The Arkansas River Glacial Lake Outburst Flood Problem: Geomorphological Evidence and Modeling with HEC-RAS

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Abstract: During the late Pleistocene glaciers extended across the Arkansas River valley, Colorado, damming the river and forming a lake. Flood boulders on terraces downstream from the lake suggest at least two flood events. We propose to model these floods to learn more about water depth downstream of the dam breach, and thus possibly reduce future disasters elsewhere.

Setting:

Keenan Lee (Lee 2008) was one the first (with Scott, 1975) to find evidence for glacial lake outburst floods in the Arkansas River valley, Colorado, during the Pleistocene.

Flood landforms are features of these catastrophic events. Landslides (namely Kobe, Mt Massive and Empire Gulch landslides) also occurred at the same time as the floods, owing to a reversed hydraulic gradient. Lakes impounded behind the glacial dam did not cut clear shorelines, but ice rafted boulders dropped from icebergs, both in the lake basin and clustered on shore, are the testimony to the previous extent of these lakes.

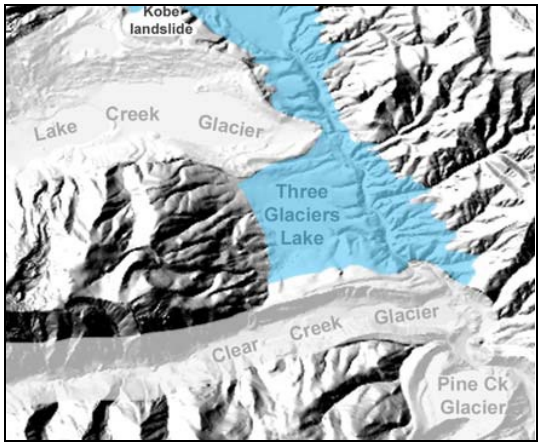

Fig. 1. Geographical settings: Three glaciers lake impounded by a glacial dam formed by northern Clear Creek and southern Pine Creek glaciers during Pleistocene, figure taken from (Lee 2008).

The origin of this debris that provides a way to reconstruct the extent of the glacial lakes is the same as that of boulders that we find now downstream: The Sawatch Range, hosted glaciers flowing from the west; these glaciers crossed the Arkansas River and slammed into the Mosquito Range on the east side of the valley. These ice rafted boulders give evidence of the extent of water at the moments of the outburst floods, but this evidence does not constrain the depths of the floods sufficiently well.

Objectives:

HEC-RAS is an open-source software developed by the USGS that can be used to reconstruct these floods. It has been used by Jürgen Herget (2005) to constrain Pleistocene ice-dammed lake outburst floods in the Altai Mountains, Siberia. Our goals are similar to his and we will try to follow a similar methodology to model the water depth downstream from the dam breach. We primarily need to incorporate cross-sections, with a chosen spacing, from a map of the Arkansas River valley into the software, starting downstream and proceeding upstream. Initially we will use Brugger et al.'s (2010) estimates of discharge.

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Atmospheric Circulation Influences on West Greenland Precipitation

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Abstract: This preliminary study uses the 56-year Japanese Meteorological Agency Reanalysis to examine the influence of North Atlantic teleconnections on precipitation over West Greenland.

Recent decades have brought significant warming and glacier retreat to West Greenland. By understanding changes in atmospheric circulation that deliver heat and moisture to the region, we may gain valuable insight into future climate and sea-level rise. Two centerpiece patterns over the North Atlantic Basin, the Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO), play a major role in global climate (Parker et al., 2007). The impact of the NAO and AMO on West Greenland remains less well understood. Here, we present results from a preliminary examination of these North Atlantic teleconnections using JRA-55 (Kobayaski et al., 2015), a state-of-the-art reanalysis model spanning 1958-present.

The AMO defines the fluctuation (~70 year period) of average sea surface temperature (SST) in the North Atlantic Basin from 0-70 N, whereas the NAO defines synoptic modes of atmospheric circulation arising from the sea level pressure difference between the Azores High (AH; measured at Lisbon, Portugal) and Icelandic Low (IL; measured at Reykjavik, Iceland). These climate patterns are linked on decade timescales such that cool SSTs (-AMO) facilitate +NAO like patterns and warm SSTs (+AMO) facilitate -NAO like patterns.

The signal of West Greenland precipitation from JRA-55 shows that moisture delivery to the region increased by ~8% during the most recent transition from AMO-cool to AMO-warm (Fig. 1). The NAO shows a different story on the annual timescale. Years with totals of extreme high precipitation (1983, 1996, 2005, and 2012) show high-pressure blocking events thereby weakening the pressure gradient between the IL and AH. Moreover, the IL is weaker when compared to the four years with extreme low precipitation (1958, 1974, 1992, and 2009), showing a relatively deeper IL. A deeper IL is due to dominantly zonal flow bringing moisture eastward to Europe rather than to West Greenland. Although precipitation in West Greenland does not correlate well with the NAO index, the link between the extreme precipitation years and the NAO does point to synoptic patterns that influence precipitation in this region.

In summary, our results thus far suggest that the influences from the AMO and NAO on West Greenland precipitation are complex. The AMO warm phase does show a minimal increase of precipitation with respect to the previous AMO-cool phase. A link with NAO exists, but only during extreme years of precipitation. Although we cannot fully explain West Greenland precipitation with just the AMO and NAO, it is clear by default that other variables such as location of moisture flux sources and synoptic blocking patterns in the North Atlantic domain are potentially relevant.

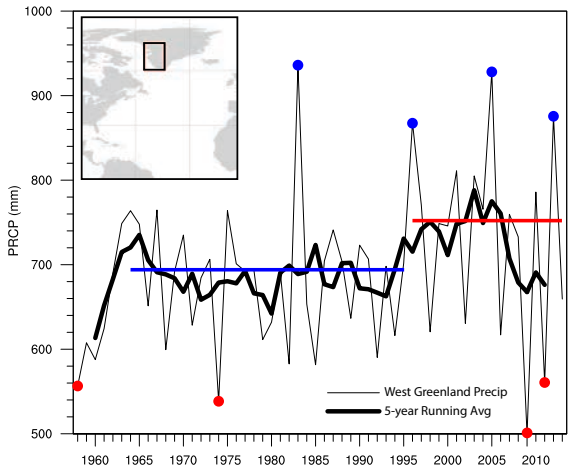

Fig. 1. West Greenland (upper left corner) precipitation registered in the JRA-55 record, 1958-2013 (thin, black line) with a 5-year running average (thick, black line). Red (blue) dots show 4 years of minimum (maximum) precipitation. Red and blue lines show average total annual precipitation during the AMO warm and cool phases, respectively.

Acknowledgements: This work is supported by NSF award PLR-1417640 (GreenTrACS) to Sean Birkel.

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Investigating Ecological Values of Rockweed Habitat to Intertidal Invertebrates along the Maine Coast

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Abstract: Rockweed (*Ascophyllum nodosum*) provides many essential ecological services to the Maine intertidal ecosystem, including habitat for many species. However, increasing commercial rockweed harvesting may affect populations of marine invertebrates. Here we attempt to investigate a connection between invertebrate community structure and rockweed in Maine.

Rockweed (*Ascophyllum nodosum*), a perennial brown macro-algae, creates complex structure and provide many essential ecological services to the intertidal ecosystem, including habitat for many ecologically and economically important species (Larsen 2012). As a primary producer, rockweed supports many secondary consumer populations. The 3-dimensional structure of rockweed canopy provides settlement, refuge, and foraging sites and significantly enhances diversity and abundance of invertebrate species (Schmidt et al. 2011). While some invertebrates graze upon rockweed, others receive protection against heat, sunlight, desiccation, and predation from it at low tide.

Despite their ecological services, rockweed in has been commercially harvested for the production of alginates, fertilizers, and animal feed. Because many species of intertidal invertebrates use rockweed as their habitats, commercial harvesting potentially affects invertebrate diversity and abundance, which in turn could impact populations of fishes and coastal birds that rely on these invertebrates as their food source.

The present study will assess the ecological importance of rockweed-dominated areas and describe invertebrate diversity and abundance in rockweed habitat along the Maine coast. Rockweed and invertebrate surveys will be conducted during low tide in summers and winters 2016-2018, at designated rockweed-dominated sites along the entire coast of Maine. At each survey site, invertebrates will be sampled within quadrats along transects perpendicular to the shore, starting at the highest rockweed location to where there is a clear transition from rockweed to different algal species or no algal species present. Invertebrates will be identified and counted.

Fig. 1. Invertebrates among rockweed

Not only will the results of this study provide a better understanding of ecological significance of rockweed-dominated areas to invertebrates as their habitat but will also help organizations to establish a better management plan and regulations regarding rockweed harvesting, in order to minimize impacts to invertebrate habitat, as well as nursery and refuge for fishes, and foraging habitat for many bird species.

Acknowledgements: Maine Costal Island National Wildlife Refuge, US Fish and Wildlife Service.

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Spatial Characterization of Maine's Lobster Fishery in a Changing Climate

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Abstract: In 2010, President Obama's Executive Order 13547 established the National Ocean Policy. As part of this policy, responsibility for Marine Spatial Planning was delegated to regional planning bodies (RPB's). The Northeast Regional Ocean Council (NROC) is the organization responsible for the New England's ocean plan, and has characterized other fisheries with GIS maps of fishing activity. Similar information does not exist for the New England lobster fishery. We undertook this project to demonstrate how external climate impacts and behavioral change within the lobster fishery intersect with the regional ocean plan, for the purpose of informing NROC.

Understanding how New England's ocean waters are used by the lobster fishery is difficult because of the limited and varied mapping that has taken place. Regional ocean planning has recognized the importance of the lobster fishery and the need for the best possible spatial characterization information available. To aid in the ocean planning process and to provide information about how the lobster fishery uses the ocean, we documented changes in Maine lobster fishing practices over the last 15 to 20 years.

Lobstermen from all Maine lobster management zones were interviewed for their perspectives on how they fish throughout the year, how lobster fishing has changed in the last 15 to 20 years, how they approach new ocean uses and ocean planning, and how they adapt to increased effort in their fishing areas. 25 lobstermen were interviewed from December 2015 to February 2016.

While the specific responses varied slightly by location along the coast, major themes did emerge. To summarize, lobstermen:

- are most concerned about future ocean uses that could restrict how they adapt to changing conditions in the environment and lobster fishery. Their business model requires mobility and flexibility; anything that reduces these is a major concern to lobstermen. They:
- are concerned about increases in effort and about new fishermen moving into their areas. A key component of how someone coming into a traditional lobstering area is perceived and treated is the degree to which they try to fit in.
- have seen lobster fishing expand spatially; this has occurred because the area in which lobsters are found has expanded rather than simply shifting away from traditional areas.
- don't use traps to hold bottom as was done traditionally. This is because lobsters are available in more areas and because lobstermen want to fish as many traps as possible efficiently rather than using traps to hold bottom.

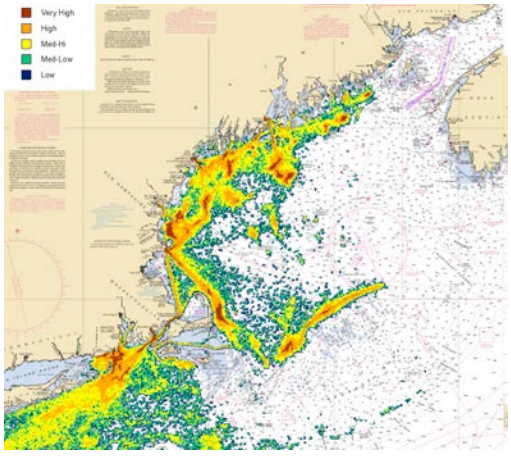

Fig. 1. NROC GIS map of herring fishing activity. Data from Vessel Monitoring Systems (VMS). Lobster fishery has no such data.

Acknowledgements: This research is supported by the Island Institute, The University of Maine Graduate School, and by the men and women of Maine's lobster fishery.

An Interactive Educational Experience Designed to Facilitate Understanding of Three-Dimensional Spatial Relationships within Archaeological Excavations

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Abstract: Spatial relationships are of essential importance when attempting to interpret an archaeological site. However, popular depictions of archaeology are often reduced to a focus on materials themselves with minimal attention to their context. This project is intended to encourage awareness of space in archaeology and the relationships that can be associated with it, utilizing touch-based tablet technology to bring the excavation experience to a general audience.

When visiting a museum or reading a book about materials recovered from archaeological sites, it can be challenging to conceptualize their original three-dimensional (3D) context or its importance. The excavation experience itself can put the participant in that three-dimensional space, a space in which concepts such as superposition and spatial clustering can be seen and interacted with. Keeping in mind that a real-world excavation experience cannot always be accessible, this project, titled "Arti-Finder," was initiated to bring a reasonable facsimile of that experience to a general audience.

Early development was focused around the Oculus Rift head-mounted display and Leap Motion infrared hand-tracker. These peripherals work in conjunction with one another, allowing the participant's head motion as well as his or her hands to be tracked in real time. A virtual environment was created in the Unity3D game engine, alongside models of some major lithic artifact classes (based on 3D laser scans of real-world materials) as well as a "virtual trowel" that could be picked up in-game using the Leap Motion and used to "dig" in the designated excavation area.

However, a number of issues discouraged forward movement with the virtual reality version of the project; the most prominent of these involved limitations within the then-current Leap Motion software development kit (SDK). The development focus was subsequently shifted to the iOS platform, though many elements of the original version were retained.

Via an orthographic camera view, the user is positioned above an archaeological excavation and can simulate digging through five visually distinct layers of dirt by dragging his or her finger across the screen. Eight artifacts are spawned each time the application restarts; their three-dimensional locations and rotation are randomized every time. When uncovered, they are collected and placed in a bucket using a tap-and-drag interaction.

When all of the artifacts are collected, the application returns a series of points that represent the original locations of all eight objects. When tapped, each point returns its corresponding spatial information alongside the name of the artifact that it represents. The post-excavation summary is currently only available in the orthographic view, but will eventually be represented in 3D, with the ability for that representation to be manipulated by the user.

Future development will include a build for the Android platform, as well as improved 3D representation and identification of spatial clusters and other meaningful associations. Another area of interest is the inclusion of haptic feedback, making it possible for the user to "feel" in-application interactions such as digging. A consumer-ready build of Arti-Finder will hopefully be available on the Apple App Store and Google Play at some point within 2016.

Acknowledgements: Appreciation is extended to the Virtual Environment and Multimodal Interaction Lab, Department of Anthropology, Climate Change Institute, and School of Computing and Information Science, all at the University of Maine, as well as to early users who have provided feedback, including, but not limited to, participants at the Central Lincoln County Teen Science Café and the 2016 Maine Science Festival.

Seasonal Analysis of Two Major Archaeological Sites in Eastern Maine Using Mollusk and Faunal Remains

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Abstract: Utilizing the pioneering work of David Sanger, Arthur Spiess and others, two archaeological sites in Eastern Maine will be analyzed using oxygen isotopic patterns to determine seasonal indicators of the season of occupation at the sites. Determining the season of occupation of a site provides crucial information as to the types of activities that took place (e.g., ritual, spiritual, or domestic) and availability of food resources. It has been hypothesized that the first site, Holmes Point West in Machiasport, Maine, was occupied by the Passamaquoddy Tribe during the summer months, while the second site, Jones Cove in West Gouldsboro, Maine, was occupied by a Native group during the winter months. Faunal remains, especially fish, and mollusks previously excavated will be analyzed and the results will be used as the determining factors of the season of occupation for each site.

Background:
As Maine has very acidic soil, preservation of faunal remains in an archaeological site within the state is unlikely unless shell is present on the site. Calcium carbonate within a shell acts as a neutralizer within the soil and allows the preservation of organic materials, e.g. faunal remains. It is because of this presence of shell that the Holmes Point West and Jones Cove sites exist. These two sites are designated as 'shell middens', which are piles of discarded materials that were no longer utilized or no longer served a purpose to the Native Americans occupying the area. These shell middens provide a wealth of information and have preserved a piece of ancestral Native American culture that otherwise may not have survived.

Holmes Point West is a shell midden located in Machiasport, Maine and is culturally relevant to the Passamaquoddy Tribe. Dr. Brian S. Robinson has worked in conjunction with the Passamaquoddy Tribe to excavate the site and recover information from the Tribe's ancestral way of life.

Jones Cove is a shell midden located in West Gouldsboro, Maine. The initial excavation of the site took place in 1928 and was led by Dr. Warren K. Moorehead. It is undetermined which native tribes occupied the site but they are believed to be an Algonquin language-speaking culture.

Purpose:
I will be looking for oxygen isotopic patterns through analysis of faunal remains, especially fish, and mollusks previously excavated from the two sites. These patterns will indicate whether the sites were of summer or winter occupation. This analysis will help to fill in cultural gaps by providing evidence and insights to help characterize past ways of life.

Methods:
I plan to use the methodologies, sectioning and analysis techniques, set forth by David Sanger and Arthur Spiess for my thesis research involving seasonality analysis.

Acknowledgements:
Funding from the UMaine Anthropology MAPI Project directed by Dr. Brian S. Robinson and Dr. Lisa K Neuman.
Graduate Assistantship through Dr. Nicholas A. Giudice, Director of the VEMI Lab at UMaine.

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Topographic Fabric and Bedrock Weakness Distribution in Glacial Erosion Models

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Abstract: Displacement along active fault systems in southeast Alaska damages bedrock, increasing fracture density and decreasing cohesive strength. These changes in material strength properties affect erosion rates and may be responsible for unusually high sedimentation rates in the Gulf of Alaska. We estimate local weakening at the outcrop scale with field observations. At the orogen scale, we estimate the range and magnitude of weakening caused by tectonic strain using Elevation Variance Analysis (EVA). Further work will focus on improving erosion models by introducing more nuanced bedrock cohesion strengths based on EVA results.

Southeastern Alaska is an area known for active glaciation caused by high precipitation and temperate climate (Birkel 2016). Convergent and strike-slip faulting along the Aleutian Megathrust and Fairweather Fault systems causes relatively frequent high magnitude displacement. The amount of bedrock damage, related to fault displacement, creates variations in cohesive strength across two orders of magnitude (Roy et al. 2015).

I measured fracture density and orientation on recently deglaciated bedrock outcrops near the Fairweather Fault system and near the Juneau Icefield. Field observations show that near faults with high displacements (the Fairweather Fault region), bedrock cohesion varies across two orders of magnitude in fault zones up to 2 km across. Outside the active fault zone (the Juneau Icefield), weakening is less pronounced and occurs in smaller regions. This pattern supports our assumption that the range in cohesive strength is due to tectonically controlled processes.

EVA measures elevation variance between a specific point on a digital elevation model and every point a set radius away. The magnitude and orientation of this variation yields information about controls on topography.

EVA results (Fig.1) for the study areas show that the Fairweather Fault region has high magnitude anisotropy with orientation trends that reflect tectonically controlled topography. In contrast, the Juneau Icefield region has low magnitude anisotropy without orientation indicating tectonic control. Using more complex cohesion estimates based on these results in erosion models may increase the accuracy of outputs.

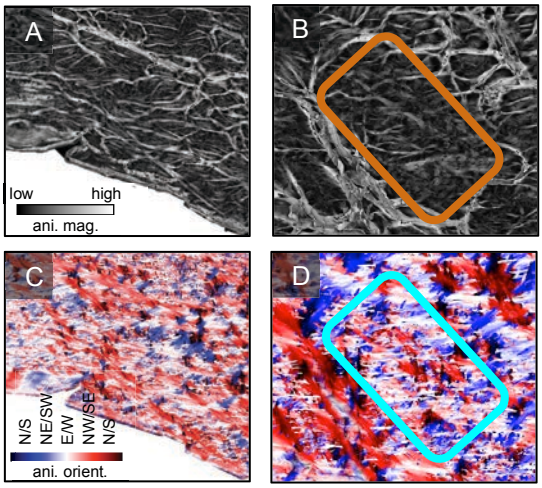

Fig. 1. Anisotropy magnitude (top) and orientation (bottom). Fairweather Fault region (A, C) shows high magnitude and strong NW-SE trends in red. Juneau Icefield region (outlined in the middle of images B, D) shows low magnitude and no trends.

Acknowledgements: Research funded by the Dan and Betty Churchill Fund for Exploration, the Juneau Icefield Research Program, and NSF Grant 1250130 to P. Koons, B. Hallet, and S. Birkel.

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Compositional, Textural, and Chronological Evaluation of Mortar at the Nadin-Gradina Archaeological Site, Croatia

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Abstract: The Nadin-Gradina Archaeological site in Croatia reflects an occupational history from the Iron Age to the later Middle Ages (ca. 400 BCE -1700 CE). This relatively continuous record provides insight into human interactions within the landscape for thousands of years. This study investigates potential changes in the composition and texture of mortar from the site, in order to construct a chronological system of changes in building technology through time.

Project Goals:

The roughly 2500 year span of occupation at Nadin-Gradina has resulted in various building styles and materials, revealed during excavation, and includes a decrease in quality between the Late Antique and Middle Ages, as exhibited by lack of carefully cut stone, reused materials, and coarsening of mortar materials. Archaeological excavation of these mortar materials took place near the summit of the hill fort and was composed of five units placed across the site (Figure 1).

Fig. 1. Location of excavation pits at Nadin-Gradina.

Samples were analyzed using an optical scanning electron microscope (SEM) and energy dispersive x-ray analysis (EDAX). Textural properties of the material were analyzed using sedimentological grain size measurements of the aggregate present in the mortar samples. Seven mortar samples were collected from wall surfaces in units B,C, and D, and ten samples were taken from the standing Ottoman walls.

Results:

The proportion of $CaCO_3$ matrix to aggregate and the sand and gravel portions of the aggregate were compared across three main cultural phases: Early Roman, Late Roman/Antique, and Ottoman periods (Figure 2).The Early Roman and Late Roman/Antique samples have comparable $CaCO_3$ averages, 58% and 49% respectively, while the Ottoman samples averaged 77% $CaCO_3$.

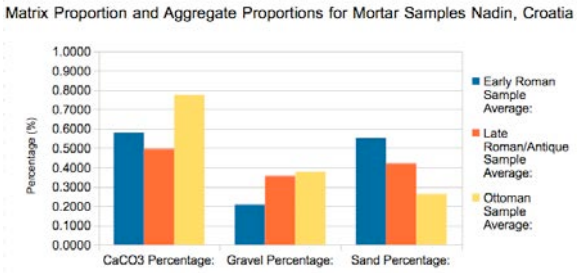

Fig. 2. Matrix and Aggregate Proportions for samples.

Future Work:

Variation in composition does exist between the mortar samples of cultural phases at Nadin-Gradina, however, the variation between values is not distinct enough to show a drastic change in building methods, particularly between the Early Roman and Late Roman/Antique periods. Future research will seek to use these same techniques to compare the textural and compositional differences between floor or fresco plaster of these same periods, as well as potential structural differences between mortars of varying matrix and aggregate proportions.

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Deciphering the Terrestrial Response to Stadial Conditions in the North Atlantic

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ABSTRACT: During the last glacial-interglacial transition, pronounced climatic disturbances now known as Heinrich Stadials interrupted the pattern of progressive warming. In the tropics and southern mid latitudes, Heinrich Stadials are increasingly associated with rapid warming and deglaciation, potentially linked to a dynamic interplay between Earths wind belts and ITCZ and the tropical Pacific Ocean. In contrast, the effect of these events on the Northern Hemisphere climate is less clearly defined. By one model, stadials are characterised by an abrupt return to almost full-glacial conditions, particularly in the North Atlantic, resulting in regrowth of ice sheets and glaciers. An alternative view invokes boreal warming and deglaciation during stadials, despite apparently cold conditions in the North Atlantic Ocean itself. To explore this problem of the manifestation of stadials, we are building a glacial record for the British Isles constrained with cosmogenic ^{10}Be surface-exposure dating. Our new data set, consisting of 19 ages, aligns with the second model, suggesting that Heinrich Stadials were characterised by extensive deglaciation and, thus, warming.

Project Goals:

We seek to understand how stadial events in the North Atlantic basin were manifested on land and, specifically, how these abrupt climate perturbations impacted the cryosphere. The North Atlantic is widely held as a key component – if not the driver – of abrupt climate change yet accounts of how this region behaved during the late-glacial period are conflicting, with strong arguments both for and against stadial cooling and renewed ice growth. Our investigation focuses on the Scottish Highlands, where exquisitely preserved glacial landforms afford the opportunity to reconstruct stadial cryospheric behaviour as a proxy for atmospheric temperature immediately adjacent the North Atlantic Ocean. Our field site is An Teallach ("the Forge"), a massif in NW Scotland where the bedrock is suitable for cosmogenic ^{10}Be surface-exposure dating. During the 2015 field season, we collected 40 samples from glacial moraines and thus far have measured 20 to provide a preliminary picture of glacier-climate evolution between the last glacial maximum (LGM: ~20,000 years ago) and the latter part of the late-glacial period.

Initial Results:

Twenty ^{10}Be ages show (i) that the last British Ice Sheet had retreated from its LGM margins on the outer continental shelf to within the cirques of An Teallach by ~15.5 Ka and (ii) that a subsequent, short-lived regrowth of ice peaked at ~13.1 Ka. Together, these data suggest both that the majority of the ice sheet was deglaciated during Heinrich Stadial 1 (18.3–14.7 Ka) and that there is no evidence for renewed glaciation during Heinrich Stadial 0 (12.9–11.6 Ka). Viewed in a global context, our data set suggests that the cryospheric response in NW Scotland to stadial conditions was similar to that of the tropics and of southern mid latitudes.

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Do Nitrogen Subsidies in Glacier Meltwater Modify the Response of Alpine Lakes to Abrupt Warming?

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Abstract: Rapid climate warming in alpine regions of the northern hemisphere has enhanced glacial meltwater inputs to alpine lakes over the past century. Glacier meltwater in the Beartooth Mountains contains high nitrate concentrations. Nitrate enrichment may decrease coherence of historic algal community changes within and across lake chain systems.

Alpine glaciers are sensitive to small changes in air temperature and glacier meltwater inputs to lakes have increased over the past 100 years because of rapid alpine warming. Alpine glacier meltwater can contain high nitrate concentrations that increase primary productivity and decrease phytoplankton species richness in glacially fed (GF) lakes (Slemmons and Saros 2012). In a GF lake chain in the Beartooth Mountain region of Montana, sediment records indicate that nitrate enrichment of the headwater (Jasper Lake) started ~1000 ya (Slemmons et al 2015). In 2015, we conducted an expedition that determined nitrate concentrations are elevated in other GF lake chain systems across the Beartooth region compared to snow fed (SF) lakes (Figure 1). This area is therefore ideal to study regional-scale effects of climate warming on GF lakes with elevated nitrate.

Coherence describes the degree of temporal variability of lake responses across a landscape to a regional-scale driver, such as warming. In this study, the response variable is algal community change, which is an important ecological indicator of broader environmental transition. Evidence suggests changes in energy inputs to lakes (i.e., irradiance) increase coherence, whereas material inputs (i.e., nutrients) decrease it (Vogt et al 2011). Glacial nitrogen enrichment is a material input. Therefore, GF (high nitrate) lakes likely have less coherence than SF lakes. We pose two questions: 1. Does glacial nitrate enrichment decrease coherence of past algal community shifts in affected lakes in response to abrupt climate warming? 2. Do lakes within the same chain have greater coherence of past algal community changes than lakes between chains?

To address these questions, we will measure algal community change over time using diatom fossils and phytoplankton pigment remains. Almost 50% of Earth's freshwater supply comes from glaciers in alpine regions experiencing rapid warming. Therefore, understanding the coherence of GF lake ecological responses to temperature is important to water security in the 21st century. This research is also timely because Rocky Mountain alpine glaciers are predicted to disappear in the next few decades.

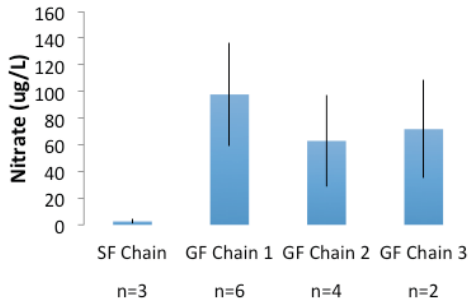

Fig. 1. Average nitrate concentrations of Beartooth Mountain lake chain systems. SF = snow fed, GF = glacially fed, n indicates the number of lakes. Error bars indicate ± SD.

Acknowledgements:
The Gokcen Fund and an A2C2 IGERT fellowship are funding this research.

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Toward a Domain-Specific Language for Patterns in Ice-Core Data

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Abstract: We describe a language for expressing simple patterns in time series data derived from ice-cores and similar sources. Such patterns use simpler features mapped to tokens by an earlier phase of analysis. In turn, they allow more complex features to be expressed and analyzed.

Introduction. Technological improvements in analysis of ice cores (such as laser ablation) are yielding datasets that are orders of magnitude larger than before. Effectively using these datasets requires tools that are qualitatively different from those that suffice for smaller datasets. Ongoing work in the *P301* project is developing tools to partly automate tasks, such as pattern matching and inference, that are likely to assist in scientific discovery, as part of a larger effort to address this problem. Here, we address a small component of this effort, viz., the specification and detection of simple patterns in time series datasets. In particular, we define a small, embedded domain-specific language for specifying patterns. These patterns are intermediate constructs that build on simpler constructs such as tokens derived from the original datasets. In turn, patterns are used to express more complex constructs.

Benefits. Such layering of concepts has the significant benefit of enabling efficient implementation that would be unlikely to result from a direct implementation of complex constructs. A well-defined pattern language enables precise and concise specification of data characteristics being studied. Further, the patterns specified in this manner, and the constructs they enable, provide a documentation of scientific conventions and procedures. For brevity, the sequel describes only a very a simple example of the realization of some of these ideas.

Tokens. Following prior work, we tokenize the time series for a single measure (e.g., SO4) into tokens representing peaks, valleys, increases, decreases, or flats within predefined windows. A (simple) token such as P.CO2 represents a peak (P) in the CO2 series. A compound token such as P.CO2|D.SO4|F.d18O denotes the concurrent (within token resolution) peak in CO2, decrease in SO4, and flat in d18O.

Patterns. The core of our pattern language is, essentially, a regular-expression language over strings over the alphabet of compound tokens. For example, consider this pattern from Nathan Dunn's thesis (expressed in his notation): SO4^ ~ d18O/ : [5, 10]. Using the SRE flavor of regular expressions, we may write:

(: “P.SO4” (** 4 9 any) “I.d180”)

Another, more complex, example from the thesis is { Fe^ ~ (O2/ \cap CO2\) : [1,2] } ~ d18O/ : [5,10], which we may express as:

(: “P.Fe” (** 0 1 any) (and “I.O2” “D.CO2”) (** 4 9 any) “I.d18O”)

Implementation. The above use of a token-like syntax, such as P.CO2, may be mapped to the regular expression language by viewing it as short-hand for a very verbose expression of the form

(or "P.CO2.|I.Fe|...|..." "P.CO2|P.Fe.|...|..." ...)

assuming a setup with four time series. Mapping our pattern language to regular expressions, which have been studied extensively in both theoretical and practical contexts, allows us to use any of several mature and optimized libraries for the computationally intensive task of matching the patterns to large datasets. For instance the very large or-expression may be mapped to an efficient implementation of character sets.

Acknowledgements. Supported in part by US NSF grant EAR-1027960. Work benefited from earlier joint work with Nathan Dunn, reported in his honors thesis (U. Maine, 2015), and from interactions with the P301 group.

Niche Evolution Across a Gradient of Ecological Specialization

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Abstract: Elucidating factors that determine species' ranges is a central question in ecology and evolutionary biology. A species range is broadly defined as it's niche, a set of biotic and abiotic conditions in which a species can persist. Species that specialize on a narrow set of resources may be better able to outcompete rivals for those resources. However, this competitive advantage may come at a cost over the long-term, whereby specialists have a reduced ability to adapt to a changing environment. Hence, specialists are often thought to be more vulnerable to rapid environmental change. We know a species' niche can vary over space and time, yet factors that determine niche breadth, or degree of specialization, remain poorly explored. We will determine if niche breadth is correlated across niche axes to determine how niche evolution is constrained.

Introduction:

Ecological specialization is often synonymous with narrow niche breadth, resulting from trade-offs between competitive ability and adaptive capacity (MacArthur 1972, Futuyma 2001). Specialization is often a key concept in predicting adaptive response of populations to fluctuating environments (Levins 1968), and is associated with recent population declines (Correll 2015). However, a species niche breadth can be defined along multiple dimensions, or niche axes (Hutchinson 1957), and most species are likely specialist on some axes and generalist on others (Poisot et al. 2011). Yet, specialization is rarely quantified across several ecological niche axes, and the degree to which niche breadth is correlated among niche axes has received little attention (Bonetti and Wiens 2004).

We will explore factors that facilitate or constrain niche evolution by quantifying niche breadth across morphological, physiological, behavioral, and habitat-specific traits. This information will help elucidate if niche evolution is constrained by endogenous (narrow niche breadth across multiple traits) or exogenous (limited by narrowest environmental axes) factors

Tidal marshes provide an ideal system to explore factors that constrain niche evolution. They are highly productive, yet high salinity and daily tidal inundation pose a barrier to colonization. Six species of Emberizid sparrows have colonized tidal marsh habitats at different time scales (and thus show variation in the degree of specialization within tidal marsh habitats). These species also show convergence in a suite of traits to deal with the unique adaptive challenges. Tidal marshes further possess a gradient in salinity and tidal influence that varies systematically with distance upriver. Thus, traits measured across this gradient may reflect associations between habitat characteristics and organismal ability to both occupy a wide array of environments (i.e., generalism) and possess adaptations for specific environmental challenges (i.e., specialism). This information will help elucidate if niche evolution is constrained by endogenous (narrow niche across multiple traits) or exogenous (limited by narrowest axes) factors.

Acknowledgements: Funding for my research has been provided by the U.S. Fish & Wildlife Service and the University of Maine.

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Conditions for Collective Action and Cooperation to Enhance Adaptation to Abrupt Climate Change in Chile's Territorial Use Rights in Fisheries Policy

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Abstract: Fisheries policy often assumes fishers act within homogenous social, economic, and ecological situations which reinforces poverty, excludes fishers from the political process, and makes them vulnerable to abrupt climate change (ACC) impacts. Chile's management policy, TURFs, offers a solution to this by devolving some rights and responsibilities to fishers, yet the policy continues to have disparate outcomes. This research examines the conditions under which fishers act collectively and sustain cooperation to enhance adaptation to ACC.

Project Goals:

This project examines the conditions under which small-scale fishers in Chile's Territorial User Rights in Fisheries (TURFs) act collectively to form and sustain local institutions to enhance adaptation to Abrupt Climate Change in Chile's coastal zone. Chile faces ACC impacts that may cause marine ecosystem regime shifts and irrevocably harm the gastropod *Concholepas concholepas* (*loco*) on which fishers depend as a primary source of income.

Fig. 1. Fishers in Caldera process *piure*, a tunicate.

Chile is home to over 90,000 small-scale fishers who are given access rights and form local institutions that design management plans with the state.[1] Rights-based co-management of marine resources intends to ensure social, ecological, and economic vitality of Chile's coastal communities.

However, the policy has had disparate outcomes; some TURFs succeed while others struggle and fail. Fisheries policy often assumes fishers act within a homogenous geographical and socioeconomic space which can make fishers vulnerable to climate change.[2] Thus it is essential to understand under what conditions fishers make decisions and cooperate in order to create policy that is adaptive and supports diverse epistemologies, patterns of behavior, and sociocultural norms.

Figure 2. Fishers repair boats in Estaquilla.

This research is in its preliminary phases, but aims to use mixed methods to look at three TURFs with varied outcomes; operating, operating in doubt, and failed, to examine; the factors that contribute to institutional formation and sustained cooperation, fishers' perceptions of resilience and adaptation, and fishers' adaptive strategies to cope with ACC impacts.

Acknowledgements: Advisor, Dr. Christine Beitl. NSF Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Using Diverse Proxies to Study Climate Change at Nevada Coropuna Volcano, Peru

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Abstract: Nevada Coropuna in southern Peru is a high elevation volcanic complex with one of the largest tropical glacier masses on Earth. It is a critical water source for >100,000 people, who are also at risk from a variety of hazards from future volcanic eruptions. We are conducting a multi-proxy study of the climate history at Coropuna by examining modern-day changes in ice extents, century-scale changes in climate using cores of lake sediments, and millennial-scale changes by identifying ice-contact lava flow deposits. Integration of information from these studies will provide constraints on climate across a broad-range of time-scales to help better understand the processes that control climate in this part of Peru.

The Coropuna volcanic complex in southern Peru has a unique range of climate proxy records, including long-lived ice, lake sediment records, and ice-contact volcanic deposits. In June 2015 we began a collaborative study at Coropuna in conjunction with the Peruvian volcano observatory (OVI) to catalogue the variety of proxies that record climate around the complex. We are presently focusing on studies of each of these three areas to investigate changes in climate for this high-altitude, tropical location.

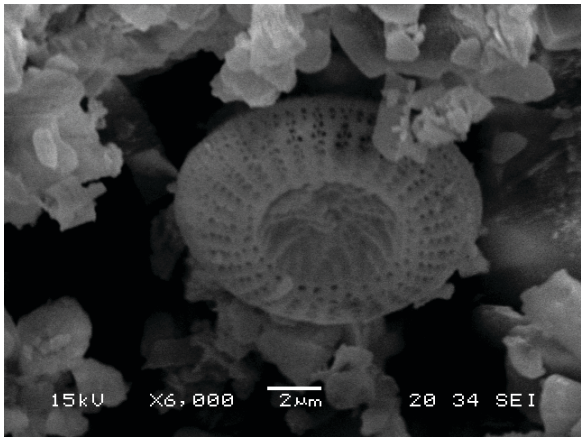

Fig. 1. Diatom in layer of volcanic ash deposited in Lago Pallarcocha at the western end of the Coropuna volcanic complex.

At the decadal time-scale, we have used the LandSat archive to identify changes in ice extent at the complex for 30+ years. See presentation by Kochtitzky et al (this symposium) for details. This study shows that ice loss is apparently slower than many previous estimates. Its short time-scale provides a high resolution base for understanding processes that inform longer term changes.

We also collected two lake sediment cores from Lago Pallarcocha, which is a small high altitude lake located at the western end of the volcanic complex. The cores were subsampled at 0.5 cm increments in the field, and both cores contain a distinctive layer of volcanic ash that has been correlated with the 1600 AD Huaynaputina eruption from southern Peru. Assuming constant sedimentation rates, this means that the 20+cm cores likely record deposition in the lake for the past 2000 yrs. We are conducting detailed diatom population surveys through the core, sediment size analysis measurements, Loss-on-Ignition measurements, and identification of mineralogical variation throughout one of the cores. Preliminary results show possible changes in lake circulation regimes as well as changes related to deposition of the ash layer.

We also have begun a longer-term study to identify volcanic deposits formed by glaciovolcanic eruptions. Several lava flows on the western flank have textural characteristics indicating the presence of ice when lava flows were emplaced. Once ages are obtained from these lavas we will be able to document significant changes (expansions of several kms) in the Coropuna ice over time-scales of 10,000+ years.

Our studies will have important implications for present-day climate adaptation planning, understanding ancient societal climate adaptation, and improve plans for future volcanic hazards.

Acknowledgements: This project is funded by Dickinson College and the Churchill Fund.

What is Driving Range Expansion of Vector Deer Ticks in Maine, USA -- Climate, Hosts, Habitat, or Human Behavior?

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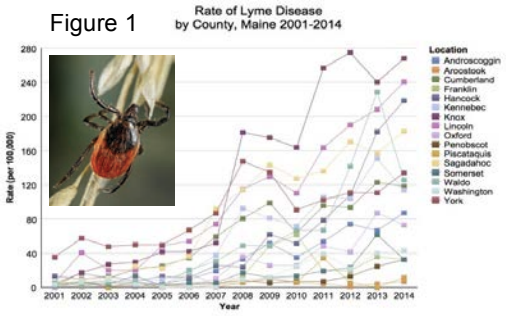
Abstract: In 2014 Maine had the highest incidence of Lyme disease among US states (88 cases per 100,000). Incidence is higher in mid-coast counties and higher yet on off-shore Maine islands. Lyme and other tick-borne illnesses (anaplasmosis, babesiosis) are correlated with deer tick abundance. On a univariate basis, deer tick abundance is correlated with warm winters, wet summers, deer, invasive plants (such as Japanese barberry), and human behavior, manifested as resistance to tick control strategies and clashing values over resource management. Models will explain relative contribution of climate, hosts, habitat, and humans and inform adaptation.

Project goals

The goals of the research are to predict the range expansion of the deer tick in Maine through 2050, and inform adaptation and resilience to the threat of vector-borne disease through informed policy-making.

Lyme borreliosis and other tick-borne diseases are spreading in both North America and Europe, following contemporary climate warming and northward range expansion of vector Ixodes ticks[1]. Lyme disease cases in Maine have risen dramatically (Fig. 1) since the first case in 1983. In 2014 Lyme incidence in Maine was greater than in any other state (88 per 100,000 people), still greater in the mid-coast counties (268/100K) and astronomically high on some off-shore islands (up to 2,693/100K). Lyme is correlated with temporal statewide range expansion of the vector deer tick, *Ixodes scapularis*[2].

Figure 1



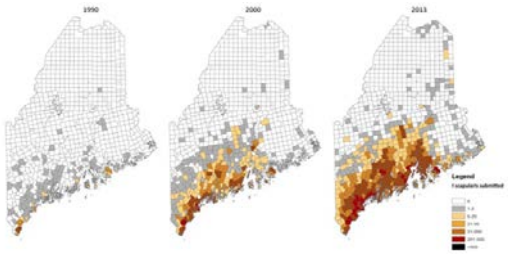


Figure 2. Range expansion of the deer tick

Tick-borne human and veterinary illness is tied to white-tailed deer density, habitat, and human behavior. Research objectives are to 1) use a Bayesian hierarchical spatiotemporal model to determine relative contributions of climate, hosts, and habitat 2) use weather forecasting models to predict future tick abundance, and 3) through an island case study, ascertain attitudes toward tick control.

Initial Results

Deer tick abundance is correlated with warm winters and wet summers. Warmer winters allow completion of the tick life cycle at higher latitudes, and rain events rescue nymphal ticks in summer from desiccation.

Acknowledgements: This research is supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423. Any opinions, findings, conclusions or recommendations expressed are those of the authors and do not necessarily reflect the views of the NSF.

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Estimating Freshwater Fluxes from Ice Mélange in Glacial Fjords

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Abstract: Icebergs calved from marine-terminating glaciers account for nearly half of the recent mass loss from the Greenland Ice Sheet. These icebergs act as a distributed source of freshwater as they traverse fjords. Despite their potentially significant freshwater contribution to fjords, their meltwater fluxes are unconstrained by observations. Here we show preliminary meltwater flux estimates derived from repeat satellite remotely sensed images for two major Greenland fjords.

Iceberg discharge from the Greenland Ice Sheet has increase over the last two decades, likely in response to increased surface and submarine melting driven by warming air and ocean temperatures[1]. Although a portion of the freshwater stored in the icebergs is exported to surrounding ocean basins, a potentially large fraction of the iceberg meltwater is released as the icebergs traverse Greenland's kilometers-long fjords. An increase in iceberg meltwater fluxes to glacial fjords due to an increase in iceberg abundance or warmer water temperatures may influence fjord stratification and circulation. Thus, in order to understand ice-ocean interactions in glacial fjords, it is imperative that spatio-temporal variations in iceberg freshwater fluxes are quantified. We expand upon our earlier analysis of iceberg melt rates obtained from repeat stereo satellite images to estimate freshwater fluxes from the ice mélange (i.e., matrix of icebergs, bergy bits, and sea ice) in Sermilik and Ilulissat fjords in East and West Greenland, respectively.

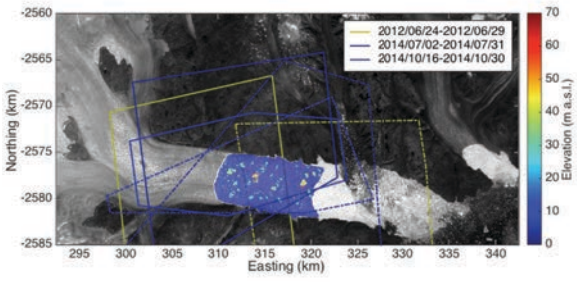

Fig. 1. High-resolution DEM overlain on a Landsat image of Helheim Glacier/Sermilik Fjord. Colored lines outline DEM footprints for each date pair.

For each fjord, we construct repeat high-resolution digital elevation models (DEMs) from stereo satellite images. We use observations of iceberg size and surface elevation within the portion of the mélange area covered by the DEM and the full mélange area measured in near-contemporaneous Landsat images (Fig. 1) to estimate the submerged area of the mélange. The freshwater flux from the mélange is then calculated as product of the submerged area and the averaged iceberg melt rate, which is obtained using a DEM-differencing approach[2].

We find that the freshwater flux from ice mélange may exceed the surface meltwater flux over the entire glacier area for most of the year. However, we also find that freshwater fluxes vary considerably with changes in submarine melt rates and the submerged iceberg area over weekly to inter-annual time scales. Based on these results, we suggest that models of glacial fjords must take iceberg melting into account. Further, we recommend that glacier submarine melt rates are interpreted with extreme caution if inferred from hydrographic observations collected down-fjord of icebergs.

Acknowledgements: This project is funded by NSF award ANS1417480 to E. M. Enderlin.

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Whole-Watershed Experimental Acidification Validates Regional Evidence for Initial Forest Soil Recovery in the Northeastern U.S. and Canada

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Abstract: Significant declines in atmospheric sulfur and nitrogen deposition have resulted from changes in policy and technology that reduced emissions from fossil fuels. Evidence in Europe and the U.S. is demonstrating an emergent recovery of surface waters from acidification, but evidence has been absent for recovery in soils. This year a collaboration of long-term research sites in eastern Canada and the northeastern U.S. reported the first evidence of soil recovery. In addition, the long-term watershed manipulation study at the Bear Brook Watershed in Maine (BBWM) provided experimental support for the interpretation of the empirical regional results.

Policy changes such as the U.S. Clean Air Act, and improvements in technology, have resulted in dramatic declines in atmospheric deposition of acidifying pollutants. For example, in Acadia National Park, sulfur deposition has declined 70% and inorganic nitrogen deposition has declined 37% since 1980 (1). This has resulted in improvements in surface water quality in the affected regions (2). To determine whether there was evidence of recovery in soils, participants in the Northeastern Soil Monitoring Cooperative evaluated soil data from 27 forested watersheds in eastern Canada and the northeastern U.S. with a history of soil resampling (3). Significant trends were reported for decreases in the concentrations of exchangeable aluminum in the O horizon, and increases in pH in the O and B horizons. One site in the network, BBWM, also includes a paired whole-watershed acidification experiment that allowed the researchers to test what a lack of recovery would look like. Figure 2 shows soil aluminum concentration changes over time for all sites together, as well as the reference and experimentally acidified watersheds at BBWM. For both forest types in the experimentally acidified watershed, there was no evidence for declines in exchangeable aluminum. However, the reference watershed conformed to regional trends, providing experimental support for empirical evidence of a linkage between soil recovery and declines in acid deposition.

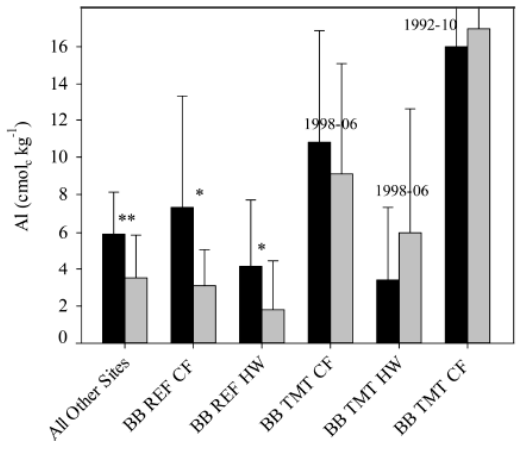

Fig. 2. Mean exch. Al concentrations in O horizons for initial (black) and final (gray) collections for resampling studies at Bear Brook (BB) and all 27 regional sites. HW=hardwoods, CF=conifer forest, REF=reference watershed, TMT=treatment watershed. From Lawrence et al. (2015).

Acknowledgements: This research is supported by the Maine Agricultural and Forest Experiment Station and the National Science Foundation.

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Elevated Dust Inputs to SW Greenland Lakes: Effects on Surface Water Dissolved Organic Carbon Concentration and Quality

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Abstract: Recent declines in dissolved organic carbon (DOC) concentration of southwest Greenland lakes have important implications for lake ecosystem function. Increases in regional glacial outburst flooding, concurrent with the observed changes in DOC, are likely magnifying proglacial dust activity and extent. It is well-known that iron (Fe) oxides, which are present in proglacial dust, can bind to humic DOC and precipitate from the water column, effectively reducing DOC concentration. We performed experiments to explore the effects of dust addition to lake water DOC concentration and quality.

Saros et al. (2015) discovered that DOC concentration in a group of study lakes in SW Greenland has declined by 14-55% in the period between 2001-2003 and 2011-2014. This shift is DOC may be an indicator of broader climate-mediated trends that are affecting lake catchments and is important for lake ecosystem function (Williamson et al. 2009)

Between the periods of 1979-2000 and 2007-2012, surface air temperatures in Greenland increased by almost 3˚C (Mayewski et al. 2014). This surge in temperature is likely a key driver of the increased frequency of glacial outburst flooding from the Russell Glacier. The glacial till left behind after floodwater recession is easily deflated, and can be transported long distances as dust. Dust in this region is known to contain Fe, which can bind to some fractions of humic DOC, flocculating and then precipitating from the water column.

We performed experiments to determine how dust additions to lake water impact DOC concentration and quality. We added dust to filtered water from three lakes, and incubated the treatments in ultraviolet (UV)-exposed conditions and in the dark. DOC concentrations increased in UV-exposed conditions, regardless of dust addition, indicating an additional source of DOC production, i.e. microbial. Absorbance at 254 nm decreased in UV-exposed conditions (Figure 1), signifying a decrease in DOC aromaticity, which indicates a shift in source of DOC from terrestrially-derived to microbially-derived.

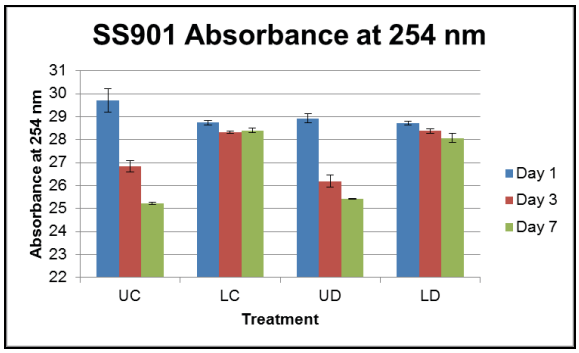

Figure 1. Absorbance at 254 nm of dust treatments and controls throughout experiment.

Acknowledgements: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Testing for Biotic Feedbacks in Tidal-marsh Community Stability in the Face of Sea-level Rise

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2. *Bird Group, Maine Department of Inland Fisheries and Wildlife.*

Abstract: The persistence of insectivorous birds in tidal marshes is unlikely in the face of rapid sea-level rise. It is unclear, however, how their loss will influence the broader tidal-marsh ecosystem. In the summers of 2014 and 2015, we conducted predator-removal experiments in Northeastern US tidal marshes to test if the exclusion of avian predators would result in measurable changes in lower levels of the food web. Birds are considered important top predators in marsh food webs, and we report the changes in both invertebrate abundance and plant biomass as measures of direct and indirect effects.

Introduction:

Tidal-marsh songbirds face an imminent threat of extinction this century with sea-level rise (Hodgman et al. 2015). The effects of losing these species from the marshes are unclear. Food webs shape the structure of ecological communities through direct and indirect interactions. The loss of an invertebrate predator, like these birds, can trickle down to the plant community by influencing when and where herbivores forage and the magnitude of herbivory damage to the plant. Further, the ability of tidal marshes to maintain elevation in the face of sea-level rise is partially determined by the production of plant biomass (Donnelly & Bertness, 2001). Removing avian predators from this system may therefore alter plant biomass through indirect species interactions (a trophic cascade) and affect the resiliency of tidal marshes to climate change. To test the impact of the sparrow's absence in local food webs, we constructed avian exclosures in eight tidal-marsh systems along the Northeastern US coast. We measured temporal changes to invertebrate communities after excluding avian predators. For evidence of trophic cascades, we measured vegetation biomass.

Preliminary results show that exclosure plots have higher biomass than paired control plots (Figure 1: pvalue < 0.05), and investigations into changes to the invertebrate community are ongoing.

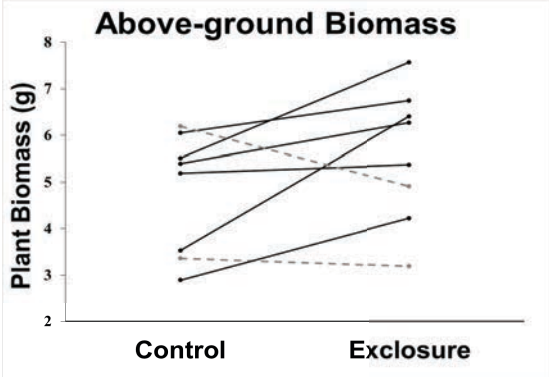

Figure 1. Above-ground plant biomass (ash-free dry mass) collected at eight tidal marshes across the Northeastern US. Lines connect values gathered at predator exclusion and control plots for the same sites. Biomass was higher (black solid lines) in the exclusion plots for six of the sites and lower (gray dashed lines) in two.

Acknowledgements: Funding for my research has been provided by the U.S. Fish & Wildlife Service and the University of Maine.

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Developing a Validated Long-term Satellite-based Albedo Record in the Central Alaska Range

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Abstract: Mountain glaciers around the world, particularly in Alaska, are experiencing significant surface mass loss from rapid climatic shifts and constitute a large proportion of the cryosphere's contribution to sea level rise. In-situ albedo measurements from our 2013 field season on the Kahiltna Glacier (Denali National Park, AK) validate the use of satellite-derived albedo values. We examine the relationships between surface albedo and glacier mass balance.

Surfaces with high reflectance values within the cryosphere such as seasonal snowpack, glacial snow and ice, and sea ice play a vital role in the global climate system and in the energy budgets of the world's glaciers. Changes in reflectance may induce feedbacks resulting in fluctuations of glacier mass balance. My objective is to understand glacier response to climate forcing by using surface albedo as a proxy for mass balance.

To understand the relationship between surface albedo and mass balance, we used an ASD. Inc. FieldSpec4 Standard Resolution spectro-radiometer to measure incoming solar radiation, outgoing surface reflectance and optical grain size on the Kahiltna Glacier and at the Kahiltna Base Camp for seven days during our 2013 field season in Denali National Park.

We derive surface albedo using the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43A3 Albedo Product, a 16-day composite with 500-meter resolution. Comparisons are made between ASD FieldSpec4 ground measurements and MCD43A3 imagery to assess the ability of MODIS to capture the variability of surface albedo across the glacier surface. The MCD43A3 albedo product performs well at Kahiltna Base Camp, but low biases in MODIS albedo appear to occur along the Kahiltna Glacier due to the snow-free valley walls being captured in the 500m MODIS footprint. Incorporating Landsat imagery will strengthen our interpretations and has the potential to produce a long-term validated satellite albedo record for steep and mountainous terrain. Once validation is complete, we will compare the satellite-derived albedo record to the Denali Ice Core accumulation rate, aerosol records, and glacier mass balance data.

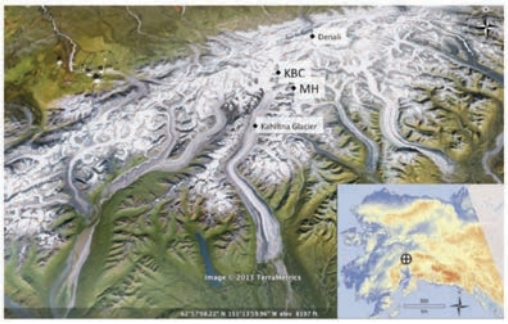

Fig. 1. Google Earth image of study locations: Kahiltna Base Camp (KBC- 2105 masl), and Mount Hunter (MH- 3910 masl). Kahiltna Glacier and Mount McKinley (Denali) also noted. Insert map (from Campbell et al., 2012) shows the Central Alaska Range (circle-plus symbol) on a DEM of Alaska (red is high elevation).

Acknowledgements: Funding from US National Science Foundation- Office of Polar Programs award 1203838 to K. Kreutz. Logistical support provided by: Denali National Park, Talkeetna Air Taxi, and CPS Polar Services.

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A 1908-1995 Major Soluble Ion Record of Dust and Anthropogenic Pollutants from Inilchek Glacier, Tien Shan

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Abstract: High-resolution major soluble ion records from Inilchek Glacier provide proxy records for dust storm activity and anthropogenic activities throughout the 20th century.

High-resolution major soluble ion records (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^- and SO_4^{2-}) covering the period 1908-1995 AD from the Inilchek Glacier, Tien Shan, Kyrgyzstan provide detailed 20th century climatic and environmental proxies. Chemical concentrations, EOF analyses and non-crustal excess calculations were used to identify natural and potential anthropogenic inputs. Dust proxy species (e.g. Ca^{2+}) reveal declining decadal trends, likely reflecting regional dust storm activity in central Asia post 1950, that has been associated with coupled atmospheric circulation variability and human activities [1,2]. Comparison between Ca^{2+} and ERA-interim climate reanalysis data indicates a strong relationship to spring surface pressure patterns in northwest China and the position and potential strength of the Siberian High. Non-crustal contributions (excess) estimates of NO_3, SO_4^{2-}, K^+, and Cl^- concentrations suggest discernable anthropogenic inputs began between the 1950s-1970s and increased into the mid-1980s and early 1990s. Excess trends coincide with Former Soviet Union (FSU) consumption, production and emission of fossil fuels and fertilizers, reflecting the rapid growth of agriculture and industry, as well as economic declines in the mid-late 1980s/early 1990s. Excess-Cl^- trends reflect timings that coincide with the construction of the Pavlodar Chemical Plant and the military production of Cl_2 in Kazakhstan. NOAA HYSPLIT back-trajectory frequency analysis suggests the Fergana Valley (located in Kazakhstan, Uzbekistan and Kyrgyzstan) to be a major pollutant source.

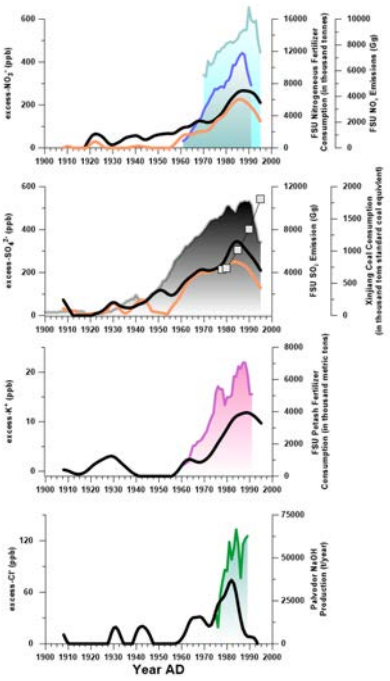

Figure 1. Comparison between Inilchek excess-ion concentrations (lines) and consumption, production and emission data from the FSU (gradients) and western China (squares).

Acknowledgements:

NSF ATM-0754644 NSF, P2C2-1401899 and NSF A2C2 IGERT DGE-1144423.

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[2] Indoitu et al., (2012). *Journal of Arid Environments*, 85, 62–70. doi:10.1016/j.jaridenv.2012.03.018.

How Do Land-Use and Seabirds Explain the Chemical Characteristics of Soil and Tussac Grass (*Poa flabellata*) in the Falkland Islands?

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Abstract: The presence of burrowing seabirds and land-use of Tussac grasslands in the Falkland Islands may explain plant biodiversity, as well as chemical characteristics of soils and plants. In February 2016, 88 plots across five locations were sampled for % vegetation cover (native vs. invasive), nutrient analysis of soil and plants, and seabird nesting density. The results will inform management and conservation efforts of degraded Tussac grasslands.

Research Description:

Seabird guano is known to support island vegetation globally (Mulder *et al.* 2011). Generally, marine-derived nutrients (i.e. nitrogen and phosphorus) of plants and soil tend to increase with seabird densities. However, there are several reasons why nutrient concentrations of plants may not increase linearly with increased seabird density across systems (Mulder *et al.* 2011). Nitrogen and phosphorus may be in forms unavailable to plants; alternately, plants may be limited by other resources (e.g. precipitation, sunlight, Ca^{2+}, Mg^{2+}, CO_2) and thus will not respond to nutrient additions from guano.

Seabirds utilize soft Tussac grass (*Poa flabellata*) peat to build nests within burrows, which are often high in organic matter. With a loss of 80% of Tussac grass habitat, and declines in seabird populations (Woods and Woods, 2006) understanding the importance of marine-derived nutrients to Tussac grasslands is critical for land-use management efforts and to the conservation of vegetation and wildlife alike.

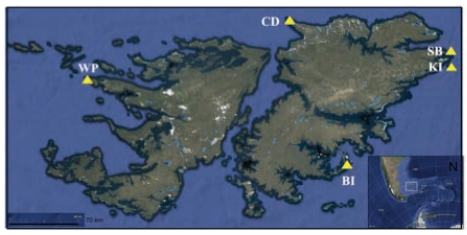

Fig. 1. Location of Tussac grasslands sampled.

Five selected Tussac grasslands represent varying land uses: seasonal rotation grazing (cattle in winter only), no grazing, historical over-grazing. At each location seabird nesting density, % vegetation cover, invasive plants, and native plants were quantified using randomized plots (5m x 5m). Soil samples will be analyzed for exchangeable nitrogen (NH4 and NO3), pH, $\delta^{15}N$, and total N, P, K. Nutrient characteristics of Tussac grasses will also be analyzed for total N, P, and K. Vegetation % cover and number of species were correlated with seabird nesting density, when possible. Preliminary results (Fig. 2) show that the number of plant species decline with an increase in the number of seabird burrows at Kidney Island.

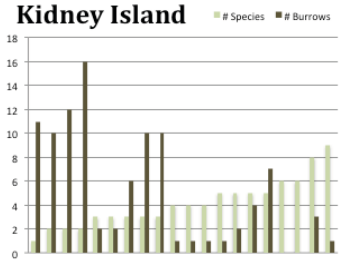

Fig. 2. Number of plant species is negatively correlated with the number of seabird burrows at Kidney Island (r^2 = -0.661, n = 20).

Acknowledgements: I gratefully thank the NSF A2C2 IGERT Fellowship, the Falkland Islands Department of Agriculture, and the South Atlantic Environmental Research Institute.

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The ATLAS System: An Autonomous Terrestrial Laser Scanner for Monitoring Large Tidewater Glaciers

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Abstract: This paper describes the development and deployment of an autonomous full-waveform, long range (6-10 km) terrestrial LiDAR scanning system for extended unattended operation (> 1 year) in a remote Arctic environment.

Tidewater glaciers draining the Greenland Ice Sheet exhibit dynamic behaviors across a range of spatial and temporal scales, posing a challenge to both *in situ* and remote sensing observational strategies. *In situ* measurements can capture variability over very short time intervals, but with limited spatial coverage and at significant cost and risk to deploy. Conversely, airborne and satellite remote sensing is capable of measuring changes over large spatial extents but at limited temporal sampling. In recent work, we have shown that long-range Terrestrial LiDAR Scanning (TLS) from fixed near-situ locations is capable of combining the rapid acquisition capabilities of *in situ* measurements with the broad spatial coverage of traditional remote sensing. LiDAR (Light Detection and Ranging) scanners have typically operated for short-duration campaigns (days to weeks) due to the technical complexity of the instrumentation, but the "snapshot" nature of observations has has limited their contribution to studies of tidewater glacier studies.

We have engineering a system that is capable of year-round unattended operation. The instrument uses an innovative 1064µm wavelength laser which has been optimized for snow and ice, and allows us to acquire multi-dimensional point-cloud measurements of a ~60 km^2 region every 6-hours. Year-round operation at high latitudes is made possible by a robust power system comprised of solar photovoltaic panels, wind turbines, methanol fuel cells, and $LiFePO_4$ battery packs. Communication and control functions are integrated with the power management, allowing for remote monitoring of system performance.

The system was deployed at Helheim Glacier, southeast Greenland in late July, 2015. Helheim Glacier is a large tidewater glacier of the Greenland Ice Sheet and the focus of a coordinated interdisciplinary program to study its dynamics and interaction with the ocean. Results from our year-round scanning instrument will provide new insights into short- and long-term ice motion and terminus behavior at temporal and spatial resolutions previously not possible.

While our primary interest is polar glaciology, ATLAS has potential applications in other remote environments for studies requiring long-term time series of high-resolution surface topography.

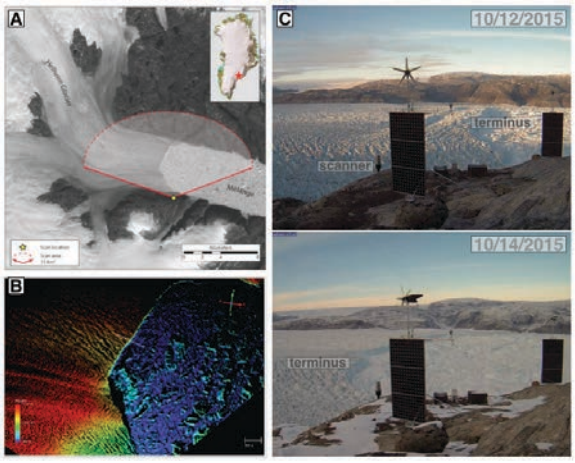

Figure 1. (a) ATLAS swath coverage over the terminus region of Helheim Glacier. (b) A digital elevation model produced by a singe scan. (c) and (d) System as deployed at Helheim Glacier, showing large terminus position changes (km-scale) over a 2-day interval.

Acknowledgements: This project is financed by the Heising-Simons Foundation, Los Altos, California.

Investigating the Human History of the Falkland Islands

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3. *Department of Anthropology, University of Maine.*

Abstract: This project aims to determine if there was a human presence in the Falkland Islands prior to European arrival in the eighteenth century and to assess the potential link between humans and the arrival time of the warrah to the islands. Using a combined approach of archaeology and paleoecological charcoal analysis, this study is the first of its kind in the Falklands and will contribute greatly to the understanding of the natural and human history of the islands.

When Europeans first arrived on the shores of the Falkland Islands they were greeted by an enigmatic canid, *Dusycion australis*, locally known as the warrah, but there were no human inhabitants present at that time. The absence of human inhabitants at the time of European arrival, coupled with a complete lack of any archaeological sites within the islands, has led to the assumption that humans had not reached the island prior to European arrival. However, the presence of the warrah, which was the only terrestrial mammal and predator native to the islands, and the discovery of multiple stone points on several outlying islands, suggest a possible alternative explanation for the human history of the Falklands.[1]

In the absence of known archaeological sites, charcoal is a useful indirect proxy for identifying a pre-colonial human presence, as background charcoal levels typically increase by an order of magnitude following initial human arrival on islands. The initial colonizers of remote islands may be few in number making it difficult to detect initial arrival through material evidence, which is where the use of indirect evidence of human activities such as landscape modification and the introduction of alien species can be revealing.[2]

During a recent expedition to the Falklands we collected several peat cores and columns from target locations throughout the islands for charcoal analysis (figure 1). Target locations were chosen based upon a combination of map surveys, landwner feedback, and paleo-landscape features that were analyzed for factors favorable for human habitation. These factors include: proximity to present day bird colonies and availability of marine resources, proximity to fresh water, availability of wind sheltered terrain, and alleged artifact locations. Finally, the availability of intact peat bogs dictated where cores were taken from.

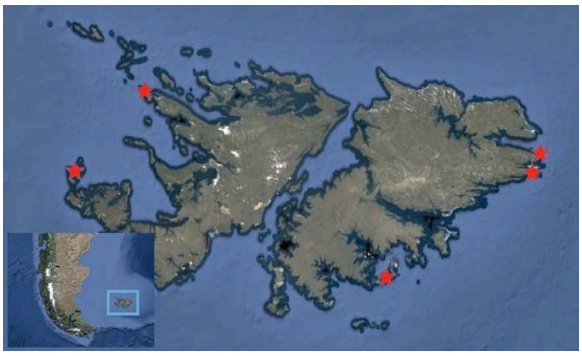

Fig. 1. Target locations where peat columns were extracted (red stars) during 2016 Falkland Islands expedition.

Acknowledgements: We would like to thank Dan and Betty Churchill, the Geological Society of America, the donors who supported our experiment.com crowdfunding campaign and the many Falklands landowners for their cooperation and support.

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A Hybrid Approach to Understanding Community Resilience in Peru

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Abstract: Unprecedented climate change (CC) impacts in the Andes pose water security issues for dependent communities throughout Peru's Santa Rio watershed. Peruvians are among those most vulnerable to CC impacts on the hydraulic system due to their increasing water dependence on rapidly disappearing alpine glaciers. While state-designed ecosystem-based adaptation (EBA) interventions are underway throughout the Peruvian highlands, they remain reminiscent of coercive management approaches that are theorized to produce unsustainable outcomes. This research project takes a multi-sited case-study approach to explore dimensions of efficacy and equity in EBA schemes in two highland communities. Additionally, the project builds on recent hybrid methodologies for assessing community resilience to CC impacts, striving to co-construct a monitoring and evaluation tool that reflects and bridges local and scientific knowledges.

Adaptation actions to climate change (CC) can be made autonomously, or without explicit planning efforts; however, little evidence suggests that this response alone will sufficiently adapt societies to intensifying CC risks. In this view, nascent adaptation policy and planning interventions are rapidly emerging across a range of geo-political scales. However, not all adaptation efforts will arrive at their intended end goals of vulnerability reduction and enhanced resilience; some will prove maladaptive, inadvertently (re)producing the vulnerabilities they aimed to redress (Marino and Ribot, 2012). While causes of adaptive policy failures are complex and not fully understood, a recent paradigm shift in environmental governance scholarship emphasizes movement away from coercive centralized management to decentralized, multilevel or hybrid governance approaches in order to achieve conservation, adaptation or sustainability goals (Lemos and Agrawal, 2006). Despite this, adaptation interventions often remain characteristic of top-down technical approaches, avoidant of local engagement.

Through a multi-sited case-study approach in the Peruvian highlands, this proposed research investigates dimensions of equity and efficacy in state-designed, ecosystem-based adaptation (EBA) efforts that seem to epitomize earlier coercive management regimes. Peruvian societies are among those most vulnerable to CC impacts on the hydraulic system due to growing state-wide water demands on a rapidly retreating glacier water supply. These ancient water towers that have served Peruvians for millennia show a rapid decline in glacier coverage of more than 25% since 1970 and are expected to completely disappear by as early as mid-century. Under these CC impacts, Peruvians are experiencing water scarcity issues across water, food, and energy sectors.

Methods: The research will employ an iterative, two-phase, mixed-methods approach with fieldwork spanning 2015 - 2017. Phase-one, consists of employing qualitative research methods including interviews, observation, and participatory action research, in order to gain contextual insights into place-based indicators of resilience, and to co-construct a resilience assessment tool merging local and scientific knowledges. Phase-two consists of developing and implementing a questionnaire to measure community resilience in two purposively sampled villages in the Peruvian highlands, aiming for insights into EBA's community resilience outcomes.

Acknowledgments: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Currents of the Past: Archaeological Evidence for Past Changes in Fish Ecology in the Gulf of Maine - Update and Review of Specialized Protocol

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2. *Climate Change Institute, University of Maine.*

Abstract: This project focuses on previously unexplored small fish remains from a series of rare Archaic-period shell midden archaeological sites along the Gulf of Maine. We have gathered archaeological samples from three sites to investigate a possible abrupt change in Gulf of Maine currents – and associated changes in fish populations – at approximately 3,800 B.P. corresponding with the disappearance of swordfish (*Xiphias gladius*) remains archaeologically.

One of the most profound changes in Gulf of Maine fisheries ecology occurred during the Late Archaic period at approx. 4200 B.P. when swordfish abruptly disappear from the archaeological record. The presence of swordfish is assumed to signal a period of warmer sea surface temperatures within the Gulf of Maine, possibly due to a shift in the Gulf Stream and an interruption of the cold-water Labrador current (Sanger 1988). Five endangered coastal archaeology sites from Frenchman Bay in Maine to the Hampton Estuary in New Hampshire preserve archaeological evidence of this possible change from warm to cold water marine fish communities *that may be the reverse of modern trends toward warmer environmental conditions*, and the associated cultural reactions. We are exploring this possible change, the degree to which it was expressed, and its broader effects on fisheries and fish ecology.

We have identified and sampled critical archaeological strata from surviving portions of three archaeological sites along the Gulf of Maine coast: the Waterside site in Sorrento, ME, the Nevin site in Blue Hill, ME, and the Seabrook Marsh site in Seabrook, NH. The Waterside site was sampled in 2013 and has been reported on previously (Heller and Robinson 2015). The Nevin and Seabrook Marsh sites were excavated during the summer and fall field season of 2015; both yielded excellent samples.

We have now completed our sampling and are moving forward with sample processing and analysis. Samples from the Seabrook Marsh site have necessitated creation of a specialized protocol to handle particular characteristics of samples recovered from a salt marsh.

The Seabrook occupation soils were covered by an accumulation of salt-marsh beginning soon after deposition and have remained submerged by ocean water during all by low tides for over 3000 years. These samples cannot be allowed to dry before processing due to increased acidification and formation of gypsum crystals as evaporation occurs. Since they must be processed wet, organics that typically would float to the surface during water processing instead sink to the bottom and are lost, requiring an alteration in processing equipment and protocol. Further, once soils have been removed, samples require fresh-water baths to remove salts before they can be allowed to dry.

Acknowledgements: We would like to thank the Archaeological Conservancy for permission and support of our investigations at the Waterside Shellheap, NextEra Energy for permission to excavate on the property of Seabrook Station, and the Maine Historical Preservation Commission for their support in our investigations at the Nevin site. This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Differential Gene Expression in American Lobster Associated with Environmental Stress and Epizootic Shell Disease Infection in the Gulf of Maine

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Abstract: The American lobster represents a major commodity throughout the species' range. However, epizootic shell disease (ESD) has become an increasing threat to the stability of the lobster fishery. We used a transcriptome-wide analysis of gene expression to evaluate the hypothesis that host susceptibility to ESD coincides with environmentally-induced physiological stress. Preliminary results indicate numerous genes are differentially expressed depending on environmental conditions and presence of ESD infection.

The American lobster (*Homarus americanus*) fishery, which represents an economically and ecologically important resource throughout the northwestern Atlantic Ocean, is currently being threatened by the spread of epizootic shell disease (ESD). An initial outbreak of ESD was first detected in Long Island Sound in the mid-1990's and was followed by the spread of ESD throughout southern New England lobster stocks, including recent expansion into the Gulf of Maine. ESD appears as disfiguring lesions on the carapace of infected individuals, consequently reducing their market value. Extreme cases can also diminish individuals' abilities to molt and reproduce, thereby potentially endangering population stability.

Environmentally-induced physiological stress has been implicated as a major contributor to host susceptibility to ESD (Tlusty et al. 2007). For instance, our research has indicated that climate change-related factors such as bottom water temperature and salinity significantly influence where the disease occurs throughout Long Island Sound. Patterns of ESD expansion also support a link to environmentally-induced stress, as the disease's northward spread has coincided with warming water temperatures along the New England coast.

We used an analyses of transcriptome-wide gene expression to evaluate whether physiological stress coincides with ESD presence. We sequenced RNA from the hepatopancreas tissue of seven lobsters from each of three groups: ESD-infected from southern Maine (i.e., presumably more stressful environment), healthy from southern Maine, and healthy lobsters from Downeast Maine (presumably less stressful environment. Initial results indicated numerous genes are differentially expressed between all sample group pairings, with the greatest number of differences evident between healthy lobsters from Downeast Maine and infected lobsters from southern Maine (Fig. 1).

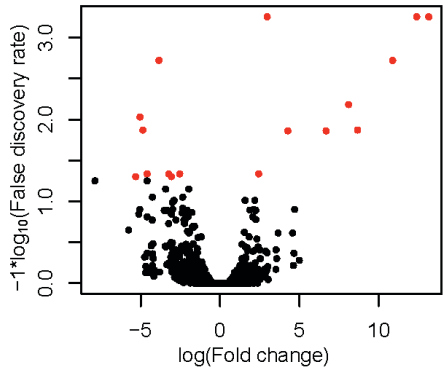

Fig. 1. Volcano plot indicating genes with significant changes in expression (fold change; red dots) between ESD infected lobsters in southern Maine and apparently healthy lobsters from Downeast Maine.

Acknowledgements: This research is supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423, US National Science Foundation project grant 1313627 and the University of Maine.

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Crevasse Extent and Lateral Shearing of the McMurdo Shear Zone, Antarctica, Using GPR and GPS Observations

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2. *School of Earth and Climate Sciences, University of Maine.*

Abstract: Lateral resistance arising from the shearing motion of the fast-moving Ross Ice Shelf (RIS) and the slow moving McMurdo Ice Shelf (MIS) likely plays a role in the stability of the western portion of the RIS. Observations of unusual crevasse geometries may be suggestive of possible weakening of the shear zone. This study incorporates GPS surveys to study the surface kinematics of the shear zone between the MIS and RIS and GPR surveys to determine crevasse location and orientation within an area of localized strain and longitudinal stretching.

The McMurdo Shear Zone (MSZ) is a 5-10 km section of heavily crevassed ice along part of the western margin of Antarctica's largest ice shelf, the Ross Ice Shelf (RIS). The stability of the MSZ, a crucial pinning point of the RIS, will likely have an impact on stresses distributed throughout the RIS in the future. In situ GPR and GPS surveys were conducted to determine crevasse extent and surface kinematics. GPS surveys spanned a 12 x 12 km grid with 29 poles surveyed over 2 consecutive field seasons. In addition, GPR surveys utilized a lightweight remote-controlled robot to tow a 200 MHz antenna within a 5 x 5.7 km grid with 50 m spacing between transects.

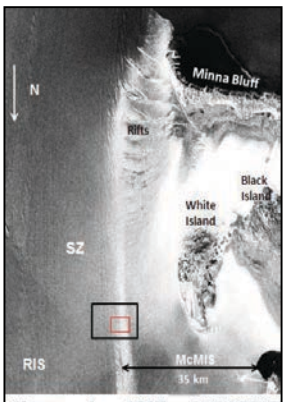

Figure 1. 1997 RADARSAT image of the MSZ. Outlines indicate the extent of GPS (black) and GPR (red) surveys

Analysis of the GPS data indicates a sharp velocity gradient across the shear zone with velocities ranging from 180 m/yr on the MIS side to 460 m/yr on the RIS side (Figure 2). Strain rates range between 0 and 0.016 yr^{-1} with crevasse initiation occurring at ~0.01 yr^{-1} which falls within the published estimates required for crevasse initiation[1]. The strongest shear strain occurs where longitudinal velocity gradient shifts from compression to stretching.

GPR analysis reveals parabolic diffractions indicative of both surface and basal crevasses. Firn crevasse strike angles typically range from 35–40° to transect direction with basal crevasse strike angles ranging from 27–50°. Spatial correspondence between near-surface and basal crevasse signatures suggests coeval fracturing.

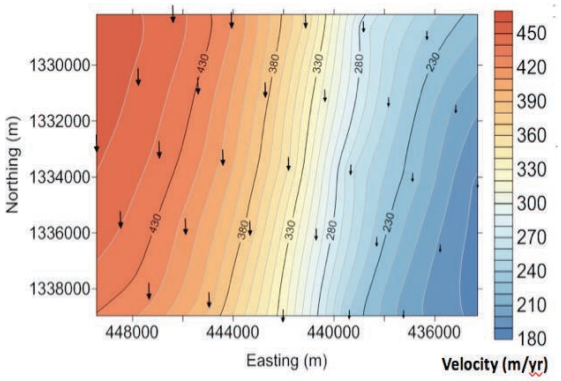

Figure 2. Velocity contours (m/yr) with overlaid vector grid. Both velocity magnitude and direction are dominated by northward velocity (downward)

Further investigation of temporal changes in crevasse extent and orientation may reveal weakening of the RIS lateral margin. Efforts to quantify this weakening and incorporate observations within an ice-sheet numerical modeling framework is currently underway.

Acknowledgements: Gratitude for the support of Dr. Gordon Hamilton, Dr. Peter Koons, and Dr. Steven Arcone with funding from the National Science Foundation grant ANT-1246400.

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Millennial-scale Reconstruction of the Last Glacial Maximum and Onset of the Termination: A ^{10}Be Chronology of the Right Lateral Moraines of the Former Pukaki Glacier, Southern Alps, New Zealand

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Abstract: The last glacial termination is the largest climate reorganization of the past 100,000 years. However, the drivers of this transition from full-glacial to full-interglacial conditions remain enigmatic. Glacial chronologies from extra polar latitudes afford insight into atmospheric temperature changes associated with the last glacial termination. The maritime glaciers of the New Zealand Southern Alps are particularly sensitive recorders of summertime atmospheric temperature. Precisely documenting when these glaciers began to recede from last glacial maximum (LGM) positions is important for addressing hypotheses for the last termination in the Southern Hemisphere. Here, we present a precise 10-Beryllium (^{10}Be) surface exposure-age chronology of glacial landforms near Lake Pukaki, central Southern Alps. This chronology documents when the ice-age Pukaki Glacier began to recede at the onset of the termination.

The Southern Alps of New Zealand are situated in the southwest Pacific Ocean and span a large latitudinal range (~40-46°S), making them ideal for studying past behavior of the southern hemisphere westerly wind belt. A working hypothesis from Denton et al. (2010) suggests the increased sea-ice extent in the northern hemisphere shifted the thermal equator south, and thereby the wind belts, during the last glacial termination. We can test this and other hypotheses of the last glacial termination by comparing an atmospheric temperature proxy to other climate records in order to determine what caused the largest climate transition in the past 100,000 years.

However, some previously published glacial chronologies of neighboring alpine systems within the Southern Alps of New Zealand afford conflicting interpretations for the timing and behavior at the onset of the termination. From the Rakaia and Rangitata systems, interpretations of surface exposure-ages indicate gradual retreat during Heinrich Stadial 1 (HS1; 18-15 ka) (Rother et al. 2014; Shulmeister et al. 2010). In contrast, multiple surface exposure-age datasets from Ohau and Pukaki valleys, and a different chronology from Rakaia valley, suggest rapid retreat initiated close to the onset of HS1, ~18 ka (e.g. Doughty et al., 2015; Kelley et al., 2014; Putnam et al., 2013).

Here I present a ^{10}Be surface exposure-age chronology of past ice extent as recorded by the right lateral moraine deposits of the former Pukaki Glacier. This chronology spans the local last glacial maximum and onset of the last glacial termination. Preliminary data indicate rapid recession at the onset of HS1, and therefore are in closer agreement with the interpretations from the studies of Doughty et al. (2015), Kelley et al. (2014), and Putnam et al. (2013).

Acknowledgements: This project was funded by the Comer Science and Education Foundation, the Quesada Family Foundation, and the NSF grant # 1102782. Project members: George Denton, Aaron Putnam, Joerg Schaefer, and Mike Kaplan. Additional field and laboratory team members: David Barrell, Roseanne Schwartz, Jeremy Frisch, Jean Hanley, and Colin Dowey.

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The Relationship Between Climate Change and the Distribution Patterns of Planktonic Diatoms in Lake Superior

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Abstract: We are investigating the ecology of key diatom species in Lake Superior that are indicators of thermal structure in smaller lakes. We are examining nearly two decades of long-term chemical and biological monitoring from several sites throughout the lake. We hypothesize that diatom indicators will have similar responses to climate in Lake Superior as they do in smaller lakes.

Introduction:
Major physical and biological changes are occurring in Lake Superior, but the relationship between the two remains a mystery. Lake Superior surface temperatures have been increasing faster than regional air temperatures, with climate implicated as potentially driving unexplained changes in the diatom community. [2]. Diatoms, microscopic algae, are ideal organisms for studying biological response to climate change since they respond quickly to environmental changes, form a major component of the Lake Superior flora, and have long been used in ecological studies. We are investigating the ecology of key diatom species in small lakes that have been used as climate indicators of epilimnion depth, the upper warm layer of lakes that forms in the summer months [3]. For example, species such as *Discotella stelligera* are associated with a shallower epilimnion (Fig. 1a), while *Lindavia comensis* is associated with an intermediate epilimnion (Fig. 1b), and *Lindavia bodanica* with a deeper epilimnion (Fig. 1 c).

Objective:
This study will help identify the role of climate in driving modern diatom changes in Lake Superior. We expect key diatoms to have similar relationships to thermal structure in Lake Superior as they do in small lakes. Results will inform the suitability of applying diatom indicators across systems of varying size, while potentially identifying new diatom indicators of climate change in large systems that may be unique or broadly applicable. This will increase our understanding of variations in diatom ecology and applicability of diatom climate indicators across systems.

Methods:
We are using monitoring data collected by the EPA since 1996 to investigate the relationship between diatoms and thermal structure. Multiple linear regressions of thermal structure and other ecological variables are being used to test previously identified diatom indicators of climate change and test potential new ones.

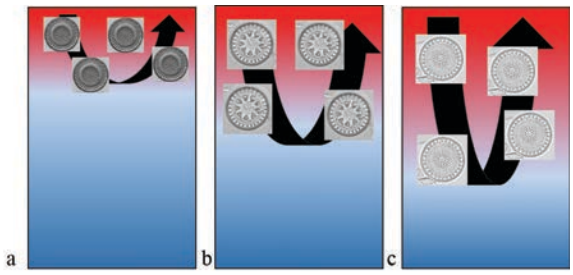

Figure 1. Conceptual diagram of hypothesized response of key diatom species to thermal structure in Lake Superior. The species are expected to be found at highest abundances at differing epilimnion depth, which increase from left to right.

Acknowledgements: This project is funded by the National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Re-analysis of Landsat Images Shows Tropical Glacier Retreat Slower than Previously Thought: Nevado Coropuna, Peru

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Abstract: We analyzed 21 Landsat images from 1980 to 2014 to measure aerial changes in the ice cap at the Nevado Coropuna volcanic complex, Peru. Although previous studies have reported ice loss rates of 1.4 km^2/yr, we estimate ice loss to be 0.41 km^2 yr^{-1}. We analyzed 258 Landsat scenes to find annual snow minimums using the Normalized Difference Snow Index (NDSI). Although some predict that Coropuna will be a non-contributor to water supply by 2025, our results suggest that this will not be the case.

Nevado Coropuna (15° 33' S, 72° 38' W, 6,425 m.a.s.l.) is the largest body of ice in the tropics and the largest supply of fresh water for Southern Peru. Because the ice sits on top of a volcano that has had activity during the Holocene, it is a threat to nearby agricultural villages in the surrounding canyons.

We measured snow and ice extents in 258 Landsat 4, 5, and 7 scenes using the NDSI from 1986 to 2014 in addition to one digitized Landsat 2 scene from 1980. We find that the ice on Coropuna is retreating at 0.41 km^{2}yr^{-1}. This is one third the rate previously published by others (Silverio and Jaquet, 2012; Peduzzi et al, 2010; Racoviteanu et al, 2007).

Previous authors have misclassified snow as ice because they have not paid close attention to the start and end times of the precipitation season. This has led to over estimations of shrinking rates (Fig. 1) and has mislead governmental organizations such as the US AID, IPCC, Peruvian Environmental Ministry, and the Peruvian Meteorological Service in reports on climate adaptation in Southern Peru to determine that the ice cap will no longer be a contributor to water supply by 2025.

The ice cap area has decreased 24.0% from 58.0 km^2 in 1980 to 44.1 km^2 in 2014. . Our work shows that care must be taken when selecting satellite imagery for determining the extents of glacierized areas to ensure that snow cover, which can obscure ice boundaries, is at an annual minimum. Precipitation seasons of the high mountains can be slightly different than surrounding lowland areas, leading to confusion regarding the precipitation season. By analyzing only those images just prior to the start of the wet season, determined via analyzing images for snow cover, measurements of glacial ice area are more likely to be accurate. This has significant implications for water planning in Peru, which relies on glacial meltwater for domestic, industrial, and agricultural uses in addition to hazard planning in the region from a future volcanic event.

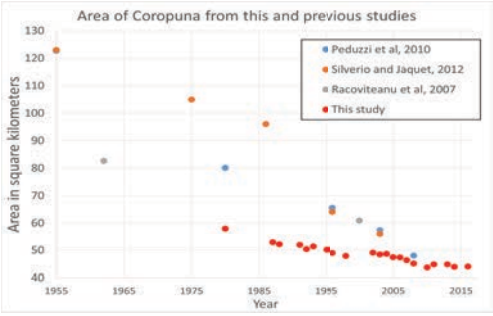

Fig. 1. Glacierized area of Nevado Coropuna, Peru. Silverio and Jaquet (2012) and Peduzzi et. al. (2010) independently found that Coropuna lost 1.4 km^{2}yr^{-1} glacierized area since 1955. We found that Coropuna is losing 0.41 km^2/yr^{-1}, or one third the rate previously thought. We show here that their estimates are much higher than reality. The error of this study is included within the size of the dot on the graph.

Acknowledgements: We would like to acknowledge Dan and Betty Churchill for supporting our 2015 field season in Peru.

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A 2060-Year Record of Atmospheric Arsenic Deposition from South Pole Ice Core

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Abstract: Using a South Pole ice core covering the last 2060 years we present a high-resolution (~9 samples/year), continuous record of As concentrations from Antarctica. We investigate the natural variability of As and evaluate the anthropogenic contribution.

Arsenic is one of the most toxic elements in the environment and can be found in low concentrations throughout the geosphere. It can enter the environment through both natural processes (mostly from volcanoes and biogenic emission), and anthropogenic activities. Several studies report increases in As concentrations during in the late 20th century in soil, water and air worldwide, and in many cases elevated As values are attributed to the human activities. Our record shows a significant increase (by a factor of ~4) in As concentration and As enrichment (by a factor of ~5) since 1970 A.D. (Fig.1). Comparison with previously reported Antarctic As records (Hong et al., 2012, Rong et al., 2016, Schwanck et al., 2016) shows that the recent increase in As concentration is widespread. As enrichment in recent decades has been caused by anthropogenic emissions, in particular, from copper production in Chile and from coal combustion throughout the Southern Hemisphere.

Our records suggest, that human activities affected atmospheric As deposition not only in the 20th century, but in early periods too. We observe several periods of increased As concentrations during the last 2060 years. Our estimation of the natural contribution shows that crustal dust and marine aerosols input is negligible. Volcanic contributions, mostly from Mount Erebus, could be significant. During intervals with increased As concentrations, however, volcanic input explains only ~13% of the total As. The other important natural source for As is marine biogenic emission, however, published studies do not provide sufficient data to allow us to make a quantitative estimation.

We also observed simultaneous increases in Pb, Cu, Zn, Mn and Cd (elements with high EF values), suggesting that human activities were contaminating the atmosphere long before the 20th century.

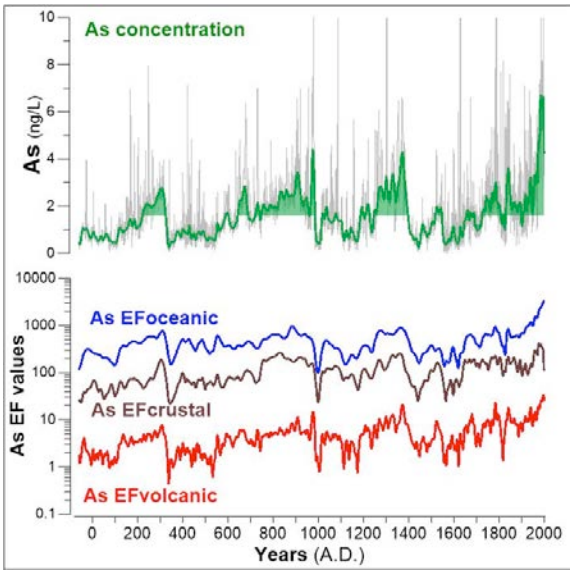

Fig. 1. SPRESSO As concentrations, and crustal, oceanic and volcanic enrichment factors (EF) values for the period from -60 to 2000 A.D.

Acknowledgements: NSF OPP

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A 40,000+ Year Ice Core Record of Southern Hemisphere Climate Variability From the South Pole

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4. *Department of Earth Sciences, Dartmouth College.*
5. *Department of Chemistry and Biochemistry, South Dakota State University.*

Abstract: The South Pole ice core project is a U.S. effort funded by the National Science Foundation to drill and recover a new ice core from South Pole, Antarctica. The ice core will provide an environmental record spanning approximately 40,000 years that will be used to investigate the magnitude and timing of changes in climate and climate forcing through time.

The ice core was drilled to a target depth of 1500 meters and will provide records of stable isotopes, aerosols, and atmospheric gases spanning approximately 40,000 years. The South Pole site preserves unique climate records by combining cold temperatures typical of East Antarctica with a relatively high accumulation rate due to West Antarctic influence. The South Pole ice core extends the international array of ice cores used to investigate environmental change before, during, and since the last glacial/interglacial transition. The scientific goal is to assess and understand changes in atmospheric chemistry, climate, and biogeochemistry. Drilling was planned for the 2014-2015 and 2015-2016 field seasons, and a new intermediate-depth drill was used to recover the ice core, developed and built by the Ice Drilling Design and Operations (IDDO) group at the University of Wisconsin Madison.

Drilling was completed in the 2014-2015 (~700 m / through the Holocene) and 2015-2016 (to 1751 m / ~50,000 years) field seasons. The upper 500 m was processed at the National Ice Core Laboratory in summer 2015, and samples are currently being analyzed at our collaborative facilities. The UMaine portion of our group is responsible for measuring the physical (concentration and size distribution) and chemical (trace element concentration) composition of dust. In particular, we are focusing on the bioavailable fraction of several key elements, in an attempt to quantify the impact of dust fertilization on Southern Ocean productivity.

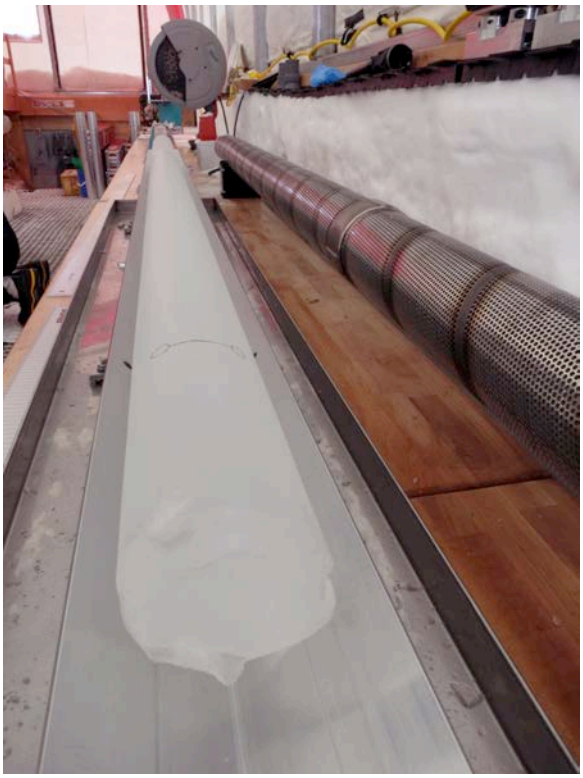

Fig. 1. Newly drilled South Pole ice core, 2016 (Murat Aydin).

Acknowledgements: Funding for the project is provided by NSF PLR-144397.

The Impact of Climate Change on Harmful Algal Blooms and Algal Toxin Effects on the Development of Neurodegenerative Disorders

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Abstract: Rapidly increasing global temperatures will likely lead to an abrupt increase in fresh water harmful algal blooms (HAB) and their associated toxins. Chronic exposure to one HAB toxin, BMAA, has been associated with the development of sporadic Amyotrophic Lateral sclerosis (ALS). Using zebrafish to study the effects of environmentally relevant concentrations of BMAA in public freshwater bodies in New England will improve our understanding of how increased exposure to the toxin could affect people's health, and may provide an avenue for the development of novel treatments for ALS. Results of this project will be disseminated to policymakers and the general public.

The goal of this project is to study the effects of environmentally relevant concentrations of fresh water HAB toxins on zebrafish neuromuscular fitness, a model system for Amyotrophic Lateral Sclerosis. Increasing surface temperatures (**Figure 1**) will likely lead to an increase in water temperatures globally, including in New England's fresh water sources. Furthermore, increasing water temperatures may increase the prevalence of HABs and their associated toxins. Chronic exposure to one toxin, BMAA, has been associated with an increased prevalence of ALS (Banack et al. 2015; Holtcamp, 2012). Studying how abrupt climate change will affect the concentrations of BMAA in New England lakes will improve our understanding of how increased chronic exposure may affect people exposed to the toxin through local drinking water sources.

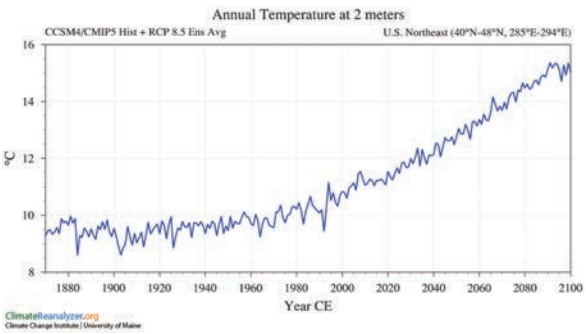

Figure 1. 2-meter surface temperature profile for New England states (U.S. Northeast) from 1880-2100 using the CCSM4 Historical + RCP 8.5 dataset. Temperatures are predicted to rapidly increase in New England states over the next several decades.

Zebrafish will be used to study ALS. Studying the effects of BMAA on zebrafish neuromuscular fitness may lead to novel drug therapies to prevent or reduce the symptoms associated with environmentally-induced ALS.

With the assistance of Maine's DEP and CDC, the results of the project will be distributed to local communities via seminars, posters, pamphlets, news articles, or a website to inform the general public about the potential health effects of BMAA in their local drinking water supplies. The project results will also enable policy makers to develop or modify policies to improve or reduce the prevalence of BMAA in local drinking water sources.

Acknowledgements: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Cryptotephra in Maine

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Abstract: Recently, almost a dozen very fine-grained volcanic ash (cryptotephra) layers were found in the peatlands of Maine, Nova Scotia and Newfoundland (Pyne-O'Donnell *et al.* 2012; Jensen et al. 2014; Mackay *et al. 2016) contributing to the emerging North American tephrochronological framework*. Tephra-based isochrones help to reconstruct past carbon accumulation rates required for realistic parameterization of carbon cycling in existing and future computer models.

Background: Traditionally, tephrochronology has been a major tool for paleoclimate work, but was only useful in areas within a few hundred kilometers of the volcanic source. However, in recent years, cryptotephra layers have emerged as important, widespread, time-stratigraphic markers (isochrones). The microscopic volcanic glass particles found in Maine peat cores (see Fig. 1) may be geochemically fingerprinted and have already been tied to several known Holocene eruptions from the US West coast, Alaska, Kamchatka and Japan.

Fig. 1. Sites with cryptotephra layers are shown in red.

The chronology of these cryptotephra layers offers a unique opportunity to study regional postglacial landscape evolution, interaction of land–sea systems, and determination of precise rates of carbon removal from the atmosphere.

We propose to improve the quantification of carbon accumulation rates in peat bogs in the eastern US and Canada using expertise and methodologies already developed by our collaborators from University of Southampton, Aberystwyth University, and Queen's University Belfast, Swansea University.

The new data will help to establish a baseline for past and present regional climate variability in Maine required for improving modeling of future climate and, most importantly, for realistic parameterization of carbon cycling in existing and future computer models.

We will update the status of this project and discuss future research plans.

Acknowledgements: Method development was partially supported by NSF grants PLR-1142007 and 1142069. S.A. Norton assisted with the Caribou Bog site.

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Diagnostics, Trends and Climate Model Projections of U.S. Summer Heat Waves

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Abstract: Heat waves can have myriad impacts ranging from adverse effects on human health, to increases in energy and water demand, to crop stress. This new project will undertake a comprehensive study of U.S. summer heat waves, including their regional frequency and persistence characteristics, linkages to the large-scale atmospheric circulation and regional associations with land-atmosphere coupling. Heat wave definitions that include atmospheric moisture will also be considered. Station observations, various atmospheric reanalysis products and output from coupled climate model simulations and projections will be utilized in the analysis.

Project Goals

The overall goal of the study is to enhance our current understanding of U.S. summer heat waves, investigate the ability of climate models to capture the observed characteristics and examine how such characteristics will change in the future. Diagnostic analyses will include linkages to the large-scale circulation (Figure 1), heat budgets and comparison of behavior between observations and climate models.

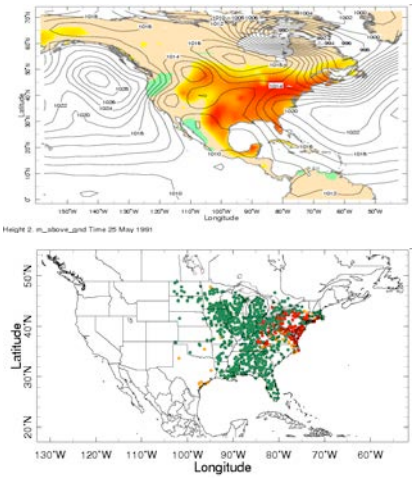

Fig. 1. (Top) Sea level pressure and specific humidity anomaly patterns during the heat wave of May 1991 (a "humid" heat wave). (Bot.) Red dots indicate heat wave conditions in maximum temperature, green in minimum temperature, and orange in mean temperature. Maps are for a single day in the middle of the heat wave (May 21, 1991).

The work will involve extensive use of observational data, reanalysis products and coupled climate model output. Regional variations in heat wave behavior are of particular interest as is the role of land surface condition in enhancing the likelihood of heat waves (Figure 2). Changes in the land surface condition (e.g. soil moisture) alters the surface energy balance and thus surface air temperature.

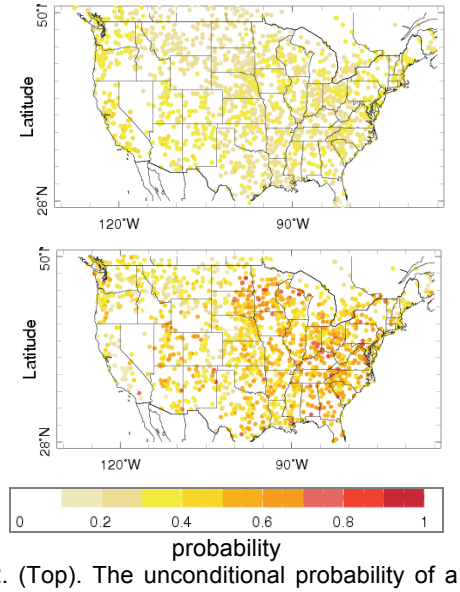

Fig. 2. (Top). The unconditional probability of a heat wave occurring during June-August (1971-2000). (Bot.) The conditional probability given antecedent drought conditions during the same summer months.

The contribution of other dynamical and thermodynamical processes to extreme daily temperatures will be quantified via heat budget analyses. Source regions of atmospheric moisture for heat waves with high specific humidity will be evaluated as a function of region and heat wave persistence characteristics.

Acknowledgements: Funding for this project is provided by a grant from the National Oceanic and Atmospheric Administration, grant number NA140AR4310204.

Deciphering the Mechanisms Behind Climate-driven Changes in the Relative Abundances of the Diatom *Cyclotella*

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Abstract: Many paleolimnological studies have reported increases in the relative abundance of *Cyclotella* across many lakes in the Northern Hemisphere. However, the actual mechanisms responsible for these changes are still not evident. The primary goal of this study is to decipher those mechanisms behind the climate-driven changes in the relative abundance of *Cyclotella.*

Cyclotella, is a small size planktonic diatom. Diatoms are photosynthetic algae, that have a siliceous cell wall and are found in almost every aquatic environment. Several paleolimnological studies across the Northern Hemisphere have reported a sudden increase in the relative abundance of *Cyclotella*, which is thought to be a key indicator of warming across lakes in arctic, alpine, and boreal regions [2,3,4]. However, this change is not uniform across all regions, as some studies have reported decrease in abundances in the same regions over similar time frames[1]. The potential mechanisms for this expansion have been associated with direct climate impacts through temperature[2] or indirect climate impacts through interactive effects of water column stability, i.e. mixing depth (light), and nutrients[3].

The primary objective of this project is to investigate the interactive effects of temperature, light and nutrients on *Cyclotella* abundances and growth rates. To do so, we conducted (2x2x2) factorial design experiments in-lakes with 2 different levels of temperature, high (11-13°C) and low (7- 8°C); along with 2 different levels of light, high (60% of ambient PAR) and low (25% of ambient PAR); and two levels of nutrients, with nutrients (Nitrogen 8 µM and Phosphorus 1 µM) and without nutrients. The secondary objective is to determine how the structure of phytoplankton communities alters the response of *Cyclotella stelligera* to abiotic factors. Since it was a common species in both lakes, we analysed the response of *Cyclotella stelligera,* one with phytoplankton assemblages dominated by diatoms, and one dominated by other phyla in the same set of experiments. We found variability in the responses of *Cyclotella* taxa to interactive effects of temperature, light and nutrients. Each species responded differently to tested variables. In high temperature treatments with high light and nutrients addition, *Cyclotella stelligera* cell densities increased in a diatom-dominated lake and decreased in a phytoplankton dominated lake. This study will provide more ecological information for key species to improve our ability to assess variable changes across these systems.

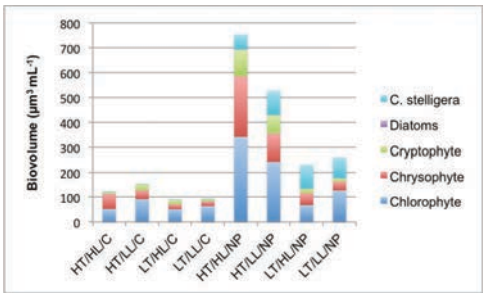

Fig1. Biovolume of *Cyclotella stelligera* in a phytoplankton-dominated lake, under high temperature (HT), low temperature (LT), high light (HL), low light (LL), nutrients (N) and control (C).

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Project BISON: Bison Industry & Science Observation Network – A New Stakeholder Citizen Science Collaboration

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2. *Climate Change Institute, University of Maine.*
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Abstract: Climate change is likely to threaten agricultural sustainability, but the impacts of increased temperatures on large livestock operations, such as bison, remains unknown. The fossil record suggests bison decrease in size during warmer climates, but modeling the relationship between climate change and morphology requires contemporary calibrations across geographic regions. The citizen science initiative, Project BISON, will fill this critical knowledge gap while building partnerships with ranchers to transition to adapt to climate change.

Background: Food security, especially grazing livestock, is reliant upon a predictable climate for sustainable production[1]. Bison have adapted to climate changes in the fossil record by changing their body size; as temperatures increase, bison shrink[2]. Diminishing body size reduces meat production. To assess similar contemporary morphological changes, cooperation with bison ranchers is essential. However, this requires robust comparative fossil and modern bison calcaneal datasets for morphological analysis; currently 1197 fossil and 30 modern are curated.

To solve this critical knowledge gap, we created a new initiative: Project BISON (www.projectbison.net), which leverage bison ranchers as citizen scientists. Ranchers provide a hock (see Fig. 1) from each bison upon its death (either natural or culled).

Fig. 1. Hock location on bison; left, bison with 'clothes on' and, right, bison with 'clothes off.'

The hock contains the calcaneum, a bone that indicates body size because it is weight bearing, additionally, preserves well in the fossil record. We will also collect environmental data that influence body size, to better isolate the importance of climate: weight, age, sex, weaning date, a broadside photograph of animal prior to harvest, hanging weight, diet, and geographic location. We will also survey ranchers to learn about operation factors, e.g. - quantity of breeder animals and average age, frequency of trade, and regional bison association participation. Once samples are received, we will macerate each hock to isolate the bones. These will be regressed against the geographic data collected in our surveys to isolate the variables influencing body size, and to identify geospatial patterns.

Ultimately, Project BISON results will be used to isolate the variables that most strongly affect body size, i.e., temperature, precipitation, diet strategy, and herd dynamics management. A long-term goal of this project is to develop regional climate-scenario adaptive management strategies, as well as capacity building with stakeholders. Results will be disseminated directly with the community.

Initial Results: Nine ranches have enrolled and filled out the initial survey from CO, ID, MN, OR, UT, WI, and WY representing small and large ranches (herd pop.: 13-3500; acreage: 10-28000). We are awaiting shipments of hocks from ranchers (autumn harvest is typically) and enrolling additional ranchers to the project.

Acknowledgements: Rachel Martin, Gloria Lima, Chason Frost, Trevor Lessard. NSF IGERT program grant DGE-1144423, Western Bison Association, Larry D. Agenbroad Legacy Fund, and Throlson American Bison Foundation.

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Developing a Methodology for Characterizing Pollutant Flow Through a Glaciated Ecosystem

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Abstract: Pollutants released by industrialized nations between 1960 and 2004 have been transported northward through atmospheric processes and deposited into glaciated alpine ecosystems. Many of these chemicals retain their original structure and are absorbed into the biota thousands of miles away from where they were originally utilized. With a warming climate increasing the melt of alpine glaciers, these glaciers may be introducing growing amounts of toxins into the watershed. While studies have demonstrated the existence of resident pollutants within glaciated ecosystems, no one has used standard toxicological testing methods to assess the risk posed by these compounds when released in glacial outflows. The goal of this study is to develop a framework to assess the conditions under which glacial release of persistent organic pollutants are a risk to the health of downstream communities.

Field work in the Eastern Alaskan Tanana Mountains (figure 1) led by Dr. Chris Gerbi and Dr. Seth Campbell is currently looking at the rheology and morphology of Jarvis Glacier. This glacier is located southeast of Fairbanks, and is the top of the watershed for over 200,000 local residents. While taking ground penetrating radar measurements in order to gain an understanding of the structure of the glacier, we will also be taking samples to understand the potential release of pollutants as Jarvis Glacier continues to lose mass.

Methodology developed by the Environmental Protection Agency to measure legacy pollutants and industrial pesticides in urban watersheds can be adapted to sample snow, ice and glacial meltwater. Sampling these three phases will allow researchers to develop a baseline understanding of pollutant flow through the glaciated watershed. Methodology for testing recent snowfall utilizes permeable membrane filtration technology created for testing urban drinking water, although quantities tested are exponentially greater than in an urban setting. The second phase of sampling to determine concentration of pollutants in summer melt utilizes lipid-coated filtration technology that samples large quantities of streamflow through passive sampling. The final phase will incorporate ice core sampling to gain an understanding of pollutants in glacial firn and ice. Pollutants in glaciers are found in trace amounts, and sampling must subsequently represent large quantities of water, filtered to separate the hydrophobic pollutants from the meltwater. The Jarvis Glacier sampling of recently deposited snowpack, legacy glacial firn and ice and meltwater will allow the research team to create a profile of the movement of pollutants through the glacial system, and into the ecosystem below.

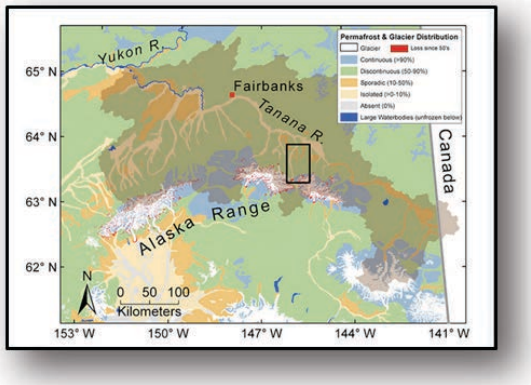

Figure 1. Map of Jarvis glacier sampling site. *UAF WERC Group*

Acknowledgements: Gratitude for the support of Dr. Karl Kreutz, Dr. Chris Gerbi, Dr. Brian Perkins, Dr. Jules Blais, Dr. Aaron Putnam, Dr. Shaleen Jain and Dr. Sean Birkel. Thank you also to Dr. Carol Kim and Scott Delcourt for their ongoing support. Support provided by the NSF Adaptation Abrupt Climate Change IGERT program grant DGE- 1144423 and NSF award PLR-1503924.

New Technique to Monitor Airborne Pollen using Rainwater Particulate Filters

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Abstract: The National Atmospheric Deposition Program filters particulates, including airborne pollen, from precipitation samples collected at 265 sites in the U.S. and Canada. Recovery and identification of pollen from the filters will expand the current limited scope of airborne pollen monitoring to enhance allergy and asthma treatment, define floristic zones, and document phenology response to climate change and increasing CO_2 levels.

Project Goals

This project seeks to expand areal monitoring of airborne pollen from the current 30 monitoring sites in Canada and ~24 National Allergy Bureau monitoring sites in the United States. Identifying the timing of release of tree and herb pollen is critical for effective treatment of pollen-induced allergies and asthma. Establishing bloom time response to climate shifts and increasing atmospheric CO_2 will further enhance proactive asthma treatment, better define floristic zones, and aid in forecasting effects of climate change.

Traditional rotor rod capture of airborne pollen provides real-time monitoring for both quantitative (pollen/m^3 air) and qualitative reporting. However, the equipment is expensive to install and requires ongoing supplies and personnel time. Monitoring sites are limited to ~24 urban locations and reporting format is inconsistent among sites.

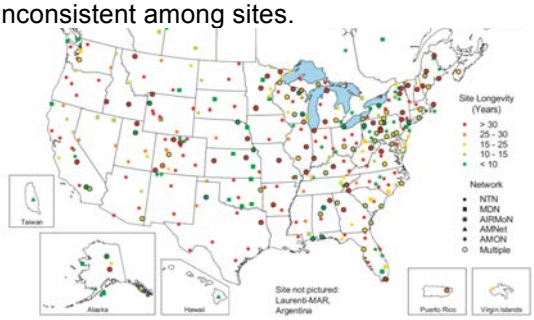

Figure 1. Active NADP stations. NADP, 2015. NADP 2014 Annual Summary. NADP Data Report 2015-01. Illinois State Water Survey, University of Illinois at Urbana-Champaign, IL.

The National Atmospheric Deposition Program (NADP) monitors precipitation chemistry at 265 sites throughout Canada and the U.S. with nine collections sites in Maine. Precipitation is collected weekly, with samples sent to the NADP laboratory in Illinois where particulates are filtered out with a 0.45µm polyethersulfone membrane filter, and the water is analyzed for inorganic solutes. For this project, instead of discarding the filters, NADP sent a set of filters to CCI for exploratory pollen analysis.

Research Component

Before we can identify the pollen, we must separate the cells from the filter. Two methods proved effective: 1) wash the cells from the filter using 5% KOH under pressure with a vacuum filter holder; 2) dissolve the filters in n-methyl-2-pyrrolidone (NMP). Once the cells are free of the filter, they can be cleared with acetolysis for definitive identification, excess water removed with alcohol, put into deionized water for FlowCam analysis, and stored in silicon oil for traditional pollen examination.

Initial Results

Here we report the first results from methods development and comparison of the two extraction techniques. Rinsing the cells under pressure recovered 89% of the pollen cells. Dissolving the filters in NMP recovered 100% of the captured pollen cells. The latter procedure is time consuming and uses expensive and hazardous chemicals. While we cannot quantify pollen from the filters with this method, we can identify bloom times, establish dominant pollen type, and improve taxonomy over traditional methods. If successful, this approach could inform evidence-based climate adaption drawn from synergy among environmental monitoring programs.

Acknowledgements: We thank the Council of State and Territorial Epidemiologists and Centers for Disease Control for endorsing this project.

A Pleistocene Disturbance Event Drives Modern Diversity Patterns in Coastal Marsh Birds

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Abstract: We test for the ability of ecosystem disturbance events occurring over multiple time scales (from decadal to millennial) to predict the modern bird community in the tidal marshes of the Northeastern US. The strongest predictor was the timing of deglaciation and marsh formation. Older marshes are dominated by specialist taxa that likely prevent colonization by generalists, while more recently deglaciated landscapes (further from glacial refugial populations) are dominated by generalist colonist taxa. Diversity peaks at marshes of intermediate age.

Paleo-drivers of bird community structure:

There is growing evidence that paleo-timescale events are important determinants in the present-day distribution of organisms. Long-term climate patterns are known to drive both ecological and evolutionary mechanisms operating over millennia and to create patterns persisting into the modern era. We measured both specialization and species diversity in tidal-marsh bird communities to explore the relationship between these indices and several potential drivers of biodiversity across several orders of timescale magnitude. These drivers included 1) a recent, intense hurricane event driving a large-scale perturbation of this ecosystem (2 ya), 2) gradual modification of marshes through installation of human infrastructure (~200 ya), and 3) marsh formation and development after the Last Glacial Maximum (LGM, ~20,000 ya).

We found that both habitat specialization and species diversity patterns were best explained by regional patterns of marsh establishment following the retreat of the Laurentide ice sheet. We hypothesize that the formation of marsh millennia earlier in the southern part of our survey area allowed for either the persistence of or the earlier evolution of marsh specialization by bird species than those occupying much younger, northern marshes. This is the first demonstration of vertebrate functional diversity patterns driven by paleo-climate events at this large of a spatial scale, and it highlights the potential importance of historical contingency for shaping biodiversity.

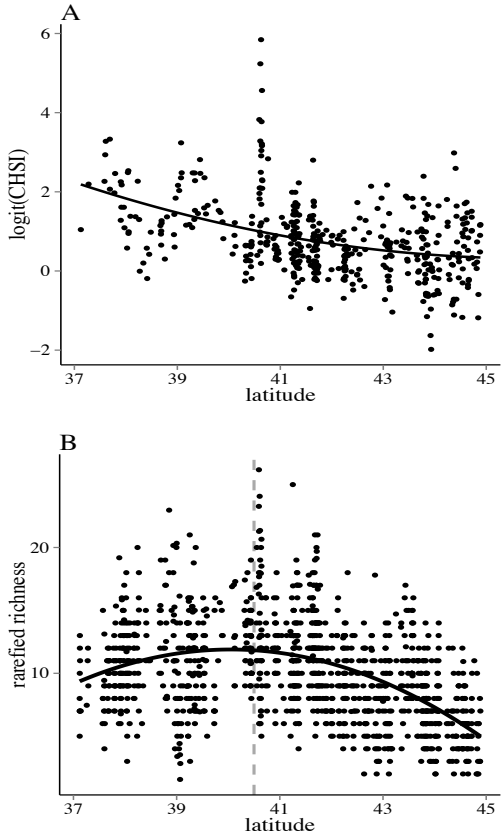

Fig. 1. The relationship between either (A) the mean of a Community Habitat Specialization Index (CHSI) or (B) species richness and latitude. Diversity peaks at the LGM (dashed line), while specialism peaks in the oldest marshes.

Acknowledgements: Primary funding through the National Science Foundation (DGE-1144423 & DEB-1340008) and the US Fish and Wildlife Service (P11AT00245, 50154-0-G004A, U2-5-R-1).

Cathedral Glacier: A Shrinking Cirque Glacier in Northern British Columbia

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Abstract: The Cathedral Glacier located in northern British Columbia, Canada is a small cirque glacier at the eastern edge of the Juneau Icefield. Small glaciers make up roughly 10% of the glacial mass in the world playing an important role in sea level rise. Small glaciers also respond faster to changes in climate due to their small thermal mass and higher surface area to volume ratio. The Cathedral Glacier has been retreating since about 1920 and from when the first map was made in 1977 to today has lost roughly half its volume.

Project Goals:

The goal of this project was to quantify the mass loss of the Cathedral Glacier using a photogrammetric map made in 1977 to a 3D model made in 2015 using Structure from Motion. The ice loss will also be compared with the changes in temperature and precipitation in the area over the same time period.

The archive photographs show intermediate terminus locations.

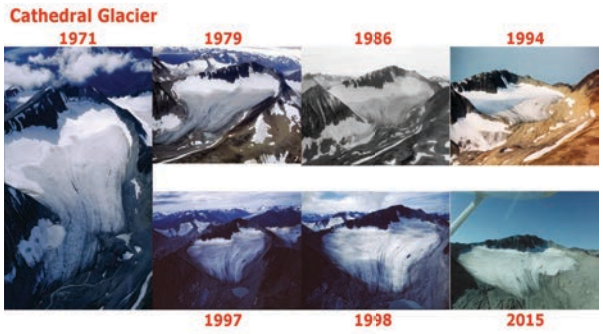

Fig. 1. Time series of the Cathedral Glacier 1971-2015

Initial Results: Using the average temperature and precipitation from period 1921-1950, the period from 1970 to 2015 was detrended to show anomalies from the 1921-1950 normal. (Fig. 2 & 3). The five year moving average temperature was hotter through almost the entire period than the normal; the five year moving average precipitation was lower for almost the entire period.

Being in a continental climate that has low precipitation to begin with these two changes in climate result in the Cathedral glacier and nearby glaciers disappearing.

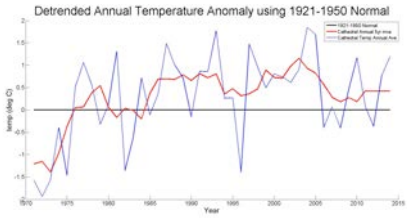

Fig 2. Annual Temperature Anomalies 1970-2015

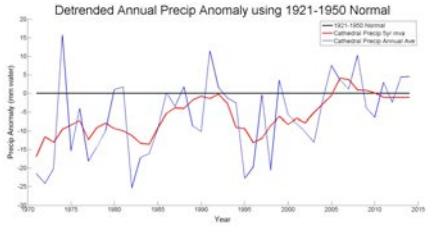

Fig 2. Annual Precipitation Anomalies 1970-2015

Acknowledgements: Travel funding provided by the Dan and Betty Churchill Exploration Fund. Logistics support from the Juneau Icefield Research Program. Photos of the glacier from Dr. Keith Mountain, Steve Wilson and the Dr. Maynard M. Miller photography archive.

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Falkland Islands Research to Address the Cause of Ice-Age Terminations

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Abstract: In 2015 we carried out fieldwork in the Falkland Islands to document glacial recession during the last termination. The results of current laboratory work will allow us to reconstruct glacial fluctuations to gain insight into the sequence of events that ended the last ice age.

The Falkland Islands (~52°S, ~59°W; Fig. 1) lie in a climatically sensitive area just north of the Subantarctic Front in a zone of compressed oceanic gradients. Past glacial fluctuations provide a proxy of climate change in the Falkland Islands during the last glacial termination.

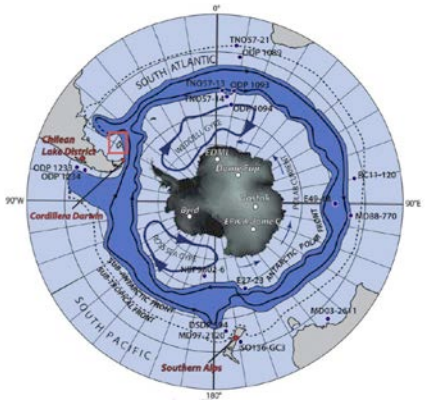

Fig. 1.Location of the Falkland Islands (red box).

The goal of our project is to produce a chronology of glacier recession following the Last Glacial Maximum. Estimates of past climate variations will come from reconstructions of past fluctuations of cirque glaciers, which are very susceptible to changes in summer air temperature (Clapperton, 1971).

Fieldwork consisted of mapping glacial deposits on satellite images to delineate former ice margins; collecting rock samples for ^{10}Be dating to define the ages of the glacial deposits; and producing an ice-recession chronology by coring pond sediments in areas formerly covered by ice, to obtain the oldest organic materials (Hall et al., 2013).

The stratigraphy of the cores has been analyzed, and the magnetic susceptibility of each core has been measured, providing a record of magnetic minerals, and to some extent grain size. This allows a first-order separation between cold and/or dry periods with mineral sedimentation vs. warmer and/or wetter times with more organic growth. Future work will include obtaining a chronology for the cores; it is anticipated that the cores will afford a record of the structure of the last deglaciation in the Falkland Islands, including periodic shifts in climate that may relate to changes in the position of the westerly winds. This record will provide key information about the termination of the last ice age (Denton et al., 2010; De Deckker et al., 2012).

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Kilimanjaro Northern Ice Field 2015 - Preliminary Results

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4. *Department of Geosciences, University of Fribourg, Switzerland.*
5. *Department of Geosciences, University of Massachusetts.*

Abstract: Analysis of ice collected from the Northern Kilimanjaro Glacier ice cliff in 2015 indicates that the climate record is still preserved.

Ice core paleoclimate studies focus primarily on the Polar Regions. In recent decades, more ice cores have been recovered from high mountain glaciers around the globe. Despite the recent collection effort, a large spatial data gap remains between the mid latitudes and the tropics. To help fill the gap, ice from Kilimanjaro Glacier Northern Ice Field ice cliff (>5700 m, 3°3'S, 37°20'E) was collected in September 2015. Kilimanjaro's summit ice fields are rapidly disappearing, taking with them unique paleo-environmental information stored in the ice, information that can still be retrieved by drilling ice cores.

Mt Kilimanjaro is located in a zone of seasonal dry tropical climate (Müller, 1983). The distribution of precipitation over the year follows the intertropical convergence zone. Rainfall and temperature vary with altitude and exposure to the dominant wind from the Indian Ocean. Two distinct rainy seasons occur on Kilimanjaro, one from March to May and another from October to November. The driest period is from August to October (Mölg et al., 2006).

The Northern Ice Field is classified as a plateau glacier system. Kilimanjaro Glacier surface ice temperature is close to 0°C, this suggests that surface melting is common. Field observations during drilling reveal melt features on the glacier surface and water in the borehole. So far, the ice cores drilled on Kilimanjaro have been interpreted as quasi-continuous Holocene climate records, going back about 11,700 years within about 50 meters of ice thickness (Thompson et al. 2002). Clearly this requires a large number of very thin annual layers.

Preliminary glaciochemical laser (Fig. 1) and isotopic analyses of the basal cliff ice indicate that the climate record is still preserved. Mean annual layer thickness in the basal ice is about 1 cm based on visual stratigraphy. Standard ice core continuous melting procedures could not have detected such thin annual layers. Kilimanjaro ice core record may reveal past atmospheric circulation patterns over this part of the tropical African continent.

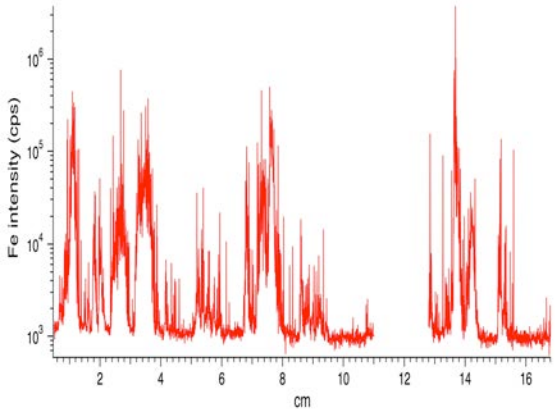

Fig 1. Laser ablated ICP-MS Fe data (the break in the record is associated with a break in the ice sample).

Acknowledgements: The National Geographic Society's Global Exploration Fund - Northern Europe.

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Unraveling the Impacts of Temperature, Flow, Prey Availability, and Competition on Juvenile Atlantic Salmon (*Salmo salar*) Performance in a Rapidly Changing Climate

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4. *U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit.*

Abstract: Atlantic salmon face multiple threats stemming from climate change and invasive species. Extreme precipitation events (flooding /droughts) and heat waves are expected to occur more frequently and with stronger magnitudes in the future than is currently experienced. We are investigating how Atlantic salmon performance is modified by competition with invasive smallmouth bass and native brook trout under different temperature, flow, and prey regimes. We anticipate that our research will better inform management solutions by helping managers identify and prioritize critical salmon nursery habitat for stocking, dam removal or culvert replacement in light of climate changes that may occur rapidly in the state of Maine.

Research Goals

Extreme precipitation events and heat waves are expected to occur more frequently in the future[1] and could impact the recovery of Atlantic salmon (*Salmo salar*) in Maine streams, alter competition with native brook trout (*Salvelinus fontinalis*), and facilitate range expansion of non-native warm-water competitors, such as smallmouth bass (*Micropterus dolomieu*). However, little is known about the impacts of smallmouth bass competition on salmon performance despite the fact that invasive smallmouth bass have a history of prolific range expansion in Maine.

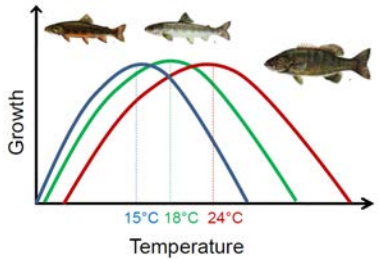

Figure 1. Approximated growth curves for brook trout, Atlantic salmon, and smallmouth bass along a gradient of stream temperature. Optimal temperatures for growth are identified.

We will be using a combination of bioenergetic modeling based on growth (Figure 1) and empirical data to accomplish the following four objectives: 1.Determine how salmon performance (foraging behavior and energetics) is influenced by competition with native brook trout and invasive smallmouth bass along gradients of temperature, flow, and prey availability; 2.Use microhabitat-based foraging and bioenergetics models to predict and explain variation in growth due to competition along environmental gradients; 3.Test these model predictions with experiments in stream mesocosms that simulate realistic conditions of habitat complexity and prey diversity at low and high flow conditions; 4.Field-test predictions of habitat suitability by assessing performance of stocked salmon fry among streams that vary in temperature, hydrology, geomorphology, prey availability, and competitors.

We anticipate that our research will help better inform adaptive management solutions for managers who seek to anticipate impacts of climate change on juvenile salmon production.

Acknowledgements: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423 and Maine Sea Grant.

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The P301 Web API

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Abstract: The P301 Web API is a RESTful interface that allows P301 users to share data that have been uploaded to the P301 system. The system supports accessing data in JavaScript Object Notation (JSON) and Extensible Markup Language (XML) formats, which helps to facilitate the development of Web-based applications. A variety of queries for accessing the data in the system allows for flexibility in client system designs.

P301 Web API Design

The P301 Web API allows users to access P301 data in JSON or XML formats. The system provides current P301 users a straightforward mechanism to expose their data to the public. Any data that has been loaded in the P301 system can be shared through the public P301 Web API by marking it in the system as publicly viewable. The API has been designed using a RESTful approach that has two immediate outcomes: data is accessible for public investigation; and the interface allows developers flexibility in creating applications for the data sets.

The API is written in Java, which allows the P301 Web API to make use of a variety of functions previously written for the core P301 system. The Postgres database is shared by the two systems so that query results and Java objects can be used by both code bases.

The JSON and XML responses generated by the P301 Web API are created when a query to the API is made. As shown in Fig. 1 to the right, the queries are first processed and checked for correctness. If everything passes muster, then a Postgres database query is performed. The results of the query are converted to Java objects. The Java objects are then converted into JSON or XML and sent back to the Web client.

Querying Data

In order to better understand how interaction with the P301 Web API works, consider a few example queries.

First, “What are the available data sets provided by the system?” This can be achieved by sending a formatted string to the P301 Web API that indicates data sets have been requested. The type of the result data list (JSON/XML) is specified in the request's header.

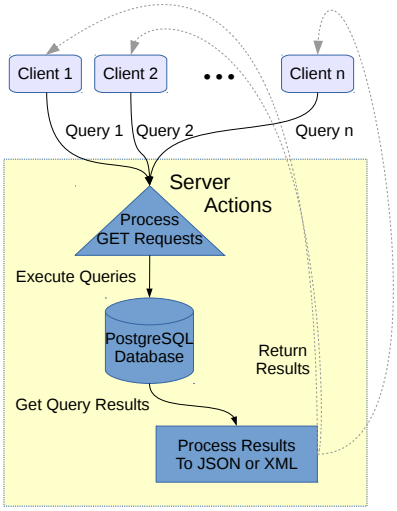

Fig. 1. P301 Web API query processing. Multiple clients can access P301 data through a common interface. Database queries and JSON processing happens on the server and is shown in the yellow area.

Second, “How can I get more information about a data set?” This is answered by appending the desired data set name to the query string sent to the server, which allows the client to select either meta data or actual data in the results.

Specifying a number of optional attributes can be used to further filter the query results. These features help to facilitate development of Web-based applications for the climate-related data stored in the P301 system.

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Quantifying the Role of Lakes in the Arctic Carbon Cycle

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Abstract: Rapid, recent changes in the concentrations of dissolved organic carbon (DOC) concentrations in lakes of southwest Greenland raise questions about broader changes in carbon cycling in the Arctic. We are beginning to quantify carbon (C) pools and fluxes in a suite of lakes spanning from the Greenland Ice Sheet to the coast to better quantify carbon dynamics in this area.

The important role of lakes in regional C cycles at lower latitudes has been increasingly recognized recently, with synthesis papers focusing on "active pipe" models that incorporate lakes as reactors for organic carbon (Cole et al. 2007; Tranvik et al. 2009). These syntheses have revealed several important points: 1) terrestrial ecosystems deliver approximately twice as much C to inland aquatic systems as to the ocean; 2) net C fluxes tend to be greater per unit area in freshwater systems compared to the surrounding terrestrial area; 3) freshwater systems affect regional C balances and need to be included in terrestrial C budgets. Broadly, lakes are sites of intense organic C mineralization and hence CO_2 emission but can also sequester large amounts of C in their sediments (Cole et al. 2007), with a three-fold higher burial of organic C than oceans. This underscores the need for a more comprehensive understanding of C dynamics in arctic lake ecosystems to improve regional C budgets.

While it is expected that C dynamics are likely changing in lakes across the Arctic, southwest Greenland is one of the few locations where lakewater DOC concentrations and their changes over time have been measured (Saros et al. 2015), with substantial declines occurring sometime between 2003 and 2013 (Fig. 1). We infer that these changes in lakewater DOC are signaling broader changes in the C cycle of the area, as it does at lower latitudes.

We are currently conducting additional measures of C pools and fluxes across a suite of lakes in southwest Greenland spanning from the ice sheet to the coast. These lakes have low C burial efficiencies; we are focusing on water column measurements of CO_2 as well as dissolved and particulate C.

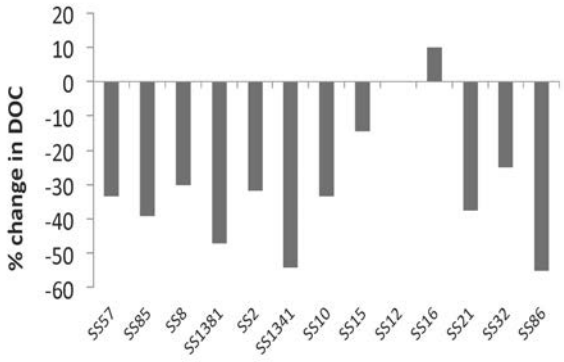

Fig. 1. Percent change in DOC concentrations in a sub-set of lakes in southwest Greenland between 2003 to 2013 (Saros et al. 2015), showing that DOC declined substantially in most lakes.

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Inferring Greenland Fjord and Coastal Bathymetry Using Icebergs

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Abstract: The transport of heat in warm Atlantic Waters exerts an important control on the mass loss of Greenland's marine terminating outlet glaciers. Fjord bathymetry places an important constraint on the ability of this heat to reach glacier termini, yet the bathymetry of most of Greenland's fjords is not well resolved. Here methodology is developed to infer fjord bathymetry using icebergs as observed in remotely sensed datasets. Preliminary results in regions with bathymetric measurements validate the method.

The response of the Greenland ice sheet (GIS) to climate changes has become increasingly pronounced over the past two decades. These changes are extremely evident along the margins of the ice sheet, where outlet glaciers channel ice from the ice sheet interior and often terminate in marine environments. Here, heat transported in relatively warm, salty, dense Atlantic Waters circulating off the coast of Greenland (e.g. Straneo *et al*. 2010) comes into contact with the marine terminating outlet glaciers and exerts an important control on their mass loss.

One of the controlling factors determining whether or not these warm Atlantic Waters penetrate into the fjords is the fjord bathymetry; the presence of a shallow bathymetric sill acts as a barrier and can prevent these warm waters from entering the fjord (Holland *et al*. 2008). Yet the bathymetry of most of Greenland's fjords is not resolved in sufficient detail to indicate the presence or absence of a sill, limiting our ability to predict dynamic ice responses to an increased flux of heat from the ocean.

Here we develop a methodology to infer fjord bathymetry using icebergs observed in remotely sensed datasets. First, we identify regions where icebergs become lodged as they flow out of the fjord (iceberg stranding). Then, we extract the stranded iceberg freeboards (height of the iceberg above the water surface) from digital elevation models (DEMs). From the freeboard we estimate the iceberg draft (depth of the iceberg below the water's surface) and hence the maximum water depth. Preliminary results in regions where bathymetric measurements are available validate the method and encourage its application in uncharted fjords.

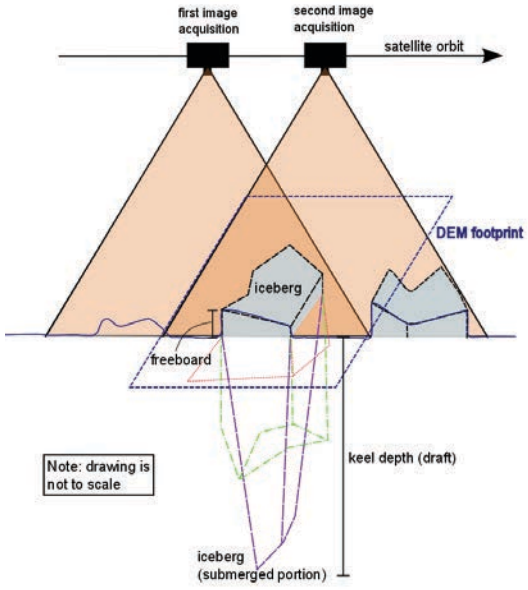

Figure 1: A conceptual model illustrating how iceberg keel depth (draft) is approximated. Shown here is the keel depth for the hypothetical submerged iceberg profile outlined in purple.

Acknowledgements: This work is supported by a NASA NESSF dissertation fellowship (grant NNX15AP08H) and by the US NSF A2C2 IGERT program (grant DGE-1144423).

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Do United States Protected Areas Conserve Nature's Environmental Stage?

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Abstract: Diversity within the physical environment, such as climatic, geologic, and topographic heterogeneity, provides the vital stage for biodiversity and ecological processes. Despite this, our protected areas are often designed to protect focal endangered species or communities, and not diverse physical environments. I propose to analyze how well United States' protected areas reserves capture the available environmental diversity. This information could highlight physical environments which are under-protected, and foster more climate change resilient reserves.

Protecting biodiversity in the face of climate change requires us to anticipate that species ranges will move, and recognize that establishing protected areas around current locations of may be insufficient for protecting future biodiversity. Thus, some have argued for protecting unique and heterogeneous physical environments as a 'coarse filter' strategy (Hunter et al. 1988) which could more effectively conserve a large number of species, in contrast with a 'fine filter' approach designed around individual species in decline. A coarse filter reserve design would aim to protect climates, soils, geomorphology, and topography, with the expectation that diverse physical environments will remain species-rich in a range of climatic conditions. This perspective has been termed 'conserving nature's stage' (Anderson et al. 2010, Gill et al. 2015), and recently been a focus for a special issue in the journal *Conservation Biology* (2015).

There is mounting evidence that regions with high climate, geologic, and edaphic heterogeneity harbor increased biodiversity (Anderson et al. 2010). Yet, despite the growing recognition that physical diversity is important for conserving biodiversity, we do not know how well our current protected areas capture this abiotic diversity. This is critical because protected areas are one of conservation's most relied upon tools in preventing biodiversity loss, and United States protected areas have been criticized for over-emphasizing biological diversity relative to abiotic diversity (Brilhá 2002).

Using the USGS protected areas database (Schruben et al. 1994), I propose to assess how well United States Protected Areas capture the available environmental diversity. Environmental variables analyzed will include climate, geologic bedrock, and topography. I will also test whether protected areas with more physical diversity contain more species. This will assess how well our current reserves function as a coarse filter strategy, and could highlight aspects of the physical environment which are under-represented in our parks.

Acknowledgements: I would like to thank Jacquelyn Gill, CCI and SBE for supporting this research, and USGS for making the data necessary for this study available.

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The Nevin Shellheap: Deconstructing a Red Paint Cemetery

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Abstract: The Nevin Shellheap is located in Blue Hill Bay, Maine. It contains one of the most significant cemeteries of the Moorehead Burial Tradition. Preservation of human remains and the associated elaborate funerary artifacts and ecofacts within the shell midden has made this site unique from other Archaic period cemetery sites in the Gulf of Maine despite the destructive effects of erosion due to sea level rise over the last 5,000 years.

The Archaic period in Maine was a time of transition and innovation in response to complex regional variations of the environment. These variations influenced technological, social and ritual patterns that defined this distinct time period.

The Moorehead Burial Tradition is a broadly defined burial pattern known for its formal cemeteries with intensive use of red ochre and elaborate funerary offerings (Robinson 1996). When human remains are not identifiably present, diagnostic funerary artifacts and ecofacts are the most visible characteristics to identify cemeteries.

Mortuary rituals can be complicated and often difficult to interpret from the archaeological record. The rituals form deliberate sacred spaces that serve to symbolically integrate kinship groups and to provide continuity through time of buried descent groups (Hutchinson 2002).

This research project consists of an analysis of the cemetery at the Nevin Shellheap with emphasis on the spatial and temporal relationship of the burials and diagnostic artifacts (including incised moose bone daggers, swordfish sword foreshafts and ground stone tools) within the complex stratigraphy of the shell midden.

Also vitally important in the analysis is the relationship of funerary objects with individuals in each burial, in particular gender and age and their aligned placement within each grave as primary or secondary interments.

The Nevin Shellheap was originally excavated in 1936-1937 by Douglas Byers and Fred Johnson representing the R.S. Peabody Foundation in Andover, Massachusetts. What was originally thought of as a habitation site with complex stratigraphy, the Nevin Shellheap revealed a rare, well-preserved formal cemetery.

This research will contribute to a better understanding of mortuary behaviors and their integration with other cultural sub-systems, such as settlement and subsistence, during the Archaic period.

Fig. 1. Funerary Assemblage Sample

Acknowledgements: Assistance has come from the University of Maine Climate Change Institute and Department of Anthropology, the R.S. Peabody Museum in Andover, Massachusetts, the Wabanaki NAGPRA Committee and the Abbe Museum in Bar Harbor, Maine.

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Success in Finding the 'Oldest Ice' at the Allan Hills Blue Ice Area, Antarctica

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Abstract: For the first time high resolution, high quality ground penetrating radar (GPR) data have been collected from the Allan Hills Blue Ice Area (AH BIA), Antarctica. These data provide a significant contribution to the ongoing search for the 'Oldest Ice'.

Comparison of δD_{ice} and $\delta^{18}O_{atm}$ measurements from ice core S27 and surface samples collected along the primary flowline (transect A-B) within the AH BIA to those from other published ice core records points to ages up to at least 400 ka. $\delta^{40}Ar/^{38}Ar$ measurements of an ice core collected away from the primary flowline (BIT-58) give an average $^{40}Ar_{atm}$ age of 990 ka ± 110 ka. This 1 Ma unit is a good representation of how old ice can be present in the area. The complicated subglacial topography of the region provides ideal conditions for trapping and preserving pockets of very old ice, including along the primary flowline.

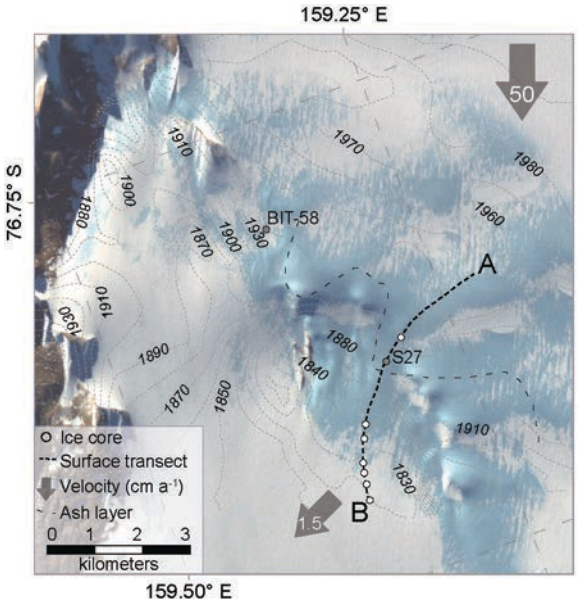

Fig. 1. Map of the main icefield of the AH BIA showing ice core drilling sites. The ash layer here is the 115ka marker in Fig. 2.

A recent NSF award (PLR-1443461) provided the funding necessary to conduct a comprehensive ground penetrating radar (GPR) survey aimed at tracing the signature of the 1 Ma ice layer throughout the region. The profile shown in Fig. 2 illustrates how potentially very old ice could be trapped in several locations in the area.

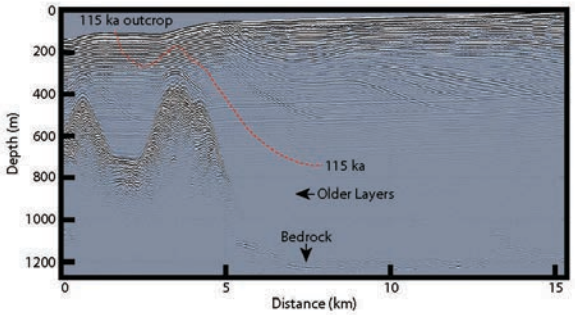

Fig. 2. 7MHz RES profile illustrating undisturbed stratigraphy at ~1000m and ~450m of undisturbed ice older than 115 ka (H. Conway, personal communication)..

Acknowledgements: Funding for this research provided by NSF OPP through grants 0838843, 0229245, 9527571, and 1443461. We also gratefully acknowledge field assistance from Mike Waszkiewicz, Kristin Schild, Melissa Rohde, Erik Venteris, Leigh Stearns, and Laura Kehrl. Flights by Kenn Borek Air Ltd. Logistics by Raytheon Polar Services (2004-2011) and Lockhead Martin's Antarctic Support Contractor (2016).

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One Must First Create a Time-Scale – LA-ICP-MS at Colle Gnifetti

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2. *Initiative for the Science of the Human Past, Harvard University.*
3. *Institute for Environmental Physics, Heidelberg University.*

Abstract: Comparison of well-dated LA-ICP-MS signals from the Colle Gnifetti ice core with written records of European cultural activities form the backbone of a collaboration between the Climate Change Institute and the Initiative for the Science of the Human Past at Harvard University.

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) offers minimally destructive ice core impurity analysis at unsurpassed sub-mm resolution. This method is uniquely suited for exploring the closely spaced layers of ice within samples collected at low accumulation sites or in regions of highly compressed and thinned ice.

The Colle Gnifetti glacier (Monte Rosa, Swiss-Italian Alps – Fig. 1) is the only European ice core drilling site with an annual net snow accumulation low enough to archive multi-millennial records in spite of its limited ice thickness. However its rapid layer thinning limits the use of layer counting in creating age-depth models when traditional melt-based signals are used. Thus, an instrument like the W.M. Keck LA-ICP-MS is needed to create a time-scale at this glacier.

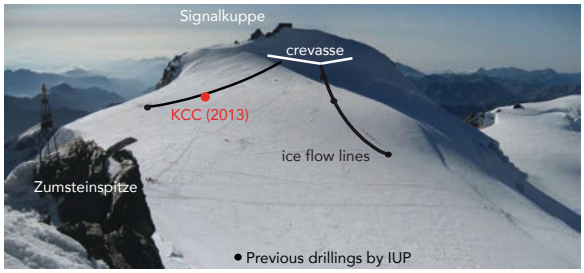

Fig. 1. The Colle Gnifetti glacier and the location of the 2013 ice core (KCC) in relation to the full array.

Over the past 2.5 years ice core KCC, drilled in 2013, has been sampled more densely than any other ice core - ever. Using the 1.5 million laser calcium data points collected in combination with 0.5cm resolution melt-based data (Fig. 2) and discrete ICP-MS samples, a time-scale has been created covering the past 3000 years. Preliminary comparisons of additional elements, including those derived mainly from anthropogenic activities - like lead and copper- with written accounts show exciting parallels thereby increasing confidence in the age-depth scale.

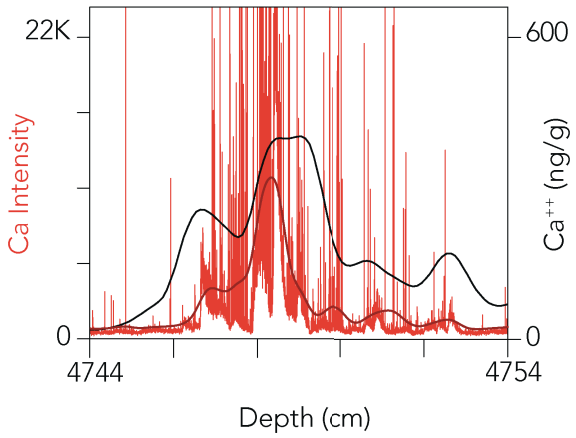

Fig. 2. Comparison of state of the art LA-ICP-MS measurements (raw = red, 0.5cm smooth = maroon) with melt-based measurements (black) at shallow depths confirms the values of annual layer counting of LA-ICP-MS signals at greater depths.

Acknowledgements: Financial support from the Arcadia Fund and the Initiative for the Science of the Human Past at Harvard University. Thanks also to: Physical Institute Uni Bern for drilling the 2013 CG ice core, our field team, the University of Fribourg, the staffs of the Capanna Margherita Hut, AirZermatt and Alpin Cargo, Sepp Kipfstuhl and Johannes Freitag for their assistance during processing of KCC at AWI, and Mike Handley and Andrei Kurbatov for helpful discussions about ICP-MS operation and experimental design, respectively.

The University of Maine Climate Change Capacity Discovery Survey – Preliminary Results

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Abstract: A survey aimed at determining institutional capacity in the realm of climate change at the University of Maine was conducted in January of 2016. An online directory of expertise is the anticipated deliverable of this campus-wide survey, though intangible benefits including an increase in collaboration resulting from the growing awareness of our collective work are also expected.

The University of Maine is nationally and internationally recognized for expertise across a broad range of physical, biological, chemical, social, and economic disciplines related to climate change. This work is housed in highly identifiable units like the Climate Change Institute as well across many of the research centers, outreach organizations and academic units at the University of Maine. This work encompasses energy, human health, natural resources (food systems, forest resources, freshwater and oceans), the built environment, and increasingly includes the arts and humanities. In 2014 the University of Maine administration designated Climate Change as a Signature Area of Excellence.

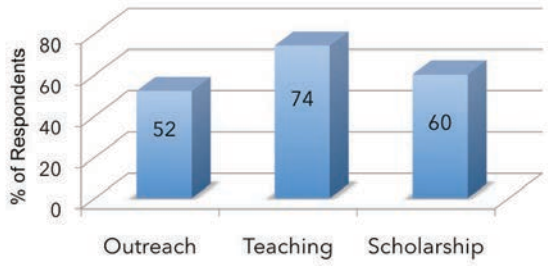

Fig. 1. Percent of respondents reporting involvement in outreach, teaching, and scholarship related to climate change.

In January of 2016 a survey was conducted by the Climate Change Institute, under the auspices of that designation, to better define the expertise and resources at the University of Maine on the broadly defined subject of our changing climate and to strengthen awareness, communication and coordination at our institution. This survey was intended to identify both those who consider climate change part of their program identity, as well as those whose expertise relates to changing patterns of temperature, moisture, and atmospheric chemistry and the consequences of these changes. Collectively, these faculty and staff represent the depth of resources and expertise at the University of Maine that supports our mission to serve students and society on climate concerns and opportunities. The goal was institutional capacity discovery leading to a directory of expertise, and hopefully the synergies that would flow from a growing awareness of our collective work. The directory is to be posted on the Maine Climate News web site.

Sea Level Rise Impacts on Archaeological Resources as a Result of Population Resettlement: A Case Study

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Abstract: Coastal communities in the United States are facing challenges posed by sea level rise. As coastal areas are inundated and subjected to coastal processes, mitigation of threats to the archaeological record are generally limited to immediately threatened sites of great local significance, while the destruction of sites by the resettlement of affected communities has been given little attention. We report a pilot study in Casco Bay, Maine, using archaeological survey data, digital elevation models, coastline geology, local sea level rise and flood projections, tax records and census data to predict the potential locations of impact to cultural resources beyond the immediate impact zone through landward relocation housing and associated infrastructure.

Project Goals:

Casco Bay has a wealth of archaeological resources, located in densely populated coastal areas as well as less-developed inland regions. Impacts of climate change, particularly rising sea levels[1], increases in frequency and severity of storm surge and riverine inundation, and erosion will disproportionately affect coastal settlements. Globally, communities have begun to armor coasts, protect infrastructure, and even relocate.

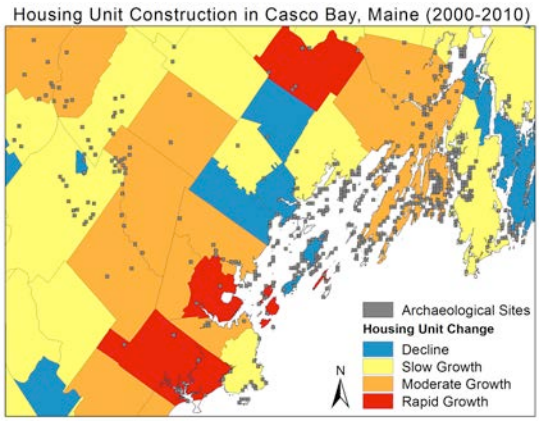

Fig. 1. Development threatens archaeological sites.

This project aims to establish the groundwork for communities to mitigate threats to cultural resources by identifying where populations are likely to expand, and by indicating where sites may be negatively impacted as a result.

Initial Results:

Census data show increases in population density in Portland, but also increases in housing construction elsewhere, particularly in non-coastal Sagadahoc County[2], and in more distant 'turnpike towns'. While coastal urban centers may be vulnerable to impacts of climate change, mitigation of threats through improved infrastructure may increase resilience of these hubs to sea level rise in comparison to rural areas where economic incentives to fortify coasts or replenish eroding beaches do not exit. In this scenario, urban populations may also become denser, in turn threatening cultural resources. Densification in these formerly less developed areas will bring new individuals into contact with archaeological sites, increasing risk of destruction (Fig. 1). In towns prioritizing mitigation, reinforcement of coastlines and other construction will also negatively impact cultural resources. It is imperative for archaeologists to work with climate scientists, urban planners and communities to identify and protect sites threatened by secondary impacts of climate change. Growing an engaged public archaeology through concerted education will help promote understanding of and participation in stewardship of our archaeological resources.

Acknowledgements: This research is funded by a Climate Change Institute Research Assistantship. Archaeological survey data and support graciously provided by Arthur Spiess (Maine Historic Preservation Commission) and Nathan Hamilton (USM), GIS data from MEGIS.

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A Bi-Hemispheric Perspective on the Last Glacial Termination From the Southern Alps of New Zealand and the Altai Mountains of Western Mongolia

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Abstract: **An understanding of the last glacial termination will help hone our understanding of the processes that drove warming to completion and of the climate system sensitivity to natural and human forcing factors, such as atmospheric CO_2. Here, we test possible drivers of the last glacial termination by comparing chronologies of mountain glacier recession in the middle latitudes of both polar hemispheres. We present ^{10}Be surface-exposure chronologies and glacial geomorphologic maps of mountain glacier recession since the Last Glacial Maximum in the Southern Alps of New Zealand (44°S, 170°E) and in the Altai Mountains of western Mongolia (49°N, 88°E).**

The last glacial termination (~18,000 – 11,000 yrs ago) represents the last great global warming and the last time CO_2 rose by a substantial amount before the industrial period. In addition, a prominent version of the Milankovitch (1941) hypothesis of ice ages is that variations of Earth's ice sheets are paced by periodic changes in Earth's orbit and consequent seasonal redistribution of incoming solar radiation at 65°N latitude.

Extra-polar mountain glaciers are highly sensitive to atmospheric temperature, and glacier landforms afford insight into past climate conditions. I present ^{10}Be surface-exposure chronologies and glacial geomorphologic maps of mountain glacier recession since the Last Glacial Maximum in the Southern Alps of New Zealand (44°S, 170°E) and in the Altai Mountains of western Mongolia (49°N, 88°E) (Figure 1). I used the ^{10}Be exposure-age dating technique to determine the chronology of glacial landforms northeast of Lake Pukaki.

The highest-elevation, left-lateral deposits of the former Pukaki glacier reveal six glacier advances during MIS 4, 3 and 2. This chronology reveals that glaciers in the Southern Alps of New Zealand repeatedly achieved full-glacial extents throughout Marine Isotope Stages (MIS) 4, 3 and 2. The results suggest that the timing of millennial-scale maxima and minima of glaciers in the Southern Alps of New Zealand are not correlated with orbitally-driven insolation changes. Rather, the ^{10}Be surface-exposure record of this study provides evidence that the climate of the Southern Hemisphere mid-latitudes responded to other climate drivers.

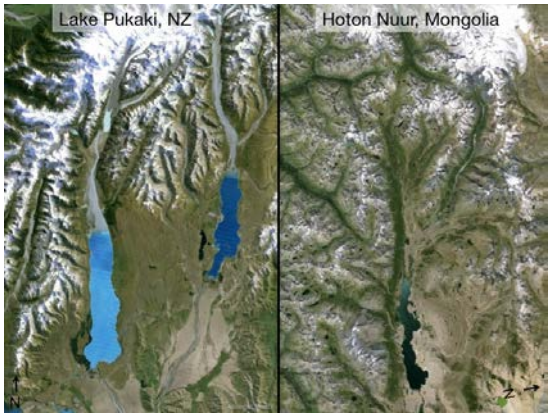

Figure 1. Comparison the Lake Pukaki valley, New Zealand and Hoton Nuur valley, Mongolia

In the Mongolian Altai, preliminary ^{10}Be ages indicate that the last glacial termination may have been underway prior to that in New Zealand. On the basis of these two chronologies, we evaluate the relative roles of rising atmospheric CO_2, local insolation forcing, and ocean-atmosphere reorganizations in driving the warming that ended the last ice age.

Acknowledgements: We thank the Gary C. Comer Science and Education Foundation, the National Science Foundation, and the Quesada Family Foundation for support.

Modeling Spatiotemporal Variability of the Bioclimate Envelope of Homarus Americanus in the Coastal Waters of Maine and New Hampshire

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Abstract: A bioclimate envelope model was developed to evaluate the potential impacts of climate variability on American lobster (*Homarus americanus*). Bioclimate envelopes were defined by season-, sex-, and stage- specific Habitat Suitability Indices (HSI) based on (1) bottom temperature, (2) bottom salinity, and (3) depth. This study provides a modeling framework to reconstruct climatically suitable lobster ranges that can be used to formulate climate-based hypotheses for future studies of this species.

American lobster, *Homarus americanus*, is a large benthic crustacean present throughout coastal Northwest Atlantic waters. Due to its ectothermic nature, climate change could significantly impact *H. americanus* abundance by altering bottom-up forces (e.g. climate-driven changes in environment and resources).

A bioclimate envelope model was developed to evaluate spatiotemporal variability of a climate-driven habitat suitability *H. americanus* in the coastal waters of Maine and New Hampshire from 1978 to 2013 (Tanaka and Chen 2016).

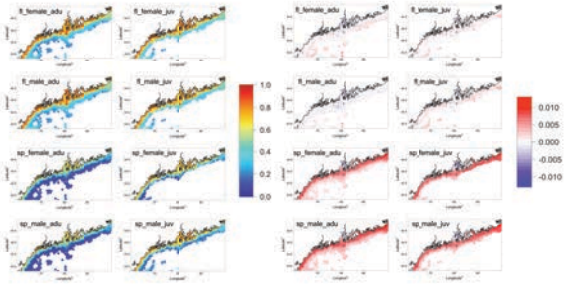

Fig. 1. Left: Season, sex, and stage specific maps illustrating the spatial distribution of the median habitat suitability index (HSI) over 1978 - 2013 in the coastal waters of Maine and New Hampshire for *Homarus americanus*. Right: Season, sex, and stage specific heat maps illustrating change in HSI over 1978 - 2013 in the coastal waters of Maine and New Hampshire for *Homarus americanus*. fl: Fall (September-November); sp: Spring (April-June); adu: Adult (>60 mm carapace length); juv: Juvenile (<= 60 mm carapace length).

The model predictions indicated higher habitat suitability in inshore waters for both adult and juvenile lobsters. A statistically significant increasing trend in habitat suitability was observed for both sexes and stages (juvenile and adult) during the spring (April-June), while no significant trend in habitat suitability was observed in the fall (September-November).

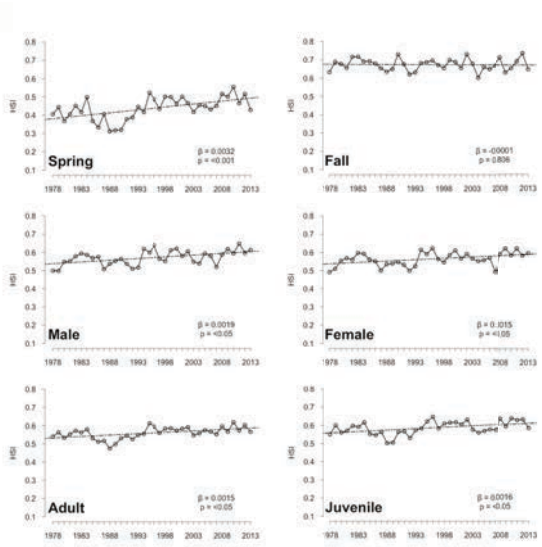

Fig. 2. Median habitat suitability index (HSI) for each year from 1978 to 2013 (solid line). The trend in both seasons-sexes, and stages was shown by the fitted linear regression model (dashed line).

Acknowledgements: This study was funded by the NSF Adaptation to Abrupt Climate Change IGERT program (DGE-1144423) and NSF Coastal SEES program.

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Epilimnion Thickness of Lakes in Acadia National Park: Biological Implications in a Changing Climate

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2. *Environmental Science Department, Dickinson College.*
3. *Acadia National Park Service, Maine.*

Abstract: The clarity of lakes in Acadia National Park has been declining over the past two decades, as has the thickness of the epilimnion, a trend linked to increases in dissolved organic carbon (DOC). In this study, we explore the biological implications of declining in lake clarity and epilimnion thickness, focusing specifically on phytoplankton biomass and community structure.

In recent years, water clarity in Jordan Pond and across lakes in Acadia National Park has been declining. There are several unknowns about how the recent change in lake clarity is influencing lake biota currently and how it will do so in the future.

The recent change in lake clarity has been accompanied by a thinning of the epilimnia, the warm mixed surface layer of lakes. A previous study in Acadia National Park pairing historical monitoring data with high frequency data from Jordan Pond revealed that the declining trends in clarity and epilimnion thickness were largely due to changes in dissolved organic carbon (DOC) concentrations (Strock et al. 2016, in press).

Few studies have manipulated the biological implications of altered thermal structure predicted to occur with changes in DOC, despite its essential role in regulating light and nutrient availability for phytoplankton. In this study, experiments were performed in Jordan Pond (a low DOC, high transparency system) and Seal Cove (a high DOC, low transparency system) to test the effects of altered light conditions experienced under altered simulated epilimnion thicknesses on phytoplankton biomass and biovolume.

In Seal Cove, the experiment revealed that in high light conditions of a thinner epilimnion, total biovolume did not change between treatments, but total chlorophyll did change significantly. Therefore, the experiment reveals that low light (i.e. a thicker epilimnion) resulted in higher chlorophyll concentrations. The experiment in Jordan Pond revealed no significant changes in biovolume or biomass.

These experiments suggest that the altered light conditions that accompany changing epilimnion thickness may have stronger effects on phytoplankton physiology than abundance or diversity, and that high DOC systems are likely to exhibit a pronounced response to changes in epilimnion thickness. Experiments such as this are essential to understanding how climate change will influence lake ecosystems and water quality in the changing climate.

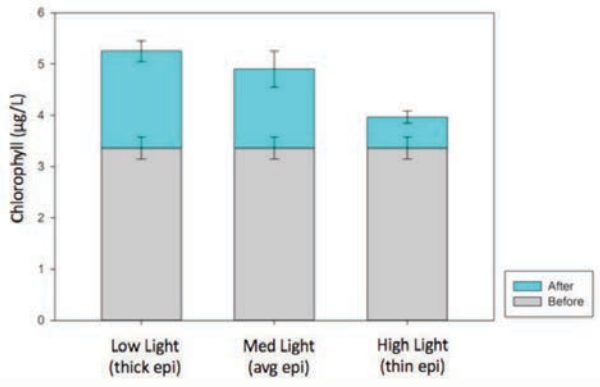

Fig.1 Results from Seal Cove Experimental Manipulation of Epilimnion Thickness.

Acknowledgements: This research was funded by a grant from Canon, Inc.

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Development of a Modeling Framework to Assess the Effects of Environmental Heterogeneity in Sea Scallop (*Placopecten Magellanicus*) Abundance, Distribution, and Growth: Application to the Maine Fishery

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Abstract: This project will develop a modeling framework to project spatio-temporal variability in sea scallop (*Placopecten magellanicus)* habitat, distribution, and growth rates with respect to underlying environmental conditions in the Gulf of Maine. Modeling outputs will be used to evaluate potential impacts of climate change on scallop population dynamics and to improve stock assessment and management for this fishery.

Sea scallop (*Placopecten magellanicus*) abundance, distribution, and life history parameters are impacted by environmental variables such as depth, bottom type, current velocity, temperature, and salinity. Habitat characteristics affect scallops throughout their entire life cycle, e.g., settlement in the larval stage or feeding, growth, and predation risk in juvenile and adult phases (Shumway and Parsons, 2006). Despite the clear influence of habitat on scallop distribution and life history parameters, quantitative studies on scallop-habitat relationships remain rare (Mendo et al., 2014).

This study will develop a modeling framework to quantify potential impacts of environmental variability on scallop population dynamics, and to incorporate possible habitat variability into the assessment and management of the Gulf of Maine (GoM) scallop population. The framework will comprise a variety of approaches to quantitatively describe different aspects of scallop ecology including a habitat suitability index (HSI) model (see Fig. 1), a scallop distributional model, and habitat-life-history models.

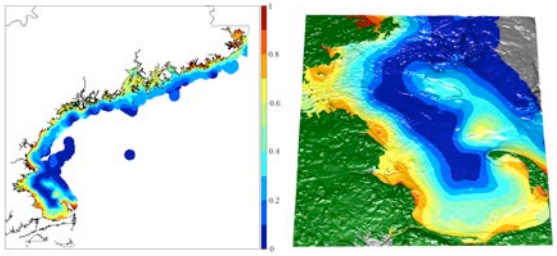

Fig. 1. Preliminary outputs from habitat suitability index (HSI) model predicting habitat value for sea scallops (*Placopecten magellanicus*). HSI values range from 0-1, with 1 being most the suitable habitat.

In light of recent extreme warming events within the Gulf of Maine (Mills et al., 2013) it is becoming increasingly important to view resource management from within the context of climate change. This project will provide an unprecedented opportunity to evaluate the potential impacts of abrupt climate change on the dynamics of scallops. The modeling framework developed for this project will be used for forecasting how scallop populations are likely to respond to a warming Gulf of Maine ecosystem under various climate change scenarios, and to evaluate effectiveness of possible future mitigation efforts.

Acknowledgements: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423 as well as the Maine Department of Marine Resources.

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Effects of Geese on Nutrient and Carbon Inputs to Arctic Lakes in Southwest Greenland

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Abstract: Global goose populations have nearly doubled since the 1970's which is mainly attributed to a lower winter mortality rate. With the majority of geese breeding ground being located in the Arctic this could lead to numerous ecosystem implications. With few studies examining the effects of geese on freshwater systems, the impacts of this population increase on arctic lakes is unclear. We are investigating whether geese enhance nutrient and organic carbon loading rates to lake ecosystems in Southwest Greenland.

Climate change in the Arctic generates a complex series of stressors that could change catchment hydrology, vegetation, and habitat for wildlife. It also alters wildlife distribution, expansion, and foraging behaviors. Low nutrient freshwater bodies are susceptible to changes in external inputs of nutrients and carbon, altering their biogeochemistry (Ghislain et al 2010).

Geese in particular may have a large impact on artic freshwater systems. To date, only a few studies have been conducted on the effects of geese on Arctic lake systems. Grazing and grubbing (act of foraging under the soil surface) by geese have led to the large scale destruction of salt marshes and in some areas goose activity has led to 30-75% increase in nutrient loading rates in freshwater systems. (Jefferies 1998; Walker et al. 2003). Geese populations have been on the rise since the turn of the century due to an increase in winter survivorship most likely due to changes in southern agricultural practices allowing for a larger food supply and elevated winter body conditions (Ghislain et al 2010).

The goal of this project is to understand the effects of geese on nutrient and carbon inputs to Arctic lakes of Southwest Greenland. This research will allow us to understand how changes in geese population size and duration at these lakes will alter lake water chemistry. This will give insight into what to expect in the future and possible management plans in order to address these changes.

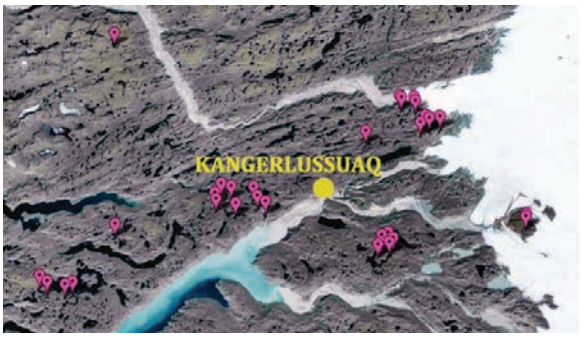

Fig 1 Map of the study area, with all lakes with available water chemistry data indicated. A subset of these lakes will be used in this study.

Acknowledgements: We are very grateful to The Dan and Betty Churchill Exploration Fund.

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Investigating the Response of Maine's Drinking Water Resources to Extreme Precipitation Events

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Abstract: Increases in dissolved organic carbon (DOC) in aquatic ecosystems have occurred as a result of increased extreme precipitation events in the northeastern U.S. DOC is a fundamental regulator of aquatic ecosystem structure and function and little is known about the implications of elevated DOC concentrations on water quality. The goal of this study is to evaluate immediate chemical and biological changes in water quality from extreme rain events and subsequent increases in DOC on Maine's drinking water lakes.

Maine lakes serve as a high quality source of drinking water for many residents. However, this high quality water is being threatened by a rapidly changing climate, in particular, extreme precipitation events, which have increased in frequency in the northeastern U.S. by 60-70% since the 1950's (Madsen & Wilcox 2012). Analysis of a 30-year database of surface water geochemistry and watershed-specific landscape data for 84 remote lakes throughout the northeast suggests increased concentrations of dissolved organic carbon (DOC) in lakes during extreme wet years (Strock et al. 2016). Increases in DOC, an important regulator of ecosystem function, can influence overall water quality and can have implications for drinking water treatment processes. Currently, the extent to which changing precipitation is altering the type and quantity of DOC and consequently the biota of Maine's lakes is unclear.

The goal of this research is to quantify immediate changes in drinking water lakes from extreme precipitation events through measurement of key water quality metrics. These metrics include: DOC quantity, DOC quality, nutrients, algal biomass and community structure. A subset of 6 drinking water sources were sampled for these metrics 24 hours before, 24-48 hours after, 5-7 days after, and 3 weeks after an extreme precipitation event. Three types of responses were found across lakes: 1) sustained increase in DOC after an event; 2) initial spike in DOC after the event, followed by return to pre-storm concentrations; 3) no change in DOC (Fig. 1).

This research will help inform potential future modification of drinking water adaptation and management strategies.

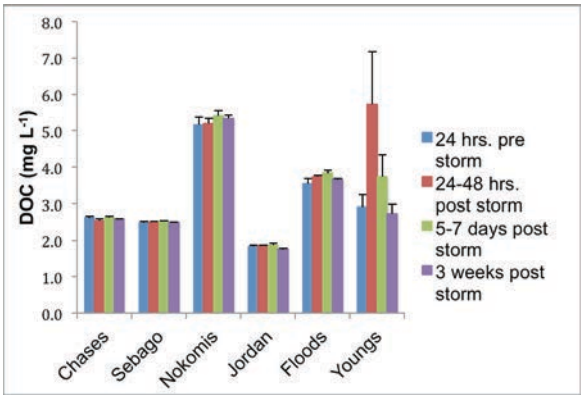

Fig. 1. DOC concentrations before and after an extreme precipitation event across 6 Maine drinking water lakes. Each DOC concentration is averaged from 3 storm events.

Acknowledgements: This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

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Adapting to Abrupt Climate Change in Palau Utilizing Traditional Environmental Knowledge and Scientific Data

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2. *Climate Change Institute, University of Maine.*

Abstract: In the Western Pacific island nation of Palau, rapid sea level rise and ocean acidification linked to abrupt climate change (ACC) threaten Palauans' subsistence and economic livelihoods. I study local perceptions of climate change to uncover Palauans' adaptive capacity to ACC impacts. I also examine how traditional environmental knowledge (TEK) can be employed alongside scientific climate data and projections to create locally appropriate and effective adaptation policy solutions.

Research

Palau is experiencing decadal scale sea level rise, ocean acidification and ocean warming (Ngemas et al. 2011). Sea-level rise is causing coastal erosion, direct inundation of infrastructure and crops, and salinization of freshwater resources. Ocean acidification and warming is resulting in coral bleaching of the near-shore coral reefs that Palauans heavily rely on for both subsistence and economic means. ACC impacts are exacerbated in Palau by preexisting anthropogenic issues such as urbanization, increasing coastal population densities, reliance on foreign aid, water pollution, and unsustainable fishing practices.

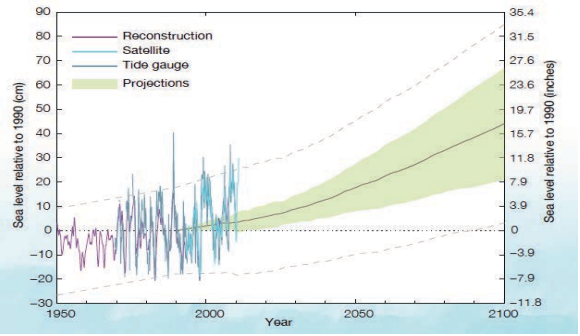

Fig. 1. Palau sea level rise under IPCC medium emission scenarios (Ngemas et al. 2011)

Palauans inhabit both low-lying coral atolls and mountainous high islands with low coastal plains. Thus Palauans can be highly adaptable to ACC through the synthesis of culturally appropriate and scientifically informed policy solutions.

Recent adaptation policy in Pacific Islands has largely failed because policy is being communicated and employed in ways that do not acknowledge local understandings, practice and knowledge systems (Nunn 2013). My research uncovers climate change perceptions in Palau that reveal Palauans' adaptive capacity to ACC impacts. Furthermore, I study TEK as a vast information base that elucidates local expertise about past environmental conditions, subtle yet important changes that have occurred in the environment and contemporary adaptive response to a changing environment. Finally, this innovative and potentially replicable research utilizes contextual, local TEK while integrating the measurements and projections of biophysical scientists to generate locally effective climate change policy solutions.

Image. 1. Palauan Subsistence Fishermen.

Acknowledgements: This research is supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423

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Ancient Ashes: New Methodology to Effectively Capture and Analyze Crypto-tephra in Ice Cores

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1. *Climate Change Institute, University of Maine.*
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Abstract: By improving ice core sampling methodology, novel analysis of super fine volcanic ash (cryptotephra) from large, tropical volcanic eruptions became possible. Cryptotephra has been elusive in ice core records for several decades; probably due to both physical and instrumental limitations. However, with new techniques, tropical cryptotephra that is essential for refining ice core chronology can be both found and analyzed.

Project Description

Previous methods for mounting tephra particles include liquid adhesive, carbon planchets, filters, carbon adhesive, double-sided tape, and epoxy. While these materials are effective for capturing large (visible) tephra particles, few have managed to both capture and successfully analyze glass shards smaller than 10 µm. Because the majority of tephra deposited from tropical volcanic events is smaller than 10 µm, our new method will help further refine timescales across multiple ice cores.

Summary of Methods

Some of the most common methods are highlighted by Kuehn and Froese (2010), most of which involve mounting the particles on a carbon planchet, which eliminates the need for applying conductive coating to the sample, a process which is necessary for analysis in multiple instruments, such as the Scanning Electron Microscope (SEM).

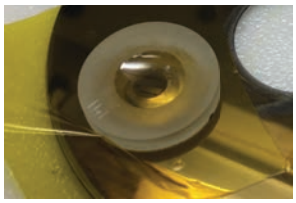

Fig. 1. Single-opening epoxy mounts, polished on each side for flatness, adhered to specially formulated tape and a super flat hard drive surface.

While Kuehn and Froese (2010) and Hall and Hayward (2014) outline several effective methods for capturing particles in the 3-5 µm range, there are multiple steps involved that can be eliminated with newer products and simpler, more efficient methodology. Instead of filling pores of a carbon planchet with epoxy, or evaporating meltwater directly onto the carbon planchet, the multiple products and steps involved in the mounting process can be replaced with Kapton Double Sided Polyimide Tape (KT) and used computer hard drive disks (see Fig. 1).

Both expensive and difficult to use, carbon planchets are no longer necessary since the hard drives are flat enough to ensure a smooth mounting surface, and the use of the temperature resistant tape can guarantee both a sealed area to prevent leaks during heating/evaporation and a smooth enough surface to keep particles in place for backfilling the sample hole with epoxy.

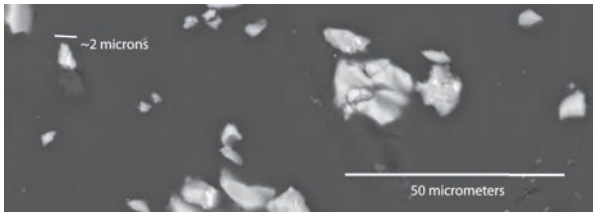

Fig. 2. View of an unpolished epoxy mount and tephra particles viewed under the SEM at 20 kV and 10 probe current in a high vacuum. Note the sub-micron particles mounted alongside the 20 µm particles.

New methods allow for effective capture of over 99% of tephra smaller than 5 µm from ice core samples, as well as the ability to view and analyze the particles under the SEM (see Fig. 2).

Acknowledgements: NSF Grant # PLR-1142007. CCI graduate scholarship. Donna Kalteyer and Natasha McWalters for laboratory assistance.

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