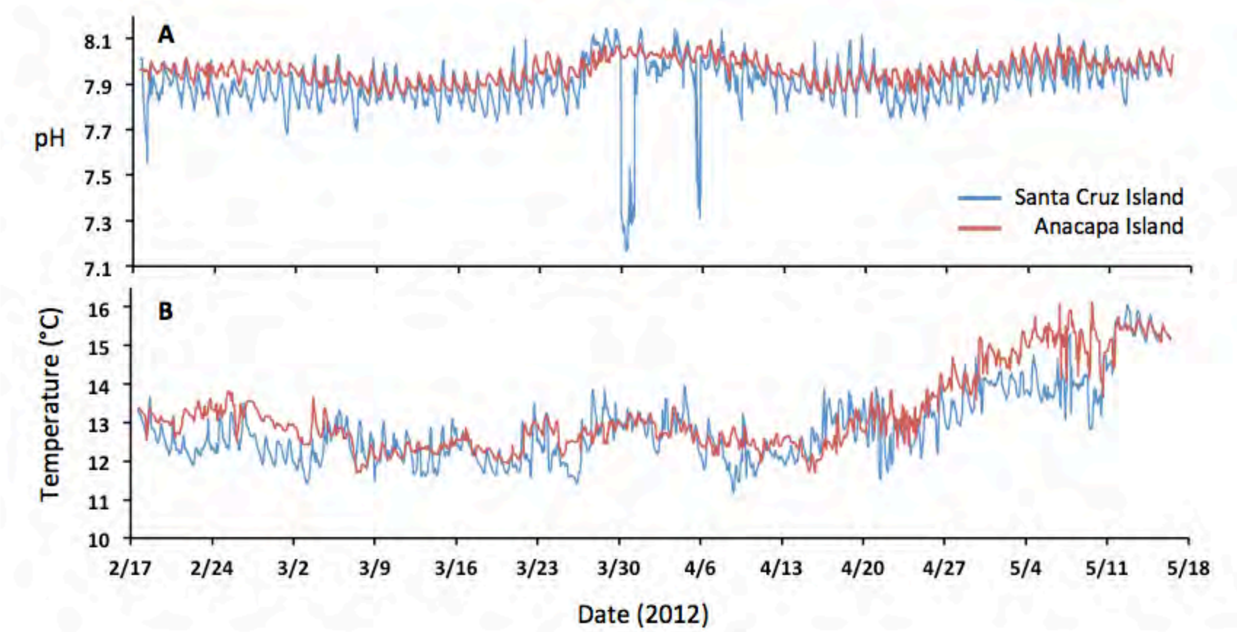
Research Approach:
Due to the complexity of the fertilization experiments, I was only able to conduct one set of fertilization experiments during the middle of the sea urchin spawning season (February – March). Furthermore, I added temperature in addition to CO_2 as an experimental variable.

Locations of Research:
Channel Islands National Park -Anacapa Island: Landing cove
-Santa Cruz Island: Prisoner's Harbor

Key Findings:

1) SeaFET data showed that pH was different between the two island sites. During a three month period, Anacapa Island (ANI) pH ranged from 7.83-8.09 and Santa Cruz Island (SCI) pH ranged from 7.55-8.15 (excluding the two large drops in pH during the middle of the deployment), and average pH was similar (7.96 and 7.91, respectively). Overall, SCI exhibited larger diurnal pH variation then ANI (Fig 1). The diurnal fluctuation is likely due to photosynthesis and respiration of the marine organisms in the vicinity of the sensor. The difference in overall pH range between ANI and SCI may be due to the topographic and oceanographic properties associated with each site.

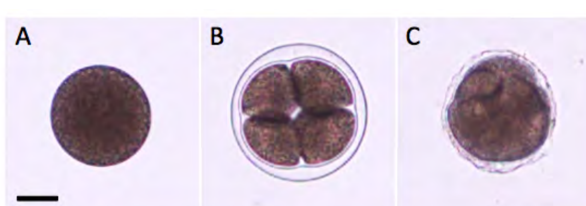
Fig. 1 pH (A) and temperature (B) recorded by SeaFETs over a 3-month observation period at two Santa Cruz Island and Anacapa Island. The large drop in pH at Santa Cruz Island is unusual and may be explained by a change in the microclimate surrounding the sensor (for example, an organisms covering the sensor).



Site	Average pH	pH range	T (°C)
Anacapa Island	7.96 ± 0.05	7.83 – 8.09	13.2 ± 1.0
Santa Cruz Island	7.91 ± 0.08	7.55 – 8.15	12.9 ± 0.9

2) Sea urchin fertilization appears to be robust at low pH (7.6) and high temperature (18°C). Sea urchins are benthic marine invertebrate that reproduce by releasing sperm and eggs into the water column. Fertilization occurs in the water column and is directly exposed to seawater conditions. My aim was to assess how sensitive fertilization is to reduced pH and increased temperature. We collected two sea urchin species (*Strongylocentrotus purpuratus* and *S. franciscanus*), from two sites (ANI, SCI) near SeaFET sensors. Adults were maintained in flow-through sea tables at the University of California Santa Barbara until spawning. Fertilization was assessed using 3 individual male x female pairs per species and site, across a range of sperm dilutions, in four treatments: pH 8.0 x 14°C (control), pH 7.6 x 14°C, pH 8.0 x 18°C, and pH 7.6 x 18°C. Approximately 2-3 hours after sperm and egg contact, fertilization was scored based on the presence of a fertilization membrane (Fig. 2). Abnormal membranes were noted.

Fig. 2 Sea urchin eggs and embryos. (A) unfertilized egg, (B) fertilized egg with 2 divisions, (C) fertilized egg with abnormal fertilization membrane and incomplete division. Species is *S. purpuratus*, scale bar = 50μm.



Fertilization success was high in all treatments (Fig. 3). There was no clear pattern of significant impacts of pH and/or temperature on sea urchin fertilization. Fertilization curves of "percent fertilized" (Fig. 3) and "percent abnormal fertilization" (Fig. 4) looked similar across both sea urchin species (panels A,B compared to C,D) and populations (panels A,C compared to B,D).

Fig. 3 Fertilization success for *S. purpuratus* (A,B) and *S. franciscanus* (C,D) of populations from Anacapa Island (A,C) and Santa Cruz Island (B,D) at pH 8.0 (blue circles) and 7.6 (red squares) at 14°C (solid symbol) and 18°C (open symbol). 200 counts; n=3; *significant.

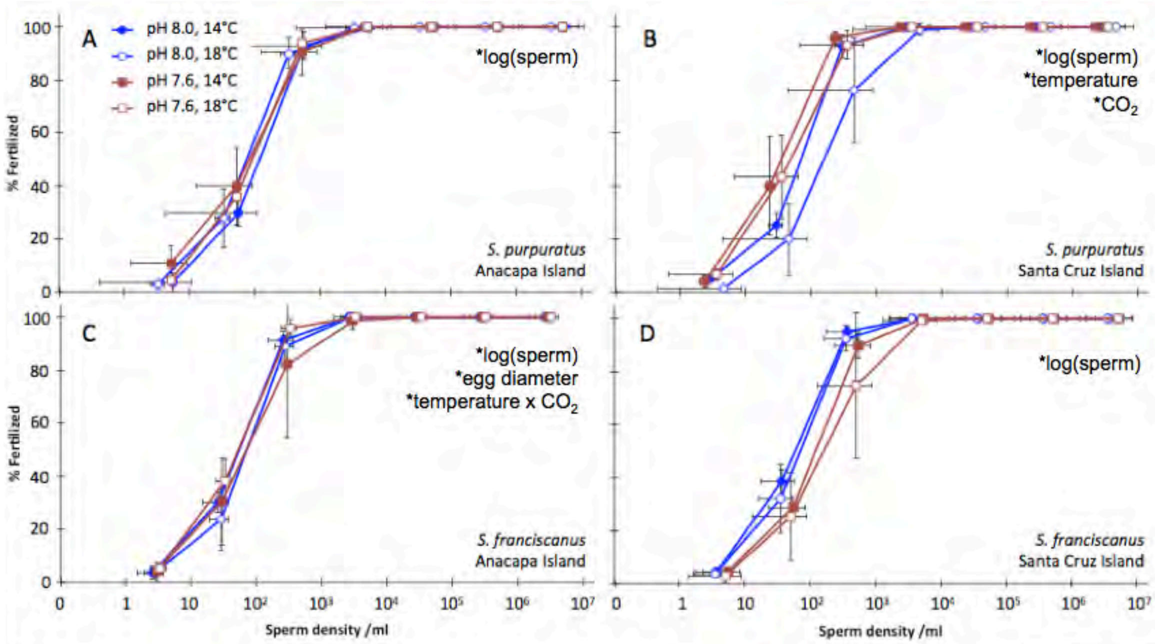
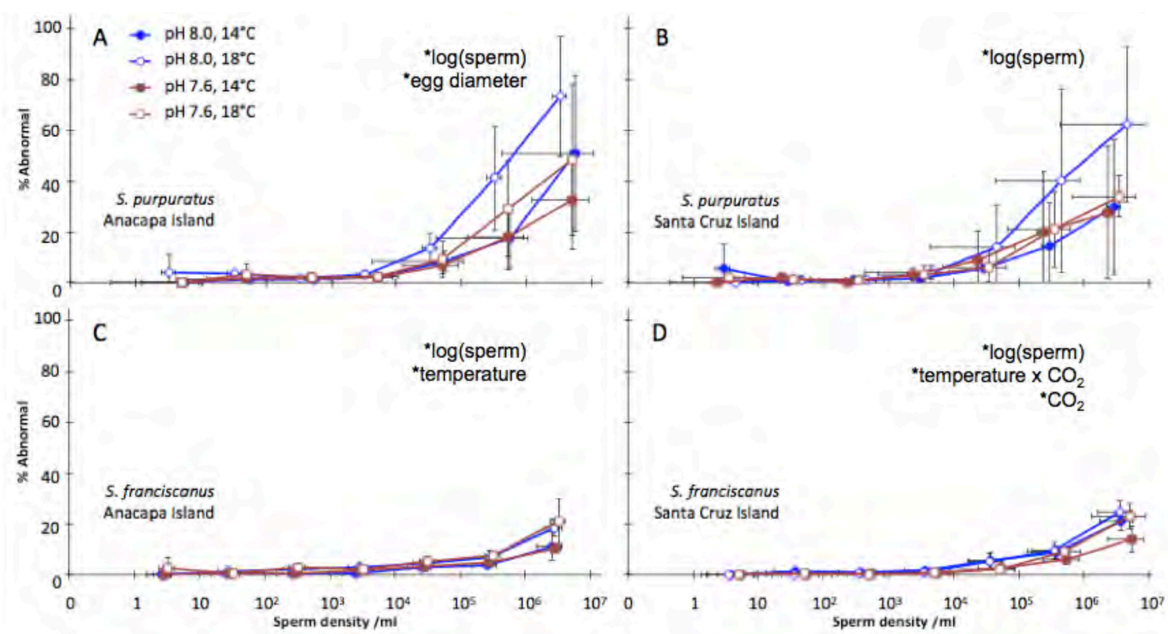


Fig. 4 Percent abnormal fertilized eggs of total fertilized eggs for *S. purpuratus* (A,B) and *S. franciscanus* (C,D) of populations from Anacapa Island (A,C) and Santa Cruz Island (B,D) at pH 8.0 (blue circles) and 7.6 (red squares) at 14°C (solid symbol) and 18°C (open symbol). 200 counts; n=3; *significant.



Deliverables/Research Products:

- Publicly available pH data through Santa Barbara Coastal Long Term Ecological Research, http://sbc.lternet.edu/, (in progress).
- Informational webpage on ocean acidification for the Park website/visitors center, at discretion of Park managers (TBA).
- Oral presentation for the final report at the Channel Islands National Park Service office for Park managers and employees. Ventura CA (July 30, 2012).
- Oral presentation at the National Park Service 'Climate Change in America's National Parks: Climate Change Research from the Next Generation' webinar, recording available upon request (June 14, 2012).
- Poster presentation at the California Islands Symposium, Ventura CA, October 23-26, 2012 (attached separately), see abstract below.

OCEAN ACIDIFICATION: ASSESSMENT OF pH IN THE CHANNEL ISLANDS NATIONAL PARK AND ITS EFFECT ON SEA URCHIN FERTILIZATION

*Lydia Kapsenberg** and *Gretchen E. Hofmann*
Department of Ecology, Evolution and Marine Biology, University of California Santa Barbara, Santa Barbara, CA 93106 lydia.kapsenberg@lifesci.ucsb.edu

Ocean acidification, the decline of seawater pH as a direct result of anthropogenic CO_2 dissolving into surface oceans, is expected to affect the marine ecosystem of the Channel Islands National Park. The objectives of this project were two-fold: (1) to deploy two autonomous pH sensors to characterize near-shore pH at Anacapa Island and Santa Cruz Island and, using pH sensor data, (2) to conduct laboratory based experiments testing fertilization of two sea urchin species (*Strongylocentrotus purpuratus*) and (*S. franciscanus)* at two pH levels (8.0, 7.6) and temperatures (14, 18 °C) from both sites. Here we present the first record of a pH time series in this National Park in order to establish baseline pH levels in the face of future ocean acidification. Over a three-month deployment period, pH ranged from 7.83-8.09 and 7.55 to 8.15 at Anacapa Island and Santa Cruz Island, respectively. Additionally, there was no clear trend of an effect of pH and temperature on the fertilization success. Both species exhibited high fertilization success in all experimental treatments. Although the Channel Islands marine ecosystem already experiences low levels of pH, it appears that sea urchin fertilization is robust to current and future levels of ocean acidification.

Additional Funding:
I have submitted a proposal for the 2013 Student Equipment Loan Program' by Sea-Bird Electronics, Inc. and WET Labs, Inc. to gain access to more oceanographic instruments to better characterize the near-shore carbonate system in the Channel Islands National Park. The proposal requests two SBE 37-SMP-IDO MicroCAT (conductivity, temperature, dissolved oxygen) to be deployed alongside the SeaFETs.

Other:
I really enjoy working with the Channel Islands National Park Service. The staff is very supportive and helpful, and along with volunteers, they are always very interested in the contraptions I bring on board the boat in order to collect water samples. Due to the success

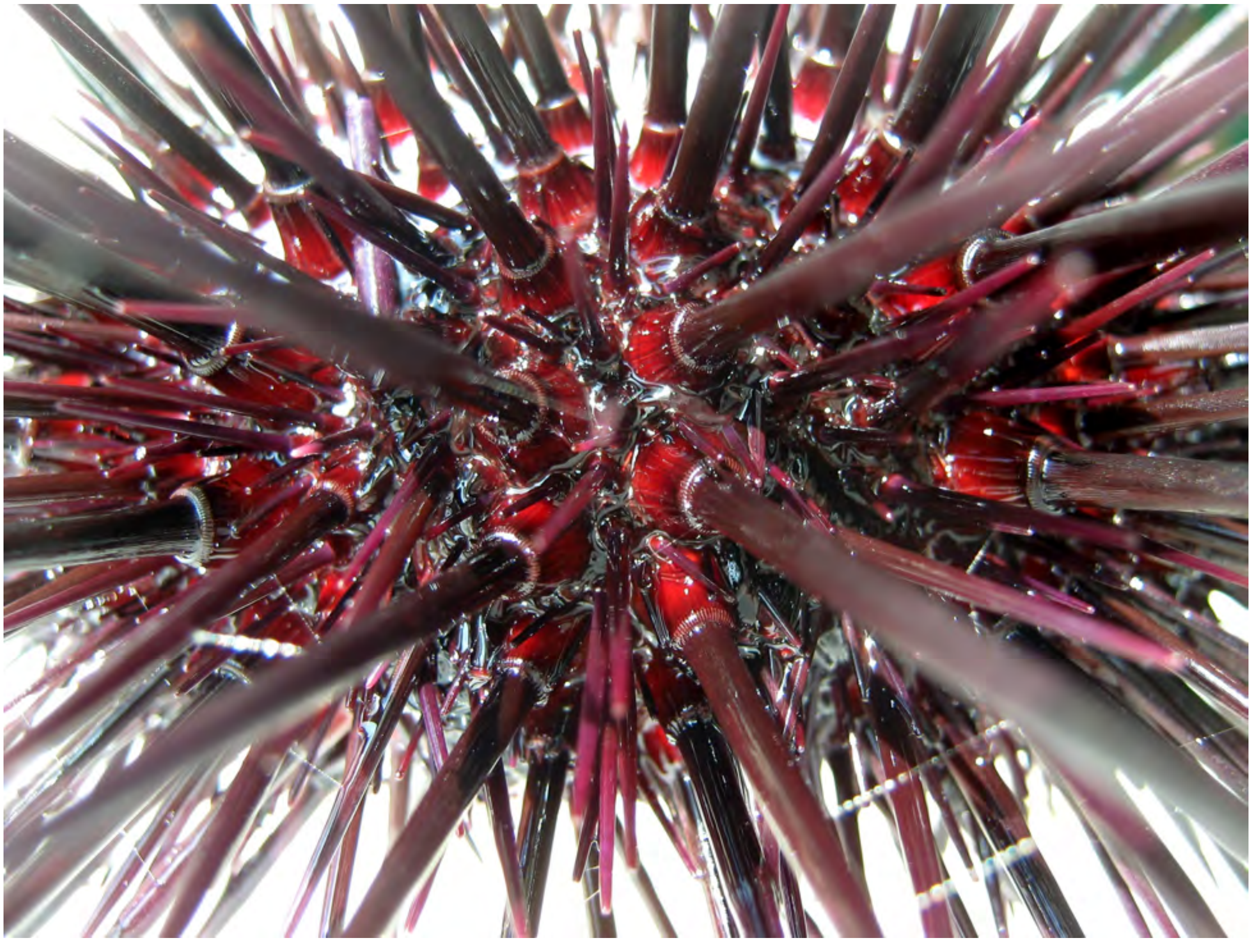
of the project and the Park's interest in ocean acidification research, I will continue to partner with the Channel Islands National Park Service and expand the pH monitoring project this fellowship has funded. The SeaFETs are currently on their 3rd deployment.

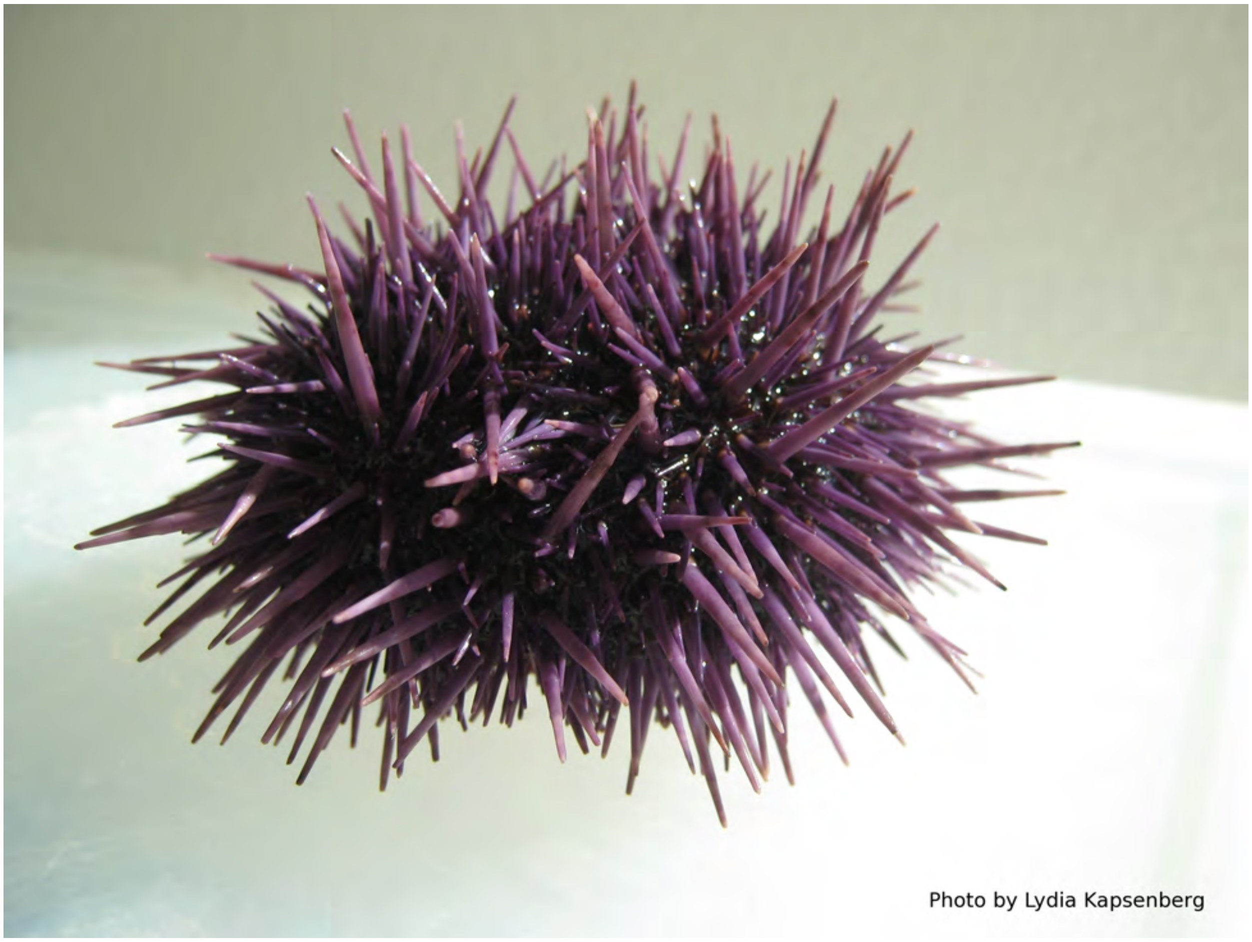
Photographs:

Lydia Kapsenberg deploying the SeaFET pH sensor at Anacapa Island (photo by David Kushner).

Lydia Kapsenberg collecting a seawater sample using a Niskin bottle, at Santa Cruz Island. These seawater samples are used to calibrate the SeaFET pH sensor (photo by Calla Martyn).

Lydia Kapsenberg collecting eggs and sperm from the Red Sea Urchin, *Strongylocentrotus franciscanus* (photo by Brian Rivest).


Red Sea Urchin, *Strongylocentrotus franciscanus* (photo by Lydia Kapsenberg)



Purple Sea Urchin, *Strongylocentrotus purpuratus* (photo by Lydia Kapsenberg)

2011 NPS George M. Wright Climate Change Youth Initiative

Fellowship Research Final Report
December 31, 2012

Fellow Name: Caitlin McDonough
University: Boston University
Start date: May 2011
End date: August 2011

Brief project summary:
Climate change threatens natural communities across the globe. National Park managers must be able to monitor the ecological effects of climate change in order to protect the ecological integrity of some of the country's most iconic and biologically significant places. Phenological monitoring — monitoring the timing of biological events, such as flowering — has been embraced as a useful, accessible, and effective method for tracking the ecological effects of climate change. Warmer temperatures causing shifting plant phenology can lead to disruptions in community interactions, losses of species, increases in invasives, and changes in ecosystem functions. However, new phenological monitoring programs lack the long-term data to uncover trends in flowering over long time periods. Without a historical context, monitoring programs do not have the ability to compare current flowering times to the historical norm.

Acadia, the oldest National Park east of the Mississippi, contains arguably one of the richest collections of natural history observations made at a single location in the United States. The Park's Herbarium collection, housed at the College of the Atlantic, contains over five thousand plant specimens collected within Acadia's boundaries and some that pre-date the Park by thirty years. In the late 19th century a group of natural history enthusiasts and Harvard students formed the Champlain Society with a mission to explore nature on Mount Desert Island. The Mount Desert Island Historical Society now holds the Champlain Society's records of fieldwork and photographs from their summers in the park. There is also a weather station in the park with daily temperature and precipitation records dating back to 1895.

These resources, held on Mount Desert Island, were hidden in archives and herbarium cabinets, and have been minimally used by ecologists to date. This project took advantage of the wealth of natural history records to examine long-term changes in the plant communities on Mount Desert Island. I digitized the entire collection of herbarium specimens from Acadia at College of the Atlantic and made them publicly available through the Park's IRMA database. I used the 1894 *Flora of Mount Desert Island*, co-authored by an original member of the Champlain Society, as a record of historical species abundance for over seven hundred wildflowers. These historical abundances were compared to abundance descriptions compiled for the recently published "Vascular Flora of the Acadia National Park Region, ME." By providing a historical context for today's phenology monitoring, this study will inform management decisions and enhance park efforts to communicate with the public about climate change.

Research Approach:
While the original question centered on flowering phenology, the available historical data led me to focus on changes in the plant communities on Mount Desert Island. The 1894 *Flora of Mount Desert Island* provided historical abundance descriptions for over 700 species of wildflowers, while the authors of the 2005 "Vascular Flora of the Acadia National Parks Region, ME" and 2010 *Plants of Acadia National Park* generously provided me with their abundance records for Mount Desert Island today. A species-by-species comparison analyzed changes in abundance over the past one hundred and seventeen years. I also looked for trends in plant families, habitats, habits, non-native, and invasive species. Additionally, I compiled a dataset for the almost three hundred wildflower species that are found both on Mount Desert Island and in the extensively-historically-studied flora of Concord, MA. While trends in historical flowering phenology have not yet been analyzed, in pursuit of this type of data I digitized the entire collection of Acadia National Park herbarium specimens held at College of the Atlantic.

Location(s) of Research: Acadia National Park, Maine

Key Findings:
The flora of Acadia National Park is not a static collection of species. Since the late nineteenth century, Mount Desert Island has lost 18.5% of the flora catalogued by the authors of *Flora of Mount Desert Island.* Another 29.3% of the species have declined in abundance since that time. There has been an increase in the proportion of the flora that is non-native, and twenty-six invasive species have appeared. However, these trends do not seem to be linked to changes in the landscape; when divided into habitat categories, I found no significant relationship between habitat type and species loss. All of Acadia's habitats seem to be shedding species at an unexpected rate for such a protected landscape. Future research into the link between phenology, climate change, and species loss in plant communities on Mount Desert Island is a pressing need. Any climate change vulnerability assessment in this park must consider these factors.

Deliverables/Research Products: (Please list.)

Changes in the Flora of Acadia National Park, presented both at the Schoodic Education and Research Center for the Josslyn Botanical Society and at Acadia National Park Headquarters for the Resource Management team (July 2011)

120 years of changes in flora and flowering in Acadia National Park, presented as a part of the NPS Climate Change in the National Parks webinar series (June 2012)

Climate Change in Acadia National Park and Beyond: Long-term Trends in Flowering Phenology and Floral Abundance, Poster Presentation at Ecological Society of America Annual Meeting (August 2012)

Phenology & Plant Communities in a Changing New England: Acadia National Park, ME & Thoreau's Concord, MA, presented at Phenology 2012 Meeting in Milwaukee, WI (September 2012)

Additional Funding:
I received a travel scholarship from the Phenology 2012 Meeting to fly to Milwaukee and present my research, which included work completed during my GMWCCFP Fellowship in an oral session.

Other:
I ended up immersing myself in the notebooks of the Champlain Society. Initially, reading through century-old logbooks began as an effort to understand their methods, but it became an epic adventure story and a fascinating study. I wrote about my historical ecology research, and my affinity for the Champlain Society boys, in a guest post on the Smithsonian's Field Book Project blog. The post can be found here:
http://nmnh.typepad.com/fieldbooks/2012/07/the-boys-of-summer.html

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.*


TO THE MEMORY OF
EDWARD LOTHROP RAND
1859 — 1924
IN GRATEFUL RECOGNITION OF
HIS PIONEER SERVICE AND LABOR OF LOVE
IN MAKING KNOWN
THE FLORA OF MOUNT DESERT
AND COMPILING MAPS OF
ITS WOODLAND AND MOUNTAIN PATHS

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Lauren E. Oakes
University: Stanford University
Start date: June 2011
End date: June 2015

Project summary:

Extending north from British Columbia through Southeast Alaska's Alexander Archipelago, yellow-cedar (*Callitropsis nootkatensis*), a species of high cultural, economic, and ecologic value, has been dying off since the late 1800's, with increasing rates observed in the latter part of the 20th century. Recent studies implicate factors related to climate change as key drivers in this species mortality. In the Tongass National Forest, yellow-cedar mortality covers nearly 500,000 acres, with little understanding of succession in the forest community. Glacier Bay National Park & Preserve (GLBA) sits at the northernmost boundary of this forest ecosystem and protects intact cedar stands at the current latitudinal limit of mortality. Standing at the interface of ecology, land change science, and resource management, my research addresses ***what happens next*** in the dying yellow-cedar forests from a social-ecological perspective. Central questions include the following: 1) In response to yellow-cedar decline, what is the process of forest development, and 2) What is the social response to yellow-cedar decline?

By establishing sites across yellow-cedar forests that died at various time intervals (1900's to present) and comparing changes in stand dynamics to live forests, this research advances understanding of changes in the forest community, extending south from Glacier Bay National Park. By design, it also provides an assessment of presence/absence and the current status of yellow-cedar populations within the National Park boundaries. Increasing knowledge of how the forest structure responds to yellow-cedar decline may ultimately provide insight into possible future changes within park boundaries and help broaden understanding of how climate change impacts to forest populations pose challenges for resource managers. Semi-structured, in-depth interviews will be conducted with individuals selected to capture a range of multiple-uses, as defined by Tongass National Forest and National Park land designations (e.g. Science, Logging, Tourism, Native, Subsistence). Analysis will focus on how perceptions of yellow-cedar decline and values associated with yellow-cedar forests influence priorities for forest management and conservation. As a case study for examining social and ecological responses to a species dieback, this research thus, is an effort to understand the process of forest development in yellow-cedar forests that moves beyond pure ecology, to understanding a process of ecological change in the context of local use patterns and valued services. Research will contribute to the regional and national needs to advance understanding of how resource managers and policymakers address long-term changes in population dynamics associated with climate change on state and national lands.

Research Approach:
Please describe any significant changes to the original questions, hypotheses, or approach you used in your research.
There are no significant changes to my research plan, but since the time of application, I have further developed the social aspect of my research. Additionally, due to data availability and time restraints regarding the scope of my work, it is unlikely I will be able to test the results of my analysis of my chronosequence (space for time) data with historic USDA Forest Service inventory data (time for time). Given interest from the National Park, I am working to develop a partnership with another researcher who may add an aspect of future scenario modeling to this research. We would work with the temperature data I collected and available climate models to consider possible future change within Park Boundaries.

My advisors have encouraged me to continue balancing the various aspects of this project together, in order to continue advancing my interdisciplinary approach as I work towards final publications and contributions.

Location(s) of Research:
Glacier Bay National Park, Alaska (Graves Harbor & Dick's Arm, Outer Coast)
West Chichago-Yakobi Wilderness, Tongass National Forest, Alaska (Slocum Arm & Klag Bay, Outer Coast)

Key Findings & Current Analysis:
Aerial, boat, and ground surveys document a south to north trend in the onset of mortality from the base of Slocum Arm, north to Klag Bay, as well as the presence of live healthy yellow-cedar forests in Glacier Bay National Park. Preliminary maps are included in Appedix A. This stratification of yellow-cedar mortality ("Old" – early 1900's, "Mid" – Middle 1900's, "Recent" – 1970's onward), as well live yellow-cedar forests in the West Chichagof Yakobi Wilderness and Glacier Bay National Park provided the sampling structure for sites established and measured to analyze succession post decline. Aerial surveys conducted with research partners from USDA Forest Health resulted in a detailed map (Appendix B) of yellow-cedar presence/absence for the National Park. Results show yellow-cedar occurrence estimated on 60,000 acres of land within Glacier Bay National Park.

Preliminary results from analysis of plot data suggest significant increases in conifer regeneration (saplings, non-cedar conifer species) in the mid time since death (TSD) strata, possibly indicating increased competition with access to light and/or nutrients post yellow-cedar decline. No yellow-cedar saplings were observed in the old strata indicating poor yellow-cedar regeneration, or survival of seedlings to sapling stage post decline. Preliminary analysis of overstory data suggests significant increases of Western hemlock *(Tsuga heterophylla)* and Mountain hemlock *(Tsuga mertensiana)* live basal/area in the old strata, indicating a possible turnover from yellow-cedar population to other conifer species. I am currently preparing sapwood area data to test for significant differences in vigor between conifer species, as a function of time since death. I intend to build life histories for each conifer species, to descriptively show the population level changes from seedling to sapling stage between my strata.

Preliminary results suggest multiple trajectories of succession based upon site productivity, indicating sites with low productivity where yellow-cedars die may be unsuitable for other conifer species. These preliminary results are currently being tested in rigorous analysis with the final data set, recently compiled from both field seasons of work. In order to explore and test possibly for variations in successional trajectories based on the productivity of these sites, I will proceed to analyzing stand dynamics in a multivariate model, controlling for key factors such as light and productivity. Initial summaries of understory data suggest an increased abudance of Vaccinium plants post decline (also relevant for wildlife species of interest such as the Sitka Black-tailed deer (*Odocoileus hemionus sitkensis)*, rufous hummingbird *(Selasphorus rufus),* and Olive-sided fly catcher *(Contopus cooperi).*

We observed increased signs of stress (flagging in live yellow-cedar trees) in some sites established in the live strata in West Chichagof sites, indicating early stages of yellow-cedar decline and a continued northerly spreading of mortality. I am currently testing for significant differences in yellow-cedar regeneration between the live sites, as well as indicators of stress, to assess the status of yellow-cedar populations within Glacier Bay National Park, as compared to those live populations just further south.

During the summer of 2012, I completed pilot interviews for the social aspect of my work. I am still in data collection for this aspect of my study with interviews planned for the Spring of 2013.

Deliverables/Research Products: 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.

Completed

- Public presentation at Glacier Bay National Park (July 2012)
- Research writing for broad public audience: *New York Times Green Blog* (June-Sept 2012) See http://green.blogs.nytimes.com/author/lauren-e-oakes/
- Project update for USDA Forest Health Protection Report. See http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5360665.pdf
- Map of yellow-cedar presence/absence in Glacier Bay National Park (Completed with leveraged funding by research partner Dustin Wittwer following 2012 aerial surveys – Appendix B)
- Visual documentation of remote forests for Glacier Bay National Park

Planned

- Summary of research findings for Glacier Bay National Park and Tongass National Forest
- Academic publication from dissertation research (3 papers by dissertation defense: 1) Ecologically focused on succession and stand dynamics in forests affected by decline; 2) regionally focused on the spread of decline and comparisons between forests in GLBA and Chicagof; 3) Socially-focused on knowledge and values of yellow-cedar forests, attitudes towards decline and priorities for management & conservation.
- Additional writing for public audience (New York Times, and/or monograph)

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.

Research in Alaska is costly and the weather window for fieldwork is a small one! I secured additional funding from a variety of sources in order to address funding needs beyond the initial support of the Wright Fellowship.

The following list details funding sources:

Gloria Barron Scholarship, The Wilderness Society
Morrison Institute for Population and Resource Studies
USDA Forest Service, Forest Health
Emmett Interdisciplinary Program in Environment and Resources
Stanford School of Earth Sciences
National Forest Foundation

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

- The project has brought together researchers from Alaska to the lower 48 and developed new partnerships with various NGO's. Given the remoteness of my work, many people have volunteered their time and services to help complete the fieldwork, and I have valued the opportunity for educational exchange in this process.
- My research has allowed for mentoring of undergraduate students at Stanford through research assistantships and provided fieldwork opportunities for local Alaskans and graduate students at other institutions. This past summer, an undergraduate student at Stanford developed her own research project to explore possible impacts on nutrient levels in understory plants, associated with yellow-cedar decline. She sampled across the chronosequence and is currently working with Stanford's Carnegie Department of Global Ecology to analyze plant samples collected.
- Outside the scope of my dissertation, my field assistant and I collect Wilderness Monitoring data for a larger initiative throughout the duration of my field seasons. In 2005, the chief of the Forest Service adopted a 10-Year Wilderness Stewardship

Challenge (WSC) to have all wilderness areas managed to standard by 2014, the 50th anniversary of the Wilderness Act. Although a part of the National Wilderness Preservation System set up by the 1964 Wilderness Act, each wilderness is set aside as a separate management unit and is considered unique by Congress. District managers recently identified the West-Chichagof Yakobi Wilderness as wilderness area with outstanding opportunity for solitude and recreation but at "high risk" for impact. Observations collected over both field seasons contribute to this Stewardship Challenge but also to contribute to a regional dataset of the current status of these lands, south of the National Park.

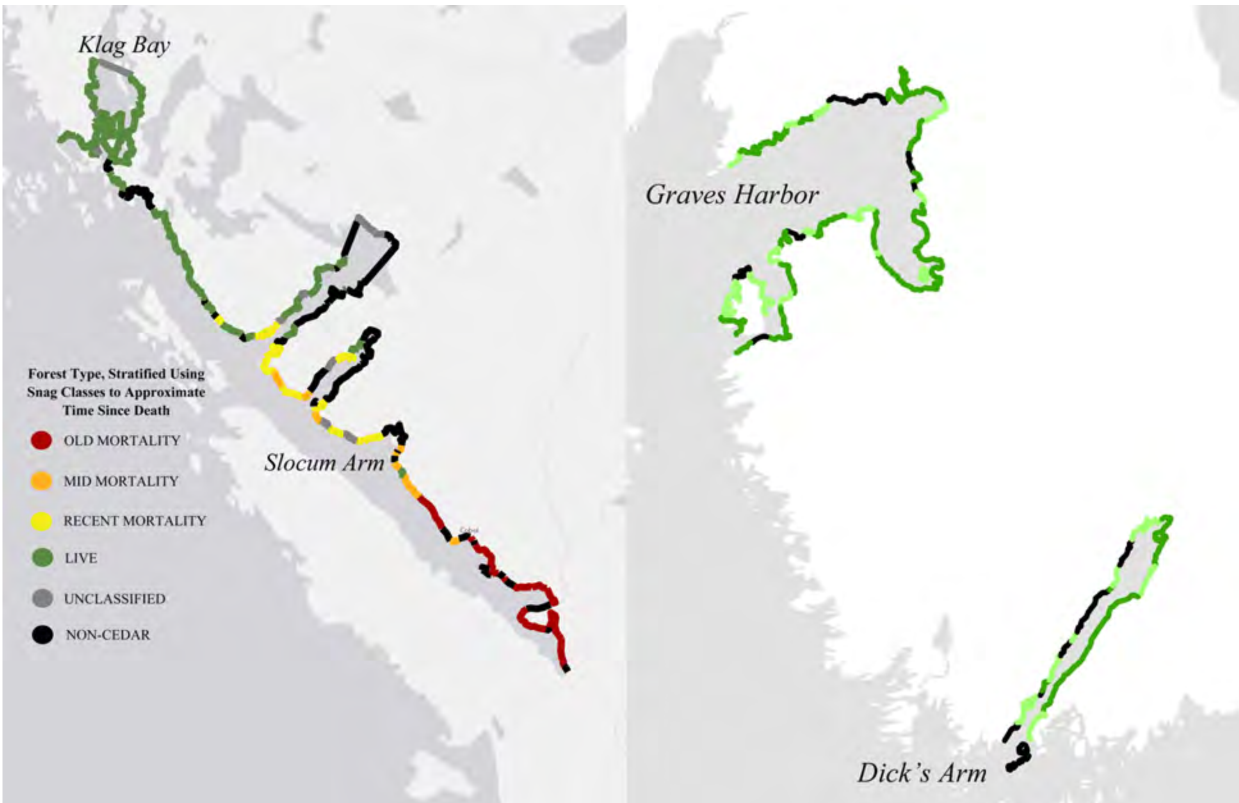
- Executive Director Gregg Treinish from Adventurers and Scientists for Conservation joined my final trip to sites for collection of temperature data. We are working to develop a plan for him to return to my sites with "citizen scientists" next year for continued Wilderness Character monitoring and collection of temperature devices.

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.*

Live - Dead

Appendix A

Preliminary Map of Mortality Spread and Live Yellow-cedar Presence In Study Area



West Chichagof-Yakobi Wilderness 2011

Glacier Bay National Park 2012

Stratification based upon observations of dead trees (using a snag class system to estimate time since death) and live trees from boat surveys conducted over two field seasons. 51 sites were established and measured across this chronosequence to study the process of forest development, in response to yellow-cedar decline.

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Krista Slemmons
University: University of Maine
Start date: June, 2011
End date: September, 2012

Brief project summary:
Evaluating the response of alpine lakes to changing glacial runoff is an imperative step toward understanding the future of lake biota and water clarity as glaciers disappear. Lakes that are glacially fed (GSF) are biologically and physically different to those that are snow fed (SF). The degree of these differences, however, is poorly understood. Predicting the fate of these communities in the future is difficult without understanding the biological fluctuations in structure and function of these lakes in the past.

The goal of this research was to investigate the impacts of glacial recession and cessation on lake ecosystems. Given that algal groups provide fundamental clues regarding lake productivity and water clarity, analysis of these metrics provides valuable information regarding the influence of glacial melting. The impacts of glacial nutrients on phytoplankton have far reaching consequences for fish and wildlife populations reliant on these essential primary producers. In order to assess impacts of glacial recession temporally, diatoms were examined from sediment cores of GSF and SF lakes within Glacier National Park. It was expected that there would be differences in primary producers through time as the result of changing glacial volumes. Changes in the base of the food web will have significant impacts on lake productivity and water clarity and furthermore will have profound effects on the ecosystems services that these lakes provide including alterations in lake aesthetics and habitat for endangered fish. These results will better inform park management of predicted changes influencing water clarity and lake productivity and ultimately influence the success of invasive fish species once glaciers ultimately disappear.

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

- Due to difficulties in extracting cores from Lake Ellen Wilson and Upper Two Medicine Lake, the number of lakes proposed in the original research approach was changed from six to four.
- Additional GIS analysis on historical aerial photos and ecological modeling of changes in lake habitat as they relate to glacial recession (as noted in Research Objective II and III) will be conducted and included as a component of the manuscript submitted to Journal of Paleolimnology but as of yet are not included in this report.

Location(s) of Research: Glacier National Park, Montana

Key Findings:
The objective of this research was to investigate the influence of glacial meltwater on lake ecosystems and phytoplankton communities and to predict the ecological consequences of a depletion of nitrogen rich glacial meltwater in the future. Complete reduction in glacial runoff may lead to a regime shift in the overall ecology of these systems. This research explored changes within the lakes of Glacier National Park (GNP), a high-profile ecosystem affected by climate change and predicted to lose its namesake glaciers in the next two decades.

Glaciers have been shown to be a source of nitrogen for alpine lake ecosystems. As a consequence, the structure and function of aquatic communities may be altered by the presence, reduction or elimination of glacial meltwater in a variety of ways. By analyzing algal functional groups (via algal pigment analysis), diatom community assemblages, and diatom species richness, this study aimed to relate changes in these metrics to changes in glacial systems over the last 150 years. Algal functional groups provide fundamental clues on the function of lakes in terms of lake productivity and water clarity. Analysis of these metrics provided an indication of the degree of glacial influence in the past and may be useful in predicting the consequences of glacial loss into the future. This study focused on the following research question:

Research Question
How have changes in glacial input influenced the biotic and abiotic response of lake ecosystems throughout the last 150 years in terms of:

Q1: lake productivity?

> **H1***:* Lakes with a reduction in glacial coverage over the last 150 years will show a decrease in algal primary production due to a decline in nitrogen rich glacial meltwater.

Q2: phytoplankton assemblages?

> **H2**: Lakes receiving glacial runoff will have lower diatom diversity (in terms of species richness) due to phosphorus limitation of algal growth. Beta diversity, the rate of turnover, will be greater for lakes with glacial subsides given fluctuations in nutrient supply over the last 150 years.

Site Description
Glacier National Park (Lat: 48°41'45" Long: 113°48'25") part of the Northern Rockies and located in Northern Montana, contains in excess of 400 lakes, 200 of which are glacially fed. Currently the park has 25 glaciers, along with several ice packs no longer to be considered large enough to classify as glaciers. This 1,013,572 acre park straddling the continental divide is characterized by U shaped valleys, glacial cirques and peaks ranging from 1000-3000 meters in elevation. This region is ideal for this study given extensive but changing glacial coverage and numerous lakes. Two glacially and snowpack-fed lakes (GSF) and two snowpack-fed lakes (SF) were selected for this study (Figure 1). The glaciers feeding the GSF lakes in this study are remnant ice patches and are no longer defined as glaciers (based on the USGS criteria of glacier as having an area greater than 25 acres ($0.1 km^2$)).

METHODOLOGY (BRIEF SUMMARY)

Paleolimnological use of sediment cores can be used to illustrate long term changes or shifts in algal community structure. Preserved in sediment the silica cell walls of diatoms (Bacillariophyceae), one of the most abundant groups of phytoplankton in oligotrophic, alpine lakes, can serve as a proxy for environmental variables such as pH, nitrogen and phosphorus concentration. As a result, climatic conditions and nutrient concentrations through time may be inferred based on modern community structure and chemical parameters.

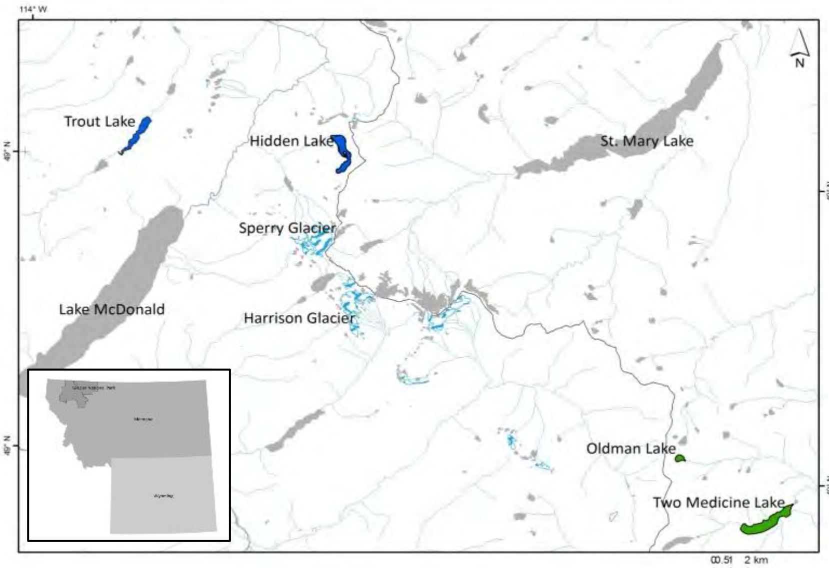


Figure 1. Location of study lakes situated in Glacier National Park of the central Rocky Mountains of North America.

Sediment cores were extracted from four lakes (two GSF and two SF), dated using ^{210}Pb dating techniques, and analyzed for percent organic carbon and algal pigments. Lakes were sampled for general limnological parameters. Diatom assemblages were enumerated and identified. These values were used to determine species richness and beta diversity (the amount of turnover within the system) over time.

KEY RESULTS

Chemical and physical parameters **–** General limnological parameters were measured in the pelagic zones of all study lakes (Table 1). Among the four lakes in this study the average nitrate concentration in the GSF (or formerly GSF lakes) was 64.5 μg L^{-1} (range= 31 - 98 μg L^{-1} NO_3^-- L^{-1}) while the average of the SF lakes was < 1 μg L^{-1}

Table 1. Physical and chemical features for the 4 lakes in this study. *Data for Oldman are from WACAP 2008. One percent attenuation depths for photosynthetically active radiation (PAR) determined from diffuse attenuation coefficient (K_d) values ($Z_{1\%} = 4.6 / K_{d\ PAR}$). Quantification limits for nitrate values were 1 μg L^{-1} and were average water-column measurements. Some metrics were not measured (indicated by na).

Lake	Type	Mixing Depth (m)	Z_{max} (m)	TP (μg L^{-1})	pH	Epi temperature (°C)	Specific conductivity (μS cm^{-1})	NO_3^--N (μg L^{-1})	$Z_{1\%}$ PAR (m)	% perennial ice & snow coverage	Watershed area (km^2)
Trout	GSF	3	20	2	8.1	18	53	98	15	0.43	41.2
Hidden	GSF	5	45	2	7.5	16	80	31	34	0.59	7.2
Two Medicine	SF	7	na	2	7.6	15	35	<1	na	0.1	69.3
Oldman	SF	na	17*	0.55*	8.2*	na	159	<1*	na	na	2.3

Paleolimnological assessment of diatom diversity and community structure
Diatom assemblages were examined from the tops (modern) cores and from the bottom of the cores. For the GSF lakes, two bottom dates were selected from approximately 1892, for direct comparison with the SF lakes, and from approximately 1852, to examine diatom assemblages during the maximum extend of the Little Ice Age. Dates from the sediment cores are provided in Table 2.

Table 2. ^{210}Pb dates of sediment cores from the four study lakes. Two different depths were selected from the bottom of the GSF cores representing ~1850 and ~1890.

Lake	Type	Bottom core depth (cm)	Date	Top richness	Bottom richness	Average bottom date
Trout	GSF	11.0-12.0	1855	27.9	42.6	1852
Hidden	GSF	4.0-4.5	1848	23	25.9	
Trout	GSF	15.0-16.0	1902	27.9	37.7	1892
Hidden	GSF	3.5-4.0	1881	23	33.4	
Two Medicine	SF	15.0-16.0	1893	35.1	28	1892
Oldman	SF	7.0-7.5	1890	27.6	30.7	

Diatom species richness was 1.2 times lower (although not significantly) in modern GSF lakes compared to modern SF lakes. Richness did not differ between core bottoms (both circa 1850 and circa 1890) compared to the past SF bottoms. Modern GSF lakes show a decline in species richness from 1850 samples although not significantly ($p = 0.09$; Figure 2).

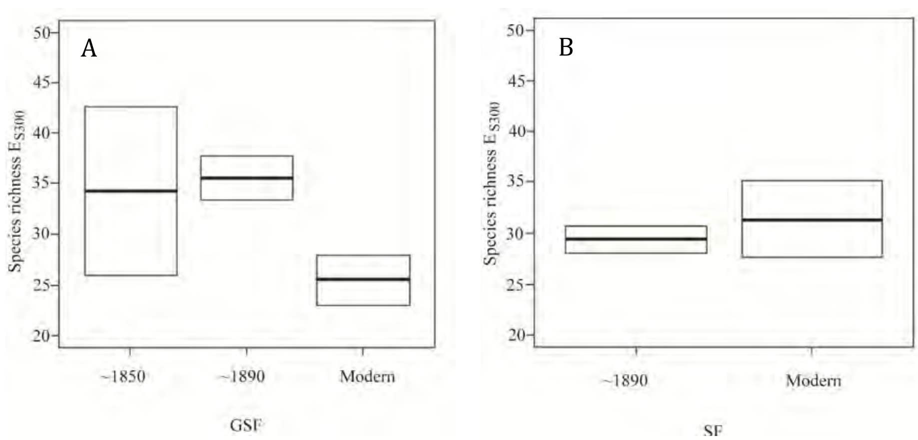
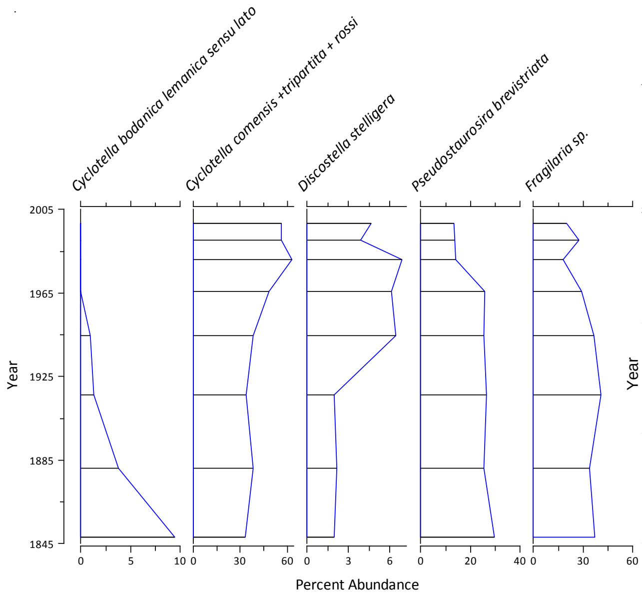
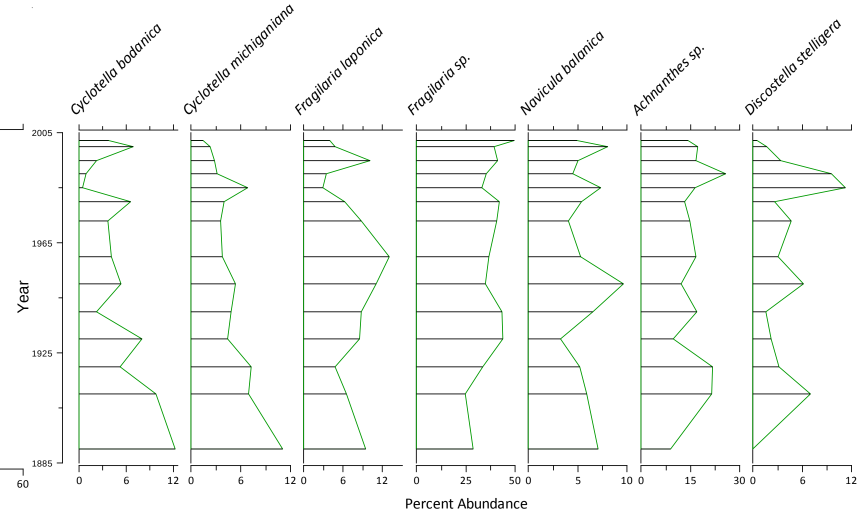


Figure 2. Taxonomic richness of sediment diatom assemblages based on rarefaction analysis (n= 300 [E_{S300}] for every sample): (A) species richness from GSF lakes including samples from 1850 and 1890 and modern assemblages; and (B) species richness SF lakes including a sample from 1890 and modern sample. Due to the inability to extract longer cores from the SF lakes, samples are limited to the1890's.

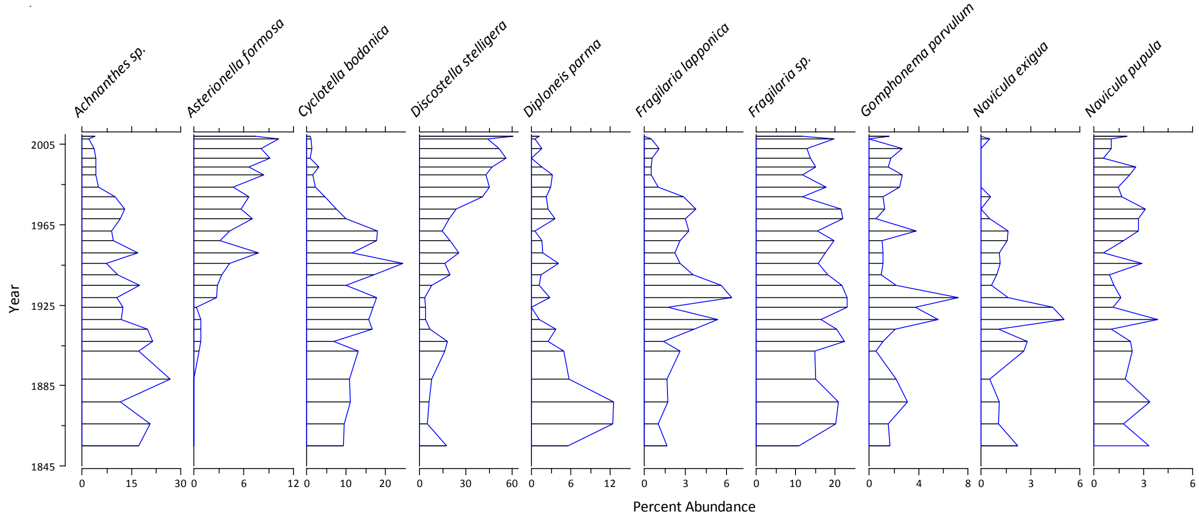
GSF lakes show distinct changes in species assemblages over the last 150 years. Both Hidden and Trout Lakes have stark increases in *Discostella stelligera* with corresponding declines in *Cyclotella bodanica* (Figure 4A, 4C); these trends are not evident in the SF lakes (Figure 4B, 4C). Both Trout (GSF) and Two Medicine (SF) show a sharp increase in the more modern samples of *Asterionella formosa,* an indicator of nitrogen enrichment (Figure 3). The average β-diversity was higher in the GSF lakes (average = 0.737, range 0.665-0.747) compared to the SF lakes (average = 0.676, range 0.431- 0.921) although this difference was not significant. The change in DCA scores from the top and bottom depths was used as a metric to illustrate the degree and trajectory of change within each individual lake. All lakes show a high degree of change in species assemblages from the bottom (~1850-1890) to the top (modern) of the cores (Figure 4).



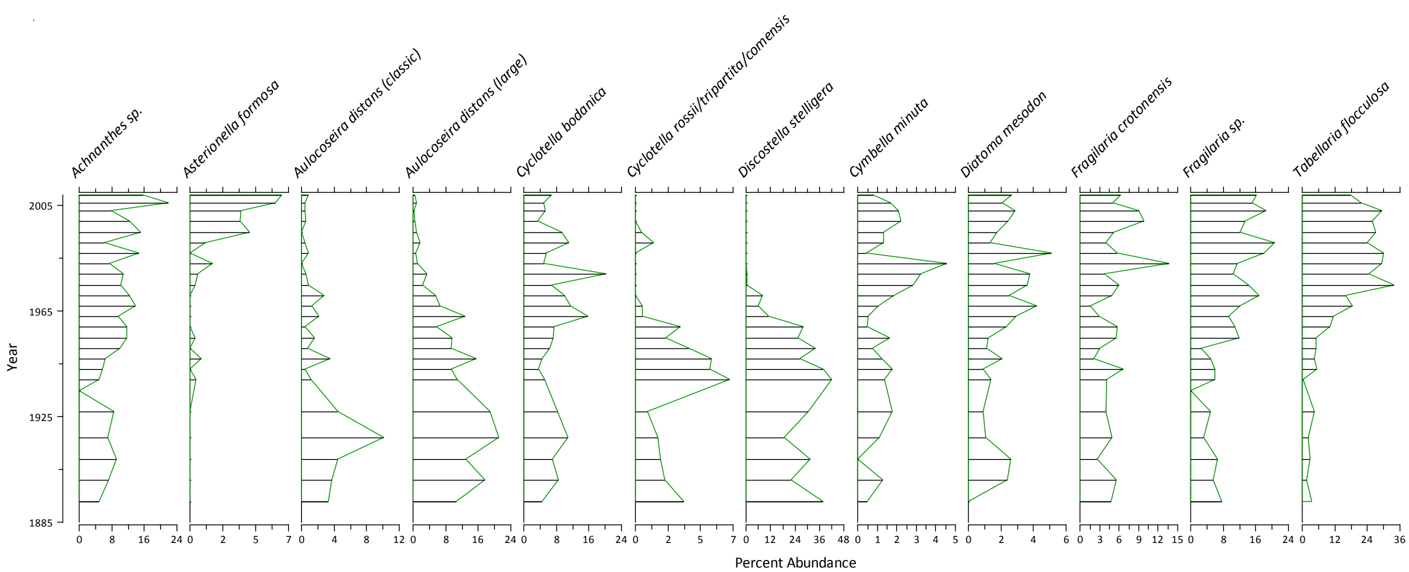
A) Hidden (GSF): ΔDCA 1=0.5117, ΔDCA 2 = -0.221, β = 0.665



B) Oldman (SF): ΔDCA 1 = 1.67, ΔDCA 2 = -0.271, β = 0.431



C) Trout (GSF): ΔDCA 1= 1.29, ΔDCA 2 = 0.048, β = 0.747



D) Two Medicine: ΔDCA 1= = 1.673, ΔDCA 2 = -0.271, β = 0.921

Figure 4 A-D. Diatom stratigraphies for 4 lakes (A. Hidden, B.Oldman, C. Trout, and D. Two Medicine) in Glacier National Park with the change in DCA Axis 1 and 2 scores from the top and bottom of the cores (a means to identify compositional change between modern and past diatom communities), and β-diversity values (overall species turnover over entire span of core. Species assemblages represent only the top 5% of the entire assemblage. SF lakes are in green, GSF lakes in blue.

Paleolimnological assessment of productivity

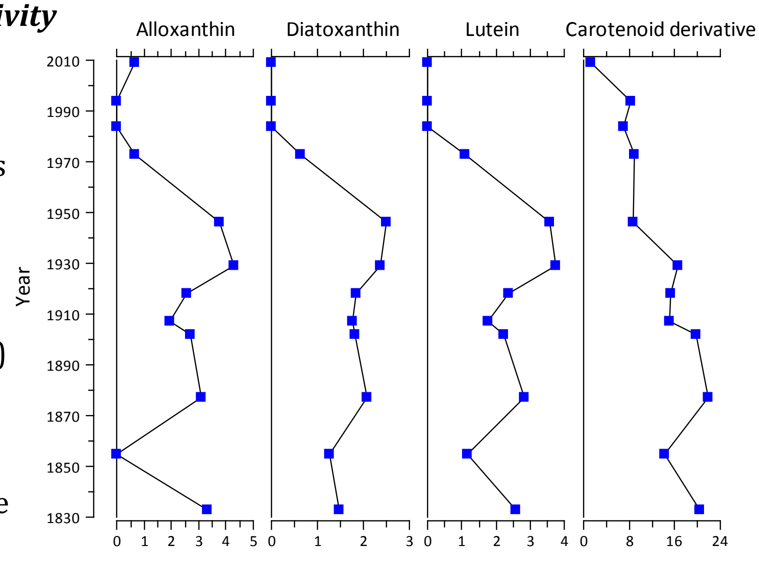


Figure 4. Select pigments from Trout Lake, a glacially-fed lake, showing overall declines in carotenoid pigments since 1850 indicating an overall decline in lake productivity over time.

Pigments were examined coarsely throughout each lake sediment core to assess changes in major algal functional groups over the last 150 years. Carotenoids such as lutein, alloxanthin, diatoxanthin were used as stable indicators of lake productivity. Decreases over time in lutein, diatoxanthin and a carotenoid derivative were evident in Trout Lake (GSF) (linear regression, $p < 0.05$; Figure 4). As illustrated in aerial photos from 1966 (Figure 5), this particular lake has shown substantial declines in glacial cover over the last 150 years and consequently expected corresponding declines in nitrogen subsidies to the lake. Alloxanthin declined in the more recent samples taken from Hidden Lake (linear regression, $p < 0.05$) but no other pigments in these lakes showed similar trends. Two Medicine Lake (SF) showed no significant trends in pigment production over the last 150 years.

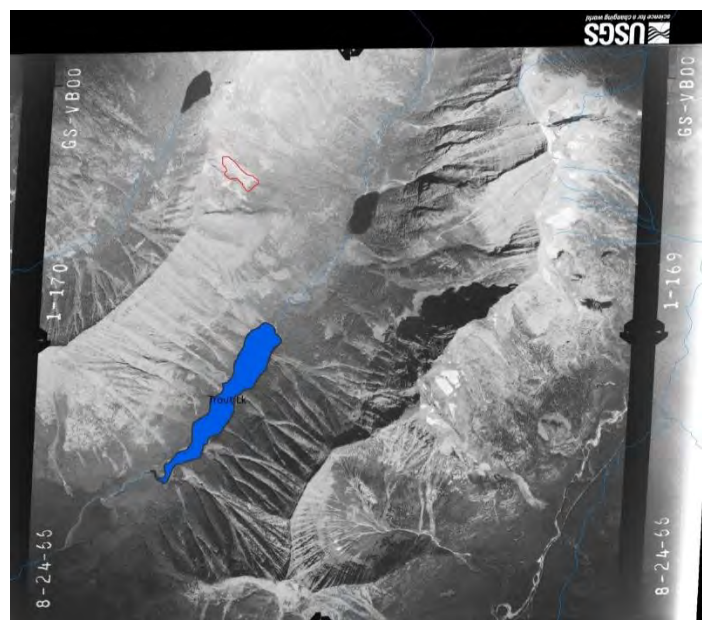


Figure 5. Historic 1966 aerial photo with red outline indicating the presence of a now extinct ice patch (USGS historical aerial photo taken September 4, 1966 accessed at http://earthexplorer.usgs.gov).

Linear regression was conducted to identify trends in species richness over time. Both GSF lakes showed a decline in richness over the last 150 years (linear regression, $p < 0.05$). Species richness increased over the last 150 years in Two Medicine Lake (SF) (linear regression, $p < 0.05$). Oldman Lake showed no significant trends in species richness.

While species richness in Trout Lake showed a slightly negative correlation with organic carbon (the proxy for glacial input, with high organics indicating low glacial cover), this correlation was not significant (Pearson's correlation, $p = 0.059$). There was a negative correlation between pigments and percent organic carbon in Two Medicine Lake (Pearson's correlation, $p < 0.001$).

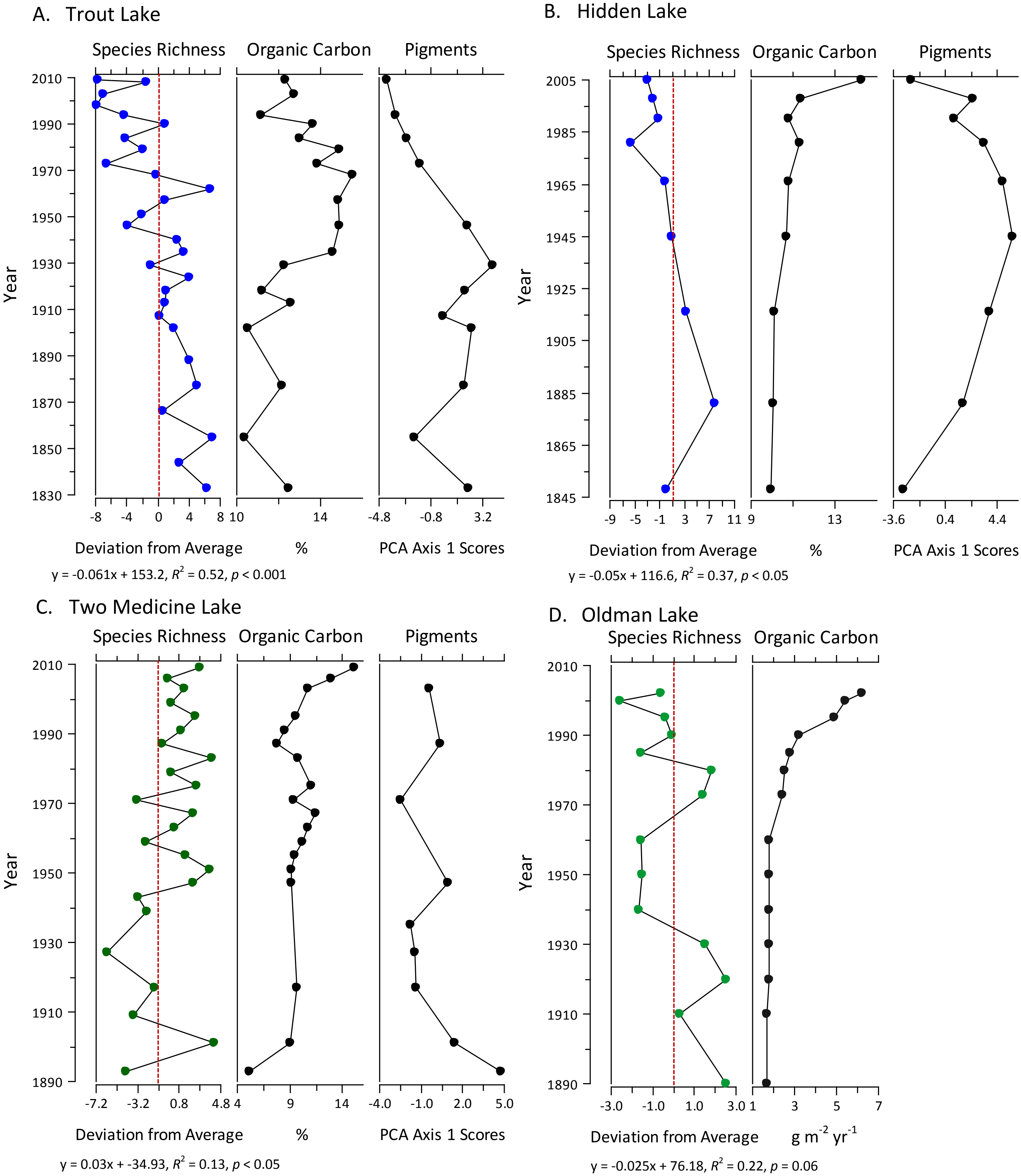


Figure 6. Stratigraphies of four study lakes showing species richness, percent organic carbon and PCA Axis 1 scores of pigments. Species richness values are deviations from the average with the red dashed line representing the average richness over the entire span of the core. Linear regression equation for species richness over time given below each species richness plot. Dates were based on ^{210}Pb dating.

SUMMARY
These results suggest that lakes in glaciated watersheds demonstrate differences in ecosystem structure and function, with these lakes showing declining species richness compared with modern SF lakes and a decline in overall lake productivity in the last 150 years as indicated by a lower concentrations of algal pigments, and greater variability in dominant diatom species over the last 150 years compared to SF lakes. These results demonstrate that even remnant glaciers, where nitrogen rich-meltwater has slowed and ceased, may set in motion a series of biochemical and ecological changes in aquatic systems and can produce profound change in oligotrophic lakes. For the GSF lakes in this study, which once received strong N enrichment, it remains unclear how these lakes will respond once glaciers disappear entirely.

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.

Publication:

- Slemmons, K. E. H., and Saros J. E. 2012. *Implications of nitrogen-rich glacial meltwater for phytoplankton diversity and productivity in alpine lakes.* **Limnology and Oceanography***.* **57**: http://www.aslo.org/lo/toc/vol_57/issue_6/index.html (available November, 2012).
- Slemmons, K.E.H., and Saros, J.E., in preparation for **Global Change Biology.** *Investigating how climate induced changes in alpine glaciers alter phytoplankton communities and lake habitat in Glacier National Park*.

Presentations:

- *Slemmons, K.E., and J.E. Saros. 2013. Slemmons, K.E. and J.E. Saros. *Release of reactive nitrogen by melting alpine glaciers: Effects on ecosystem structure in function in lake over the last century*. **American Society of Limnology and Oceanography (ASLO) Annual Meeting**. New Orleans, LA.
- Slemmons, K. E. 2012. *Investigating how climate induced changes in alpine glaciers alter phytoplankton communities and lake habitat in Glacier National Park*. **National Park Service Webinar**.
- Slemmons, K.E**.** 2012. *Release of nitrogen by melting glaciers: Effects on lake productivity in alpine lake ecosystems over the last 1000 years*. **University of Nottingham,** Nottingham, England.
- Slemmons, K.E. and J.E. Saros. 2012. *Release of nitrogen by melting glaciers: Effects on primary productivity and nutrient limitation patterns in alpine lake ecosystems.* **19th Annual Harold W. Borns Symposium**, Climate Change Institute, University of Maine, Orono, ME.

***anticipated presentation**

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, Graduate School Grant, $638.00
- University of Maine, Dan and Betty Churchill Exploration Fund, $2,517.00
- University of Maine, Alston and Ada Lee Correll Fellowship, $26,400.00

Other:

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

  All listed above

- 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.*

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Jackson Webster
University: University of Colorado, Boulder
Start date: June 15th, 2011
End date: September 15th, 2012

Brief project summary:

Over the five-year period leading up to 2006, the number of fish consumption advisories for fresh waters in the United States increased by seven-fold. Mercury was responsible for nearly 80% of these advisories. This rapid increase in fish consumption advisories due to mercury illustrates that bioaccumulation in freshwater fish is a concern for ecological and human health. The problem of mercury transport in forested watersheds may be compounded by the occurrence of forest fires. Forest fires are increasing in frequency and magnitude in the United States, and climate change predictions for much of the western U.S. favor a continuation of this trend. Furthermore, fuel management practices critical to preserving forests and minimizing wild fire intensity may indirectly influence the fate of mercury species in forest soils.

This project investigated the effects of fire on mercury-sulfur binding in forest soil. I hypothesized that oxidation of organic sulfur due to fire will decrease the abundance of reduced-sulfur functional groups capable of strong mercury binding. To test this hypothesis, soil samples were collected from the organic litter layer (O horizon) at unburned, burned, and prescribed burned sites throughout Mesa Verde National Park. The mercury binding properties of these soils were investigated using a series of mercury (II) leaching and adsorption experiments.

Research Approach:

For the purpose of mapping soil mercury concentrations across the park, 120 points were sampled from unburned, prescribed burn, and naturally burned areas. Preliminary sampling locations were identified by laying an 800 meter point grid over a Park map. Individual points were selected based on accessibility and Park management recommendations. Sampling was limited to reasonably accessible terrain and prioritized by the ability to sample efficiently during the months of June, July, and August 2011. Once a sampling location was determined, the burn history was established based on NPS fire history mapping.

At each sampling location, triplicate 10 cm soil cores were collected using 2.5 inch (3.8 cm) PVC core barrels. The soil cores were placed on ice for storage and transport.

Once in the laboratory the soils were extruded and composite samples for each depth increment were created. One subset of 25 cores was extruded in four 1 cm increments to determine mercury distribution in the depth profile for burned and unburned soils. The remaining cores were extruded in two 2 cm increments classified as the soil O horizon and a subsurface sample containing the transition zone between organic (O horizon) and mineral soils (A horizon). Following extrusion and compositing, the samples were freeze dried to stabilize the soils and reduce degradation and mercury losses. Freeze dried samples were homogenized using a mortar and pestle. Rocks, sticks and large roots were removed with a 2 mm stainless steel sieve. Soil organic matter content was measured by mass loss on ignition (LOI) for two hours at 550 °C. Soil mercury was measured using thermal decomposition / catalytic reduction / atomic absorption spectroscopy (DMA-80 mercury analyzer).

Soil-mercury binding was first assessed through a series of leaching tests. In each test, 400 mg of soil were added to 40 mL of deionized (DI) water in acid cleaned stoppered glass vials. Soil-water solutions were equilibrated for 24 hours on an end-over-end rotating wheel. Following equilibration, the solution was transferred to 40 mL Teflon vials and centrifuged at 14,000 RPM for 15 minutes. Samples were then passed through Supor 0.45 μm filters using disposable syringes. Sample splits were transferred into 40 mL amber glass vials and stored for no more than two weeks prior to measurement of UV absorbance at 254 nm and DOC analysis using an OI 700 total organic carbon analyzer. Filtered samples were immediately stabilized per EPA method 1631 for mercury analysis. The separated solid phase soil was air dried prior to mercury analysis.

Strong mercury binding capacity and soil water distribution constants were assessed using adsorption isotherms. To establish mercury-soil adsorption isotherm behavior, mercury as $Hg(NO_3)_2$ was added to pre-equilibrated soil water solutions in concentrations ranging from 10^{-8} M to 10^{-4} M. The solution pH was then adjusted to 5 ± 0.5 using 1M NaOH and HCl as needed. The soil-water-mercury solutions were placed on a shake table at 150 rpm for 24 hours. The samples were vacuum filtered through a 0.45μm Supor filter. Care was taken to ensure collection of all soil particles on filters. Following air drying, filters were weighed to determine solid recovery. Dry filters were submerged in an aqua-regia solution for 24 hours to remove adsorbed mercury from the solid phase. The liquid filtrate solutions, as well as the diluted (1:20) aqua-regia solutions, were then stabilized with 1% bromine monochloride. The concentration of aqueous and solid mercury was determined by analyzing the solutions using cold vapor atomic fluorescence spectroscopy (CVAFS) following EPA method 1631.

Conditional binding constants for mercury binding to soil were measured using a competitive ligand exchange method described by Khwaja *et al*. (2006). Briefly, 0.1 g of soil was added to twelve vials. Mercury was added as $Hg(NO_3)_2$ to half of the 40 mL vials at a concentration of 5nM. D-Penicillamine was then added to three vials without mercury and three vials with mercury at a concentration of 0.1 mM. Sodium perchlorate was added to a concentration of 0.1 M and vials were topped off to 40 mL with deionized water. Vials were placed on and end over end mixer for 48 hours. Following equilibration, samples were centrifuged at 14,000 RPM for 15 minutes. Decanted liquid from the Teflon tube was filtered using 0.45 micron filters. The solids in the vial were rinsed using a 0.1 M sodium Perchlorate solution and centrifuged. Solids were then collected and air dried prior to mercury analysis.

Total sulfur for select samples was measured at the LEGS laboratory at the University of Colorado, Boulder. We are currently planning on conduction further sulfur analysis using XANES spectroscopy is conducted at the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL), but has yet to be completed.

Key Findings:

Mercury distribution in the park was found to be dependent on past burn history (Figure 1). Soil mercury concentrations in first the two centimeters of burned soil were found to have a median concentration of 24.1 ng g^{-1} (min =8.8, max= 63.1, n= 66). This was significantly less (ANOVA, p = 0.05) than the unburned soils in the park which had a median value of 66.9 ng g^{-1} (min= 22.0, max= 169.2, n= 31). Furthermore, the distribution of the mercury in the soil profile was correlated with the soil organic matter ($R^2 = 0.55$). In unburned soils, mercury and soil organic matter concentrations were highest in the surface layer and decreased with depth, a trend not observed in burned and prescribed burn soils.

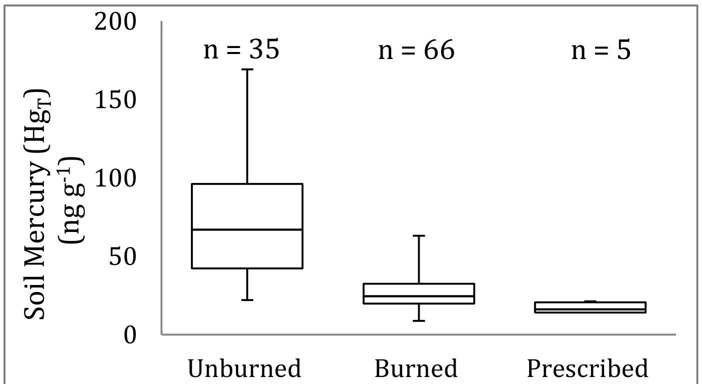


Figure 1: Soil-mercury concentrations for burned, unburned and prescribed burn soils.

Leaching of soils into deionized water appeared to result in slight differences in the amount of total soil mercury leached from burned and prescribed burn soils when compared to unburned soils (Figure 2). Some burned soils had a greater tendency to release more mercury than their unburned counter parts; however, this was not consistent across all burned samples. Prescribed fire samples appeared to release about twice as much initial soil-mercury than burned and unburned soils. Mercury release was consistent with laboratory heating experiments which show typical ranges from 1-8 % initial mercury, and increases with heating. DOC leaching was dependent on the initial organic matter content of the soil. Unburned soils, which contained more initial organic matter, tended to release a greater amount of dissolved carbon. Specific UV absorbance (SUVA), a measure of aromatic structure content in organic molecules, was measured in DOC leaching experiments. SUVA values of dissolved organic carbon from leaching tests showed no dependence on burn history.

Adsorption isotherms were generated from unburned soil, burned soil, prescribed burn soil, and soil heated at 550 °C for 2 hours. The slope of an isotherm yields a soil-water distribution value (K_d), which indicates the tendency for a compound of interest to be dissolved in water (easily transported) or sorbed (attached) to the soil (relatively immobile). These are generated by adding increasing amounts of mercury to a soil-water solution and measuring the concentration in each after equilibration. The slope of the line when the two measured values are plotted (soil vs water concentration) indicates the tendency for the mercury to be associated with the soil. In this experiment, unburned soils maintain a constant soil-water distribution (the slope, or K_d, of the line does not change). This indicates a strong tendency sorption of mercury by the soil over a wide concentration range. K_d values (the slope of the distribution) in unburned soils were around 3000 for most of the mercury concentrations of interest. This indicates that mercury favors being associated with the soil by about three orders of magnitude over the aqueous phase. The point at which the slope begins to decrease indicates the saturation of strong binding sites. At this point, mercury has "filled" the preferred binding sites and starts staying in the water. This point is the strong binding capacity of the soil. Interestingly, the soil subject to heating and fire appeared to reach their strong mercury binding capacity at an aqueous mercury concentration of $10^{-7.25}$ M, while unburned soils reached capacity at 10^{-5} M. Further information on sulfur speciation may elucidate the reason for this observed difference in binding capacity. These soils are currently in queue for XANES analysis, the results of which will be provided in future deliverables and publications. These findings appear to support the initial hypothesis that heating reduces strong mercury binding capacity of soil.

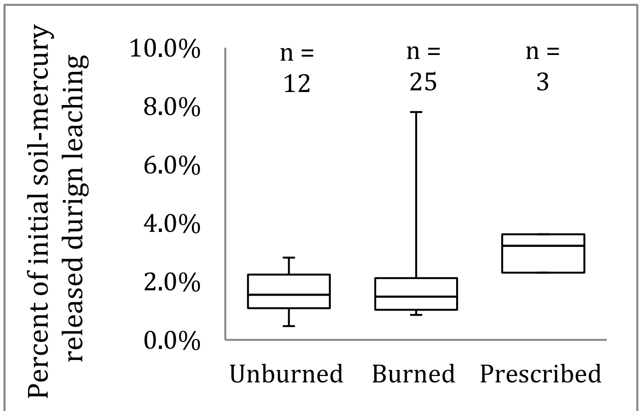


Figure 2: Release of mercury from unburned, burned, and prescribed burn soil within Mesa Verde National Park.

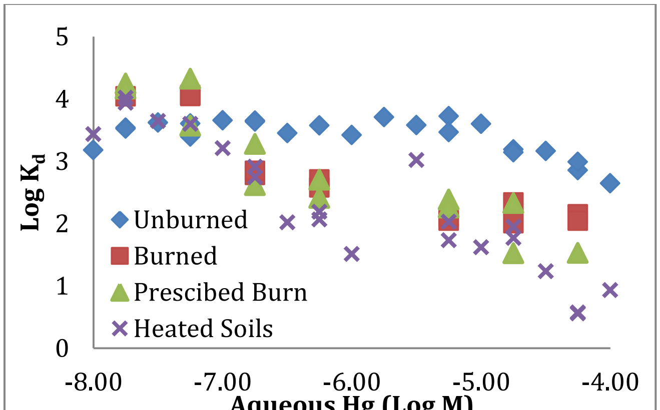


Figure 3: Soil:water distribution (K_d) values for measured aqueous mercury concentrations. Values presented in this figure represent the slope of the distribution curve each aqueous mercury concentration shown. Actual distribution curves were not included in this report.

Deliverables/Research Products:

Posters/Talks

Webster J.P., Kamark B.L., Ottenfeldt C.F., Ryan J.N., Aiken G.R., Nagy K.L., Nano G., Manceau A., 2011. Changes in the binding of mercury to forest soils following natural and prescribed fire and furnace heating. Presented at the American Chemical Society National Meeting, Denver, Colorado, August 2011.

Webster, J.P., Ryan, J.N., Aiken, G.R. 2012. Does Wildfire Affect Mercury Mobilization, Transport, and Fate in Aquatic Ecosystems? Presented at the Four Corners Air Quality Forum 2012, Durango Colorado, May 2012.

Webster, J.P., Ryan, J.N., Aiken, G.R. 2012. Effects of Wild Fire on Soil-Mercury Distribution and Binding Trends at Mesa Verde National Park. Presented at the U.S Geological Survey Fall Seminar Series, Boulder, Colorado, September 2012.

Deliverable in Progress:

- Ph.D. dissertation chapter
- Paper for submission to refereed journal
- Scheduling for a talk at Mesa Verde National Park

Other:

One of the neat aspects of this work has been the involvement of many students and multiple institutions. The first year of the project I was able to leverage our collaboration with the Mountain Studies Institute (Silverton, Colorado) to bring two undergraduate students onto the project; Crystal Kelly, from Fort Lewis College (Durango, Colorado) and Doug Winter from the University of Colorado, Boulder. Both were participating in a summer internship at Mountain Studies Institute and their involvement in the sampling effort was a major factor in the success of this project. Doug Winter has continued to work on wild fire related projects and is currently an intern at the U.S. Geological Survey in Boulder, CO. Secondly, each summer I have been able to bring on a Research Experiences for Undergraduates (REU, funded by the NSF) student to gain laboratory experience. Chelsea Ottenfeldt from Tennessee Technological University (Cookeville, Tennessee) and Michelle Hummel from Case Western Reserve University (Cleveland, Ohio) have both contributed to this body of work and were able to develop their own summer projects from different aspects of this project.

Photographs:

Photo 1: Mountain Studies Institute Intern Doug Winter collecting soil cores for a typical burned site in the Park.

Photo 2: Doug Winter Sampling a typical unburned location on the Chapin Mesa.

Photo 3: Myself, Jack Webster, extruding one of the many soil cores into 1 cm increments at the laboratory in Boulder, Colorado.

2011 NPS George M. Wright Climate Change Youth Initiative
Fellowship Research Final Report
December 31, 2012

Fellow Name: Kristie S. Wendelberger
University: Florida International University
Start date: June 1 2011
End date: December 31 2012

Brief project summary: Coastal communities in Florida are threatened by increased salinity from sea level rise (SLR). The sea has risen along the coast of southern Florida ±2mm/year for the last 100 years and is predicted both to continue to rise and to increase in rise rate in the future. Everglades National Park (ENP) harbors 43 critically imperiled species, 21 of which are threatened by SLR; rare species richness tends to be negatively correlated with salinity in these threatened habitats. The upland coastal communities supporting most of the rare species—Hardwood Hammocks and Buttonwood Forests—average 29 and 23cm above sea level, respectively, while Buttonwood Prairies, which harbor few rare species, are lower in elevation at 19cm above sea level. As the sea rises, it is expected that the coastal communities in southern Florida will migrate up the elevational gradient, pushing out upland rare plant communities and replacing them with lowland communities or water.

To form a realistic conservation action strategy in the face of large-scale change, land managers need to prioritize species under greatest extinction threat. With this information, they can decide how to allocate resources and funding, making the best decisions to preserve the greatest amount of biodiversity.

I address this issue in three ways:

1) Creating a baseline map of coastal plant communities in a 122km^2 area around Flamingo, ENP, through remote sensing technologies. I am using WorldView-2 satellite 2x2m resolution data with 8 multi-spectral bands to map these communities. I will then compare my results to a vegetation map created in 1981 to assess how the plant communities in this area have changed over the last 32 years.
2) Testing whether salt-tolerant species (halophytes) change their environment by elevating soil salinity to the detriment of salt-sensitive species (glycophytes). The rare species in this coastal area tend to be glycophytic. When salinity levels reach a certain point, halophytes can continue utilizing saline soil water while, under the same saline conditions, glycophytes cannot; this should allow halophytes to out-compete co-occurring glycophytes and become more abundant. In a greenhouse experiment, I am evaluating the ability of halophytes to increase soil salinity under varying halophyte/glycophyte densities; my results will inform predictive models assessing plant community change due to increased salinity levels and sea level rise.
3) Assessing whether seed germination or seedling establishment are most vulnerable to increasing salinity levels (0ppt, 5ppt, 15ppt, 30ppt, and 45ppt salinity levels) for 6 coastal plant species found in varying densities in the upland Hardwood Hammocks (29cm above sea level) and Buttonwood Forests (23cm above sea level). This information will assist ENP managers in monitoring community shifts due to increased salinity levels from SLR by telling them the order in which species will stop reproducing by seed in each community. In this way, they will be able to monitor efficiently in order to detect change in time to prepare conservation action strategies for the most vulnerable species.

Research Approach:

There were no significant changes to my original questions, hypotheses, or approach used in my research in sections 2 and 3 above; however, the question for section 1 has changed. Instead of looking at the percentage of coastal Buttonwood forest understory dominated by the halophyte *Batis maritima* as opposed to glycophyte species, I am mapping the major plant communities in my study area and comparing my results to a map that was created in 1981 to assess whether the plant communities in this area shifted to more salt tolerant communities over the last 32 years. My hypothesis is that there will be an increase in halophyte prairie percent cover and a decrease in upland forest percent cover in my study area over this period. Wet season 2011 satellite data has been purchased; however, this work is pending the purchase of the second set of satellite data during the dry season (April) 2013.

Location(s) of Research:

- Coastal plant communities in the Flamingo area of Everglades National Park.

Key Findings:

Section 1: pending the purchase of satellite data in April 2013.
Section 2: research in progress; I have begun this experiment. It will run until March 2013.
Section 3: The mean seed germination and seedling establishment of all species tested show varying sensitivities to increased salinity levels (Figs. 1-4). All species show a marked decrease in germination at 15ppt; *Swietenia mahagoni* showed the largest decline in germination from 5ppt to 15ppt, followed by *Eugenia foetida,* then *Chromolaena frustrata* (Fig. 1). When looking at seedling growth, all species tested showed a consistent decline in both shoot and root length and biomass with an increase in salinity. *C. frustrata* showed the largest decrease in shoot and root biomass, beginning at 5ppt and having no substantial biomass at 15, 30, and 45ppt salinity levels (Figs. 2a and 2b). *Conocarpus erectus* and *S. mahagoni* also showed declines in shoot and root growth and biomass at 15ppt and continued to decline with 30 and 45ppt salinity levels (Figs 3a, 3b and 4a, 4b, respectively). This pattern suggests that *C. frustrata* seedling establishment may show the first signs of decline with increased sea levels, followed by *S. mahagoni* and *E. foetida* seed germination and *C. erectus* and *C. frustrata* seedling establishment and seed germination, respectively.

For the federal, endangered-species candidate *Chromolaena frustrata,* seed germination and seedling establishment is highly sensitive to increasing salinity levels. In addition to a decrease in seed germination at 15ppt, no germination in 30 or 45ppt salinity levels (Fig. 1), and a marked decrease in seedling establishment at 15ppt salinity levels (Figs. 2a and 2b), 88% of *C. frustrata* seedlings in 0ppt survived to 126 days, while 8% of seedlings in 5ppt and 0% of seedlings in 15, 30, and 45ppt survived to 126 days.

Conservation actions need to be evaluated and implemented for *C. frustrata.* Sea levels in south Florida have been rising ±2mm/year for the last 100 years. *C. frustrata* currently exists in an area that averages 23cm above sea level. A different plant community (Buttonwood prairie) is supported at 19cm above sea level. At current rates of sea level rise, the areas where *C. frustrata* currently exists will be at 19cm above sea level in 20 years, likely turning *C. frustrata* habitat into Buttonwood prairie habitat and no longer supporting the *C. frustrata* populations that are there today.

Figures

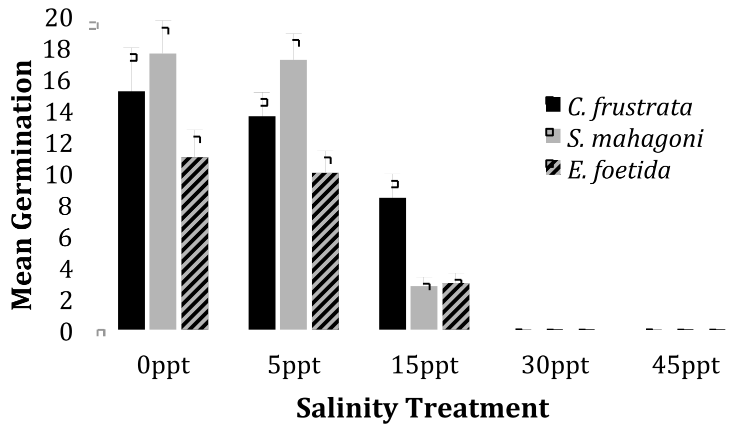


Figure 1: Mean + standard deviation of seed germination for three coastal species, *Chromolaena frustrata*, *Swietenia mahagoni*, and *Eugenia foetida*. Data are number of seeds germinated out of 20 seeds per petri dish.

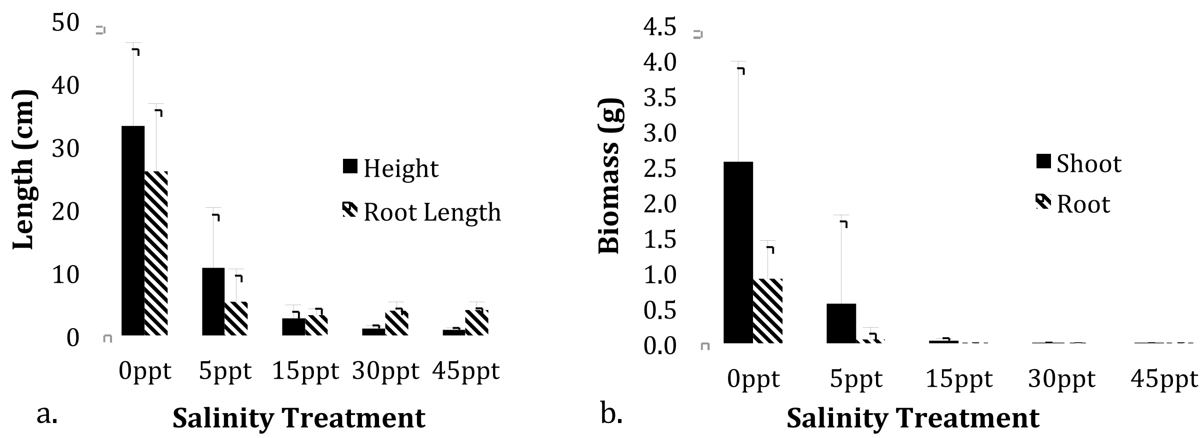


Figure 2a. Mean + standard deviation of *C. frustrata* height and root length; and **b.** shoot and root biomass across salinity treatments after three months growth.

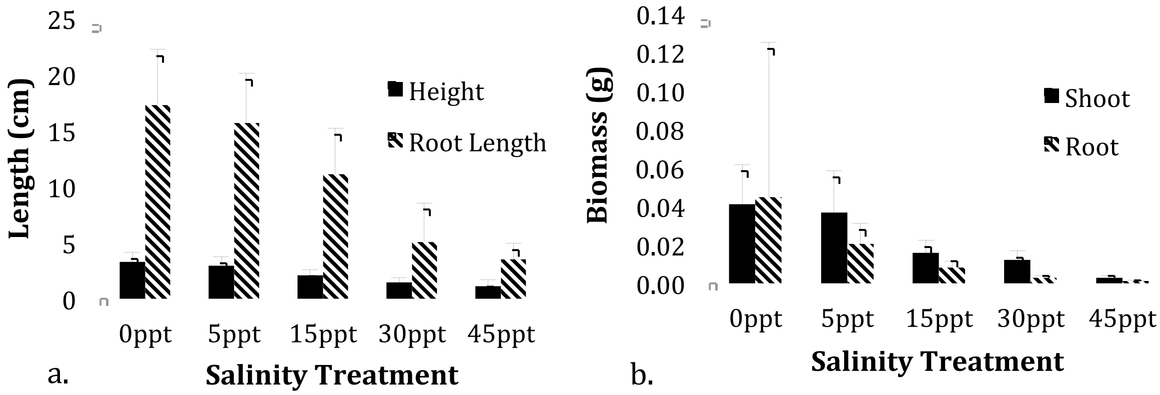


Figure 3a. Mean ± standard deviation of *C. erectus* height and root length; and **b.** shoot and root biomass across salinity treatments after three months growth.

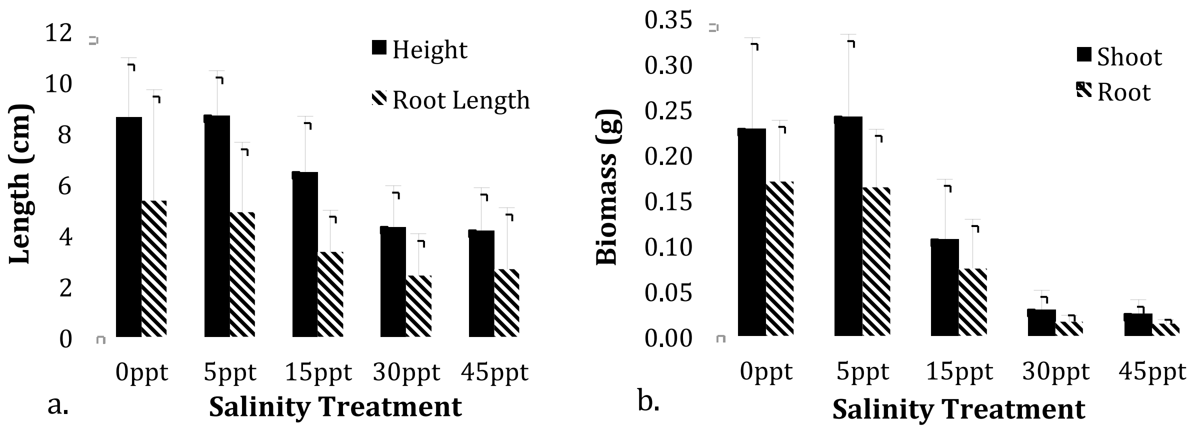


Figure 4a. Mean ± standard deviation of *S. mahagoni* height and root length; and **b.** shoot and root biomass across salinity treatments after three months growth.

Deliverables/Research Products:

Conferences/Meetings

- **Wendelberger, K.S.**, J. Sadle, S. Saha, and J.H. Richards. 2012. Detecting Long-term Community Shifts in Response to Sea Level Rise and Everglades' Restoration. 9th INTECOL International Wetlands Conference Wetlands in a Complex World Conference Abstracts. June 3-8, 2012. Orlando, Florida, USA. Available at: http://www.conference.ifas.ufl.edu/intecol/Abstracts.pdf
- Pearlstine, L., S. Friedman, S. Romañach, T. Doyle, J. Sadle, S. Saha, T. Smith, D. DeAngelis, M. Turtora, L. Sternberg, **K. Wendelberger**, R. Best, and E. Swain. 2012. Modeling coastal vegetation community succession using the Everglades landscape vegetation succession model. 9th INTECOL International Wetlands Conference Wetlands in a Complex World Conference Abstracts. June 3-8, 2012. Orlando, Florida, USA. Available at: http://www.conference.ifas.ufl.edu/intecol/Abstracts.pdf

Workshops/Summits

- Empowering Capable Climate Communicators Workshop Training Series. University of Miami, FL. February 2012.
- Everglades Landscape Vegetation Succession & Coastal Communities Workshop. Florida Atlantic University, Davie FL. January 25, 2012.
- Southeast Florida Regional Climate Change Compact: 3rd Annual Southeast Florida Climate Leadership Summit. Key Largo, FL. December 8-9, 2011.
- Florida Climate Change Task Force State University System Climate Change Workshop. University of Florida, Gainesville, FL. November 14-15, 2011.

Additional Funding:

- Florida International University Kelly Tropical Botany Scholarship: $500.
- National Science Foundation, Florida Coastal Everglades Long-term Ecological Research, Research Experience for Undergraduates: $8,000.

Other:

- I mentored 7 undergraduate students who volunteered and/or worked on this project, two of whom were NSF-funded REU students. Of those 7, 4 were women and all were minorities of Hispanic or Asian descent.

- Anecdotes or stories from my project:

  Prior to working on this project, I thought of sea level rise as being something that is far off—an issue to prepare for, but 50 to 100 years into the future. After thinking about these issues for coastal plant communities harboring rare species in south Florida, I realized this is a much more pressing event. When you understand that the sea has been rising in south Florida at a rate of $\pm$2mm/year for the last 100 years and that plant communities here are distributed across the landscape based on elevation, hydroperiod, salinity, and rainfall, you can imagine one “upland” community residing at 23cm above sea level transitioning into the next lower plant community, which resides at 19cm above sea level in approximately 20 years, not 100. This rapid change has the potential to threaten rare species in our lifetimes, not that of our children or grandchildren.

Kristie Wendelberger GPSing in Flamingo_Everglades National Park

Kristie Wendelberger GPSing in Flamingo_Everglades National Park

The federal candidate Chromolaena frustrata germinating in 0ppt salinity