A Four-Member Monthly Ensemble of 3rd Generation Climate Reanalysis Models, 1979-2013

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Abstract: We are developing and evaluating a global monthly ensemble (1979-2013) of the current leading reanalysis models, NCEP CFSR, ECMWF ERA-Interim, JMA JRA-55, and NASA MERRA.

Reanalysis models are numerical frameworks that reproduce past atmospheric conditions from periodic input of meteorological station, radiosonde, and satellite measurements (Kobayashi et al., 2014; Rienecker et al., 2011). The 3rd and latest generation global reanalysis models include NCEP Climate Forecast System Reanalysis (CFSR; Saha et al., 2010), ECMWF Reanalysis Interim (ERA-I; Dee et al., 2011), Japanese Meteorological Agency 55-Year Reanalysis (JRA-55, Kobayashi et al., 2014), and NASA Modern-Era Retrospective Analysis for Research and Applications (MERRA; Rienecker et al., 2011). Each of these model frameworks use different horizontal and vertical grid resolutions and different data assimilation methods (Table 1). Third generation reanalyses are considered to be more reliable than previous versions for their improved physics and integration of satellite data. Despite the robustness of CFSR, ERA-I, JRA-55, and MERRA, each model has strengths and weaknesses that result in different estimates of past weather. We are combining these latest reanalysis models into a four-member monthly ensemble 1979-2013 (GEN3-ENS) in an attempt to improve solution realism.

	CFSR	ERA-I	JRA-55	MERRA
Horizontal Resolution	0.5	0.75	0.562	0.5 x 0.667
Vertical Levels	64	60	60	72
TOA	0.266	0.1	0.10	0.01
Data Assimilation	3DVAR	4DVAR	4DVAR	GOES IAU

Table 1. Reanalysis datasets used. Horizontal resolution in degrees. Top of atmosphere (TOA) in hPa.

In what is the initial phase of work, we have begun plotting surface variables in order to assess how each member departs from the reanalysis ensemble average (e.g., Figure 1). Our analysis thus far indicates that individual ensemble members have correlation coefficients > 0.96 but regionally there are biases. Work is ongoing. When complete, the GEN3-ENS methodology and evaluation will be published, and data files will be made available to the broader climate research community.

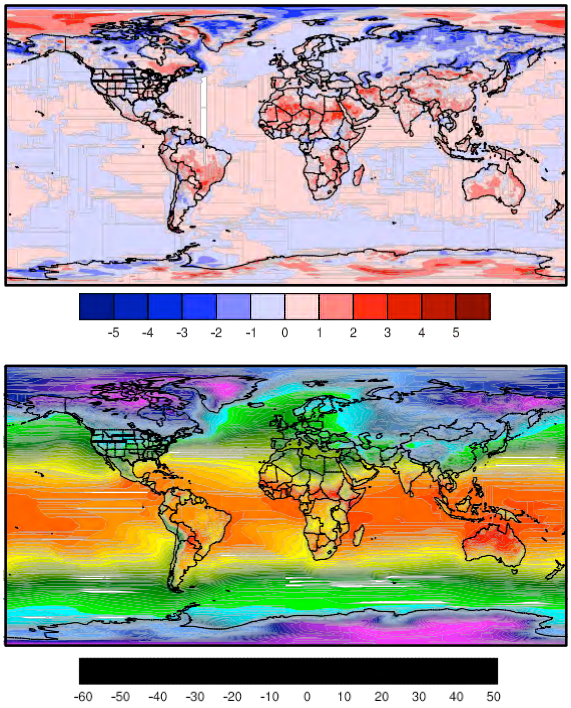

Fig. 1. Plot showing surface temperature from GEN3-ENS subtract CFSR (top) and GEN3-ENS (bottom). February 1990.

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Bibliography:

Dee, D. [and others], The ERA-Interim reanalysis: configuration and performace of the data assimilation system. *Quart. J. Royal Met. Soc.* 137 (2011): 553-597.

Kobayashi, S., [and others], The JRA-55 Reanalysis: General Specifications and Basic Charateristics. *J. Met. Soc. Japan* 93 (2015): 440.

Saha, S., [and others], The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Met. Soc.* 91 (2010): 1015-1057. I.

Reinecker, M. [and others], MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Clim.* 24 (2011): 3624-3648.

Providing Marine Harvesters with Tools to Handle a Rapidly Changing Ocean

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Abstract: The rapid rate of environmental change occurring in the Gulf of Maine, coupled with the depletion of marine stocks from overfishing and ecological change, highlights the need for marine harvesters to reduce their vulnerability to potential future changes through diversification. Aquaculture is often presented as an appropriate means of diversification. To this end, a series of aquaculture training courses designed for marine harvesters have been delivered in several Maine towns to help facilitate potential adaptation efforts. Social science research is being done in conjunction with these efforts to improve harvester's successful transition to aquaculture.

Project Goals

The goal of this project is to provide marine harvesters with the skills and information needed for the practice of aquaculture. Due to the rate of change experienced in the Gulf of Maine (GoM) over the past decade,[1] and especially over the last several years (**Figure 1),** Maine fishermen are being encouraged to reduce their vulnerability to such changes by diversifying their businesses through aquaculture.

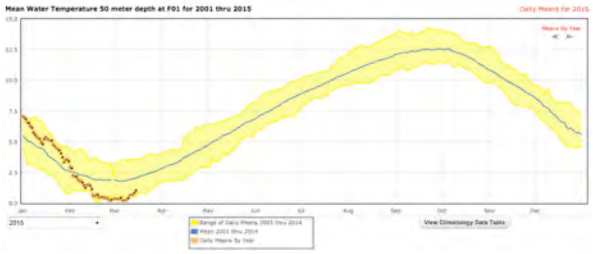

Figure 1. 2015 temperature profile for GoM. Temperature ranges is already 7.5°C.

Aquaculture differs from wild harvest in the same manner as a farming differs from a hunting and gathering. Transitioning between the two necessitates an education in the technical aspect of husbandry and a cultural shift from harvesting. In 2015 municipal employees from the towns of Brunswick and Harpswell worked with various groups to develop and deploy an 8-week aquaculture-training program. This program is designed to give wild harvesters the information necessary to consider an aquaculture business and the skills required to start one.

[1] Record, N 2014. Maine waters warming fast, *Bigelow Laboratory for Ocean Sciences Transect* 6:8-9.

The research component of this project involves: identifying potential barriers to the successful adoption of aquaculture, assessing general attitudes towards aquaculture, and an overall assessment of the course itself. These will help tailor future classes and can potentially facilitate harvester's successful transition to aquaculture.

Image 1. Harvesters from Harpswell and Brunswick learn about bivalve biology and ecology.

Initial Results

A total of 18 fishermen enrolled in the course. Several harvesters have expressed pursuing Limited Purpose Aquaculture leases with the majority of the class indicating they were likely to be involved in aquaculture in the future. Several barriers have been identified including: information deficits, application logistics and community interactions. Classes provide an excellent model for training other harvesters to deal with future changes in the GoM.

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Erosion and Migrating Shell Middens on Machias Bay

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Abstract: Erosion-based loss of coastal archaeological sites on Machias Bay complicates coordination of prehistoric living areas with changing styles of rock art spanning 3000 years. Analysis of shifting shell middens and sub-midden living areas at Holmes Point West will increase understanding of what has been lost and relationships between diverse cultural activities.

The University of Maine archaeological field school has been excavating two sites on Machias Bay, working with the Passamaquoddy tribe to correlate living areas and activities with 3000 years of rock art on the bay (Soctomah 2009). A major problem is that time and sea-level rise have significantly eroded the shoreline (Shipp 1989), causing site loss and an inland migration of more recent sites as a direct consequence of erosion.

Work has focused on a small, weakly-stratified shell midden at the Holmes Point West site. Artifacts of both indigenous and European origin occur throughout much of the midden, suggesting the possibility that it dates perhaps only a few centuries prior to the arrival of Europeans. However, artifacts and features below the midden have been dated to at least 2400 years ago.

Previous work in the region suggests that house floors were often located behind associated shell middens (Sanger and Chase 1983). Given the presence of cultural material dating to the Early Woodland period, but with no corresponding shell midden, our problem is to understand what has been lost to erosion, and precisely how the shell midden has migrated over old living floors. A series of floors, fire hearths, and animal bone deposits have been excavated at the base of the shell midden; these appear to have been covered by shell shortly after their deposition. A workshop of densely-scattered lithic tool debris may provide a key to how the activity areas overlap. Radiocarbon samples are being prepared from precisely correlated events as determined via assistance from Andrew Heller's analysis of microstratigraphy.

Cataloging of the recovered archaeological materials from the last three field seasons has proven a substantial task that must be completed before the spatial analysis of artifact activities can commence. The artifacts recovered have included rare stone tool fragments originating in northern Labrador, as well as a considerable amount of lithic material from the Minas Basin region in Nova Scotia. Refining the dating and stratigraphy associated with these artifacts will help us understand how these cultural materials and events relate to one another, as well as their relationship with the nearby concentration of Passamaquoddy rock art.

The analysis of the artifacts excavated in the 2014 field season is currently in progress. These excavations were designed and executed specifically to address the previously-identified problems of overlapping and shifting features.

Acknowledgements: Maine Academic Prominence Initiative (MAPI), Passamaquoddy Tribal Historic Preservation Office, Climate Change Institute, University of Maine Department of Anthropology.

Bibliography:

Sanger, David and Thomas Chase. "An Introduction to the Roque Island Group, Maine." Paper presented to the Canadian Archaeological Association, April 1983.

Shipp, R. Craig. "Late Quaternary Sea-Level Fluctuations and Geologic Evolution of Four Embayments and Adjacent Inner Shelf along the Northwestern Gulf of Maine." PhD diss., University of Maine, 1989.

Soctomah, Donald (ed.) *Petroglyph Management Plan for Machias Bay: Protection and Documenting the Uniqueness of Machias Bay*. Passamaquoddy Tribal Historic Preservation Office. Report submitted to the National Park Service, 2009.

Implications of Heterogeneous Strain Weakening of Bedrock Underlying the Highly Active Glacio-tectonic System of Coastal Alaska

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Abstract: Glacial erosion formulations include tools to model glacial erosion and sediment output, but use an oversimplified homogeneous strength model for the underlying bedrock. By measuring fracture density and material cohesion in profiles across regional fault zones, we are constraining actual bedrock strength calculations, and will use these to model more realistic erosion rates.

We examine the interactions between tectonics, climate, and erosion, and how these factors create and control topography. The St. Elias Region of Alaska is an area of active tectonics and heavy precipitation, resulting in rapid orogenic uplift and erosion (Koons et al., 2013).

Traditional glacial erosion models are based on ice thickness and velocity, but do not take into account bedrock cohesion. Current fluvial erosion models show that erosion rates vary across orders of magnitude based on non-linearities in the erodibility due to material strength variation of the bedrock. (Roy et al., 2015). We hypothesize that with similarly heterogeneous bedrock cohesion, similar ranges of erosion rates as a function of material strength exist in glacial erosion rates.

To quantify the strength of the bedrock, we use a Geologic Strength Index (GSI) that uses both fracture density and weathering to estimate cohesion. (Hoek and Brown, 1997).

We measured fracture density in bedrock outcrops near the Fairweather Fault in Yakutat Bay and near off-shoots of the Denali Fault in the Eastern Alaska Range. Near the Fairweather Fault, the bedrock was highly fractured. It had a GSI rating of very poor surface quality and disintegrated/foliated structure (~15, Fig. 1). Further from the faults, the bedrock was substantially less fractured. It had a GSI rating of fair surface quality and blocky structure (~60, Fig. 2). We hypothesize that glacial erosion has proceeds more quickly in fault controlled valleys, removing less cohesive bedrock. This forms a positive feedback mechanism: the glacier removes the weaker rock, channelizing glacier flow into fault-controlled valleys, and the valleys are subject to increased glacier flow and erosion.

In 2015 we will collect data in recently deglaciated valleys of the Juneau Icefield in southeast Alaska. The area is subject to a simpler tectonic regime, but similar erosion processes.

Fig. 1. Bedrock in fault zone with low cohesion.

Fig. 2. Non-Fault damaged bedrock with high cohesion.

Acknowledgements: Funding for this research is from the Churchill Fund and the NSF.

Bibliography:

Hoek, E., Brown, E.T. 1997, Practical Estimates of Rock Strength. Int. J. Rock Mech. Min. Sci., 34,8: 1165-1186.

Koons, P.O., et al. 2013, Tectonic Aneurysms and Mountain Building. *in* Shroder, J.F. and Owen, L.A., eds., Treatise on Geomorphology, Vol. 5, Tectonic Geomorphology. San Diego, Academic Press, p. 318-349.

Roy, S., et al. 2015. The influence of crustal strength fields on patterns and rates of fluvial incision. Journal of Geophysical Research: Earth Surface

Detecting the Effects of Atmospheric Rivers on Glacier Mass Balance in Denali National Park, Alaska

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An atmospheric river made landfall over Alaska on January 23, 2014. This system advected moisture and heat from the Pacific Ocean east of Hawaii to Alaska over the course of two days causing anomalously high temperatures, heavy rainfall, avalanching, and disruption of human infrastructure (NCDC, 2014). There likely was also rainfall at higher elevations, which would cause a significant change in the mid-winter energy and mass balance of regional glaciers.

To investigate whether there is a detectable physical and chemical signature of the atmospheric river event in Central Alaska glaciers, we collected geophysical and geochemical data on the Ruth, Kahiltna, and Mt. Hunter Plateau Glaciers during May, 2014. High-frequency (400 MHz) ground penetrating radar (GPR) transects over a total of 10 Km were collected on the Ruth Glacier to determine the spatial continuity of an ice layer potentially created by the event. Two snowpits on the Ruth Glacier (1.2 and 3.5 meter depths), one on the Kahiltna Glacier (3 m depth), and one on the Mt. Hunter Plateau (4.05 m depth) were sampled for δ18O and δD analysis.

Based on simple isotope fractionation modeling, we hypothesize that moisture from the atmospheric river event would be isotopically heavy relative to typical mid-winter precipitation in the area. We observe a positive δ18O deviation in the Mt. Hunter and eastern Ruth Amphitheater snowpits at 3-3.5 meter depth, which given estimated snow accumulation rates may be consistent with the river event.

We will discuss ongoing statistical comparison of snowpit physical and isotope data, processing and interpretation of the GPR data, and detailed time-series analysis of the river event using climate reanalysis and station data.

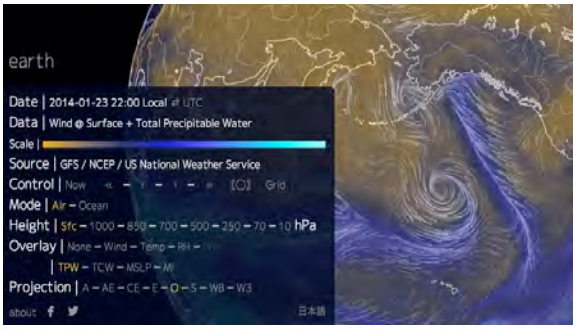

Fig.1. This image displays the total precipitable water and winds associated with the atmospheric river event of January 23, 2014, which extended from near the Hawaiian Islands to Alaska (Beccario, 2014).

Acknowledgements:

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I would also like to thank the Center for Undergraduate Research (CUGR) for funding this research and its dissemination.

Bibliography:

Beccario, Cameron. “Wind and TPW, 1/23/2014”, earth ::, 2014, http://earth.nullschool.net/#2014/01/24/0000Z/wind/surface/level/overlay=total_precipitable_water/orthographic=-159.52,29.69,362.

NCDC (National Climatic Data Center), “Quality Controlled Local Climatological Data”, 01/2014, Talkeetna Airport, AK, NOAA, http://cdo.ncdc.noaa.gov/qclcd/QCLCD.

Bacterial Nutrient Limitation in Arctic Lakes of Southwest Greenland

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Abstract: Nutrient dynamics of Southwest Greenland's Arctic lakes may be changing in response to inputs from permafrost thaw. In order to elucidate biological nutrient demands across these lakes, the activities of bacterial enzymes (EEAs) involved in nutrient acquisition were determined. We found that certain EEAs are tightly correlated to dissolved organic matter (DOM) concentration, suggesting DOM as a potential nutrient source. This study will be important to determine what factors influence the diverse nutrient dynamics across these study lakes.

Arctic lakes in Southwest Greenland exhibit dynamic and variable nutrient patterns across the landscape. The region is underlain by continuous permafrost. The lakes are mostly closed-basin and low in biological productivity. These lakes are chemically dilute, and so they are very sensitive to small changes in nutrient concentrations. Changes in inputs from landscape permafrost thaw may be affecting nutrient dynamics.

Bacterial EEA is a sensitive way to measure biological nutrient demands. Enzymes are excreted to degrade organic substances into simple molecules that can be transported across bacterial cell membranes. They are produced to scavenge for nutrients that are otherwise unavailable. Therefore, nutrient limitation patterns can be inferred from activities of enzymes specific to acquisition of carbon (C), nitrogen (N), or phosphorus (P).

The objective of this study was to determine 1) environmental factors associated with bacterial EEAs in Southwest Greenland Arctic lakes, and 2) relationships between EEAs and lake nutrient dynamics.

Enzyme activities specific to C, N, and P acquisition significantly increased from the spring to summer months in 2013. This may be due to changes in bacterial demand for nutrients, or may simply reflect an increase in bacterial biomass.

Lake EEA results from spring and summer 2013 also indicated greater bacterial phosphorus demand (inferred via alkaline phosphatase, AP activity) with increasing lake DOM (measured as DOC; Figure 1). Conductivity (lake salinity) and the concentration of total nitrogen (TN) covaried positively and significantly with DOC and AP activity as well.

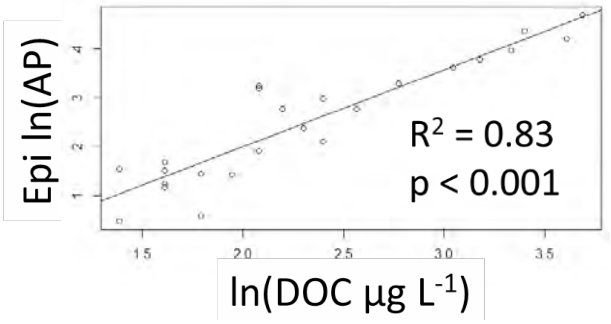

Fig. 1. Bacterial P demand correlated with DOC.

Interactions between enzyme activities can provide important information about bacterial investment in nutrient acquisition. When these interactions were analyzed, we found that bacterial investment in N acquisition relative to that for P (inferred via EEA ratios) was negatively correlated to DOM ($R^2 = 0.58$, $p < 0.001$).

It is possible that these data are suggesting that DOM is an important N source. Alternatively, DOM could contain significant quantities of organically-bound P that are only available via enzymatic breakdown. Further research will elucidate DOM characteristics and will determine how enzymes respond to lake chemistry.

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Interactive Exploration of Time Lines from Ice Core Data Sets

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Abstract: Time lines are derived from ice core data typically by counting layers or peaks in sequences of measured values. This work (in progress) explores the extent to which automation and interactive exploration may assist this task.

Introduction: The primary goal of this work is to partly automate the task of deriving time lines from ice core, and similar, data sets by using methods from pattern detection, machine learning, and optimization. A secondary goal is quantifying the robustness of time lines, both human- and machine-derived. In essence, time lines are derived from ice core data typically by counting layers or peaks in numerical sequences. There are, of course, several subtleties that require expert knowledge and a variety of scientific and background information, so that the task is unlikely yield to full automation. However, it is interesting to consider to what extent automation may assist.

Methods: We classify methods for automation-assisted exploration of timelines into four levels: Level 1 method detect peaks automatically as a function of a few key parameters. These parameters include height above background level, height above a windowed average, width of the averaging window, and minimum distance from neighboring peaks. Level 2 methods are essentially Level 1 methods augmented with sensitivity analysis. A time line that is robust over large variations of parameter values is likely to be preferable to one that is very sensitive to those values. Level 3 methods are based on a comprehensive computation of solutions over all combinations of parameter values within some ranges. To ensure computational tractability, such methods must avoid exhaustive computations using inferencing. Level 4 methods use quality metrics to define and compute optimal solutions. An important complementary task for all levels, possibly except 4, is the presentation of the methods' outputs in a form that is easily comprehended by a human expert. For example, Level 3 methods conceptually produce a timeline for each point in a large multidimensional space. Segmenting and projecting that space into two, or possibly three, dimensions is important for effective presentation.

Implementation: The implementation builds on work on data-stream processing in order to process large data sets with high throughput and low memory footprint. Processing data in a streaming manner means that operations on data are limited to those that can be performed by storing only a fixed (independent of data size and characteristics), and typically small, amount of auxiliary data while reading the source data only once in a linear manner. A related but distinct technique that is also helpful, especially for interactive exploration that may need only a small portion of the entire conceptual output, is that of lazy evaluation. Evaluating data transformations lazily means that operations are evaluated only when the resulting values are needed for output to the user or some user-discernible side-effect. As a trivial illustrative example, consider computing the prime factorization of a list of a million very large numbers, followed by printing the 10th element of that list. Lazy evaluation will result in only one number (the 10th) being factored.

Evaluation: We evaluate the methods using two classes of criteria. The first class focuses on computing performance, using metrics such as running time, response time, memory footprint. scale-up to larger data, and scale-out to multiple cores. The second class focuses on effectiveness of the methods using metrics such as similarity to time lines generated by human experts, internal consistency, and robustness.

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Specialist Avifaunal Collapse in Northeastern Tidal Marshes

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Abstract: Tidal marshes of the northeastern United States are particularly vulnerable to sea-level rise due to their placement along the coast. Here we quantify trends in bird populations within tidal marshes from Maine to Virginia and show significant decline in specialist species over time, while generalist populations remain stable over the same time period.

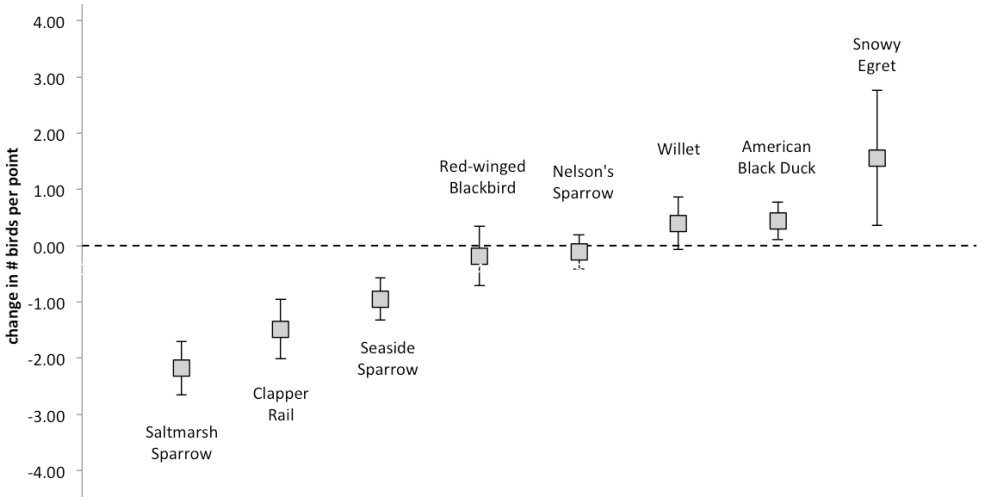

Figure 1. Trends in birds observed per survey point between Maine and Connecticut, 1997 - 2012, organized by species and degree of specialization. Error bars indicate standard error.

Tidal marshes along the Northeastern seaboard of the United States support a significant portion of the world's vertebrate endemics to this habitat. Tidal-marsh specialist birds such as the saltmarsh sparrow (Ammodramus caudacutus) are especially at risk of habitat loss due to sea-level rise (Greenberg et al 2006). Generalists such as the red-winged blackbird (Agelaius phoenicius) may respond differently than their obligate counterparts to climate change due to their supplemental use of non-tidal habitat for breeding and foraging grounds. Collaborators within the Saltmarsh Habitat and Avian Research Program (SHARP) conducted bird surveys at 1700 points over the 2011 and 2012 breeding seasons in tidal marshes between Maine and Virginia. We compared these data to historical bird surveys conducted within the same study area between 1997 and 2000 to identify hotspots of change in our focal species. Overall, we detected decreases in the tidal marsh habitat specialists such as the saltmarsh sparrow, seaside sparrow, and clapper rail, but detected no change in birds that use tidal marshes as their primary but not exclusive breeding habitat, such as the Nelson's sparrow, willet, and American black duck. Tidal marsh generalists did not show any positive or negative changes over the same time period.

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Bibliography:

Greenberg, R, Maldonato, J, Droge, S, and McDonald, M.V. 2006. Tidal marshes: a global perspective on the evolution and conservation of their terrestrial vertebrates. Bioscience 56:675-685.

Abrupt Climate Change Effects on Lake Level and Diatom Habitat Modeling of Southwest Greenland Lakes

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Abstract: The 20,000 lakes in Southwest Greenland that are relatively untouched by anthropogenic disturbance are ideal locations for climate change studies. Diatoms preserved in sediments from these lakes indicate a record of recent variability. To interpret these changing signals, we are using diatom habitat models that show how diatom assemblages respond to changes in regional water balance.

Lake level change is influenced by several variables, many of which fluctuate naturally, but are also amplified by climate change. Changes in temperature and precipitation affect moisture balance, and effects of glacial meltwater, snowmelt, and permafrost can alter water depth. These drivers of lake level depth can influence planktic vs. benthic (P:B) diatom habitat.

Fossil diatom assemblages from dated sediment cores give information about past regional climate changes. Marked changes in diatom community structure have occurred in Arctic lakes over the past 150 years, but diatom assemblages from SW Greenland do not follow similar patterns of variability (Perren et al. 2009). Between 1999 and 2013 sampling events, distinct differences were observed in P:B diatom assemblages of SW Greenland lakes. These differences could be an indication of lake level variation as a result of rapid climate change. The rapid shift to warmer Arctic conditions in 2007 (Zhang et al. 2008) is encompassed within these sampling dates, and our goal is to determine whether diatom assemblages were affected by moisture balance changes during this period of abrupt climate change.

Diatom analysis is currently being performed on a 15-cm sediment core from SS32, a nunatak lake in SW Greenland, and ^{210}Pb dating of the core has been completed. Using a 3D visualization software called Surfer®, we have modeled expected P:B habitat ratios for chosen lake levels of SS32 (Figure 1). The P:B habitat model for SS32 will be compared to the diatom relative abundance data for this lake to evaluate efficacy of the model, and these results will help guide future diatom habitat modeling efforts. The more we understand about interactions between diatom community structure and climate, the better equipped we will be to interpret climate signals embedded in diatom assemblages.

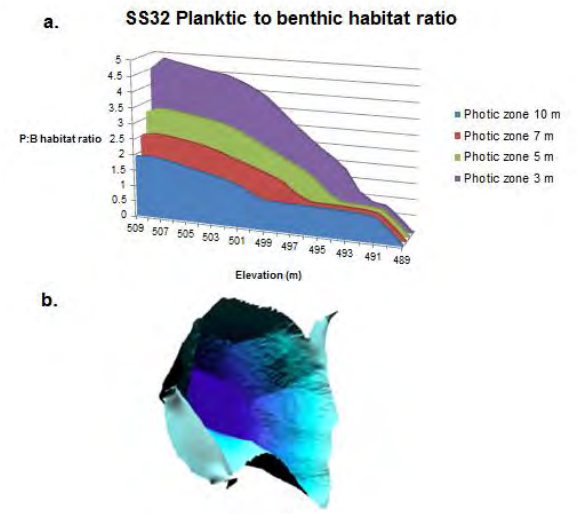

Fig. 1. P:B habitat model (a) and 3D surface map (b) of SS32 in Southwest Greenland.

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

Bibliography:

Perren, B.B. et al. 2009. Diatoms reveal complex spatial and temporal patterns of recent limnological change in West Greenland. *Journal of Paleolimnology,* 42: 233–247.

Zhang, X. et al. 2008. Recent radical shifts of atmospheric circulations and rapid changes in Arctic climate system. *Geophysical Research Letters,* 35: L22701.

Termination 1 Glacier Fluctuations in Mackenzie Stream Valley, New Zealand

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Abstract: Beryllium-10 surface-exposure dates of boulders from Mackenzie Stream valley reveal rapid and extensive deglaciation in the early stages of Termination 1 (18.5 to 16.9 ka), a late-glacial readvance that culminated at ~14 ka, and net glacier retreat from ~14 to ~12 ka.

Existing records of glacier retreat in the Southern Alps of New Zealand during Termination 1 (18-11 ka) are in conflict. Three moraine chronologies show rapid collapse of large ice tongues beginning at ~17.7 ka (Putnam et al., 2013a, Putnam et al., 2013b, Strand, 2014). In contrast, a fourth moraine chronology suggests that near-glacial conditions persisted in the Southern Alps until 15 ka, perhaps indicating that glacier-marginal lakes, rather than climate warming enhanced the retreat of large ice tongues (Rother et al., 2014). Determining the precise timing and character of glacier retreat in the Southern Alps is necessary in order to assess potential drivers of Termination 1 climate shifts in the Southern Hemisphere mid-latitudes.

We present a record of glacier retreat in Mackenzie Stream valley, a steep alpine valley in the Ben Ohau Range that excludes the formation of an ice-marginal lake. The record is based on glacial-geomorphologic mapping and 39 ^{10}Be surface-exposure dates of the mapped deposits.

Constructional glacial landforms in Mackenzie Stream valley are limited to Last Glacial Maximum moraine ridges at the mouth of the valley and late-glacial moraine ridges preserved in two cirques at the valley head. The outermost sampled moraine at the valley mouth dates to ~18.5 ka and provides a maximum-limiting age for the onset of glacier retreat. Inboard, a low-relief recessional moraine dates to 16.9 ± 0.7 ka. In the eastern upper catchment, five boulder-rich late-glacial ridges mark a re-advance that culminated at ~14 ka followed by net glacier retreat until 12 ± 0.2 ka.

Eight erratic boulders less than 280 meters outboard of the ~14 ka moraine ridge are indistinguishable in age from the recessional moraine at the valley mouth. These dates indicate that the snowline rose to at least ~14 ka levels by ~16.8 ka.

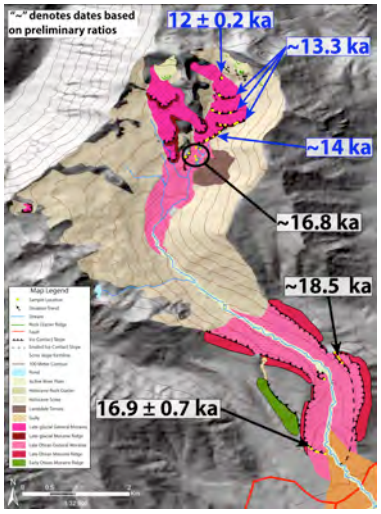

Fig. 1. Geomorphic map of Mackenzie Stream valley.

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

Bibliography:

Putnam, A.E., *et al.*, 2013a. "The Last Glacial Maximum at 44°S documented by a ^{10}Be moraine chronology at Lake Ohau, Southern Alps of New Zealand." *Quaternary Science Reviews* 62:114-141.

Putnam, A.E., *et al.*, 2013b. "Warming and glacier recession in the Rakaia valley, Southern Alps of New Zealand during Heinrich Stadial 1." *EPSL* 382:98-110.

Rother, H., *et al.*, 2014. "The early rise and late demise of New Zealand's last glacial maximum." *PNAS* 111:1630–11635.

Strand, P. D., 2014. "A ^{10}Be Surface Exposure Chronology of Left-Lateral Moraines of the Pukaki Glacier, Southern Alps, New Zealand." University of Maine Master's thesis.

Iceberg Melting in Two Greenland Glacial Fjords

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Abstract: Icebergs calved from marine-terminating outlet glaciers draining the Greenland ice sheet act as distributed freshwater sources to Greenland's glacial fjords and surrounding ocean basins. Although changes in the freshwater fluxes from icebergs can potentially impact fjord stratification and circulation, in turn influencing the dynamic contribution of Greenland outlet glaciers to sea level rise, iceberg freshwater fluxes have not been quantified. Here we estimate iceberg freshwater fluxes in Sermilik Fjord, East Greenland, and in Ilulissat Fjord, West Greenland, from 2011-2013 using repeat very high-resolution digital elevation models (DEMs).

As icebergs transit glacial fjords, they produce freshwater via surface and submarine melting. Assuming that surface melting scales with air temperatures, surface melting can easily be estimated using surface air temperature observations from nearby weather stations or from reanalysis models. The magnitude of submarine melting is strongly dependent on the temperature of the water and the velocity of the water with respect to the submerged ice face (Jenkins, 2011) but hydrographic observations for Greenland's glacier fjords are quite sparse due to logistical constraints.

In order to estimate iceberg freshwater fluxes and area-averaged melt rates, we constructed a time series of very high-resolution digital elevation models (DEMs) from stereo pan-chromatic imagery collected by the WorldView satellites. Temporal differences in iceberg surface elevation are used to estimate changes in iceberg volume over time (i.e., volume fluxes). Volume fluxes are converted to freshwater fluxes and area-averaged melt rates by assuming icebergs have a constant density and cylindrical shape below the waterline.

Here we derive freshwater fluxes for 18 icebergs in Sermilik Fjord, East Greenland, during the 2011-2013 boreal summers, and for 33 comparably sized icebergs in Ilulissat Fjord, West Greenland, during March-April 2011 and July 2012. We find that iceberg melt rates for Sermilik Fjord are in good agreement with simulated melt rates along the vertical terminus of Helheim Glacier in winter, i.e. when melting at the glacier front is not enhanced by subglacial discharge, providing an independent validation of our technique. The good agreement between large iceberg melt rates and the simulated glacier melt rate also suggests that iceberg melt rates can be used as a proxy for glacier melt rates.

We also find that variations in freshwater fluxes from icebergs are primarily related to differences in the submerged area of individual icebergs (Fig. 1), which is consistent with theory. The freshwater flux dependence on submerged area, suggests that changes in the characteristics of icebergs (size/shape/keel-depth) calved from a tidewater glacier will alter the magnitude and distribution of meltwater fluxes within the fjord, which may in turn influence fjord circulation and the heat content delivered to the glacier terminus.

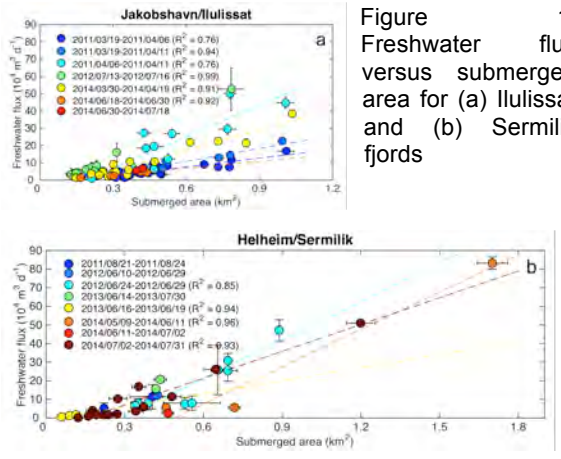

Figure 1: Freshwater flux versus submerged area for (a) Ilulissat and (b) Sermilik fjords

Acknowledgements: Project funded by NSF grant ANS1417480.

Bibliography: Jenkins, A (2011). Convection-driven melting near the grounding lines of ice shelves and tidewater glaciers. *J. Phys. Oceanogr.*, *40*(10), 2298-2312.

A Vernal Transition on the Move in Terrestrial Ecosystems in Maine

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Abstract: Climatic warming increases the length of the growing season, and changes the timing of snowmelt in terrestrial ecosystems, referred to as the vernal transition. Research is developing to both define the complexities of the vernal transition, and to evaluate the implications of these changes for the sequence of interacting chemical, physical and biological processes that follow the transition to a snow-free system.

Increasing average annual temperatures have resulted in a lengthening of the snow-free season resulting in an earlier spring in the northeastern U.S. by 1-2 weeks over the past century (1,2). A series of studies are developing to better understand the implications for these changes in the vernal transition for Maine. This research includes monitoring, snow removal experiments, K-12 citizen science and laboratory studies. Figure 1 demonstrates the abrupt transition that takes place in the physical environment upon snowmelt.

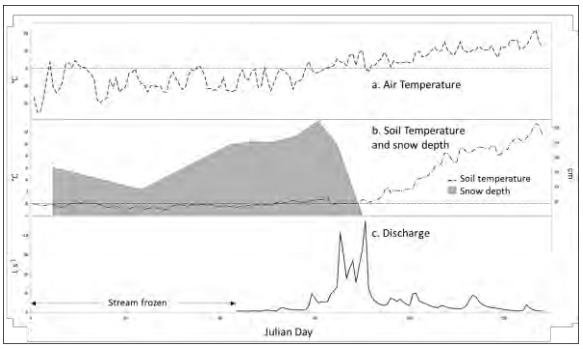

Fig. 1. Daily averages at the Bear Brook Watershed in Maine (BBWM) for the year 2014 to date – air temperature (4a), soil temperature and snowpack depth (4b), and East Bear stream discharge (4c) (3).

The rapid transition from a snowpack to direct insolation results in rapid soil warming, accelerated hydrology, increases in soil microbial dynamics with subsequent rapid acceleration in carbon (C) and nitrogen (N) cycling, followed by a sequence of phenological events such as the initiation of root growth followed by aboveground vegetation changes and associated changes in fauna. Decreased snow cover in winter leads to colder soils, so warming results in more soil freezing, creating an interesting paradox as a consequence of a warming climate (4). This area of research draws on the integration of biogeochemistry and ecosystem phenology, with a particular emphasis on understanding asynchronies that may be emerging with a shifting seasonality.

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

Bibliography:

1. Melillo, J.M., T.C. Richmond, and G.W. Yohe, editors. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. US Global Change Research Program
2. Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. Maine's Climate Future: 2015 Update. Orono, ME: University of Maine. 24pp.
3. Patel, Kaizad, Ivan Fernandez. 2014. Climatic trends at the Bear Brook Watershed in Maine – Biogeochemistry of the vernal transition. BIOGEOMON 2014, The 8th International Symposium on Ecosystem Behavior. Bayreuth, Germany.
4. Groffman, Peter M., Lindsey E. Rustad, Pamela H. Templer, John L. Campbell, Lynn M. Christenson, Nina K. Lany, Anne M. Socci, et al. 2012. "Long-Term Integrated Studies show Complex and Surprising Effects of Climate Change in the Northern Hardwood Forest." Bioscience 62 (12): 1056-1066.

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

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Abstract: The persistence of insectivorous birds in tidal marshes is unlikely in the face of current rates of sea-level rise. It is unclear, however, how their loss will influence the broader tidal marsh ecosystem. In the summer of 2014, we conducted predator-removal experiments in Northeastern tidal marshes to test if the exclusion of avian predators would result in a measurable trophic cascade. 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 of excluding avian predators in a terrestrial food web.

Introduction:

Tidal-marsh songbirds face an imminent threat of extinction this century with sea-level rise. 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 therefore trickle down to the plant community by influencing when and where herbivores forage and the magnitude of herbivory damage to the plant (Greenberg et al., 2000). Further, the ability of tidal marshes to maintain elevation in the face of sea-level rise, however, is partially determined by the production of plant biomass (Donnelly & Bertness, 2001). Birds are important predators in some ecosystems, and their presence can be positively related to plant biomass (Mäntylä et al. 2011). Removing avian predators from this system may alter plant biomass through indirect species interactions (a trophic cascade) and thereby 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 Coast. We measured temporal changes to invertebrate communities after excluding avian predators. For evidence of trophic cascades, we measured vegetation biomass. In addition, we conducted the exclosure experiments across a latitudinal gradient to provide insight into food-web dynamics across a spatial cline.

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

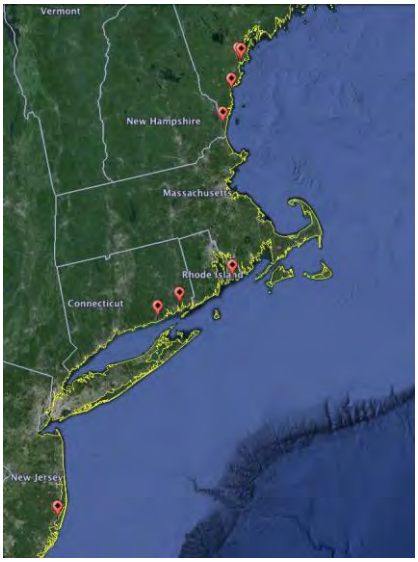

Figure 1. Location of avian exclosures. Image by GoogleEarth

Bibliography:

1. Donnelly, J. P., & M. D. Bertness. "Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise." *Proceedings of the National Academy of Sciences* 98:25 (2001): 14218-14223.
2. Greenberg, R., P. Bichier, A. C. Angon, C. MacVean, R. Perez, & E. Cano. "The impact of avian insectivory on arthropods and leaf damage in some Guatemalan coffee plantations." *Ecology* 81:6 (2000): 1750-1755.
3. Mäntylä, E., T. Klemola, & T. Laaksonen. "Birds help plants: a meta-analysis of top-down trophic cascades caused by avian predators." *Oecologia* 165:1 (2011): 143-151.

A Mouse's Eye View of Rancho La Brea: Assessing Millennial-scale Community Stability Using Highly-Resolved Mammal and Vegetation Food Webs

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Abstract: Present-day communities are changing in many ways: local populations are lost to human land use or climate change, the increasing rarity of the earth's largest species is leading to a "trophic downgrading" of the planet's biodiversity, and novel communities and ecosystems are forming. Understanding drivers and responses of in-progress biodiversity changes is difficult without adequate baselines. We are identifying small mammal and vegetation components of the Rancho La Brea tar pits for integration into multi-trophic paleo food webs. These analyses will not only permit exploration of paleo food web structure and dynamics, but will allow verification of the dynamical predictions against known future extinctions in the ecosystem.

How stable are food webs through time?

We propose to reconstruct changes in the composition and structure of a tightly coupled component of the ecological network (large to small mammals and vegetation) in California across the late Quaternary (<60,000 years). This project adds value to the extensive existing records of mega carnivores and megaherbivores at one of the most significant paleontological sites in the world, by 1) providing a better understanding of the full biodiversity in the region around Rancho La Brea during the late Quaternary and 2) generating useful datasets that can be mobilized to put ongoing single-species research in a broader ecological context.

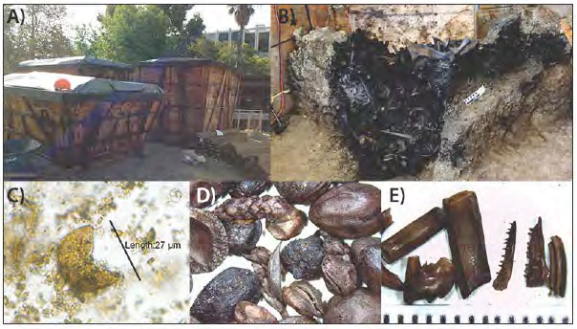

Figure 1. Boxes (A), In-process excavation (B), pollen (C), plant macrofossils (D), and small mammals (E) from Project 23.

The Bayesian framework developed for this proposal can be applied to both paleo and modern food webs to facilitate integration of multiple proxies that better characterize areas of certainty and uncertainty in understanding past ecological interactions. By exploring the structure and stability of food webs through time, we will determine cross-trophic linkages in a system that has previously focused extensively on the upper trophic levels of communities.

By predicting the likely responses of species to global changes, then testing these predictions using the known megafaunal extinction events across the Pleistocene-Holocene transition, we will improve understanding of the importance of intact ecological networks for the vulnerability and/or resilience of taxa in a tropically downgraded Anthropocene.

The first three contributions alone will significantly advance understanding of both paleontological methods as well as provide insight into the paleoecological structure of a site of international importance. The final contribution will connect the findings from the fossil record with understanding of how present-day ecosystems may change given current and future global change. This project also represents the first characterization of paleovegetation and small mammal communities at Rancho La Brea, and includes a citizen science component involving middle school classrooms.

CLIMATE CHANGE INSTITUTE

Examining the Relationship Between Surface Albedo and Glacier Mass Balance in the Central Alaska Range

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Abstract: 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 spectroradiometer to measure incoming radiation, outgoing surface reflectance and optical grain size on the Kahiltna Glacier for seven days during our 2013 field season in Denali National Park.

We derive surface albedo using the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43A3 data product, a 16-day composite with 500 meter resolution. Comparison of the MCD43A3 albedo to the ASD FieldSpec4 data shows a strong correlation. This strong correlation between satellite imagery and in situ data suggests that the satellites accurately capture what we see and measure in the field. Therefore we are using the MODIS data to characterize changes in albedo across the glacier for the previous 14 years. Preliminary results support possible detection of volcanic activity (i.e. 2009 Redoubt eruption) and changes in glacier mass balance through changes in the glacier's surface albedo.

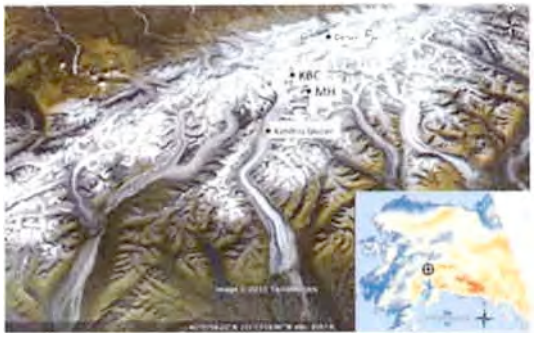

Fig. 1. Google Earth image of study locations: Kahiltna Base Camp (KBC- 2105 masl), and Mount Hunter (MH- 3910 masl). Kahiltna Glacier and Mount McKinley (Denali) also noted. Insert map (from Campbell et al., 2012) shows the Central Alaska Range (circle-plus symbol) on a DEM of Alaska (red is high elevation).

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.

Bibliography:

Campbell, Seth, et al. "Flow dynamics of an accumulation basin: a case study of upper Kahiltna Glacier, Mount McKinley, Alaska." *Journal of Glaciology* 58, no. 207 (2012): 185-195. Doi: 10.3189/2012JoG10J33.

20th Century Trends in Anthropogenic Pollutants Over Central Asia.

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Abstract: Concentration trends and enrichment/excess calculations from Asian Ice Core Array suggest 20th century increases in anthropogenic lead, cadmium, copper nitrate, sulfate and chloride.

High-resolution records from the Asian Ice Core Array (AICA) have provided detailed 20th century glaciochemical time-series. Ice core records covering the past several hundred years have allowed the investigation and assessment of the evolution of anthropogenic pollutants at high-elevation sites across central Asia. Chemical concentrations, EOF analyses, crustal enrichment and excess calculations were used to identify potential anthropogenic inputs. Trace element and major soluble ion analysis suggest that rises in the anthropogenic inputs of nitrate (NO_3^-), sulfate (SO_4^{2-}), chloride (Cl^-), lead (Pb), cadmium (Cd) and copper (Cu) began to rise during the 1950s-1960s in regions of central Asia.

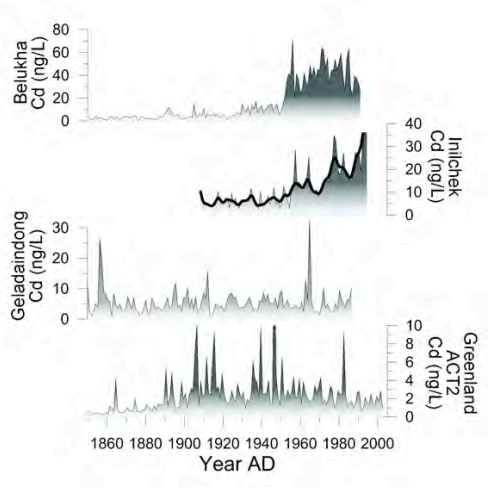

Fig. 1 Cadmium records from Asia and Greenland

This time period corresponds to large rapid increases in local and regional agriculture, industry and population. Northern AICA sites (Belukha and Inilchek) display pollutant trends similar to the growth and collapse of the Soviet Union and potentially the expansion of industry in western China. These regional characteristics of Asian ice cores suggest that the variability of anthropogenic pollutants over the Tibetan Plateau have been controlled by economic production (growth/retraction) rather than by any air quality legislature, as evidenced in European and North American ice cores [1,2].

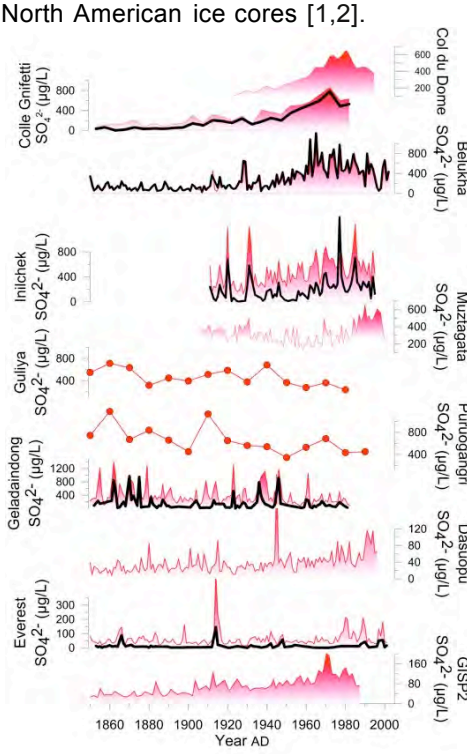

Fig. 2 Sulfate records from the Northern Hemisphere

Acknowledgements:

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

Bibliography:

[1] Eichler et al., (2012) *Environ. Sci. Technol.*, *46* (8),DOI: 10.1021/es2039954

[2] Osterberg, E., et al.(2008) Geophys. Res. Lett., 35, L05810, doi:10.1029/2007GL032680.

Climate Change in the Falkland Islands: A New Paleoclimate Proxy?

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Abstract: Paleoenvironmental reconstructions facilitate tests of the associations between past ecosystem dynamics and past climate changes. We propose a pilot study to develop a novel proxy to reconstruct precipitation and temperature using the stable isotope ($\delta^{18}O$, δD, and $\delta^{13}C$) values of alpha cellulose tissue of preserved tussac grass (*Poa flabellata*) leaf material from Volunteer Point, Falkland Islands. A modern validation study will be used to calibrate tussac grass as a novel proxy reconstructing paleoclimates from preserved leaves in peat. This information will provide insight into how seabird populations and associated tussac grass communities responded during past climate changes in the Falkland Islands.

Research description:

Various proxy records indicate southern hemisphere westerly winds gradually strengthened over the last 3,000-5,000 years and are currently as intense as they were during the last glacial maximum and the Little Ice Age [1]. Westerly wind fluxes show a reduction during the early Holocene and preceding the Little Ice Age [1]. Latitudinal shifting and wind strength of the Westerlies influence both marine and terrestrial ecosystems. The variation in zonal wind speeds and southerly shifting of the Southern Hemisphere westerly wind belt will be characterized using isotopic compositions of precipitation. Decreases in $\delta^{18}O$ are hypothesized to relate to increases in mean annual precipitation, corresponding with increases in zonal wind speed and southerly shifting of the Southern Hemisphere westerly wind belt [2].

Preserved tussac grass (*Poa flabellata*) leaves are ubiquitous in a sediment column taken from Volunteer Point, Falkland Islands in 2014. We propose a study to develop a new proxy using tussac grass as a regional climate record for past precipitation and temperature. $\delta^{18}O$, δD, and $\delta^{13}C$ values recorded in the cellulose of plant tissues vary among plant species in the way they record precipitation and temperature [3]. A modern calibration study will evaluate how modern tussac grasses record temperatures and precipitation using $\delta^{18}O$, δD and $\delta^{13}C$ analyses. Few paleoenvironmental reconstructions exist for the Falkland Islands. The application of tussac grass as a proxy for reconstructing paleoclimate parameters in the Falkland Islands can be used across its geographic extent, including Tierra del Fuego and South Georgia, the locations of important wildlife habitat utilizing tussac grasslands today. This information will provide valuable associations between past ecosystem dynamics and advance our understanding of past climate changes and the biological responses of seabirds and tussac grass.

Acknowledgements: I gratefully thank the Climate Change Institute, NSF A2C2 IGERT Fellowship, Dan and Betty Churchill Exploration Fund for research travel, the South Atlantic Environmental Research Institute and crowd funding from 189 public donations.

Bibliography:

1. Shulmeister, J., I. Goodwin, J. Renwick, K. Harle, L. Armand, M. S. McGlone, E. Cook, J. Dodson, P.P. Hesse, P. Mayewski, and M. Curran. 2004. The southern hemisphere westerlies in the Australasian sector over the last glacial cycle: a synthesis. Quaternary International 118-119: 23-53.

2. Daley, T.J., Barber, K.E., Street-Perrot, F.A., Loader, N.J., Marshall, J.D., Crowley, S.F., Fisher, E.H., 2010. Holocene climate variability revealed by oxygen isotope analysis of *Sphagnum* cellulose from Walton Moss, northern England. Quaternary Science Reviews 29, 1590-1601.

3. van Geel, B., Middeldorp, A.A.,1988. Vegetational history of Carbury bog (Co.Kildare, Ireland) during the last 850 years and a test of the temperature indicator value of 2H/1H measurements of peat samples in relation to historical sources and meteorological data. New Phytologist 109, 377–392.

Sub-Seasonal Reconstruction of an Ice Core Recorded Abrupt Climate Change 84.6 ka Transition

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Abstract: In this paper we offer the first sub-seasonal view of a glacial age abrupt climate change event. We focus on the abrupt ~84.6 ka climate transition from cold stadial to warmer interstadial conditions originally captured in the Greenland Ice Sheet Project 2 (GISP2) ice core records for stable water isotopes, soluble major ion records (IC), laser light scattering (LLS), and electrical conductivity measurements (ECM). We utilize the ultra-high resolution capabilities of newly developed laser ablation- inductively couple plasma-mass spectrometry (LA-ICP-MS; 121 µm sampling resolution) system capable to conduct a multi-parameter glaciochemical analysis on the oldest section of an ice core thus far accomplished utilizing this technique. Major findings include: (1) Mean summer and winter accumulation rates nearly double (2) timing of chemical proxies for atmospheric circulation shows iron is more likely to peak earlier annually during the transition and interstadial and (3) high levels of iron deposition continue past the point where calcium, potassium and sodium substantially decrease in concentration. Because we find iron may be more marine in source during the transition and interstadial than during the stadial, we postulate a change in ocean circulation as a major driver in the climate transition, potentially driven by changes in the hemispheric wind field.

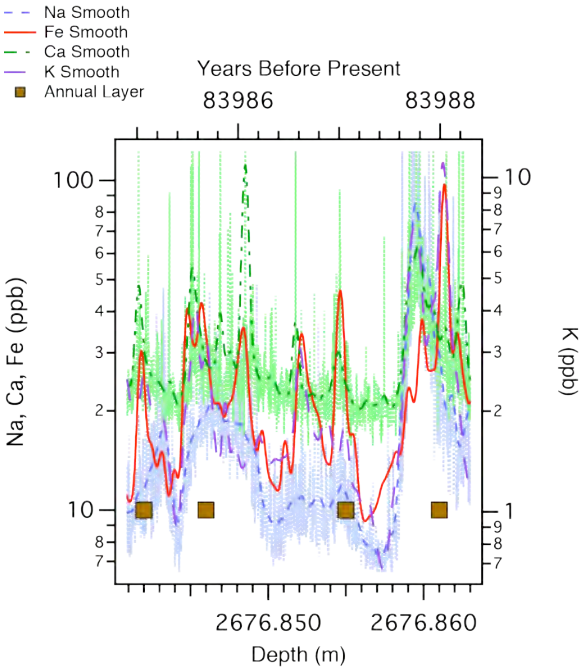

Figure 1. Annual layer counting example taken from sample D (see figure 2 for location in GISP2 ice core archive). A ~3 cm section shown for sodium (blue), calcium (green), and iron (red) plotted on left axis scale. Potassium (purple) plotted on the right axis scale. Brown boxes are annual layer picks, centered on winter/spring season maxima. 5 years are shown.

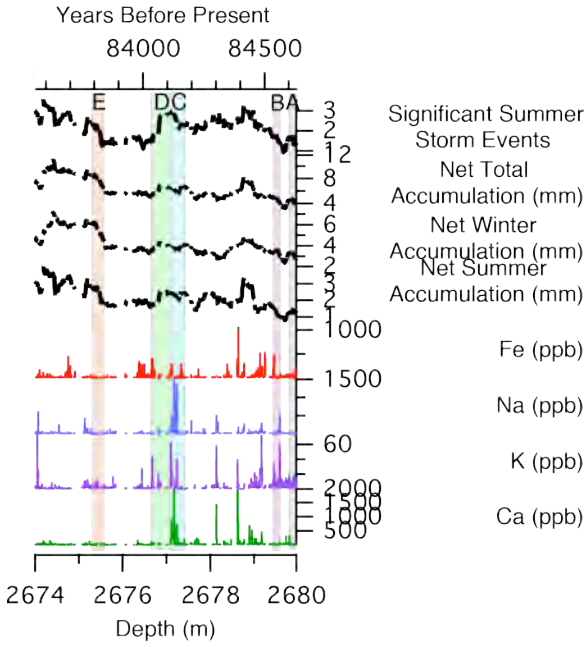

Figure 2. Seasonal and "storm scale" results (top 4 time series) plotted with LA-ICP-MS results (bottom 4 time series). 30-point (30 years) moving average smooth shown on top 5 time series. LA-ICP-MS results shown with 200-point binomial smooth. Shown in highlighted color are the 5 sample intervals used in study: A, B, C, D, and E, highlighted in grey, purple, blue, green and orange, respectively

Acknowledgements: NSF grant ARC-1203640

References:

Mayewski, P.A. et al. (1997), J. Geophysical Research, 102

Mayewski, P.A. et al. (2013), J. Quaternary Science, 29

Sneed, S. B, et al. (2015) J. Glaciology, 61

Thomas, E. R., et al. (2009), J. Geophysical Research, 114

Recent Changes in the Northeastern Sctor of the Greenland Ice Sheet

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Abstract: The northeastern sector of Greenland has hitherto not experienced the profound changes in ice dynamics observed elsewhere around the margin of the ice sheet. A new analysis of satellite remote sensing datasets shows increasing evidence of important changes underway in the ocean and coastal margins of the ice sheet. A rapid deglaciation of NE Greenland has significant consequences for global sea level.

The northeastern sector of Greenland has so far not experienced the profound series of changes observed elsewhere around the margin of the ice sheet. One explanation is the presence of relatively cold ocean waters in the nearby Fram Strait, far removed from the warming waters of the subpolar gyre that are hypothesized to have provided the forcing for the changes observed elsewhere around Greenland. However, recent observations suggest that this relatively stable situation might not persist.

The Northeast Greenland Ice Stream (NEGIS) is the dominant feature in this sector of the ice sheet. This corridor of fast flow extends nearly all the way to the ice divide and feeds ice from the interior into three marine-terminating glaciers: Nioghalvfjerdsfjorden (79N), Zachariae Isstrøm (ZI), and Storstrømmen. NEGIS sits in a trough that is below sea level far inland of the current grounding line, making is particularly susceptible to rapid retreat and dynamic thinning. The floating ice shelves of 79N and ZI provide resistance to the inland ice and might play a critical role in preventing grounding line retreat. Thus there is great interest in characterizing the behavior of these ice shelves.

ZI's floating tongue recently completed its total disintegration and inland ice is now terminating directly into open water. The ice shelf collapse occurred progressively over the last decade, probably in response to a combination of ocean and atmospheric forcing (note the extensive melt ponds in Figure 1).

79N's floating tongue remains intact, but recent work (Sneed, 2013 PhD thesis) shows a modest increase in submarine melt rates over the last 15 years. Sustained thinning might cause the ice shelf to retreat from its current pinning points.

Taken together, these observations point to an increasing pace of change in the northeastern sector of the Greenland Ice Sheet. Continued grounding line retreat of ZI coupled with a similar retreat of 79N may expose a substantial portion of Greenland to rapid deglaciation.

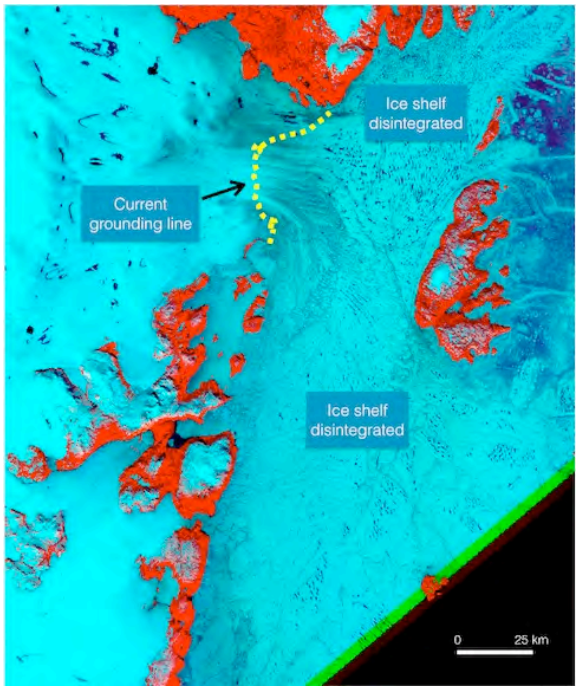

Fig. 1. Portion of a Landsat TM satellite image acquired in 1998, showing ZI's extensive floating tongue. Disintegration of the ice shelf in the last ~5 years has caused the terminus to retreat to the position shown by the dashed yellow line.

Humans and the Falkland Islands Wolf: Investigating the Origins of an Extinct Endemic Canid

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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 Falkland Islands Wolf to the islands.

The Falkland Islands Wolf (FIW), or "warrah," (*Duscicyon australis*) was the only terrestrial mammal native to the Falkland Islands when Europeans arrived in the seventeenth century. The lack of definitive evidence of a pre-European human presence, coupled with the expansive channel separating the islands from mainland South America, raises questions about how and when the extinct, endemic *D. australis* arrived in the islands. Two competing theories seek to explain the presence of *D. australis* on the Falklands: 1) the FIW crossed a hypothetical ice bridge at the Last Glacial Maximum when sea levels would have been lower than present day, and 2) prehistoric humans traveling from southern South America brought *D. australis* to the Falklands via canoes (Austin et al., 2013; Buckland and Edwards, 1998).

To date, there is little archaeological evidence indicating a pre-European human presence in the Falklands; however, there is anecdotal evidence of prehistoric artifacts, such as stone tools and dug-out canoes, being found throughout the islands. Furthermore, there is archaeological evidence from South America to substantiate a close link between humans and *D. australis*' closest relative, *Duscicyon avus* (Prates, 2014). Due to the harsh environment of the interior of the Falklands, pre-European humans would have likely situated themselves along the coast where they would have had easy access to a robust supply of marine resources. It is here that they would have likely left behind shell middens, stone or bone tools and flakes, or large pieces of charcoal.

Aside from finding definitive archaeological evidence of a pre-European presence in the Falklands, charcoal records could also provide a promising way forward in resolving this debate. When humans first arrive in a location, background charcoal levels have been shown to increase by as much as an order of magnitude in many island systems (Burney et al., 1994). By establishing background charcoal levels from lake and peat cores collected from the islands, we hope be able to detect the timing of initial human arrival. Furthermore, new radiocarbon dates from several fossil FIW individuals will provide a minimum arrival time for *D. australis* to the islands. Additionally, morphometric analyses of *D. australis* and *D. avus* bones will elucidate whether these sister taxa show evidence of domestication. Together, these data will help to resolve an ongoing debate about the arrival of the warrah, its relationship to humans, and the broader paleoecology of the Falklands.

Acknowledgements: We would like to thank Dan and Betty Churchill for their support in making this project a possibility as well as the many donors who supported our crowdfunding campaign through experiment.com.

References:

Austin, J.J., Soubrier, J., Prevosti, F.J., Prates, L., Trejo, V., Mena, F., Cooper, A., 2013. The origins of the enigmatic Falkland Islands wolf. Nature communications 4, 1552.

Buckland, P.C., Edwards, K.J., 1998. Palaeoecological evidence for possible pre-European settlement in the Falkland Islands. Journal of archaeological science 25, 599-602.

Burney, D.A., Burney, L.P., MacPhee, R.D., 1994. Holocene charcoal stratigraphy from Laguna Tortuguero, Puerto Rico, and the timing of human arrival on the island. Journal of archaeological science 21, 273-281.

Prates, L., 2014. Crossing the boundary between humans and animals: the extinct fox Dusicyon avus from a hunter-gatherer mortuary context in Patagonia (Argentina). Antiquity 88, 1201-1212.

Institutional Responses to Climate Change and the Reproduction of Social Vulnerability in Hampton Roads, Virginia

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Abstract: This paper presents research results from a case study investigating institutional responses to climate change within the urban coastal context of Hampton Roads, Virginia. Through the lens of political ecology, I investigated the socio-political landscape in which institutional adaptation activities (e.g. planning and decision-making) are unfolding, seeking to understand how the needs of the previously identified most vulnerable social groups to climate change impacts were being addressed. Data gathered from semi-structured interviews with key institutional actors, direct participant observation at regional adaptation forums, and content analyses of local and federal adaptation planning documents, produced empirical evidence that regional adaption planning efforts are producing and reproducing social vulnerability to climate change for the region's most vulnerable, the poor. This paper suggests that the reproduction of the vulnerability of the poor to climate change impacts is constructed through dominant institutional attitudes of fear, insecurity, and uncertainty and their materialization in processes of inclusion and exclusion, institutional discourse, and prioritization and allocation of adaption projects.

As the biophysical effects of anthropogenic climate change enter into a socially stratified world - altering assets, meaning, and security - how a place or person experiences climate change will uniquely vary over space and time. This paper presents a case study investigating the social process of adaptation in Hampton Roads - a politically and geographically defined region of coastal Virginia comprised of 16 municipalities.

Through the lens of political ecology (Agrawal et al. 2012), this research gives acute attention to issues of scale, equity, and ethics while investigating institutional (government and NGO) actor perceptions, discourse, and decision-making in response to climate-related flooding risks from storm surge, sea level rise, and heavy precipitation storms. Although flooding risks are not new to Hampton Roads, the frequency and intensity of flooding events have been increasing as a direct result of three factors: 1) the biophysical effects of climate change (warming of surface water temperatures and sea level rise), 2) the local geomorphology (shallow slope and land subsidence), and 3) the human impacts of urbanization and population growth within the region (Kleinosky et al. 2007).

Due to differentially experienced climate change impacts across Hampton Roads, coupled with the deeply stratified social landscape, vulnerabilities to climate impacts are disproportionately experienced among the residents of Hampton Roads.

I argue with empirical findings that institutional responses to climate change are re-producing existing social inequalities, further hindering the adaptive capacity of the most at-risk population segments in this region. This primary finding is understood through triangulation of research results. Institutional attitudes of fear, uncertainty and insecurity emerged through direct observation and interview methods as dominant institutional attitudes. When linking these attitudes to Schwartz's value theory, I suggest that institutional attitudes are driving adaption decisions that prioritize maintaining the status quo and protecting the economically productive sectors of Hampton Roads, while disregarding the risks posed to the region's most vulnerable population segments– the poor.

Bibliography

Agrawal, Arun, Maria Carmen Lemos, Ben Orlove, and Jesse Ribot. "Cool heads for a hot world–Social sciences under a changing sky." *Global Environmental Change* 22, no. 2 (2012): 329-331.

Kleinosky, Lisa R., Brent Yarnal, and Ann Fisher. "Vulnerability of Hampton Roads, Virginia to storm-surge flooding and sea-level rise." *Natural Hazards* 40, no. 1 (2007): 43-70.

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

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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 are currently gathering archaeological and comparative samples 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.

The Late Archaic period saw one of the most pronounced changes in Gulf of Maine fisheries ecology when at approx. 3800 B. P. 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 the surviving portions of the Waterside archaeological site in Sorrento, ME. Our understanding of this site has been greatly increased by the work of Andrew Heller on a micromorphology sample taken during the 2013 field season and analyzed over the past year. We have also begun processing samples retrieved during the 1970s excavations of the Turner Farm site on North Haven Island, ME. Our 2015 field season will focus on excavations at the Nevin and Seabrook Marsh sites.

To maximize identification of fish species, including those not now native to the Gulf of Maine, we use fine mesh screen samples, virtually unexplored for the Late Archaic period. Lab analysis is ongoing with the help of undergraduate Joseph Goodin who is currently preparing comparative samples donated by the

Fig. 1. Three-spined stickleback from UMaine collection and stickleback pelvic spine and articulated pelvic bone (inset) from the 1975 excavations at Seabrook Marsh.

SBE preserved fish collection. These samples include species, such as bay anchovy, not currently common in the Gulf of Maine, but considered likely to have been present during warmer conditions in the past.

Acknowledgements: We would like to thank the Archaeological Conservancy for permission and support of our investigations at the Waterside Shellheap, the Maine State Museum for allowing us access to the Turner Farm samples, and SBE for the generous donation of comparative samples to our lab. This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

Bibliography:

Sanger, David. 1988. “Maritime Adaptations in the Gulf of Maine.” *Archaeology of Eastern North America* 16: 81–99.

Eco-evolutionary Responses of Spatially Structured Species Experiencing Climatic Changes

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Abstract: Climate change often results in maladaptation of species, consequently reducing their likelihood of persistence. However, biological adaptation to altered conditions is capable of occurring at rates fast enough to prevent extinction (i.e., evolutionary rescue). Current evolutionary rescue theory rarely considers the roles of spatial population structuring and landscape heterogeneity. To address this shortcoming, we are combining empirical estimates of population connectivity for two spatially structured species with agent-based simulation modeling to identify rates and types of climate change that influence the likelihood of species persistence.

Environmental change can influence species in many ways. For instance, climate change often leads to habitat alterations that can decrease individual fitness, consequently reducing the likelihood of population persistence. However, populations are sometimes capable of adapting to altered environments at a rate fast enough to avoid extirpation (i.e., evolutionary rescue; Gomulkiewicz and Holt 1995). The likelihood of evolutionary rescue occurring is influenced by the rate of environmental change, as well as the population's degree of maladaptation that exists following the change.

Existing evolutionary rescue models typically focus on only a single population, however, and the role of spatial factors, such as complex population structure and l andscape heterogeneity, in determining population persistence is neglected. Spatially structured species are commonly composed of many subpopulations that are adapted to their local conditions. Therefore, when climatic changes occurs across a large area that encompasses multiple subpopulations, persistence likelihood may be increased by the movement of individuals from habitats to which they have become poorly adapted into habitats that recently have become more suitable. Alternatively, excessive exchange of individuals among subpopulations during periods of environmental stability may result in the introduction of maladaptive genetic variants into otherwise stable subpopulations.

We are pairing empirical analyses of subpopulation connectivity across a c omplex, heterogeneous landscape with agent-based simulation modeling to identify climate change thresholds that influence likelihood of species and population persistence. Estimates of subpopulation connectivity are based on landscape genetic analyses of Maine's spatially structured vernal pool amphibian species. Preliminary analyses suggest that individual movement among nearby subpopulations is asymmetrical and variable among subpopulation pairs. These estimates of subpopulation connectivity will be used to inform agent-based models that will be de signed to simulate environmental change across realistic heterogeneous landscapes. Using this approach, we will identify the maximum rate of climate change that can occur which allows for population persistence. Scenarios of spatially heterogeneous climate change will also be analyzed. Understanding the interplay between ecological processes such as individual movement and a daptive evolutionary processes will be es sential for identifying suitable biodiversity conservation strategies as climate change continue to progress.

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, the US Geological Survey, and the University of Maine.

Bibliography: Gomulkiewicz, Richard and Robert D. Holt. "When does evolution by natural selection prevent extinction?" Evolution 49(1995):201-7.

Visible Tephra in the RICE Ice Core

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Abstract: Geochemical composition of eight visible tephra layers from Roosevelt Island Climate Evolution (RICE) project ice core were measured using SEM and Microprobe (EMPA) instruments. The geochemical fingerprint of the 1252 C.E. tephra particles (based on the WAIS Divide ice core time scale) from the depth of 165 meters was correlated with the tephra found in four other Antarctic ice cores: Siple Dome, WAIS Divide, Taylor Dome, and Talos Dome, providing the RICE project with an age set point. The majority of the layers composition point to local Antarctic sources, but two layers are geochemically similar to South American volcanic centers.

Introduction: Glaciochemical records developed from polar ice cores reveal information about how global volcanism interacts with the climate system (Hammer, 1980; Zielinski, 2000). By geochemically "fingerprinting" the tephra particles, source volcanic centers can be determined (see recent review by Lowe, 2011). In the RICE ice core, eight visible tephra layers were sampled between depths of 165-730 meters, and geochemical composition was determined using a combination of SEM and EMPA analyses.

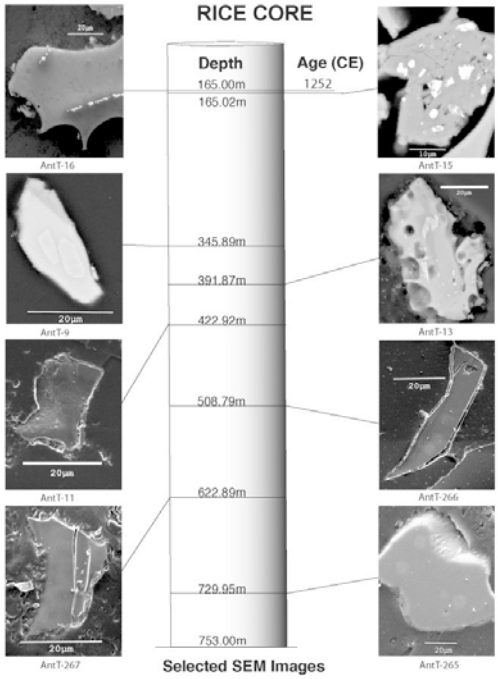

Fig. 1. Schematic of RICE ice core tephra depths.

Methods: Tephra bearing ice samples were rapidly melted under clean room conditions, filtered through 0.4µm Whatman Millipore polycarbonate isopore™ membrane filter. Tephra samples were prepared utilizing a modified tephra mounting method.

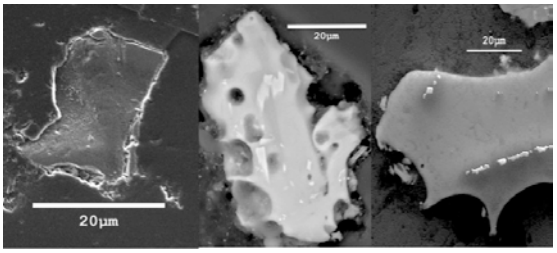

Fig. 2. Examples of RICE tephra images captured by Tescan Vega XMU SEM.

We correlated the RICE 165m layer (AntT-16) with tephra layer in Siple, Taylor, WAIS, and Talos. We also find that two layers are geochemically similar to South American volcanic sources (RICE 423m and 392m, AntT-11 and 13, respectively). Future work on the RICE project includes processing and analyzing non-visible tephra layers that are most likely affiliated with large eruptions from tropical volcanic centers.

Conclusion: Tephrochronology of the RICE ice core expands the developing Antarctic framework, required to better understand the interaction between local and global volcanism with the climate system.

Acknowledgements: Nancy A.N. Bertler, Peter Neff, Rebecca Pyne, and Andrea Tuohy for tephra samples. NSF Polar Program grant numbers ANT-1142007 and ANT-1042883.

Bibliography: 1.Dunbar, N. W. et al., (2003). Tephra in the Siple and Taylor Ice Cores. *JGR* 108, 2384. http://dx.doi.org/10.1029/2002JB002056.

2.Hammer, C, et al., (1980). Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature* 288, 230–235.

3. Lowe, D. J., et al., (2011) Tephrochronology and its application: a review (*QuaInt*, *246*(1-2), doi:10.1016/ j.quaint. 2011.08.012.

4. Zielinski, G. (2000), Use of paleo-records in determining variability within the volcanism-climate system, *QSR*, 19(1-5), 417–438.

Determining Surface and Basal Crevasse Extent across the McMurdo Shear Zone through GPS and GPR Surveys

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Abstract: Preliminary analysis of ground penetration radar and global positioning satellite data suggests the accumulation of basal freeze-on at ~160 m depth. Hyperbolic diffractions within the basal regime indicate heavy fracturing and crevassing. A visual correlation between surface and basal crevassing may indicate a similar formation process within both the firn and basal regimes.

Introduction:

The McMurdo Shear Zone (SZ) 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). Most of the shearing within this area is caused by heavy rifting as ice flows past Minna Bluff.

Methods:

During our 2014 field season, 29 GPS stations were surveyed within a 5 km x7 km grid across the McMurdo SZ. In addition, a lightweight, mobile robot towed two GPR units of 200MHz and 400MHz frequencies at near constant speed. The robot traveled orthogonal to ice flow over 100 transects to cover a 5.7 km x 5 km grid across the width of the shear zone.

Results and Conclusions:

Analysis of the GPS data reveals a sharp velocity gradient across the shear zone with velocities increasing ~240 m/yr +/- 50 m/yr from east to west.

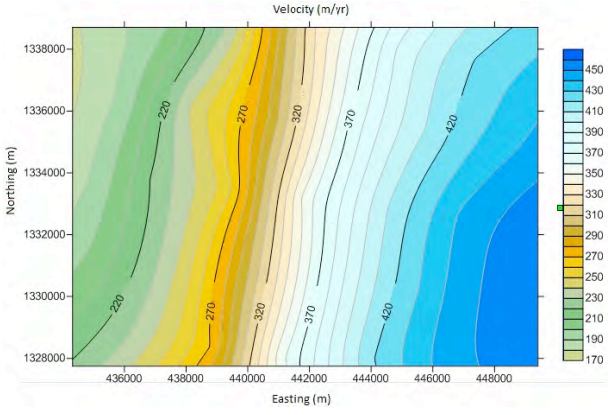

Fig. 1. Contour plot of GPS-derived velocity.

Orthometric heights were used to estimate a total ice shelf thickness of ~254 m assuming hydrostatic equilibrium.

400MHz range GPR profiles provide preliminary imaging of crevassing in the upper firn layer as well as folded and faulted stratigraphy. The 200MHz profiles reveal a sharp reflection at ~160 m depth that we interpret to be a meteoric-basal ice interface. Hyperbolic diffractions along this interface indicate fracturing and basal crevassing. A visual correlation between surface and basal crevassing may indicate a similar formation process within both the firn and basal regimes. One possible explanation is that basal marine ice may be rheologically weaker due to salt inclusion and thus shears more easily than meteoric ice. Another common hypothesis for basal crevasse formation is that their formation occurs at the grounding line. (Van der Veen, 1998) If this is the case, then these basal crevasses are not a result of lateral shearing but rather are inherited from upstream grounding line dynamics. In-depth analysis of the data, such as tracking crevasses between transects as well as coupling these signature with GPS-derived strain rates, may shed future light into their origin.

Acknowledgements:

This research was funded by an Antarctic Glaciology grant from the National Science Foundation.

Bibliography:

Van Der Veen, C. J. "Fracture Mechanics Approach to Penetration of Bottom Crevasses on Glaciers." *Cold Regions Science and Technology*, June 1, 1998, 213-23.

Timing of the Last Glacial Maximum of Hatherton Glacier in the Lake Wellman region, Darwin Mountains, Antarctica

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Abstract: During the Last Glacial Maximum (LGM), the Antarctic Ice Sheet grounded across what today is the Ross Sea. This grounded Ross Sea ice buttressed outlet glaciers flowing seaward from East Antarctica through the Transantarctic Mountains, causing them to thicken. Ice-dammed ponds formed alongside the margins of the thickened outlet glaciers. The Hatherton and Darwin glaciers formed one of these outlet systems that drained through the Transantarctic Mountains and into the Ross embayment. From the Lake Wellman area alongside lower Hatherton Glacier, we collected samples of fossil algae that grew in ice-marginal ponds. The resultant radiocarbon dates bracket the LGM moraine limit, indicating that the maximum ice extent was achieved 9-10 ka.

Far south in the Transantarctic Mountains, the timing of the maximum of Reedy Glacier varies along its longitudinal profile: near the glacier mouth it occurred ~14-17 ka, in contrast, near the glacier head, the LGM dates to 7-9 ka (Todd et al. 2010). The difference in timing of the maximum ice extent is attributed to a grounded Ross Sea ice sheet causing the buttressing effect that produced a wave of thickening up glacier (Todd et al. 2010). A similar history is suggested for the Hatherton-Darwin outlet system (Bockheim et al. 1989), located adjacent to Byrd Glacier, the largest outlet glacier in the Transantarctic Mountains. The drainage of Byrd Glacier makes up nearly a quarter of the catchment in the Ross embayment, and due to the proximity of the Hatherton-Darwin system to Byrd, the history of the grounded Ross Sea ice sheet can be studied using the drift deposits in nearby ice-free valleys that formerly contained thickened glacial ice.

Previous studies of Hatherton-Darwin system are in conflict regarding the timing and extent of the ice maximum. Radiocarbon ages of algae samples of fossil algae from relict lake deposits indicate that the maximum at the Lake Wellman region occurred 10.5 ka (Bockheim et al. 1989). A recent study used surface exposure-age dating to determine the chronology of ice history at the same site and postulated that the limit previously identified as the LGM, the Britannia limit, likely reflects a composite of multiple advances ranging from 20-400 ka and that the Hatherton limit, located within ~50 m of the present level of Lake Wellman, approximately 200 m below the Britannia limit, is the maximum ice extent of the last glacial period. This alternative maximum located just above present lake level is based on two erratics that yielded exposure ages of ~15 ka and ~19 ka (Storey et al. 2010).

Our study presents new data from the Lake Wellman area. We mapped the Britannia and Hatherton glacial deposits and collected algae that grew in ice-marginal ponds dammed by a former, thicker Hatherton Glacier. Radiocarbon dates of these algal samples collected within the drift deposits provide a chronology for the deposits. Samples that bracket the Britannia limit produced an age range of ~9-10 ka, which is in close agreement with the results from the earliest previous study in the area (Bockheim et al. 1989).

Acknowledgements: This project is funded by the NSFgrant #1246170.

References cited:

Bockheim, J. G., S. C. Wilson, G. H. Denton, B. G. Andersen, and M. Stuiver. 1989. "Late Quaternary Ice-Surface Fluctuations of Hatherton Glacier, Transantarctic Mountains." *Quaternary Research* 31 (2): 229–54. doi:10.1016/0033-5894(89)90007-0.

Storey, B.C., D. Fink, D. Hood, K. Joy, J. Shulmeister, M. Riger-Kusk, and M.I. Stevens. 2010. "Cosmogenic Nuclide Exposure Age Constraints on the Glacial History of the Lake Wellman Area, Darwin Mountains, Antarctica." *Antarctic Science* 22 (6): 603–18. doi:10.1017/S0954102010000799.

Todd, Claire, John Stone, Howard Conway, Brenda Hall, and Gordon Bromley. 2010. "Late Quaternary Evolution of Reedy Glacier, Antarctica." *Quaternary Science Reviews* 29 (11-12). Elsevier Ltd: 1328–41. doi:10.1016/j.quascirev.2010.02.001.

How Resource Availability Affects Diatom Response to Warming in the Great Lakes

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Abstract: We are investigating the extent to which major changes in Great Lakes diatom algae in past decades are driven by rising temperatures. We are examining modern and fossil diatoms from Lake Erie and Lake Superior to compare warming effects in systems with different nutrient status. We hypothesize that diatom changes in a system with limited nutrient resources (i.e. Superior) will be primarily driven by indirect responses to warming, such as changing lake thermal structure.

Introduction:

The surface temperatures in the Great Lakes have been increasing faster than air temperatures in the region [1], but the effects of these changes on lake biota remain unclear. Moreover, climate effects in systems ranging from nutrient-limited Lake Superior to nutrient-rich Lake Erie are likely to be different, as has been documented for community responses in marine systems with different resources [2]. Diatoms, microscopic algae with glass-like cell walls, respond quickly to environmental changes, leave sedimentary fossils, and are ideal organisms for studying biological responses to climate change. We will investigate how recent diatom changes are related to warming in Lakes Erie and Superior and how the effects of warming differ between these systems. We will compare modern diatom changes to those occurring during the Medieval Warm Period (950-1250 CE) for a historical context of climate-related diatom changes.

Objective:

An understanding of the biological responses to shifting climate in the Great Lakes will provide insight to the health and resilience of the ecosystem. We hypothesize that diatom communities experiencing constrained resource availability will show a more indirect response to warming climate. We would expect warming water may directly affect diatoms in a nutrient-rich system, primarily by increasing abundance. However, shifts in the lake thermal structure and mixing, an indirect response to rising temperatures, will be an important driver of community changes in both systems (see Fig. 1 for a project overview).

Methods:

We will isolate and identify diatom species from previously collected sediment cores from Lake Erie and Lake Superior and compare with diatom data from modern monitoring studies from both lakes. We will relate diatom community changes to physical lake changes caused by warming with various statistical techniques.

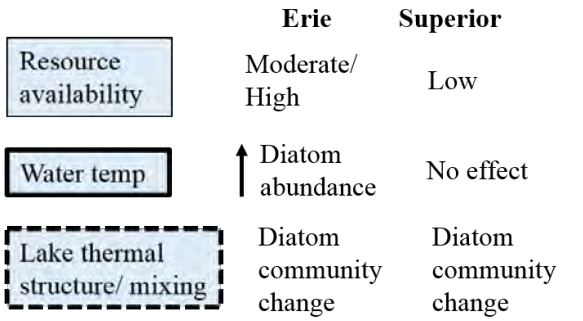

Figure 1. A comparison of Lakes Erie and Superior in terms of nutrient availability, as well as expected diatom responses to direct warming effects (bold box), and indirect warming effects (dashed box).

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

Bibliography:

1. Austin, Jay A., and Steven M. Colman. “Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback.” *Geophysical Research Letters* 34 no. 6 (2007).
2. O'Connor, Mary I., Michael F. Piehler, Dina M. Leech, Andrea Anton, and John F. Bruno. "Warming and resource availability shift food web structure and metabolism." *PLoS biology* 7, no. 8 (2009): e1000178.

Developing an Ultra- High-Resolution Record of the Last Glacial-Interglacial Transition from the RICE ice Core (Roosevelt Island, Antarctica)

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Abstract: The objective of this project is to develop an ultra-high resolution record of Na, Ca and Fe from the deep section of RICE ice core using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The analyzed section will cover the last glacial-interglacial transition, and the resulting data will help in understanding how fast climate changes occurred during the transition.

The RICE (Roosevelt Island Climate Evolution) project is an international partnership seeking to understand past, present, and future changes of the Ross Ice Shelf, a major drainage pathway of the West Antarctic Ice Sheet. The RICE deep ice core record will provide high- resolution data to investigate regional (West Antarctica) and global climate fluctuations.

A 764 m deep ice core was recovered during the 2011/12 and 2012/13 Antarctic field seasons. Ice core sections from a deep part (672 – 699 m) are being analyzed in the W.M. Keck Laser Ice Facility in the Climate Change Institute using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). This section is of particular interest because it covers the transition from the last glacial to interglacial period.

Ice core analysis by LA-ICP-MS provides ultra-high sampling resolution (<10 micrometers), which is much higher than traditional core processing using continuous flow analysis (~1cm/sample). Such high-resolution data will make it possible to determine individual storm events in the ice core record (Fig.1). It also will allow identification of annual layers, valuable in validating the depth/age scale for the deep part of the RICE ice core.

We expect to capture in great detail evidence of climate fluctuations and determine how abruptly climate changes occurred during the glacial-interglacial transition.

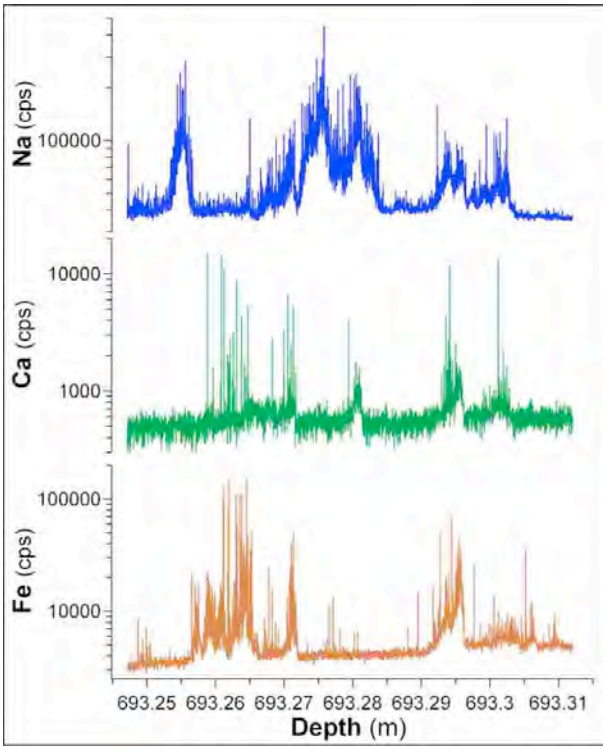

Fig. 1. RICE LA-ICP-MS Na (blue), Ca (green) and Fe (brown) intensities in counts per second.

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Geophysical Reconnaissance to Expand Ice Core Hydroclimate Reconstructions in the Northeast Pacific

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2. *School of Earth and Climate Sciences, University of Maine.*
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Abstract: By advancing the development of a spatial-temporal network of ice core accumulation records covering the past millennium in the NE Pacific, our proposed research will foster a greater understanding of regional hydrologic response to the coupled ENSO system. Our ability to do so relies on detailed geophysical investigation of relevant ice core sites, an approach that can be utilized in other regions to develop similar spatial-temporal networks.

Paleoclimate data from the Pacific basin show significant hydroclimate changes over the past millennium, possibly in response to changes in the mean state of the El Niño Southern Oscillation. One hypothesis invokes a change from a persistent La Niña-like state during the Medieval Climate Anomaly (MCA) to a persistent El Niño-like state during the Little Ice Age (LIA). A test of this hypothesis is to reconstruct and evaluate the spatial precipitation anomaly pattern in the Northeast Pacific across the MCA-LIA transition, because modern observations show an enhanced (weaker) coastal-inland precipitation gradient in the region during La Niña (El Niño) conditions. We therefore predict that the NE Pacific precipitation anomaly pattern will weaken across the MCA-LIA transition. For the past decade, we have been developing an ice core array in the NE Pacific that targets the two nodes of this precipitation dipole (i.e., St. Elias Range and Central Alaska), most recently (2013) with the recovery of two surface-to-bedrock 210-meter ice cores from Mt. Hunter (Denali National Park). To determine precipitation variability at the Mt. Hunter site over the past millennium, we rely on a suite of supporting geophysical data to constrain glacier geometry, velocity, boundary conditions, and rheological properties in a 3-dimensional finite element numerical model. The combined observational and model datasets allow us to remove influences of ice flow (which causes layer thinning) and spatial variability in snow accumulation rate to estimate temporal accumulation variability from the two ice cores. In contrast to Mt. Hunter, little is known about the geophysical characteristics of the coastal St. Elias Range ice core sites (PR Col, NW Col, King Col on Mt Logan; and the Eclipse Icefield), which were drilled in 2002 prior to advances in geophysical techniques and numerical modeling capability. This lack of information will introduce error in any comparison of the St. Elias and Mt. Hunter accumulation records, and thus evaluation of the MCA-LIA transition hypothesis. Our goal is to improve ice core-based accumulation records, and therefore hydroclimate reconstructions for the past millennium, in the NE Pacific through the collection of new geophysical data at existing ice core sites in the St. Elias Range. Our *objectives* are to: 1) develop bedrock topography maps of the Eclipse Icefield, King Col, and Mt. Logan summit plateau sites; 2) determine surface velocities at all sites; 3) map near-surface spatial accumulation rate patterns; 4) trace internal isochrones at all sites; 5) estimate ice deformation effects on layer thinning; 6) produce updated (to 2016) and corrected accumulation time series at all sites; and 7) compare corrected accumulation records from the Mt. Hunter and St. Elias sites to evaluate spatial precipitation patterns over the past millennium. Our research approach utilizes state-of-the-art ground penetrating radar (GPR), GPS, geochemical, satellite remote sensing, numerical modeling, and data synthesis techniques.

Acknowledgements: We thank NSF for ongoing support of this research program.

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

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Abstract: Several mechanisms have been suggested for the increase in 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*.

Diatoms are a group of phytoplankton commonly observed in almost every aquatic ecosystem. Recent surveys across many lakes have reported a sudden increase in the relative abundance of the small size diatom, *Cyclotella*, which is thought to be a key indicator species of warming across lakes in arctic, alpine, and boreal regions[1,2,3]. The potential mechanisms forthis expansion have been associated with **direct climate** impacts through temperature[1] or **indirect climate** impacts through interactive effects of water column stability, i.e. mixing depth (light), and nutrients[2].

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 Phosphorous 1 µM) and without nutrients as controls in Lake SS903 and SS32. The secondary objective is to determine how the structure of phytoplankton communities alters the response of *Cyclotella stelligera* to abiotic factors. In the same set of experiments we analysed the response of *Cyclotella stelligera* one with phytoplankton assemblages dominated by diatoms, and one dominated by other phyla, as it was a common species in both lake. 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 non- synchronous changes across these systems.

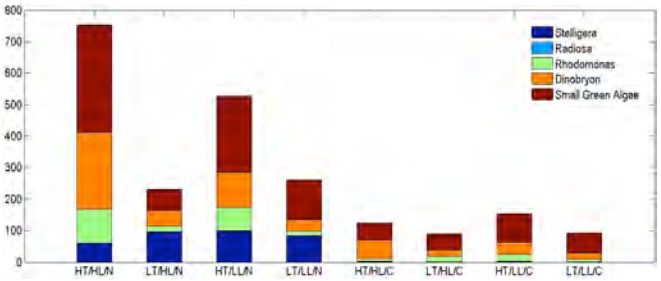

Fig1. Response of *Cyclotella stelligera* in a phytoplankton dominated lake, under high temperature (HT), low temperature (LT), high light (HL), low light (LL), nutrients (N) and control (C).

Bibliography:

1. Ruhland, K., Paterson, A.M., Smol, J. P. (2008). Hemispheric-scale patterns of climate- related shifts in planktonic diatoms from North American and European lakes. *Global Change Biology* 14: 2740–2754.

2. Saros, J. E., Stone, J. R., Pederson, G. T., Slemmons, K., E., H, Spanabuer., T, Schliep, A., Cahl, D., Williamson, C. E., Engstrom, D. (2012). Climate-induced changes in lake ecosystem structure inferred from coupled neo- and paleo-ecological approaches. *Ecology* 93: 2155–2164.

3. Smol, J. P. et al. (2005). Climate-driven regime shifts in the biological communities of arctic lakes. *Proceedings of the National Academy of Sciences.* 102: 4397–4402.

Shrinking *Bison*: A Story of Body Size Adaptation to Abrupt Climate Change and Adaptation to Modern Bison Production

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Abstract: Why are bison diminishing in body size and what effects does it have on the private bison ranch production industry? *Bison* body sizes have been shrinking due to climate change over the last 40,000 years, with an abruptly accelerated rate of shrinking in the last 14,000 years. This is evident from comparisons of modern, recent, and fossil *Bison* calcanei and crania from across the contiguous United States.

Bison survived the late Pleistocene megafaunal extinction when mammoths and other megafauna did not. Each animal has a unique suite of physiobiological characters that allows for adaptation or resilience to a range of climatic drivers, encoded in their respective genotypes.

Today, *Bison bison* are the largest native land mammal in North America at 1000 kg, but ~8,000 years ago, *Bison antiquus* (Figure 1, top right) was twice as large by mass.

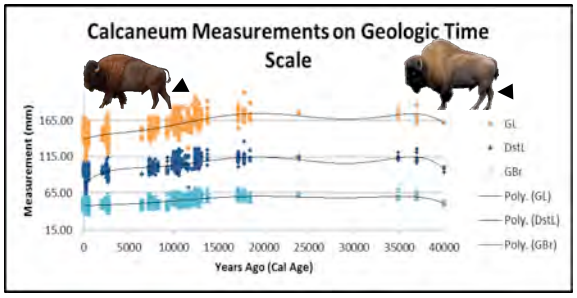

Figure 1. Thirty-four hundred *Bison* calcaneum measurements from 40,000 years ago (right, *Bison antiquus*) to today (left, *Bison bison*). Black arrows indicate the anatomical position of the calcaneum.

One of the most important bones in any animal, especially mammals, is the calcaneum; it provides the foundation and articulation of the ankle for the foot during movement (Figure 1, black arrows).

Previous studies (Craine 2013; Hill, Hill, and Widga 2008) have noted a diminution in body size of mammals and bison since the late Pleistocene. For this study, we integrate the paleontological, archeological, and modern zoological records for an interdisciplinary analysis approach.

Preliminary findings indicate that bison have shrunk due to climate change, moreover, were accelerated by human predation around 14,000 years ago when *Homo* arrived in North America. Though, there are large data gaps spatiotemporally, hopefully, these will be filled as the study progresses.

Future work will shed light on which variables are the most significant in controlling observed the shrinking effect, i.e. – human hunting, abrupt changes in temperature and precipitation, etc. These results will inform sustainable policies and regional management plans to for the bison industry to prepare to become more resilient to abrupt climate change for the future.

Acknowledgements:

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Bibliography:

Craine, JM Joseph M. 2013. “Long-Term Climate Sensitivity of Grazer Performance: A Cross-Site Study.” *PloS One* 8 (6): e67065.

Hill, Matthew E., Matthew G. Hill, and Christopher C. Widga. 2008. “Late Quaternary Bison Diminution on the Great Plains of North America: Evaluating the Role of Human Hunting versus Climate Change.” *Quaternary Science Reviews* 27 (17-18): 1752–71.

Los Morteros: Early Monumentality and Environmental Change in the Chao Valley, North Coast of Peru

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Abstract: Geoarchaeological excavations at Los Morteros and the Pampa de las Salinas Archaeological Complex have uncovered a unique example of pre-pottery monumental architecture dating more than 5000 yrs. BP. The history of this site was closely related to local landscape and environmental transformations.

Los Morteros is a mound-shaped archeological site located on the lower Chao Valley, north coast of Peru (Fig. 1). Previous excavation in the late 1970's considered this site to be a natural mound with some superficial use by pre-pottery people (Cardenas 1999). GRP explorations by a team from the University of Maine in 2006 and 2010 identified evidence of architecture underlying thick layers of eolian sand that currently cover the site (Sandweiss et al. 2010).

Geoarchaeological excavations carried out in 2012-13 have uncovered different phases of occupation of Los Morteros that include adobe-brick monumental structures (Fig. 2) and a Late Preceramic stone architecture. Recently obtained radiocarbon dates place these phases of the site between cal. 5700 and 5100 BP.

Fig. 1. Location of the Chao Valley on the Peruvian territory.

Fig. 2. Aerial photo of the adobe-brick architecture at Los Morteros, Chao Valley, North Coast of Peru.

Acknowledgements: NSF Project "Long-Term Human Ecodynamics in Coastal Peru", the National Geographic Society-Waitt Grants Program, Churchill Exploration Fund, Instituto Francés de Estudios Andinos (IFEA), the Graduate Student Government, FERCO International Fund.

Bibliography: Mercedes Cardenas, **"**El Periodo Precerámico en el valle de Chao", Boletín de Arqueología PUCP 3 (1999), 141-169.

Daniel Sandweiss, A. Kelley; D. Belknap; J. Kelley; K. Rademaker y D. Reid, "GRP Identification of an early monument at Los Morteros in the Peruvian coastal desert", Quaternary Research, Vol. 73 (2010), 349-448.

Using Agent-Based Models to Understand the Impacts of Weather Patterns on Songbird Migration Across The Atlantic Flyway

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Abstract: The scope and scale of bird migration covers the planet and involves feats of navigation and physical endurance. Through cross-breeding and orientation studies in captivity, it is clear that the controls on migratory behaviors and migratory direction is, at least in part, genetically determined. Young birds migrating for the first time regularly choose seasonally appropriate directions in captivity that are consistent with migratory routes used in the wild. The direction of flight during migration, however, should be impacted strongly by wind conditions. Under certain scenarios, a bird's heading may be relatively unimportant in determining its flight trajectory, particularly among songbirds that weigh only a few grams. Nevertheless, no study has compared the relative importance of genetically controlled orientation versus climatological drivers on the evolution and maintenance of migratory routes.

Through bird banding projects and stable isotope analysis from feathers, we know that songbirds migrating south along the Atlantic flyway in fall originate from as far north and west as Alaska. A central question of migratory route ecology and evolution is why these birds cross the continent instead of joining the Pacific or Central flyways. My dissertation explores two hypothesized origins of the evolution and maintenance of the circuitous Atlantic flyway: 1) The Atlantic flyway is the resultant vector between the instinctual southern orientation of individual birds and the prevailing westerly winds of North America or 2) The Atlantic Flyway is the result of a more complex genetic program, whereby individuals orient southeast across Canada until arriving at the Atlantic coast and then turn south-southwest following the coastline (Fig. 1).

Currently, I am collaborating with Bipush Osti, an UMaine computer sciences graduate student to create agent-based atmospheric models of bird migration. These models allows us to give the "agents" (birds) a breeding location, migratory direction, and an atmospheric field in which to migrate using high-resolution, 3-Dimensional, continuous atmospheric data from the National Center for Atmospheric Research. The model will describe the migratory path of birds with various orientation vectors, and will allow us to see if one, or both of the orientation scenarios create realistic migratory routes. We will also test whether orientation or wind or both are necessary to explain the major flyway boundaries and the known speciation events that have occurred along these boundaries. We will also validate these models by comparing their predictions to migratory bird use of habitat on the ground in Maine at both the site and regional scales. This modeling approach will allow us to test underlying assumptions of the field of migration ecology and to increase our understanding of the evolution and maintenance of migration routes in North America in relation to weather patterns.

With projected changes in weather patterns through climate change we expect to see changes in bird migration patterns. Using the validated migration model we will also model future migration patterns along the Atlantic flyway under various climate change scenarios.

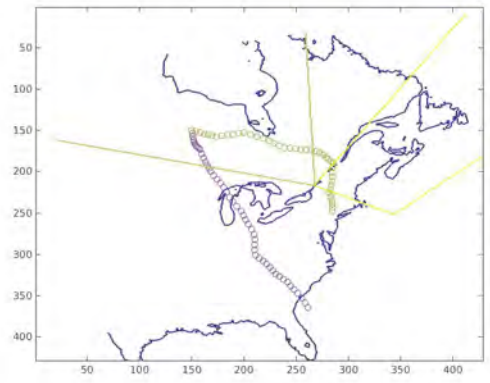

Fig 1. Ten-day test of the two hypothesis; purple bird represents the "southern orientation" hypothesis, the green represents the "complex genetic program" hypothesis.

Acknowledgements: Thank you to Bipush Osti, Peter Koons, and Sean Birkel for their continued support with this project.

Bibliography:

Berthold, P., & Helbig, A. (1992). The genetics of bird migration: stimulus, timing, and direction. *Ibis*, *134*, 35–40.

Release of Legacy Persistent Organic Pollutants (POPs) in Glacial Outflows and Mitigating Their Effect on Downstream Communities

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Abstract: During the period of 1950-1970 persistent organic pollutants such as DDT, dioxin and PCB were released in the atmosphere and distributed through precipitation onto glaciers around the world. Recent abrupt climate change is increasing the melt rate of many glaciers, potentially introducing the toxins to the watersheds at unknown rates. Studies have shown the existence of legacy pollutants in glacial ice, however neither the impact nor quantity of these toxins on downstream populations has been assessed. If these pollutants are released at toxic levels it will be necessary to create mitigation plans to lower their impact.

Since the late 1990s, researchers studying deposition of Persistent Organic Pollutants (POPs) into alpine watersheds have noticed a new mechanism of pollution introduction. Previously, atmospheric deposition and deposition through precipitation and runoff were considered to be the primary pollution sources. The impacts of this deposition were most clearly mapped in polar regions (Blais et al., 2001), correlating increase of POPs with altitudinal snow deposition. Recent studies (Bogdal et al., 2009), however, noted another correlated source of POPs in Europe, glacial melting.

Researchers have shown that the variety of human chemical use in the 20th century has been recorded within glaciers through atmospheric deposition (Wania et al., 1996). Specifically, residual chemicals from global use over the past 100 years have been dispersed through atmospheric circulation and deposited to glaciate in high alpine areas during precipitation events (Wang et al., 2010). This has made many high alpine ecosystems a reservoir of legacy pollutants. As increasing atmospheric warming continues to decrease glacial mass balances globally, these toxins will be released into the downstream communities (Blais et al., 2001).

Many of the legacy pollutants trapped within glaciers are of the dioxin or polychlorinated biphenyl (PCB) class. A highly carcinogenic and toxic class of chemicals, the side effects in humans are severe and well documented (Lawn et al., 1988). These chemicals have been outlawed in developed nations since the 1970s, but the residual chemical deposition captured in the ice are a significant human health concern. Even though ingestion of these chemicals pose significant human health risks, impacts on downstream ecosystems has not been assessed.

By developing criteria to determine which glaciers have the potential to be sources of toxins, this study will allow researchers globally to assess human health risks (Figure 1). Glacial and watershed modeling, combined with sampling at specific case study sites will allow us to determine the quantity and toxicity of these pollutants and develop mitigation strategies.

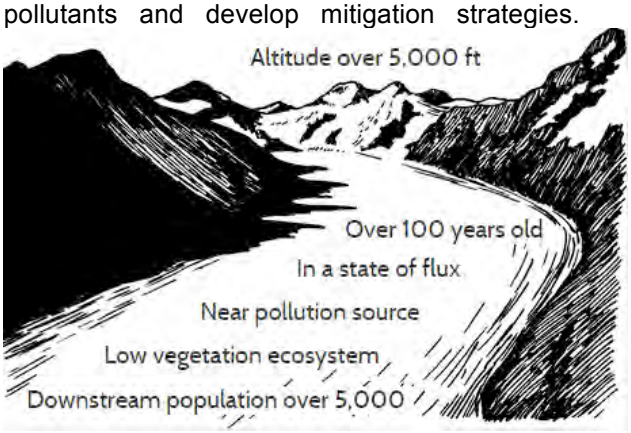

Figure 1. Conditions that indicate a glacier may be capable of distributing persistent organic pollutants

Acknowledgements: Gratitude for the support of Dr. Karl Kreutz, Dr. Lawrence LeBlanc, Dr. Adria Elskus, Dr. Jasmine Saros, and Dr. Jason Bolton of the University of Maine. Also Dr. Aaron Putnam of Columbia University. Thank you also to the NSF Adaptation to Abrupt Climate Change IGERT program grant DGE- 1144423.

Biogeochemical Patterns in Lakes Across Southwestern Greenland

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1. *Climate Change Institute, University of Maine.*
2. *School of Biology and Ecology, University of Maine.*

Abstract: In a rapidly changing Arctic, alterations to the landscape can have significant influences on key biogeochemical cycles. We examined changes to lake methane emissions as they related to increases in sulfate deposition over southwestern Greenland. Although no major relationships were found, these results suggest ample resources for both methane production and sulfate oxidation in this region in the future.

Introduction:
The Arctic is warming at a faster rate than any point in the past. Altered biogeochemical cycles are an important outcome of a rapidly altered landscape induced by climate change. In addition, positive feedbacks to climate change occur through enhanced emissions of greenhouse gases (CO_2 and CH_4) from warming tundra (Isaksen et al. 2011). Longer, warmer growing seasons may also alter the vegetative composition of tundra and influence microbial degradation of organic matter in soils and lakes.

High levels of biogenic sulfate have also been noted in Arctic Canada and Northern Greenland over the last decade (Sharma et al. 2012), coinciding with sea ice loss. While the relationship between sulfate and organic carbon is unclear, sulfate can affect soil organic matter in temperate regions. Given the increased importance of both of these processes over the past decade, we chose to examine the relationship between carbon and sulfate cycling in Arctic lakes in southwestern Greenland. In the summer of 2014, we surveyed 18 lakes near Kangerlussuaq, Greenland, along a western transect away from the ice sheet for basic water chemistry (nutrients, dissolved ions) and water-column methane samples.

Results and Discussion:
Across all lakes, there was no significant relationship between sulfate and methane (Fig. 1). This differs with other studies (e.g. Winfrey and Zeikus 1977), which found an inverse relationship from sulfate reducers outcompeting methanogens for acetate and free hydrogen (Winfrey and Zeikus 1977). Given increases in shrub tundra in this region of Greenland, and the potential for different types of organic compounds to be delivered from the landscape in the future, it is likely that both sulfate oxidation and methanogenesis will increase in the future.

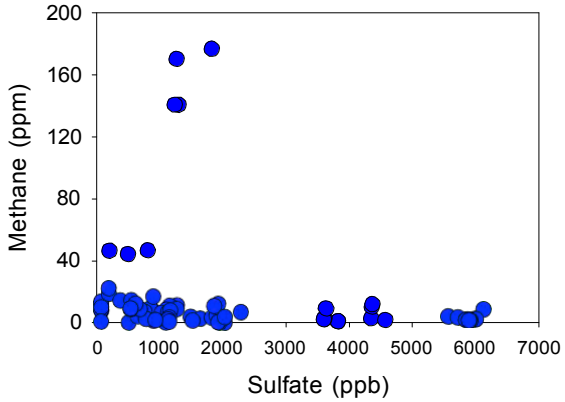

Fig. 1. The relationship between sulfate and methane in southwest Greenland lakes.

Acknowledgements: This study was supported by NSF-Arctic 1203434 to J.E.S., along with support from the Climate Change Institute.

Bibliography:
I. Isaksen, et al. “Strong atmospheric chemistry feedback to climate warming from Arctic methane emissions.” *Global Biogeochemical Cycles* 25 (2011): doi: 10.1029/2010GB003845.

S. Sharma, et al. “Influence of transport and ocean ice extent on biogenic aerosol sulfur in the Arctic atmosphere.” *Journal of Geophysical Research* 117 (2012): doi: 10.1029/2011JD017074.

M. R. Winfrey and J. G. Zeikus, “Effect of sulfate on carbon and electron flow during microbial methanogenesis in freshwater sediments.” *Applied and Environmental Microbiology* 33 (1977): 275-281.

Using Graphical Processing Unit (GPU) for Agent-Based Bird Migration and Landscape Anisotropy Modeling

Bipush Osti [1]

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Abstract: Simulations that require large data take up a really long time to run which makes it impractical as it significantly slows the progress of any research project. Using CUDA (Compute Unified Device Architecture) for the GPU can make the code run in parallel and can reduce the time taken by the simulations. The speedup achieved using CUDA is orders of magnitude more than that achieved when using a 'serial' code or when the code is not parallelized. This paper briefly explains the use of CUDA to try and solve two important problems related to Earth Sciences and Climate dependent bird migration.

I work with Sam Roy, a PhD student in Earth Sciences to create a topographic anisotropy model. Landscape anisotropy or directional dependency of topography provides valuable information about the underlying tectonic setting therefore anisotropy computation is an important step forward in answering some important questions in geology.

Variogram maps are used for anisotropy calculation for each point in an elevation grid.The variogram maps generate variance of elevation between the current point in question and points around it in multiple scales.The total number of points in the grid can be upwards of 100,000.For the map of the South Island of New Zealand that was used in the project the total grid points were 600,000. Using the unparallel version of the code even if the calculation for each point took about 6 milliseconds the total time would be 10 hours.CUDA was used to parallelize the code and reduce the total execution time taken by the simulation.

The CUDA implementation considered each elevation point in the grid to be a single 'thread' that runs parallel to each other.Thread in computer programming stands for independent computations and all the threads run parallel to each other at approximately the same time. As calculation for each point in this example as mentioned earlier takes about 6 milliseconds and all the threads or points are calculated almost simultaneously, the total time is reduced to roughly about 6 milliseconds. This allows the user to check for differences by using various input without having to wait for hours.

I work with Jennifer McCabe, a PhD student from the School of Biology and Ecology to create an agent based model for North American migrating birds. The model has birds moving in 2D space and their flight path is affected by weather factors like wind, precipitation and pressure. The birds are known to have a sense of migratory direction and the main aim of this project is to determine the relative influences of this innate sense of direction and the weather factors on the flight paths of the birds.

This project is ongoing and the code has not yet been parallelized however a plan to implement CUDA has been formalized. As with the anisotropy project the individual particles for which computation is to be performed is considered as a thread.Topographic anisotropy had each elevation data point as a thread but in this case each bird will be considered as a single thread. CUDA works best when there are no data dependencies, or when a thread does not depend on the other's result. Anisotropy naturally does not have any dependencies between elevation points. In the case of the agent based model the interactions between the birds are not considered which also makes the threads independent of each other.

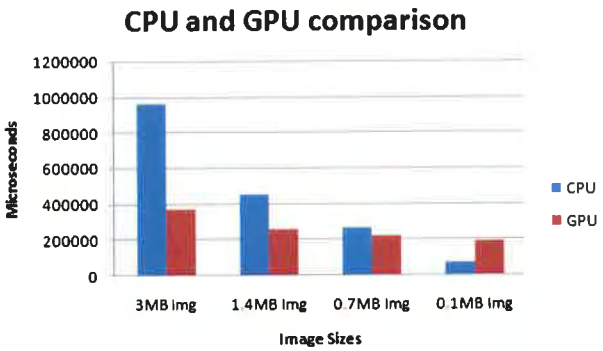

Figure 1: CPU vs GPU time for blurring images of various sizes.(From http://blog.refu.co/?m=201208)

Acknowledgement:
Thank you to Jennifer McCabe,Dr.Peter Koons and Dr.Sean Birkel for their continued support with this project.

Test Using UAV Gathered Imagery to Measure Supraglacial Lake Depths

Benjamin W. Partan[1]

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Abstract: Understanding glacial hydrology is important for understanding glacial dynamics. Supraglacial lakes are the most studied hydrological feature due to being able to be resolved in satellite imagery. Using a small UAV to collect high resolution imagery could be a low cost, efficient method for mapping, estimating volumes and discharge rates for meltwater. This project will test data collected from a UAV against existing methods of measuring lake depths from satellite imagery and physical soundings.

Supraglacial lakes are the most studied glacial hydrological feature by remote sensing due to their size being able to be resolved in satellite imagery. The drainage of supraglacial lakes in Greenland is known to correlate with increases in glacial velocity (Lampkin, 2014). The lakes often drain through moulins (Box, 2007) that offer a direct route to the englacial and subglacial hydrological systems. Several studies successfully looked at supraglacial lake bathymetry (Sneed 2007, Sneed 2011 and Box 2007) using reflectance.

Unmanned Aerial Vehicles (UAV) or Unmanned Aircraft Systems (UAS) are starting to play an important role in the remote sensing of glaciers. With advances in electronics, software and manufacturing components, UAVs are becoming less expensive, smaller and more powerful. Satellites provide images of wide areas in multiple bands but at the expense of spatial resolution and sampling frequency since they are on fixed orbits. Traditional fixed and rotor aircraft can provide higher resolution imagery of smaller areas when needed but are expensive to operate. A small UAV can fly at altitudes similar to that of a fixed wing or rotor aircraft providing high resolution images at very low cost, and surveys can be conducted on an as-needed basis.

This project will collect data flying UAVs over supraglacial lakes on the Juneau Icefield in Alaska using visible and near infrared spectrum cameras. Depths derived from these images will be compared to those obtained using the reflectance method from satellite imagery. Physical soundings will also be taken. The remotely derived depths will be compared to the physical soundings and the error will be characterized.

Acknowledgements: Thank you to the Churchill Exploration Fund for providing travel funds.

Thanks to the Juneau Icefield Research Program for use of its facilities. Thanks to Dr. Gordon Hamilton and Dr. Karl Kreutz both at University of Maine Orono, Dr. Allen Pope at UC Boulder, Paul Illsley at Nova Scotia Community College and Dr. James Partan at Woods Hole Oceanographic Institute for help with the design of the experiment.

Bibliography:

Box, J.E., Ski, K., "Remote sounding of Greenland supraglacial melt lakes: implications for subglacial hydraulics," *Journal of Glaciology,* 53 (2007) 257-265.

Lampkin, D.J., Vanderberg, J., "Supraglacial melt channel networks in the Jakobshavn Isbrae region during the 2007 melt season," *Hydrological Processes,* 28 (2014) 6038-6053.

Sneed, W.A., Hamilton, G.S., "Evolution of melt pond volume on the surface of the Greenland Ice Sheet," *Geophysical Research Letters,* 34 (2007) L03501.

Sneed, W.A., Hamilton, G.S., "Validation of a method for determining the depth of glacial melt ponds using satellite imagery," Annals of Glaciology, 52 (2011) 15-22.

Environmental Records from the Tupungatito Ice Core (Central Chilean Andes)

Mariusz Potocki[1, 2], Paul A. Mayewski[1, 2], Andrei V. Kurbatov[1], Daniel A. Dixon[1, 2], Bjorn Grigholm[1, 2], Gino Casassa[3], Rodrigo Zamora[4], Elena Korotkikh[1, 2], Michael Handley[1], Douglas Introne[1]

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Abstract: A 61 m ice core extracted from Tupungatito Glacier in 2012 reveals the history of environmental change in the Central Chilean Andes.

Future climate change in the arid Central Andes will have dramatic impacts on humans and ecosystems. Presently, the regional retreat of most alpine glaciers and increases in population, industry, and agriculture are beginning to generate unsustainable conditions for future demands on water resources (Engle et al., 2011). In addition, relatively limited seasonal precipitation in the Central Andes and declines in glacier-source water resources may magnify the regional impacts of the El Niño/La Niña phenomenon. Instrumental records of climate and environmental variability over the Central Andes are sparse and rarely extend to higher elevations. However, ice cores from the tropics and mid-latitude glaciers can provide high-resolution records of past climate dynamics and chemistry of the atmosphere ranging from seasonal to millennia time-scales (Ginot et al., 2006).

Tupungatito glacier receives the majority of its precipitation from frontal systems that develop in the Pacific Ocean and travel eastward. The region receives 80-90% of its annual precipitation from May through September. This part of Central Chilean Andes is a main source of water for Santiago and surrounding regions. (pers. comm. Jorge Carrasco Cerda, 2012).

On the basis of borehole measurements, the temperature of the Tupungatito glacier at 10m depth is approximately -15.5 ^{o}C assuring a well-preserved record. It suggests that surface melting is not common. However, lab observations reveal distinct thin (up to 8 cm) melt features in the core. Preliminary analysis reveals excellent, well-preserved annual signals in oxygen isotopes and an mean annual accumulation rate of ~0.50 m w.eq.

Trace metal analysis reveals pronounced enhancement in concentrations attributed to emissions of heavy and trace metals to the atmosphere from human activities in this part of South America, including non-ferrous metal mining and smelting, industry, agriculture, construction and large-scale land use (Nriagu and Davidson, 1986). Furthermore, it is observed that atmospheric pollution for heavy metals is not limited to Pb and Cu, but also affects several other metals such as As and Cd. Pronounced enhancements of elements like As have been observed during the last few decades in Tupungatito record. The enhancements have been attributed to the emissions of heavy metals into the atmosphere from human activities in Southern America, especially from Cu mining (Planchon et al., 2002).

Decrease in As concentration was observed in the 1990s in response to the introduction of environmental regulations enacted to reduce As emissions from the copper industry in Chile. The observed decrease suggests that governmental pollution regulations are effective in reducing air pollution at both the regional and global level (Hong et al., 2012).

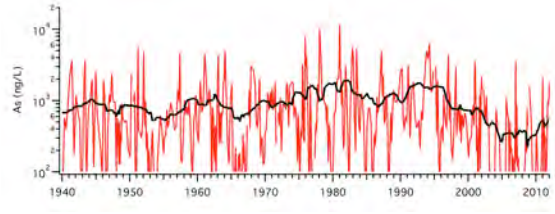

Fig 1. As concentration (ng/L) time series developed from the Tupungatito 2012 ice core.

Acknowledgements: The Garrand Family, Portland, Maine.

Bibliography:

[1] N. L. Engle et al., Ecology and Society 16(1): 19 (2011).
[2] P. Ginot et al., Ann. Glaciol. **35**: 443–450 (2006).
[3] J.O. Nriagu and C.I. Davidson, eds. Book,**17**, (1986).
[4] F. A. M. Planchon, et al., Earth and Planetary Science Letters **200**, 207-222 (2002).
[5] S. Hong, et al., Environ. Sci. Technol. **46,** 11550-11557 (2012).

Modeling the Shoaling of the Hypoxic Boundary in the Central and Southern California Current Region

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Abstract: While observations have indicated that the hypoxic boundary in the Central and Southern California Current Region has shoaled in the past 30 years, there is still debate as to why the increasing hypoxia in the water column has occurred. We use a coupled physical-biogeochemical model of the California Current Region to understand the mechanisms driving the changing dissolved oxygen levels

Introduction:

The California Current Region is the region associated with the California Current, a broad, relatively weak, eastern boundary current that flows equatorward on the west coast of the United States from Oregon to Baja, California. The California Current Region is an upwelling system. Equatorward winds produce Ekman transport away from shore which promotes upwelling of cold, nutrient-rich waters along the coast.

Due to upwelling, there is always some level of hypoxia at depth in the Central and Southern California Current regions. However, recent analysis of data indicates that the upper boundary of the hypoxic layer has shoaled in the past 30 years (Bograd et al. 2008). The level of low oxygen or hypoxic water (defined as under 60 µmol/kg or 2 ml/L) has increased its upper bound and is found at shallower depths and lighter isopycnals. A following study suggested that changing water mass properties of the California Current could account for the changing dissolved oxygen levels (Bograd et al. 2014). However, increased upwelling strength due to strengthening along-shore winds (Bakun 1990) or increased local biological respiration could also impact dissolved oxygen levels.

Methods:

We use a model of physical circulation, biological activity, and biogeochemistry for the Pacific Basin to test the different mechanisms for the dissolved oxygen changes in the water column. The physical circulation is governed by a ROMS ocean model with 12.5 km-resolution. The biology of phytoplankton, zooplankton, and the cycling of nutrients is governed by the CoSINE model based off of the work by Chai et al. (2002).

Results:

The model run for 1991-2010 reproduces a decline in the coastal dissolved oxygen over the time period that matches observations indicating a shoaling of the hypoxic boundary. The investigation of water mass variability, changing tilt of isopycnals, and local changes in respiration will suggest leading mechanisms for the cause of the observed increasing hypoxia in the water column.

Discussion:

The modeling research is important for determining how the region may respond to global warming including feedback mechanisms that are not in current global climate prediction models.

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

References:

Bakun, Andrew. "Global climate change and intensification of coastal ocean upwelling." *Science* 247, no. 4939 (1990): 198-201.

Bograd, Steven J., Carmen G. Castro, Emanuele Di Lorenzo, Daniel M. Palacios, Helen Bailey, William Gilly, and Francisco P. Chavez. "Oxygen declines and the shoaling of the hypoxic boundary in the California Current."*Geophysical Research Letters* 35, no. 12 (2008).

Bograd, Steven J., Mercedes Pozo Buil, Emanuele Di Lorenzo, Carmen G. Castro, Isaac D. Schroeder, Ralf Goericke, Clarissa R. Anderson, Claudia Benitez-Nelson, and Frank A. Whitney. "Changes in source waters to the Southern California Bight." *Deep Sea Research Part II: Topical Studies in Oceanography* (2014).

Chai, F., R. C. Dugdale, T-H. Peng, F. P. Wilkerson, and R. T. Barber. "One-dimensional ecosystem model of the equatorial Pacific upwelling system. Part I: model development and silicon and nitrogen cycle." *Deep Sea Research Part II: Topical Studies in Oceanography* 49, no. 13 (2002): 2713-2745.

Micromorphology of an Archaic Period House Floor

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Abstract: Recent excavations at the Waterside site in Sorrento, Maine confirm John Rowe's 1940 report of a 4000 year old, shell free occupation layer marked by a concentration of animal bone. Our excavations yielded abundant bone including swordfish ribs and a vertebra lying in almost direct contact with sterile subsoil. Suspecting this could be a unique semi-subterranean house floor, we collected an intact soil column through the layer, which was consolidated with polyester resin, cut, and polished. Micromorphology analysis yielded multiple contrasting layers of trampled bone that strongly support the hypothesis that this is a deeply buried Late Archaic period house floor.

A targeted ice coring campaign to investigate abrupt climate changes in The Cordillera Vilcanota, Peru: exploiting a novel glacier geometry

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Abstract: A novel ice coring campaign is planned for two glaciers in The Cordillera Vilcanota in Southern Peru. Initial ultra high resolution trace element analyses revealed well-preserved records in samples collected near the surface of a vertical exposure of annual layering on Osjollo Anante. These annual layers will be used to target sample collection and absolutely date sub-samples from cores spanning abrupt climate changes and significant El Niño events.

Photographs taken of the margin of a glacier on Osjollo Anante in southern Peru in 1984 and 1998 show obvious dark layers created by extreme melting during El Niño events in the previous years, as well as continuous layering to the bottom of the exposure. Ultrahigh resolution trace element sampling of cores retrieved from that marginal exposure in 2013 proved to record chemical concentrations with annual peaks likely linked to dry season dust loading (Rodda, et al., 2014). The Quelccaya Ice Cap, located ca. 40km from Osjollo Anante has a dated climate record stretching back 1800 years (Thompson, et al., 2013), and displays visually similar annual layering. Thompson et al. (2013) also established the strong link between El Niño events in the Cordillera Vilcanota and major climate shifts. Using the easily-identified in-situ annual layering on Osjollo Anante, we will collect samples of major El Niño events from the modern era to compare to instruments records, and thus establish a chemical signature for El Niño events in the Cordillera Vilcanota. We will then use annual layer counting to direct sampling of other major climate shifts identified in the Quelccaya record, including the end of the Little Ice Age (LIA; CE 1880), the beginning of the LIA (ca. 1550), and potentially the end of the Medieval Climate Anomaly warm period (ca. (1350). We will also be conducting a thorough reconnaissance of the Quelccaya Ice Cap to search for the distinctive 1983 and 1998 El Niño melt layers. If the two layers can be identified, samples of the same modern El Niño events sampled on Osjollo Anante will be collected, to establish the regional character of the El Niño signal. Ultrahigh resolution sampling (ca. 1000 samples/yr) will allow unprecedented precision in description of the number, intensity and timing of storm events - all critical features of El Niño precipitation anomalies.

Fig 1. Distinct annual layers on Osjollo Anante

Acknowledgements: This research benefits from the direction and funding coordination of Dr. Paul Mayewski.

Bibliography:

Rodda, et al., 2014, Borns Symposium Paper

Thompson, et al, 2013. *Science*, May 2013, 945-950.

ICD2: An Ice Core Dating Software Tool

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Abstract: We present a software program called the Ice Core Dating 2 (ICD2) that is an enhancement to a Java software package available to download from the Climate Change Institute's website. However, there are many areas in which the ICD2 software is an improvement to the previous system. The ICD2 lets users load raw ice core data in CSV format and associate interpolated dates. The system uses open source software, and it can be enhanced with additional features due to its plug-in architecture. Finally, the ICD2 system has been designed so that aspects of it may be incorporated into P301, so that users are permitted to utilize tools from that system.

Ice Core Dating 2 Tool

The ICD2 allows users to analyze ice core data and associate it with date information. The system is written in Java using Open Services Gateway initiative (OSGi) technology, which is the same open source technology used to build Eclipse. Modeled after the Ice Core Dating Software funded by CCI, this new version includes enhancements for larger data sets, incorporation of Hierarchical Data Format 5 (HDF5) data storage, integrated non-linear curve fitting for dating, and data semantic constraints.

ICD2 projects are stored in a workspace on the local machine. The workspace contains a data folder where imported cores are stored and a sessions folder that contains previously saved core dating sessions. The information stored in these folders may be copied to other systems, which enables users to easily share data and sessions between one another.

Core files that are imported by the system, undergo a number of checks to ensure that they are in fact valid. Basic checks include: the top depth of any sample is not deeper than its bottom depth; the top and bottom depths of cores are monotonically increasing; and no important core information is missing (e.g. top or bottom depth). Additional constraints may be added by the end user.

Validated core data is stored as a new HDF5 file in the workspace. This is beneficial because many types of scientific systems use this format. The HDF5 format that ICD2 uses is based on the format used by GNU Octave (Open source Matlab). This has the side effect that any core data imported by ICD2 is immediately usable in Octave. The HDF5 files are compatible with NetCDF-4 and can also be read by R applications without extra work.

The ICD2 system is composed of core dating projects and core dating sessions. A core dating project is a collection of core elements plotted against depth. A core dating session contains information that compares depth and date. The original core versus depth data is displayed on the top of the screen, and the interpolated time scale is shown on the bottom (see Fig. 1). The date and depth information is smoothed using a spline interpolation. When a new date marker is added to the current session, the interpolated year data is recalculated and displayed in near-real time.

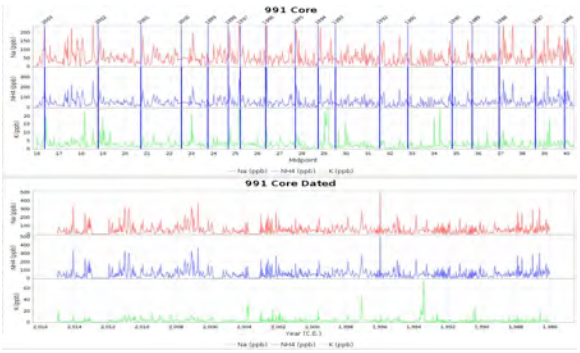

Fig. 1. An ICD2 dating session. The dated core appears in the top graph, and the interpolated, dated values, appear in the bottom graph.

ICD2 is built using open source technology so that it can be used with the rest of the scientific community. The system is composed of a plug-in framework called OSGi, which can be extended and incorporated into other systems. These features of the ICD2 system help facilitate the dating of core data.

A Whole Lake Thermal Experiment in a West Greenland Lake

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2. *School of Biology and Ecology, University of Maine.*

Abstract: Across the Arctic, lake sediment records provide some of the few key archives documenting rates of ecosystem change in this region since the last ice age. In particular, striking changes in communities of diatoms have occurred over the last 150 years, but we understand little about what these changes indicate about lake response to climate. We used a whole lake manipulation to gather key ecological information that will enhance interpretation of several existing diatom records from southwest Greenland.

In numerous lake sediment records from the high Arctic of Canada and Europe, diatom species generally associated with warmer conditions increased at unprecedented rates during the 20th century (Smol, 2005). Diatom communities in lake sediments from west Greenland are dramatically different from those in the rest of the Arctic- they are rich in these "warmer" water diatoms throughout the Holocene, not just the last century (Perren et al. 2009). This difference has raised questions about what we can use diatoms to infer in the Arctic, and suggests the need to clarify the ecological traits of key diatom taxa in order to advance our understanding of drivers of change.

We hypothesized that climate-driven changes in nutrients and water column stability (via its effects on light availability) are key factors shaping diatom community structure in these lakes. To test this, we conducted a whole- lake manipulation in 2014 in which water column stability was reduced through enhanced water circulation to assess the response of key taxa to this change. Lake SS16 was manipulated by deploying a Solar Bee hydraulic lift system into the lake (Fig. 1). The neighboring lake was left unmanipulated but monitored over the same time frame.

We found that the relative abundances of key diatom taxa are under complex control by the interactive effects of nutrients and light. Understanding the ecology of these species will provide important tools to decipher the extent to which direct and indirect effects of climate are contributing to rapid ecological change. Ultimately, diatom records from arctic lakes may be providing much richer signals of the response of these lake ecosystems to climate change than previously thought.

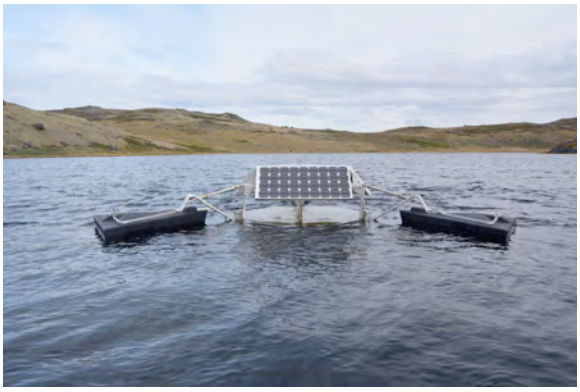

Fig. 1. *Solar Bee system in Lake SS16 during lake manipulation.*

Acknowledgements: This project is funded by NSF Arctic 1203434.

Bibliography: Perren, B.B. et al. (2009) Diatoms reveal complex spatial and temporal patterns of recent limnological change in West Greenland. J. Paleolimnol., 42: 233-247.

Smol, J.P. et al. (2005) Climate-driven regime shifts in the biological communities of Arctic lakes. P. Natl. Acad. Sci. USA,102: 4397-4402.

Latitudinal Trends in Saltmarsh Sparrow (*Ammodramus caudacutus*) Fecundity

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Abstract: In this study, we quantify fecundity, or reproductive success, of Saltmarsh Sparrows across their global species range. We observed large-scale trends, most notably that fecundity was greatest near the high-latitude range margin, rather than the range center as predicted by ecological theory.

In 1906, Joseph Grinnell hypothesized that the population growth rate of a species highest near the center of its geographic range, where the conditions are most favorable for that species. This hypothesis is very intuitive, and perhaps because of this, it is deeply entrenched in ecological and evolutionary theory. Many subsequent hypotheses have been based upon this assumption that species thrive at the center of their ranges. Additionally, this idea has formed the basis of many wildlife management actions, such as protection of habitat for endangered species. Despite the ubiquity of Grinnell's hypothesis, it has almost never been tested across the global range of a species or with demographic data. We present one of the first range-wide demographic analyses of a species as a test of Grinnell's hypothesis.

We quantified the fecundity, or reproductive success, of Saltmarsh Sparrows (*Ammodramus caudacutus*) across their global breeding range. Saltmarsh Sparrows are endemic to tidal marshes and breed exclusively in the northeastern United States (Greenlaw & Rising, 1994). From 2011-2013, we conducted intensive demographic surveys of breeding Saltmarsh Sparrow populations in Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and New Jersey. We calculated fecundity via a Markov-chain approach using programs developed by the Environmental Protection Agency (EPA). We combined nest failure probabilities with various other life history parameters such as number of eggs per nest and number of nesting attempts per year of each female to create a robust estimate of annual fecundity.

We found that Saltmarsh Sparrow fecundity increased with latitude. In contrast to the Grinnell's hypothesis, Saltmarsh Sparrow fecundity was highest near its high-latitude range margin. This result has interesting implications for ecology, evolution, and conservation. Our results suggest that Saltmarsh Sparrow populations at the range margin are not constrained by adaptations at the range center. Rather, populations at the center may be constrained by the high-latitude populations, which may be problematic for adaptation to climate change.

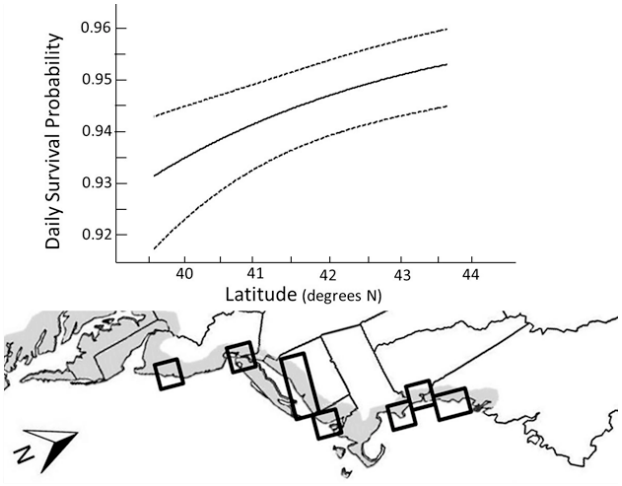

Figure 1. We observed that annual fecundity increased toward the high latitude range margin of Saltmarsh Sparrows.

Acknowledgements: Funding for my research has been provided by the U.S. Fish & Wildlife Service and the University of Maine. Thanks to the Saltmarsh Habitat & Avian Research Program collaborators, my committee, particularly Matt Etterson, and the Olsen lab.

Bibliography:

1. Greenlaw, J. S., & Rising, J. D. (1994). Saltmarsh Sparrow (Ammodramus caudacutus). Birds of North America.
2. National Audubon Society. (2007). Saltmarsh Sparrows. National Audubon Society WatchList.

Changes in Iceberg Size Distribution in Disko Bay, West Greenland

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Abstract: Recent dynamic changes along the margins of the Greenland ice sheet have caused a change in the sizes and distribution of icebergs in coastal waters. However, little work has been done to quantify these changes. Here we present preliminary results from an iceberg delineation algorithm pointing to a shift in iceberg size-frequency occurrence from a small number of large icebergs towards a larger number of small icebergs. These changes have implications for freshwater fluxes to the ocean as well as coastal maritime navigation.

Over the past two decades, the response of the Greenland ice sheet (GIS) to climate changes has become increasingly pronounced. Nowhere are these changes more evident than along the margins of the ice sheet, where outlet glaciers channel ice from the interior and often terminate in marine environments. These dynamic changes currently account for up to half of Greenland's annual mass loss, with the rest due to surface ablation (e.g. van den Broeke, *et al.* 2009). Thus, understanding ice dynamics and ice-ocean interactions is essential for improving models of how the GIS will respond to future climate changes. Icebergs are an important and relatively understudied component of this ice-ocean system. Conversations with locals in Ilulissat, West Greenland indicate that over recent decades, Disko Bay iceberg size distributions have shifted concurrent with the speedup, thinning, and retreat of nearby Ilulissat Isbræ, with impacts on coastal navigation and the fishing and tourism economies.

We have developed an algorithm to automate the collection of physical and spatial information about icebergs from optical satellite imagery (Landsat) to better understand the role of icebergs in Greenland's coastal waters. Preliminary results (Fig. 1) indicate that there has been a change in size-frequency distribution of the icebergs in Disko Bay since the turn of the century, shifting from a small number of large icebergs to a larger number of small icebergs. Future work will focus on understanding this frequency distribution in the context of natural systems by increasing the temporal resolution of this record.

Acknowledgements: This work has been supported by the US NSF A2C2 IGERT program (grant DGE-1144423) and is in cooperation with Asiaq, Greenland Survey.

Bibliography: van den Broeke, Michiel, Jonathan Bamber, Janneke Ettema, Eric Rignot, Ernst Schrama, Wellem Jan van de Berg, Erik van Meijgaard, Isabella Velicogna, and Bert Wouters (2009). "Partitioning Recent Greenland Mass Loss." *Science* 326: 984–986.

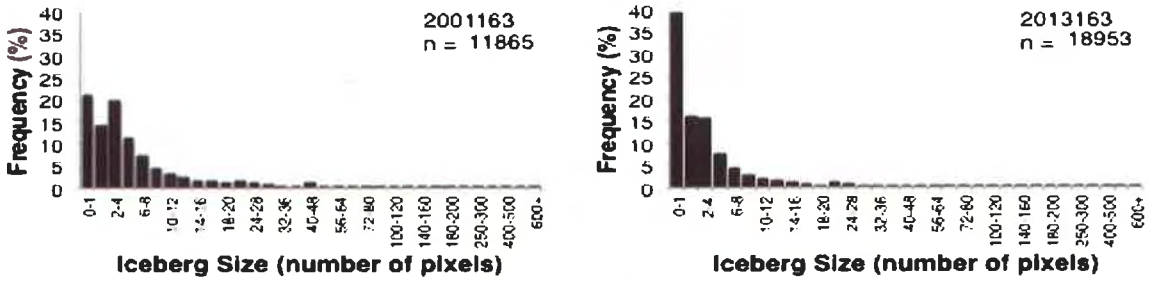

Figure 1: Representative iceberg size-frequency distributions for Disko Bay, West Greenland showing the increase in the smallest size icebergs from 2001-2013. Results shown are from Landsat images acquired 12 June 2001 (left) and 12 June 2013 (right). One pixel is 225 m^2. Note: Bin sizes are not uniform and increase in size as iceberg size increases.

Can Seed Dispersal Traits Keep Trees from Reaching Equilibrium with Climate?

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Abstract: We tested how seed dispersal traits influence the geographic ranges of North American trees. Trees with known adaptations to extinct megafauna are poorly dispersed and were used as a natural experiment to see how well they accessed potential range relative to trees with other dispersal mechanisms. Dispersal type was not found to be a significant predictor of range filling for individual trees. However, our results suggest most trees have experienced dispersal limitations following post-glacial warming, suggesting poor ability to track future climate change.

Climate is considered the major determinate of species' geographic ranges at continental scales.[1] Climate changes are expected to drive species to higher latitudes and altitudes, which has already been documented.[2] Yet our abilities to determine which species will shift and whether they can keep up with changes are poor. Species distribution models are a leading tool for predicting the effects of climate change on species' ranges, however, they assume that species are at equilibrium with climate. Dispersal limitations, where species have had insufficient time or face insurmountable barriers, can prevent species from reaching all places with a suitable climate.[1] Recent studies suggest dispersal may play a strong role in limiting the ranges of some species, particularly trees.[3] Thus, dispersal has fundamental consequences for species' ranges and our ability to forecast them as climates change.

We investigated how dispersal limitations caused by seed traits can influence climate equilibrium by focusing on species with anachronistic dispersal adaptations. Trees which possess large fleshy or woody fruits ill-suited for dispersal by extant animals are proposed to be adaptations to extinct Pleistocene Megafauna.[4] Subsequently, megafauna-adapted trees are expected to have narrower ranges relative to trees with other dispersal mechanisms.[4] We hypothesized megafauna adapted trees will show a greater disequilibrium with climate because of this. Climate disequilibrium was quantified by the proportion of its potential range a species utilizes. Potential ranges were calculated for North American trees using climate variables with known physiological linkages to survival.

North American trees were not found to be at equilibrium with their physiological climate limits (mean range filling 49%). Neither dispersal type nor megafauna-adaptations appear to influence range filling. The most significant predictor of range filling was realized range size. This suggests 1) species with larger ranges are more likely to be running up against their own physiological climate limitations and 2) climate becomes less important of a determinate as the size of a species' range decreases. Biotic factors, such as competition, may be a major limiting factor for small ranged species, widespread species have overcome by being competitively superior.[5] Overall, results suggest North American trees have not yet fully responded to post-glacial warming, and thus we would expect limited tracking of future changes.

Acknowledgements: Thanks to Jacquelyn Gill, CCI, and SBE for supporting this research.

Bibliography:

1) Svenning, Jens-Christian, and Brody Sandel. *American Journal of Botany* 100, no. 7 (2013): 1266-1286.

2) Parmesan, Camille, and Gary Yohe. *Nature* 421, no. 6918 (2003): 37-42.

3) Svenning, Jens---Christian, and Flemming Skov. *Ecology Letters* 7, no. 7 (2004): 565-573.

4) Janzen, Daniel H., and Paul S. Martin. *Science* 215, no. 4528 (1982): 19-27.

5) Brown, James H. University of Chicago Press, 1995.

Maritime Adaptation and Cultural Boundaries in Frenchman Bay, Maine

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Abstract: Shell middens in Frenchman Bay produced an unusual number and variety of bone tools. Although long known, it is unclear whether these represent a localized maritime adaptation within Frenchman Bay or an identifiable cultural region, where bone was a preferred material for tool production. This problem will be addressed through analysis of the Jones Cove shell midden site in comparison with bone and stone tool assemblages from across the region in relation to marine resources, sea level rise and site erosion.

Frenchman Bay is rich in marine resources and there is clear evidence of dependence upon marine-based food resources where localized complex seasonal settlement patterns emerged (Sanger 1988).

Cultural differences are interpreted from visible material patterns that vary significantly in content and meaning. Tool technology and ritual artifacts provide the most visible or distinctive traits to help identify cultural boundaries. A tool form known as the "simple bone point" is often the most abundant artifact found in shell middens in Frenchman Bay (Tyzzer 1936), but nearly absent in western Maine shell midden sites.

Unusual frequencies of tools might signify cultural preferences, hunting of different animal species, or different rates of erosion due to sea level rise, among other factors (Robinson 1996).

This research project consists of two parts. First, analysis of bone and stone tool technology and faunal remains will be conducted to determine if there is a correlation between tool types and specialized resources, or if the tool proportions, as a whole, could represent distinct cultural practices compared to other sites within the Gulf of Maine. Second, DNA analysis of selected bone tools will be conducted to determine if a certain species of animal was specifically chosen for bone tool production as a form of hunting and fishing ritual.

In 2006, the University of Maine Anthropology Department conducted a Maine Academic Prominence Initiative (MAPI) funded archaeological field school in Gouldsboro, Maine at the Jones Cove Site in Frenchman Bay. This Late Woodland Period shell midden was previously excavated in 1929, producing an abundance of bone and stone artifacts.

Bone tool production first caught the attention of archaeologists in the 1920's but little research has since been conducted as to the use of these abundant tool forms, or to which species of animal bone was commonly used to produce them. This new research will contribute to a better understanding of culture areas and maritime adaptation within the Gulf of Maine.

Fig. 1. Jones Cove Assemblage Sample

Acknowledgements: Assistance has come from the MAPI field school grant, the Climate Change Institute, the Department of Anthropology, and the Abbe Museum.

Bibliography:

Robinson, Brian. 1996. "Projectile Points, Other Diagnostic Things and Culture Boundaries in the Gulf of Maine Region." *Maine Archaeological Society Bulletin* 36 no. 2:1-24.

Sanger, David. 1988. "Maritime Adaptations in the Gulf of Maine." *Archaeology of Eastern North America* 16:81-99.

Tyzzer, E.E. 1936. "The "Simple Bone Point" of the Shell Heaps of the Northeastern Algonkian Area and Its Probable Significance." *American Antiquity* 1 no. 4: 261-279.

Spatio-Temporal Variability of Suitable Habitat for American Lobster (*Homarus Americanus*) in Long Island Sound

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Abstract: Using four environmental variables (bottom temperature, bottom salinity, depth, and bottom sediment type) as well as 34 years of spring and fall lobster surveys, we developed a Habitat Suitability Index (HSI) model to analyze the spatio-temporal variability of suitable American lobster (*Homarus americanus*) habitat in Long Island Sound (LIS). The suitability indices (SIs) calculated for the four environmental variables were combined to form a composite HSI model. Maps of estimated HSI values were produced using kriging interpolation for adult and juveniles in spring and fall from 1978 to 2012.

The lobster fishery in Long Island Sound (LIS) remained the third largest lobster fishery in the United States until 1998, but has experienced a substantial decrease in lobster abundance over the last 20 years. As climate change continues to alter Northwest Atlantic coastal ecosystems, it is necessary to quantify the change in availability of suitable lobster habitat over time.

Habitat Suitability Index (HSI) models are widely utilized in wildlife management to evaluate relationships between environmental variables and the relative abundance of a target species (Franklin 2010). The objective of this study is to develop a HSI model for evaluating the spatio- temporal variability of suitable lobster habitats in LIS for juvenile and adult in spring (April-June) and fall (September-October) from 1978 to 2012.

The modeling result revealed overall spatial distribution of estimated HSI values in LIS for each group of lobster (2 seasons * 2 size classes) (Fig 1). Temporal variation in availability of suitable habitat was observed in all four groups of lobster over the period of 34 years (Fig. 2). Overall, there were no statistically significant temporal trends in suitable habitat change for adult lobsters in spring and fall.

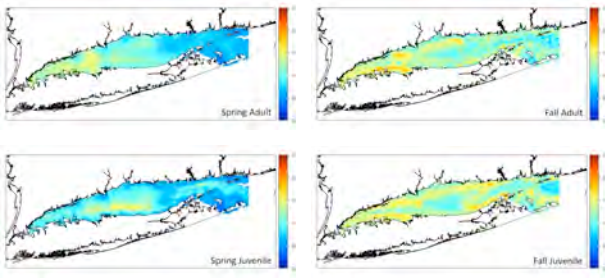

Fig. 1: Spatial distribution of the median habitat suitability index (HSI) values in the Long Island Sound over 34 years (1978-2012).

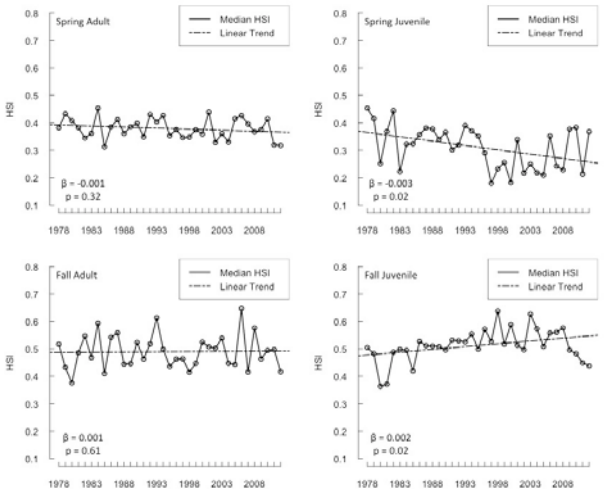

Figure 2: Median habitat suitability index (HSI) score for each year from 1978 to 2012. The trend in each group was shown by the fitted simple linear regression model.

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

Bibliography:

Franklin, Janet. Mapping species distributions: spatial inference and prediction. Cambridge University Press, 2010.

Recent Trends in Jordan Pond: The Impact of Changing Clarity and Epilimnion Thickness on Phytoplankton Community Dynamics

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Abstract: The clarity of lakes in Acadia National Park and lakes across the northeast has been declining over the past two decades. These changes have been linked to increases in dissolved organic carbon (DOC). In this study, we are exploring how changing transparency and thermal structure in Acadia lakes are affecting phytoplankton community dynamics.

In recent years, water clarity in Jordan Pond in Acadia National Park has been declining. This trend is occurring in Jordan Pond (Fig. 1), as well as other lakes in Acadia and across the northeastern United States.

There are two main drivers suspected behind these changes in lake transparency. Lakes may be returning to earlier conditions (less transparent) as a result of reduced acid deposition due to the Clean Air Act Amendment of 1990. Reduced acid deposition results in reduced ionic strength of soils, and therefore increased organic matter solubility, which results in higher concentrations of DOC in surface waters (Monteith et al. 2007). In addition, DOC could be entering the lake as a result of the increased storm frequency that is occurring as a result of climate change (Zhang et al. 2010).

The thickness of the epilimnion in lakes is determined by both DOC and wind. DOC is considered the main driver of epilimnion thickness in lakes less than 500 hectares, which includes Jordan Pond (Fee et al. 1996). With significant increasing trends in DOC in Jordan and other lakes in Acadia including Seal Cove, Eagle, and Echo, epilimnion thickness is predicted to become shallower. In this research, we are interested in exploring how changing epilimnion thickness and secchi depth will influence phytoplankton dynamics in Acadia lakes. We will address questions such as: due to the extreme clarity of Jordan Pond, will certain phytoplankton species be constrained by altered light availability? How important is mixing depth to phytoplankton community dynamics in the lake?

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. Jordan Pond is the clearest lake in Maine as well as a municipal water source and is therefore particularly important to study.

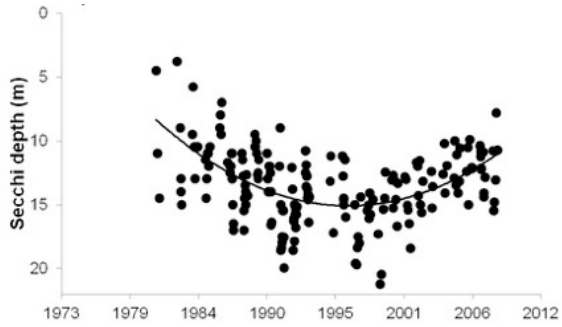

Fig. 1. Secchi disk transparency in Jordan Pond from 1981 to 2008 (Strock 2013).

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

Bibliography:

Fee E.J., et al. 1996. Effects of lake size, water clarity, and climatic variability on mixing depths in Canadian Shield lakes. *Limnology and Oceanography* 41: 912-920.

Monteith, D. T., et al. 2007. Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature* 450: 537-541.

Strock K.E.D. 2013. *Deciphering Climate Mediated Changes in Boreal Lake Ecosystems*. (Dissertation). University of Maine, Orono, ME.

Zhang, J., et al. 2010. Long-term patterns of dissolved organic carbon in lakes across eastern Canada: Evidence of a pronounced climate effect. *Limnology and Oceanography* 55: 30-42.

Glacier Change over the Last Century, Caucasus Mountains, Georgia

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Abstract: The article describes observations of glacier changes on the southern slope of the Caucasus Mountains, Republic of Georgia. Glacier area has decreased by more than 40% since the late 1800s, with the fastest rates of loss occurring since 1960. These changes are linked to observed air temperature warming in the region.

The Caucasus is one of the major mountain systems in Eurasia, stretching ~1,300 km from the Black Sea in the west to the Caspian Sea in the east and separating southwestern Russia from Georgia. The range contains ~1,200 glaciers with a total volume of ~68 km^3. On thesouthern slope, these glaciers are an important source of water for agriculture and hydropower generation in Georgia, as well as for the Caspian Sea.

Glacier research has a long history in the Caucasus. The first scientific reports of the early1700s are from the great Georgian scientist Vakhushti Bagrationi. Almost continuous observations have been carried out since 1930s. There are considerable amounts of data in the archives of the Vakhushti Bagrationi Institute of Geography.

We used the catalog of glaciers on the southern slope of the Caucasus compiled in1911 by K. Podozerskiy, on the basis of 19th century maps. The catalog is compared with glacier extents in the 1960s derived from topographic maps at 1:50 000 scale. Modern glacier extents are mapped from Landsat images of L8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) acquired in August 2014.

We show that the area of glaciers Georgia has decreased from 613.1 km^2 to 555.9 km^2 between 1911-1960, while their number increased from 515 to 786 (Fig. 1, 2). The number of glaciers increased due to the separation of tributaries from the main trunks of compound glaciers.

Between 1960-2014, the area of the glaciers has decreased from 555.9 km^2 to 355.8 km^2 and their number was reduced from 786 to 637 (Fig. 1, 2). The rapid reduction in glacierized area coincides with an observed ~0.2°C warming in the region since the mid-1950s. Continued glacier wastage will have important consequences for water resources in the Southern Caucasus region.

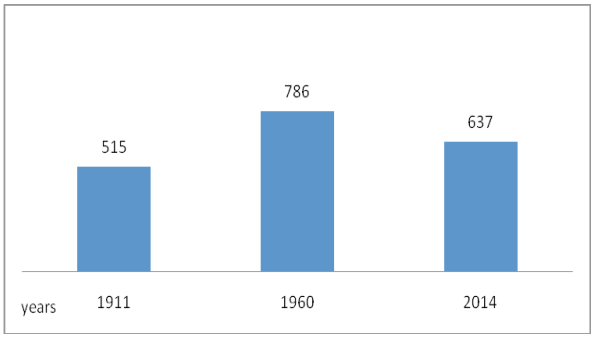

Fig. 1. Variability of the number of the glaciers of Georgia in 1911-1960-2014

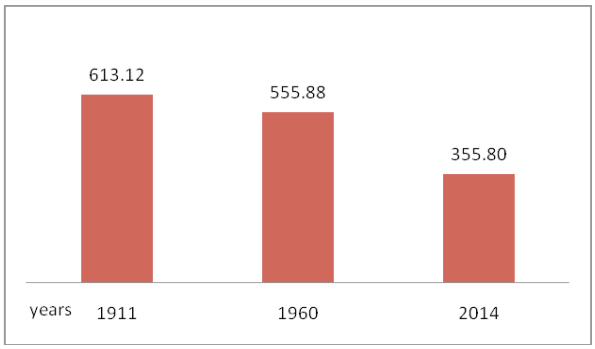

Fig. 2. Variability of the area of the glaciers of Georgia in 1911-1960-2014.

Linking Environmental Conditions to Spatio-temporal Variability in the Distribution and Growth of Sea Scallops *Placopecten magellanicus* in the Gulf of Maine

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Abstract: This project will develop the modeling framework to predict spatio-temporal variability in the distribution and growth rate of sea scallops *Placopecten magellanicus* with respect to underlying environmental conditions in the Gulf of Maine. Model outputs will be used to predict potential impacts of climate change on scallop populations along with improving spatial management design and stock assessment for this fishery.

The distribution and growth of many benthic species are closely tied to their surrounding environment, which fluctuates over space and time. Current fisheries models often assume that these parameters are homogeneous across the entire range of a population; however, Ignoring spatial variation can lead to large biases in estimates of stock sizes and make it difficult or impossible to reliably predict recruitment.

This study will develop a modeling framework to quantify the distribution and growth rate variability of sea scallops (*Placopecten magellanicus*) within the Gulf of Maine based on underlying biotic and abiotic conditions. This 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 generalized additive model (GAM), and a growth model.

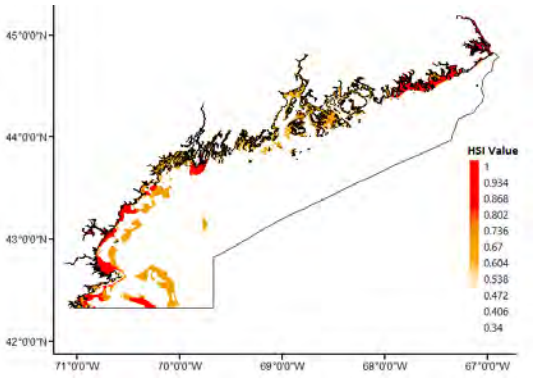

Fig. 1. Preliminary habitat suitability index (HSI) model predicting habitat value for sea scallops (*Placopecten magellanicus*) based on depth and bottom composition in the Gulf of Maine. HSI values range from 0-1, with 1 being most the suitable habitat.

Model outputs will contain the basis for forming pre-recruitment indices that will improve predictions of future scallop biomass and facilitate the fine-tuning of rotational closure parameters.

In light of recent extreme warming events within the Gulf of Maine (Mills et al. 2013) it is becoming more and more 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 distribution, abundance, and life history processes of scallops. The modeling framework developed for this project will be forecasted under various climate change scenarios to predict how scallop populations are likely to respond to a warming Gulf of Maine ecosystem, and to stimulate the development of 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.

Bibliography:

Mills, Katherine E., Andrew J. Pershing, Curtis J. Brown, Yong Chen, Fu-Sung Chiang, Daniel S. Holland, Sigrid Lehuta, et al. 2013. "Fisheries Management in a Changing Climate: Lessons from the 2012 Ocean Heat Wave in the Northwest Atlantic."*Oceanography* 26: 191–95. doi:http://dx.doi.org/10.5670/oceanog.2013.27.

Assessing the Vulnerability of Maine's Drinking Water Resources to Extreme Precipitation Events

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Abstract: Increases in extreme precipitation across the Northeastern U.S. have led to increased dissolved organic carbon (DOC) in aquatic ecosystems. DOC is an important and fundamental regulator of aquatic ecosystem structure and function, and increases in DOC may have profound implications for water quality and treatment practices. The goal of this study is to assess the vulnerability of Maine's drinking water lakes to extreme precipitation events and subsequent increases in DOC.

Maine's high water quality is threatened by a rapidly changing climate, in particular, extreme precipitation events, which have increased in frequency in the Northeastern U.S. by 60-80% since the 1950's (Madsen & Wilcox 2012). Analysis of a 30-year database of surface water geochemistry and watershed-specific landscape data throughout the Northeast suggests increased concentrations of dissolved organic carbon (DOC) in lakes during extreme wet years (Strock 2013). DOC is an important regulator of ecosystem structure and function, flows into lakes and streams via surface, ground, and soil waters and can have profound implications on the quality of drinking water and the effectiveness of water treatment practices. Algal blooms, taste and odor problems, and harmful by-products are some of the problems created by rising DOC concentrations. Currently the extent to which changing precipitation is altering the chemistry and consequently the biota of Maine's lakes is unclear. Additionally, throughout the state of Maine, many drinking water sources are not required to filter their water like other regions of the U.S. and increases in DOC pose high economic costs.

The goal of this research is to assess the vulnerability of Maine's drinking water lakes to extreme precipitation events and subsequent increases in DOC. Ecological and economic criteria were used to select a representative subset of 12 Maine drinking water lakes with varying concentrations of DOC (Fig. 1). The objectives are to quantify ecological changes from extreme precipitation events and quantify ecological and economic costs and benefits of potential changes to water quality, management, and treatment practices. This research will help to inform the development of adaptation and management strategies for Maine's drinking water sources to ensure sustained high water quality.

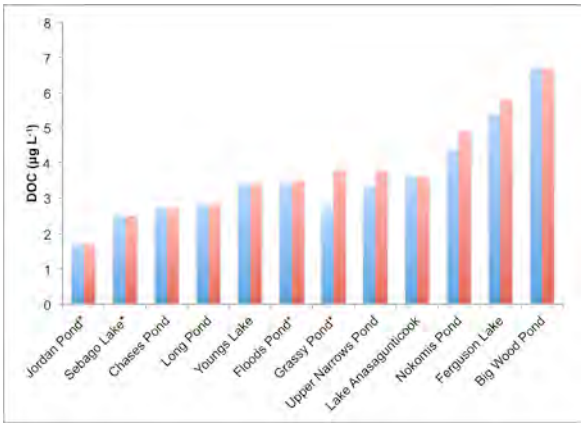

Fig. 1. Gradient of DOC concentrations shown for the selected 12 lakes in June (blue) and August (red). * indicates unfiltered water sources.

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

Bibliography:

Madsen T. and N. Wilcox. 2012. When It Rains, It pours: Global Warming and the Increase in Extreme Precipitation from 1948-2011. Environment America Research Policy Center, 43p.

Strock K.E.D. 2013. *Deciphering Climate Mediated Changes in Boreal Lake Ecosystems*. (Dissertation). University of Maine, Orono, ME.

Reconstructing Late Holocene Seawater Temperatures in the Gulf of Maine Using *Arctica islandica* Oxygen Isotopic Composition

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Abstract: We present an annually resolved, 200-year seawater temperature reconstruction for the Gulf of Maine from oxygen isotopes measured in *Arctica islandica* shells. Preliminary analysis suggests multi-decadal oscillations in Gulf of Maine hydrography, possibly as a result of changes in the strength of the Atlantic Meridional Overturning Circulation.

Introduction: The impact of anthropogenic climate change on the Gulf of Maine (GoM) is currently unclear. Satellite data suggest the GoM has been warming at a rate of 0.026°C/yr since 1982 and 0.23°C/yr since 2004, faster than 99% of the global ocean (Pershing et al., 2014). However, short-term monitoring stations within the GoM do not corroborate the rapidity of this warming (D. Townsend, personal communication, October 10, 2014). The lack of long-term, reliable instrumental records in the GoM makes it difficult to determine how much of this warming, if deemed reliable, is outside the natural variability of GoM climate and therefore attributable to anthropogenic climate change. Our research seeks to address the need for a better understanding of GoM temporal hydrographic variability by reconstructing a 200-year GoM seawater temperature record using oxygen isotopes measured in *Arctica islandica* shells.

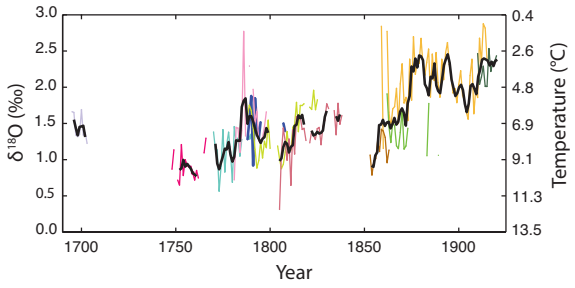

Figure 1. The oxygen isotope and derived temperature time series measured from Gulf of Maine *Arctica islandica* shells. The different colors represent different shells sampled. The black line is a three-year running average.

Methods: Over the last several years, over 400 live caught and fossil *A. islandica* shells have been collected off of Seguin Island in the GoM. Because *A. islandica* grow their shells in annual increments, the unique pattern of these increments can be used to date the collected shells using the dendrochronological technique of cross-dating (Schöne et al., 2013). Oxygen isotope data were measured in shell increments dated from 1695-1920 (see Fig.1). Seawater temperatures in the Gulf of Maine could then be reconstructed using these oxygen isotope data because *A. islandica* shells precipitate in isotopic equilibrium with seawater (Schöne et al., 2013). Oxygen isotope data were also measured in shells dated from 1921-2012. These data are currently being processed and are not considered here.

Results and Conclusions: Our 200-year temperature reconstruction in the GoM suggests substantial oscillations in seawater temperatures on multi-decadal time scales. Initial analysis of the data suggests a significant negative correlation with the strength of the Atlantic Meridional Overturning Circulation. Future work will include a comparison of recent temperature trends in the GoM to this long-term reconstruction to evaluate potential recent deviations from natural variability as a result of anthropogenic climate change.

Acknowledgements: This research is funded by a Paleo Perspectives on Climate Change grant from the National Science Foundation.

References:

Pershing, Andew J., Katherine E. Mills, Christina M. Hernandez and Nicholas R. Record. Presentation at the Regional Association for Research on the Gulf of Maine annual science meeting, Boston, Massachusetts, September 30, 2014.

Schöne, Bernd R.. "*Arctica Islandica* (Bivalvia): A Unique Paleoenvironmental Archive of the Northern North Atlantic Ocean." *Global and Planetary Change* 111 (2013): 199-225.

Urban Transformation and Landscape Change at the Nadin Archaeological Site, Croatia

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Abstract: This project will generate data from the Nadin archaeological site, Croatia, to better understand the links between urbanism, landscape change, and climate during the late Holocene. Nadin is situated near the 3,000 yr old city of Zadar.

Cities are a dominant factor in global environmental change today, but as a long-term process, urbanization has played a significant role in shaping our planet's landscapes and environments for millennia, effectively creating anthropogenic landscapes. Recognition of this point opens the door for archaeology to make significant contributions to contemporary urban/ecological issues while also generating cross-cultural knowledge about urbanism in the ancient, historic, and modern worlds.

In the Zadar region of coastal Croatia, this process has unfolded over the course of at least the past 3,000 years (Chapman et al. 1996). Zadar remains an important social and economic center in the region, but resource management, economic development, rural-to-urban migration, and environmental policy are becoming major concerns, particularly in the context of projected climate change over the coming century (Giorgi and Lionello 2008).

Fig. 1. Central Zadar with the 8th century C.E. church of St. Donat (center-right) and fragments of the Roman forum from the 1st century C.E.

Because Zadar is a living city, the archaeological focus of this project will be on the Nadin site in Zadar's hinterland. With more than 2,000 years of occupational history, Nadin affords the opportunity to investigate the relationship between phases of urban growth and decline and broader changes in landscape and environment—processes that persist around Zadar today. Excavations will recover subsistence indicators and other economic data as a measure of the links between humans and the environment, as well as data concerning chronology, urban form, and spatial organization. The results will help build a range of knowledge on human-environmental interactions in the Zadar region, offering deep-time perspectives on contemporary issues.

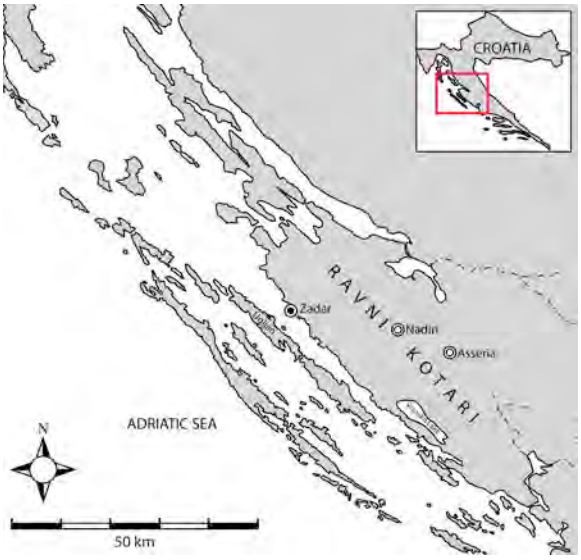

Fig. 2. Location of Zadar and the Nadin site along Croatia's Adriatic coast.

Acknowledgements: National Geographic Society (2015); Fulbright (2013).

Bibliography: Chapman, J., R. Shiel, and Š. Batović (1996). *The Changing Face of Dalmatia*. Leicester University Press, London

Giorgi, F. & P. Lionello. (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change* 63:90-104.