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SUBFOSSIL ASSEMBLAGES AS INDICATORS OF ENVIRONMENTAL QUALITY IN TEMPERATE LAKES OF WISCONSIN

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INTRODUCTION

Surface freshwater systems, like rivers, streams, and lakes are important sources of freshwater for human consumption, but many of these freshwater resources face multiple environmental threats including eutrophication, pollution from industrial and sewage effluents, surface water runoff, and introduction of invasive species (Dudgeon et al., 2006; Lokeshwari and Chandrappa, 2006; Smol, 2008; Céréghino et al., 2014), which can jeopardize their use as a natural resource and can disrupt natural ecosystem function. Preservation and restoration of freshwater systems is, therefore, vitally import, and the protection of freshwater resources is pursued on several scales, from global environmental organizations to neighborhood organizations. Methods that permit us to assess the environmental status of lake ecosystems are thus of critical importance, both to identify impacted habitats and to monitor the progress of remediation efforts already underway (Dudgeon et al., 2006; Smol, 2008; Céréghino et al., 2014). Here, we describe the development of biological and geochemical proxies for assessing human impact on lakes, both negative impacts in the form of pollution, and positive impacts including the remediation of previously polluted lakes.

GEOCHEMICAL PROXIES

In this project, we use two types of geochemical proxies to track environmental change through time in the selected lakes: heavy metal concentrations and stable isotope (oxygen and carbon) ratios. Heavy metal concentrations have been widely used as indicators of pollution and historical anthropogenic impact on freshwater systems (Renberg, 1986; Birch et al., 1996). Isotopic analysis is also commonly used, as shifts in the ^{13}C and $\delta^{18}O$ of lake sediments are responsive to changes in the local ecosystem (Talbot, 1990). In general, shifts in the $\delta^{13}C$ of lacustrine carbonate are due to changes in productivity within the lake (Schelske and Hodell, 1991); however, changes in the source of carbon (e.g. terrestrial vs. aquatic) may also cause shifts in the $\delta^{13}C$. In contrast, the $\delta^{18}O$ of lacustrine carbonates is primarily influenced by watershed hydrology and fluctuations in local climate (Anderson et al., 2001).

BIOLOGICAL PROXIES

Environmental managers and conservation biologists are increasingly becoming aware that subfossil records can be valuable tools for understanding the magnitude and context of present-day change (Kidwell and Tomasovych, 2013; Kidwell, 2013; Rick and Lockwood, 2013; Lotze and McClenachan, 2014). Paleobiological archives can provide an important baseline from which current change can be measured as well as contribute to the understanding of the range of natural variability (Dietl and Flessa, 2010). The subfossil, or "death assemblages" represent a pre-human impact baseline community (Kidwell, 2007; 2009), and can record changes in the ecosystem that may have gone undetected by conventional biological monitoring, which normally focuses on only larger animals, or animals that are economically or recreationally important. Mollusks (Tomasovych and Kidwell, 2010; 2011; Kidwell, 2013), ostracodes (Michelson and Park, 2013; Michelson et al., 2014), and diatoms have all been successfully used to identify anthropogenic impact on benthic communities.

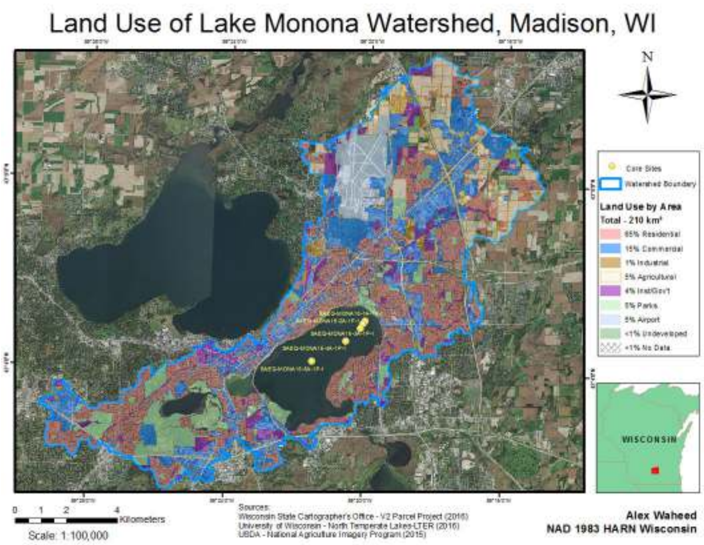

Figure 1. Map of Lake Monona, Madison, Wisconsin showing core collection locations and watershed land use.

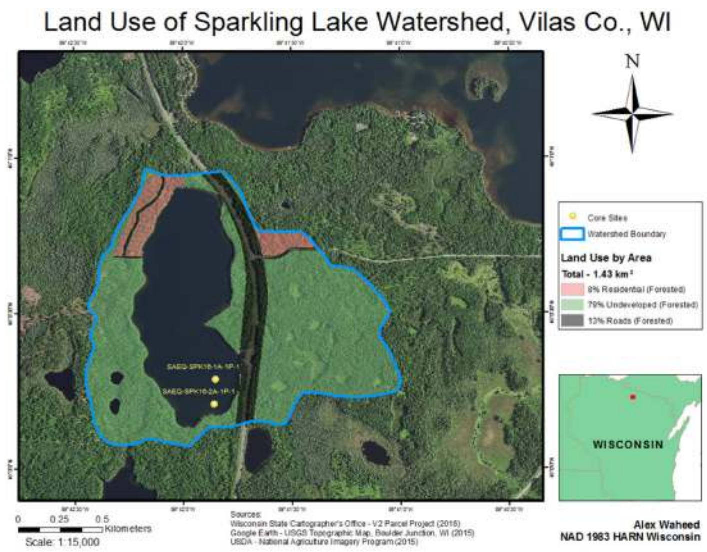

Figure 3. Map of Sparking Lake, Vilas County, Wisconsin showing core collection locations and watershed land use.

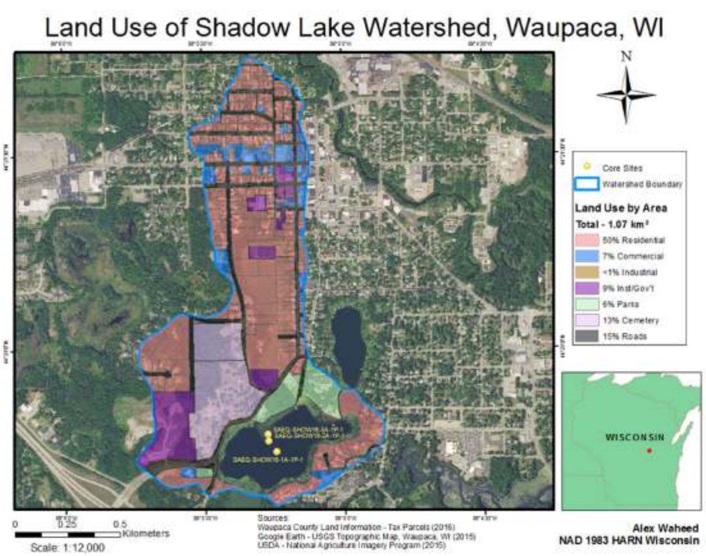

Figure 2. Map of Shadow Lake, Waupaca, Wisconsin showing core collection locations and watershed land use.

STUDY AREA

Lakes in Wisconsin provide an ideal study site for this work because these lakes contain a mosaic of impact: from relatively "pristine" lakes in Northern Wisconsin, to heavily-impacted lakes near its capital and second-largest city, Madison, and remediated lakes treated with alum to counteract the effects of acid rain in the later half of the 20th century. We identified three lakes, one heavily impacted, one remediated, and one "pristine" to sample for this project. Lake Monona (Fig. 1), located in Madison, WI, represents our highly impacted lake. Shadow Lake (Fig. 2), located in Waupaca, WI, represents our remediated lake, and finally, Sparkling Lake (Fig. 3), located in Vilas County, WI represents our pristine lake.

PROJECT GOALS

Our project involved a team of six undergraduate students and two faculty members. Our research focused on the following questions 1) Can sediment cores detect historical environmental changes, especially changes due to anthropogenic impacts? and 2) Can subfossil communities help us understand ecosystem response to these changes in the physical environment? Our overarching goal was to show the utility of geohistorical data for both understanding the history of anthropogenic impact and also in managing and restoring ecosystems.

RESEACH PROJECTS

CREATION OF AN AGE MODEL (ANDREW CONAWAY, COLLEGE OF WOOSTER)

Establishing an age-model for each lake is necessary for attributing environmental signals detected in the cores to historical human impacts. Changes in sediment composition and color were used to approximate the initial clearing of land for European settlement (1850s). The peak in the magnetic susceptibility of core sediments was used to verify this approximation. The original peak in magnetic susceptibility is inferred to correlate with land clearing by Europeans, while other peaks in magnetic susceptibility may be tied with specific historical events (e.g. diversion of storm water runoff into the lake). This age model gives an approximate sedimentation rate of 2 mm/year in Lake Monona and 1 mm/year in both Shadow Lake and Sparkling Lake. These sedimentation rates will be confirmed with Pb-210 dating of the lake sediments.

ANALYSIS OF HEAVY METAL CONTAMINATION (KHAWAJA WAHEED, WHITMAN COLLEGE)

In order to characterize the environmental history of each lake, the concentration of selected heavy metals in core sediments was analyzed using X-ray Fluorescence (XRF). Core sediments from Sparkling Lake, the most pristine lake in our study area, showed minimal change in heavy metal concentration throughout the core. In contrast, more impacted lakes showed increases in tin, zinc, arsenic, copper and lead in the upper 50 cms of the core. Increases in these heavy metals reflect both many different anthropogenic impacts, including the use of chemical herbicides (Lanthrop, 2007), the growing importance of leaded gasoline through the first half of the 20th century, and the impact of channelization and runoff on lake water quality.

ISOTOPIC ANALYSIS OF LACUSTRINE INORGANIC (JOHN DANNEHL, WASHINGTON AND LEE UNIVERSITY)

Analysis of the carbon and oxygen isotopic ratios of inorganic carbonate from each of the lakes was performed in order to better understand environmental history and human impact. Sediment from Sparkling Lake did not contain enough inorganic carbonate to perform isotopic analyses, but $\delta^{13}C$ and $\delta^{18}O$ profiles were created for the deepest core from both Lake Monona and Shadow Lake. Stable isotopic shifts from the Lake Monona core reflect the large volume of the lake, with stable oxygen and carbon isotopic ratios per European settlement. Shifts in the $\delta^{13}C$ of Lake Monona carbonates hint at a change in the source of carbon as human impact increased. Shadow Lake, which is much smaller in size, displays opposite trends. Pre-European settlement, oxygen isotopic ratios display high variability, while after European settlement variability decreases. Carbon isotopes from Shadow Lake show the predicted trend of becoming gradually, but increasingly positive, due to eutrophication. However, in the upper ~8 cm of the core $\delta^{13}C$ values begin trending again to the negative, reflecting remediation efforts to decrease nutrient load.

ANALYSIS OF SUBFOSSIL DIATOM ASSEMBLAGES (TAYLOR MOONEY, COLGATE UNIVERSITY)

Diatoms, single-celled algae with a silica frustule, are very diverse and sensitive to their physical environment; they are therefore commonly used to detect environmental change (Wigdahl-Perry et al., 2016). Diatoms were used to characterize environmental change in Shadow Lake, particularly focusing on post-European settlement, by analyzing diatom abundance and assemblage composition from the deepest core collected at Shadow Lake. Diatom assemblages suggest many changes in the environmental history of the lake, including possible deepening through time, as well as changes in nutrients levels and water clarity. Increasing abundance of the diatom *Cyclotella bodanica* post-alum treatment in the core indicates a return to lower nutrient levels in the lake (Bradbury et al., 2002).

ANALYSIS OF SUBFOSSIL OSTRACOD ASSEMBLAGES (SLOANE GARELICK, OBERLIN COLLEGE)

Ostracodes, bivalved microcrustaceans, are sensitive to the abiotic environment and are widely used as proxies of pollution (Padmanabha & Belagali, 2008; Escrivà et al., 2012) and paleoenvironmental change (Lord et al., 2012; Viehberg & Mesquita-Joanes, 2012). Ostracode assemblages from two Lake Monona and Shadow Lake were compared to in order to understand the similarities and differences in the environmental history of these two lakes. The total abundance of all adult ostracodes increased up-core at the time of presumed European settlement in both cores. Ostracodes thrive in eutrophic water as they feed on algae and decaying matter (Smith and Delorme, 2010). In Lake Monona, abundance of total ostracodes continues to increase to the present day, indicating continuing eutrophication. However, in Shadow Lake, in the very upper part of the record, above presumed remediation, total abundance drops while species found in high oxygen environment today (*Candona ohioensis* and *Cypridopsis vidua*) increase in abundance, reflecting lower nutrient conditions as a result of remediation.

ANALYSIS OF THE MOLLUSK COMMUNITY AND AMINO ACID RACEMIZATION (SEQUOYA BUA-IAM, WASHINGTON AND LEE UNIVERSITY)

Subfossil assemblages do not necessarily contain individuals that were living at the same time, a phenomenon referred to by paleontologists as "time averaging." In order to effectively use subfossil assemblages to recreate past communities, we need to understand how much time is represented by a subfossil assemblage that has been time-averaged. One way to accomplish this is to date a collection of shells from a core increment to see how much time is represented by the subfossil assemblage (the range in dates of the shells). Amino acid racemization with radiocarbon calibration is used to find the age of shells based on post-mortem deterioration of amino acids contained in the shells. Amino acid racemization of 70 gastropod shells from Shadow Lake show good agreement to expected trends, and will yield dates once radiocarbon calibration is complete.

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