Collaborative Research: The response of lakes to disturbance and climate change: calibrating sedimentary records to test the landscape position concept.

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Project Summary:

A larger proportion of the water budgets of seepage lakes low in a hydrological gradient comes from groundwater, resulting in as much as an order of magnitude higher concentration of cations (Mg++, Ca++) and silica (Si) in lakes at lower landscape positions. Landscape disturbances and climate changes that alter the chemistry or abundance of major water sources should affect lakes in proportion to their relative water budgets. Previous work at the North Temperate Lakes Long Term Ecological Research site (NTL-LTER) describes the importance of the landscape position concept in understanding the limnological differences between neighboring lakes, including the responses of lakes at different landscape positions to a four-year drought in the 1980s. A major focus of this project is to develop and calibrate a broad range of paleoecological methods to test hypotheses derived from the landscape position concept over time scales that are not accessible to modern studies. Surface sediment samples with modern lake data from 62 lakes will be used to develop transfer functions which will be tested against 24 years of limnological data from the NTL-LTER database. After testing the paleoecological methods, a multi-proxy limnological reconstruction will be carried out using sediment records of the last 150 years from two of the LTER lakes. The time series will be used to test the prediction that a lake high in the local hydrologic gradient will have more severe and longer lasting effects of 19th century logging than a lake low in the gradient. The generality of this result will also be tested with a less detailed study of the pre- and postlogging status of an additional 20 lakes across the hydrologic gradient.

The data, analysis, and results of this research will be shared with the NTL-LTER planning committee. A future goal of this research is to test the prediction that the response of lakes in different landscape positions to severe droughts (multi-decadal to century scale) will be qualitatively and quantitatively different from the responses to the relatively mild drought of the late 1980s. The current project will use several methods to reconstruct long-term climate changes that may have affected lakes differently along the hydrological gradient. Carbonate geochemical methods will be used on a nearby calcareous lake to identify periods of low lake levels during the last 10,000 years. An independent lake level reconstruction using a transect of cores and biological proxies will be compared with the carbonate geochemistry study. These results will help to identify specific, testable hypotheses about the effects of landscape position on response to drought over thousands of years.

Project Approach:

The relative hydrological position of closed-basin seepage lakes in a landscape results in a gradient of the relative importance of precipitation and groundwater in their water budgets. A larger proportion of the water budgets of lakes high in the regional hydrological gradient comes from precipitation (Fig. 1), affecting the input of solutes to lakes. Analogous to the river continuum concept (Vannote et al. 1980), landscape position correlates with many physical, chemical, and biological features of lakes (Winter 1978, Almendinger 1990, Kratz et al. 1997, Webster et al. 2000, Riera et al. 2000, Filby et al. 2002). For example, groundwater becomes enriched in cations relative to rainwater, resulting in as much as an order of magnitude higher concentration of cations (Mg^{++}, Ca^{++}) as well as silica (Si) in lakes at lower landscape positions (Kratz et al. 1997). The landscape position concept provides a framework within which the variability of neighboring lakes can be more easily understood.

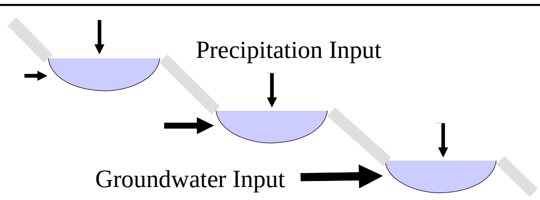

Figure 1. Relative influence of precipitation and groundwater on lakes along the same hydrologic gradient (modified from Webster et al 1996). Crystal Lake gets ~6% of its water budget from groundwater, Sparkling Lake ~25%.

Relative hydrologic position also affects the response of neighboring lakes to watershed disturbance, climate change and other ecological perturbations (Almendinger 1990, Smith et al. 2002, Donovan et al. 2002). Disturbances that alter the abundance or chemistry of precipitation and near-surface runoff or groundwater should affect lakes in proportion to their relative water budgets. For example, watershed disturbances that affect the chemistry and abundance of surface runoff are expected to have greater impact on lakes high in the watershed, where lake water chemistry is more dilute and groundwater is a smaller proportion of the overall water budget. Similarly, drought is expected to have a greater impact on lakes high in the watershed.

Continuous data collection at the North Temperate Lakes Long-Term Ecological Research site (NTL-LTER) in the Northern Highlands Lake District (NHLD), northern Wisconsin, has monitored lakes through such rare events as the four-year drought of the late 1980s. These data and groundwater modeling (Fig. 2) suggest that lakes respond differently to drought depending on their relative position in the local hydrologic gradient (Webster et al. 2000, Anderson and Cheng 1993). Evaporative enrichment resulted in increasing concentrations of Ca and Mg in the water of both high and low lakes during the 80s drought. Groundwater inputs also decreased in lakes high in the landscape, and some lakes were cut off completely from groundwater (Webster et al. 1990, Anderson and Cheng 1993, Wentz et al. 1995). Lakes low in the hydrologic gradient maintained contact with groundwater and responded to drought with a highly coherent increase in concentrations of Ca and Mg, while lakes up-gradient were more variable (Webster et al. 2000).

These observations of a four-year drought suggest that prolonged periods of drier climate would affect lakes in the same region differently, depending on their position in the local hydrologic gradient. However, the predictions are based on a single observation of a relatively short drought, and the response would be very different if the drought exceeds the water residence time (Kenoyer and Anderson 1989, Anderson & Cheng 1993, Donovan et al. 2002). For example, a drought lasting longer than the residence time of a high lake would lead to changes in buffering capacity due to decreased cation inputs from groundwater (Kratz et al. 1997). With a shift to sulfate reduction in lake sediments, the pH of the lake would fall (Anderson & Cheng 1993, Wentz et al. 1995). During the 1980s drought the pH of Nevins Lake in UP Michigan, with a residence time of only ~1.6 yr, fell from 7.03 to 6.24 (Webster et al. 1990). Although the pH of Crystal Lake, high in the Trout Lake watershed (Fig 2) did not drop during the 1980s drought, it would be expected to in a drought that lasted longer than the residence time of the lake (~13 years under current climate conditions; Kenoyer & Anderson 1989). Lakes low in the landscape will continue to have greater relative inputs of cation-rich groundwater and may not change pH unless a drought is so severe that the lake becomes a source to the local groundwater.

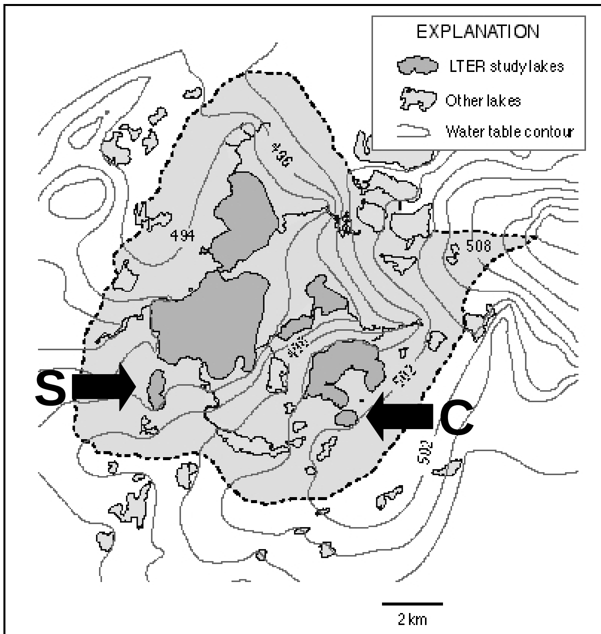

Figure 2. Trout lake area hydrologic map, with Sparkling (S) and Crystal (C) lakes marked by arrows. Contours show mean water table elevations, in m. Crystal is higher in the hydrologic gradient than Sparkling. From Anderson & Cheng 1993.

Syntheses derived from observations of lakes over the past two decades are generating new hypotheses about spatial and temporal patterning in lake districts (Soranno et al. 1999). Modern data, however, can sample very few rare events, and many of the processes that structure ecosystems happen on time scales longer than the observations thus far generated by long-term ecological research networks (Smith et al. 2002, Donovan et al. 2002). Fortunately, the NTL-

LTER lakes have been recording their own histories for 10,000 years, accumulating sedimentary records through millennia of climate changes and landscape disturbances.

Do water chemistry changes related to groundwater and runoff lead to predictable differences in response to long-term drought between lakes high and low in the hydrologic gradient? Do changes in buffering capacity in droughts lead to predictable pH changes at different landscape positions? Our study is designed to take advantage of and contribute to the NTL-LTER, where a wide range of physical, chemical, and biological data has been collected for several decades. We will use data from the NTL-LTER and a biocomplexity project on 62 surrounding lakes to calibrate sedimentary proxies that will provide records of water chemistry and plankton communities over decades to thousands of years.

We are pursuing long-term perspective on how disturbance and drought affect physical, chemical, and biological properties of lakes in a landscape context. Our current proposal is oriented primarily toward calibrating and testing paleoecological proxies and obtaining an improved Holocene climate record including long-term droughts. These results will allow us to determine whether multidecadal climatic shifts can be documented in the Holocene and to test methods that will allow us to interpret the chemical and biological responses of lakes to long-term climate change in a future project. We will use the improved calibrations to test the effects of 19th century logging on lakes in different positions in the hydrologic gradient. Our research is organized in four interrelated sections:

> **<u>Box 1.</u> A paleoecological test of the landscape position concept.** The current proposal is designed to calibrate and test paleoecological methods of reconstructing water chemistry, planktonic communities, and a detailed climate history. Improving these methods and applying them to short sedimentary records will help refine testable hypotheses related to our larger goal to test predictions of the landscape position concept on lakes in different positions in the hydrologic gradient for the last 10,000 years. Current hypotheses include: 1) Lakes high in the hydrologic gradient will experience larger lake level changes in response to multidecadal droughts than those in lower landscape positions 2) Multidecadal droughts will result in decreased concentrations of cations and silica and reduced pH in lakes high in the hydrologic gradient while concentrations of cations and silica increase in down-gradient lakes, with little change in pH. 3) Drought-related changes in community composition and trophic interactions in lakes high and low in the hydrologic gradient can be predicted from changes in water level and chemistry. Our current calibration effort, application to a historical watershed disturbance, improved climate and lake-level history, and groundwater modeling will generate the data we need to refine these hypotheses and generate specific testable predictions for a suite of lakes.

1) Calibration. Sediment proxy records will be calibrated using limnological measurements and surface sediment samples from a large suite of lakes in the NHLD.

2) Validation. The transfer functions and regressions developed in #1 will be tested by comparing reconstructed limnological changes with LTER data of the last 24 years using ^{210}Pb-dated short cores from LTER lakes. A new geochemical method for climate reconstruction in non-calcareous lakes will be tested against 100 years of climate data.

3) A 150-year test of the landscape position concept. We will use the methods and sediment profiles developed in #1 and 2 to test whether lakes high in the watershed showed greater intensity and duration of response to watershed disturbance following 19th century logging.

4) Generate a multi-proxy Holocene climate record. We will use established methods of analysis of carbonate deposition as well as a lake level history derived from sediment particle size, diatoms, chrysophytes, zooplankton, sponge spicules and pollen to determine whether multi-decadal to century scale droughts occurred in the region. An existing locally calibrated groundwater model (Hunt et al. 1998, Pint 2002) will be used to estimate equilibrium lake levels and water chemistry of NHLD lakes under the range of reconstructed climate conditions.