EVALUATING ENVIRONMENTAL RESPONSE AND RECOVERY USING A MULTIPROXY PALEOLIMNOLOGICAL APPROACH

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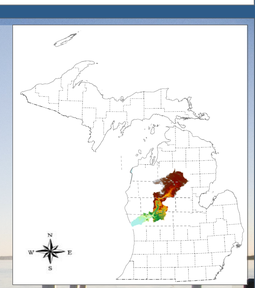
OVERVIEW

Human activity has influenced ecosystems since antiquity. Aquatic ecosystems in the Great Lakes region of North America have been significantly altered since Euro-American settlement in late 1700s and continues to be influenced by emerging stressors (e.g. invasive species. An understanding of the functioning of modern aquatic ecosystems can be gleaned from reconstructing the environmental history of a system. Integrating the historical record and ecological perturbations archived in sediment cores is an effective way to capture stressor/response relationships and evaluate human influence. A paleolimnological study of Muskegon Lake, Michigan, USA, analyzed multiple proxies to assess the system's response and recovery to human activity. Geochemical data from the core revealed suites of elements that corresponded to the source of the material, including terrestrial, productivity and anthropogenic related inputs. The anthropogenic proxy group most closely tracked the history of human activity and identified three phases of human influence. Profiles of the anthropogenic group were further used to identify geochemical reference conditions and show that modern concentrations have not decreased to pre-historical values, indicating a scenario of a continually adapting state not fully recovered. Biological data, inferred from fossil diatoms, also identified three phases related to human influence. Benthic v. planktonic dominated community structure reconstructed productivity regimes in the lake, identifying a significant shift from planktonic to benthic dominated productivity in recovery phase of the core. Integration of these proxies showed good agreement of overall system response. Importantly, results indicate sensitivity to modern stressors (e.g. invasive species), with the impacts of up and coming stressors (e.g. climate change) uncertain.

Study Area

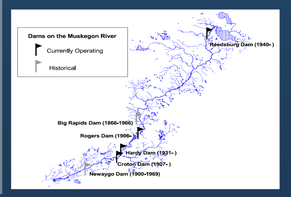
Muskegon Lake, Michigan, USA

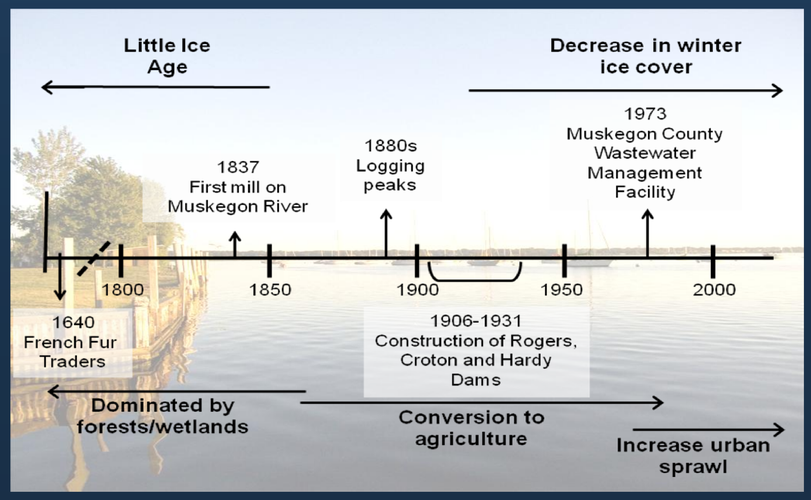


- Muskegon Lake is a 4149 acre inland lake separated from Lake Michigan by sand dunes
  - Residence time in the lake is ~23 days.
- Located at the mouth of the Muskegon River, a 350km long tributary to Lake Michigan
- The Muskegon River Watershed is part of the Great Lakes watershed, and is the second largest watershed in Michigan covering more than 7000 km^2
- Historical anthropogenic disturbances include logging, agriculture and industry; specific watershed events are detailed below.
- Environmental legislation (e.g., Clean Air/Water Acts) has improved habitat quality; however, not to predisturbance conditions

Current and Historical Perturbation

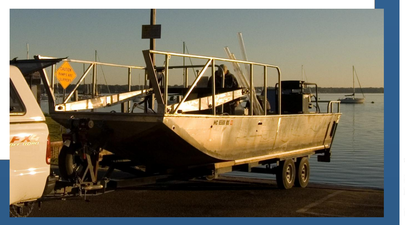
- Ottowa and Pottawotomi Indian tribes considered the first permanent inhabitants
- Logging began ~1837. At the peak, the lake had 47 sawmills on it's shores
- Dam construction altered natural hydrology
- Industry and agriculture increase after WWII
- Muskegon Lake designated an Area of Concern in the Great Lakes Basin in 1985
- Currently, 8 EPA Superfund sites in the county still on National Priority List
- Michigan DEQ issued fish consumption advisories for PCB and mercury.





Methods

- Core was collected from depositional basin of Muskegon Lake using modified Mooring Systems Model 2172 Piston Corer and the research vessel Nibi
- Core was sectioned immediately on-shore at 1cm resolution, with subsamples later split for geochemistry and diatom analyses
- Sediment geochemistry analyzed from nitric acid digested freeze-dried sediment using Inductively Coupled Plasma – Mass Spectrometer (ICP-MS)
- Separate analysis of freeze-dried sediments for total mercury performed on a Lumex R-915+ Zeeman corrected atomic absorption spectometer
- Diatom processing and taxonomical identification performed using standard methods after Batterbee (1986).

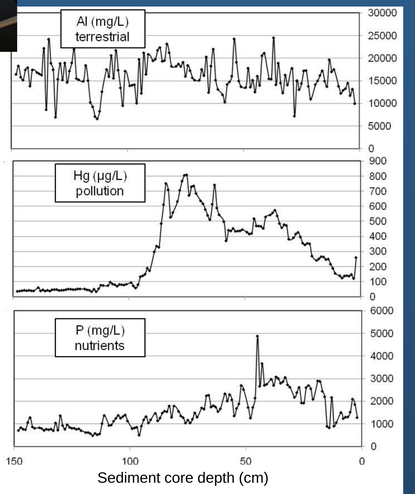


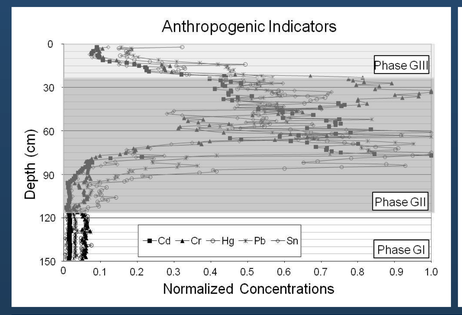
Results

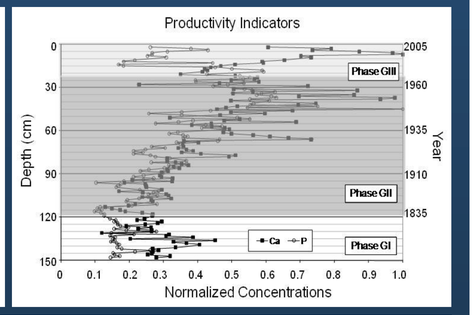
Sediment Geochemistry

Sediment geochemical chronologies of elemental proxy groups infer source material:

- Elements influenced by terrestrial processes (e.g., Al, K, Ti and Mg) reflect overall drowned river mouth conditions of Muskegon Lake, and record the response to deforestation induced erosion.
- Elements associated with anthropogenic activity (e.g., Hg, Cr, Cd, Pb and Sn) have similar profiles, but concentration peaks often depend on specific industrial activity in the watershed.
  - The system's reference condition evaluated using anthropogenic indicators (see below)
- Productivity related elements (e.g. P and Ca) indicate changes in nutrient inputs to the lake (presumably related land use change), and become uncoupled in the early 1970s.
- Redox elements (e.g. Fe) are not shown but need to be considered for post-depositional reactivity.





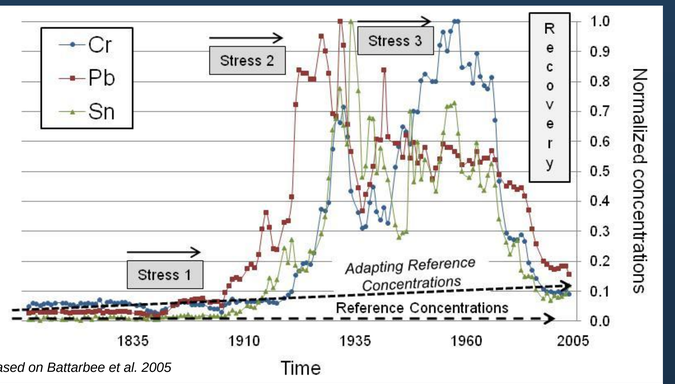


System phases and reference condition

Sediment geochemical chronologies indentify three phases of human influence (above).

1. Pre-disturbance (GI)
2. Disturbance (GII)
3. Recovery (GIII)

The systems reference condition was evaluated with normalized concentrations of Cr, Pb and Sn. Results show an adapting reference (right). *Based on Battarbee et al. 2005*



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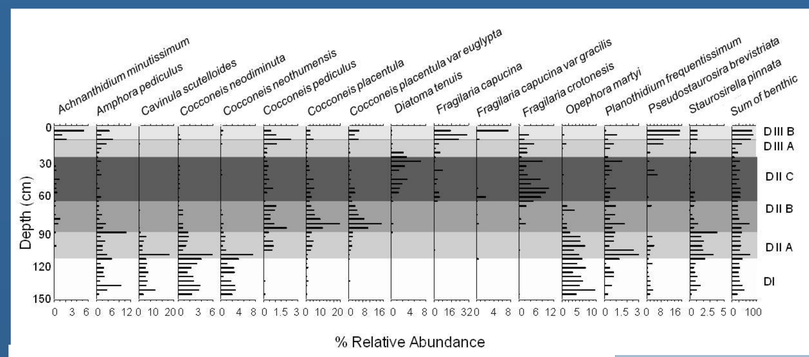
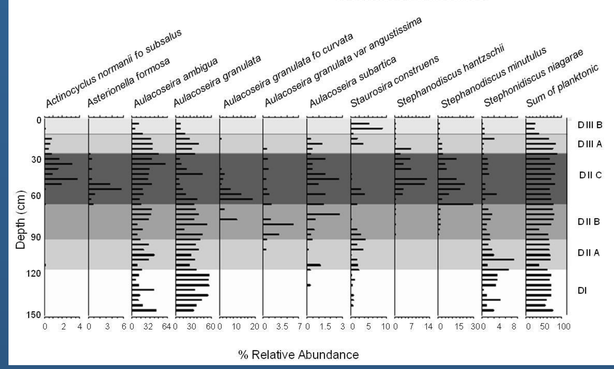


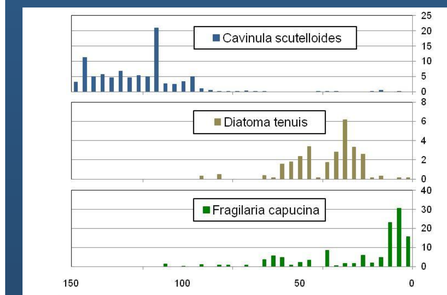


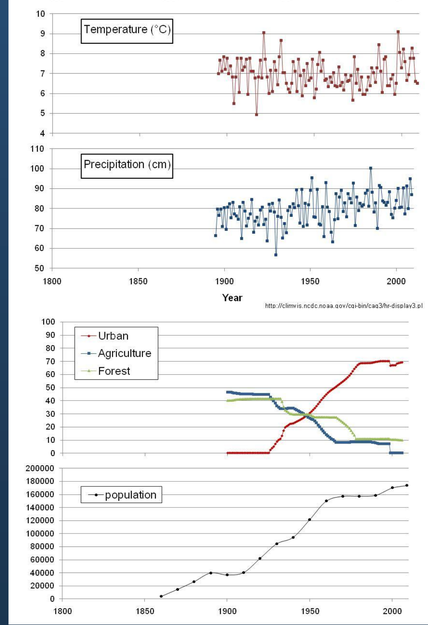
Fossil Diatoms

Three phases were identified in the diatom community structure.

1. Pre-disturbance (DI)
2. Disturbance (DII)
3. Recovery (DIII)

Importantly, data reveal a shift in dominant habitat of primary productivity following the 1973 installation of a tertiary waste water treatment system.





Integration

- The table below compiles geochemical and diatom phase s with specific watershed events, suggesting good agreement among the proxies. these phases showing response to events.
- Graphs to the left show dominant diatom taxa for each phase, regional climate data for the state of Michigan, USA (NOAA), land use change for the Muskegon river Watershed (Ray and Pijanowski 2010), and population data for Muskegon county (US Census).

Geochemistry Phase	Diatom Phase (average planktonic:benthic)	Watershed Events
GIII	DIIIB (1.97)	Flood (2004)
		Dreissena polymorpha appear (~1990)
	DIIIA (13.55)	Flood (1986)
		WWTP Installed (1973)
		Clean Air/Water Acts (1970)
		US131 opens (1964)
GIIC	DIIC (9.41)	Heavy industry and manufacturing (1950s - 1960s)
		WWII (early 1940s)
GIIB	DIIB (3.60)	Great Depression/ Dust Bowl (1930s)
		WWI (1914-1918)
GIIA	DIIA (2.41)	Logging
		1874 Fire
		Logging
GI	DI (3.21)	Pre-logging (1835)

References

Battarbee, R. W.; 1986, "Diatom Analysis", in B. E. Berglund (ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology*, Wiley, Chichester, pp. 527–570.

Battarbee RW; Anderson NJ; Jeppesen E; Leavitt PR (2005) Combining palaeolimnological and limnological approaches in assessing lake ecosystem response to nutrient reduction. *Freshwater Biology*, 50: 1772–1780

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Conclusions/Recommendations

- The integration of historical and ecological data in this study show good agreement among indicators. Further, causal agents for observed changes in Muskegon Lake are linked to human activities such as deforestation, agriculture/industry and urbanization.
- Driven in part by policy mandates (e.g. lead), the current geochemical conditions in the core reflect significant recovery from high anthropogenic concentrations; while shifts in benthic versus planktonic dominated primary productivity in the top of the core is presumably in response to the installation of the waste water treatment plant and invasion of zebra mussels.
- This study facilitated an understanding of comprehensive aquatic ecosystem response, useful for developing predictive tools to further anthropogenic influences and recommends that modern remediation targets consider the legacy/overprint of multiple stressors and be cognizant of emerging stressors.