# North Temperate Lakes LTER

The North Temperate Lakes (NTL) LTER program studies how geographic setting, climate, and changing land use interact to shape the ecology of lakes over time. Research activities focus on 7 lakes in northern Wisconsin surrounded by forested landscape and 4 lakes in southern Wisconsin in an agriculturally dominated landscape. Studies in these two distinct regions have generated new understanding of physical and ecological responses to a shifting climate, invasive species impacts, heterogeneity in water quality, and complex interactions that may lead to sudden ecosystem change. One of the world's richest long term lake datasets underpins these insights. Moving forward, NTL LTER researchers will expand on this body of work to describe, understand, and forecast shifting baselines and ecological transitions in lakes and their landscapes at local to global scales.
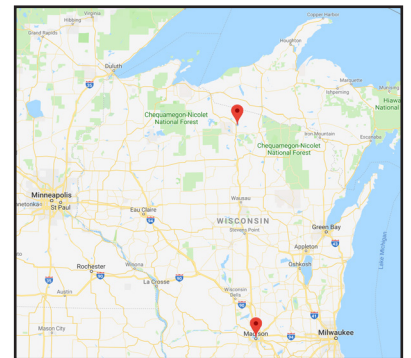
Between 2008-2018:

**45** investigators

**3** institutions represented

**30** graduate students

Freshwater

Principal Investigator:

Emily Stanley

University of Wisconsin, Madison

Est. 1981

Funding Cycle:

LTER VII

NSF Program:

Biological Sciences / Division of Environmental Biology

NSF

# Key Findings



**Divergent consequences of climate change.** Long term records show declining ice duration, lake warming, and increased variability in decadal lake level cycles. However, the magnitude of these physical changes, and their ecological consequences, differ substantially among lakes, including differences in warming rates, shifts in fish populations, and fluctuations in water clarity. [Products 7, 9, 10]

**Anticipating regime shifts in ecosystems.** Regime shifts are large, persistent, and often abrupt changes in ecosystem structure and function that may be difficult to reverse. Through long term whole ecosystem experiments and measurements, NTL LTER researchers have described regime shifts involving lake eutrophication and food web structure, and have used these case studies to develop conceptual and mechanistic models. These models are used to anticipate ecosystem shifts and evaluate the utility of management actions to prevent them. [1, 3]

**Lakes are major players in regional carbon cycling.** Terrestrial organic carbon (C) entering lakes can be stored, sent to the atmosphere as $CO_2$, or passed downstream. Long term measurements of hydrology and C were used to understand and model the fate of terrestrial C in lakes. In Wisconsin's 6,400 $km^2$ Northern Highland Lake District (NHLD), the fraction of organic C converted to $CO_2$ varied substantially among lakes due to hydrology. Nonetheless, lakes accounted for about 40% of C storage, although they represent only 13% of the region's area. [2, 4]

**Invasive species alter food web dynamics and ecosystem services.** Long term pre-invasion records provide an essential baseline for understanding invasive species effects, which can have profound consequences for ecosystems and society. In a key example, the spiny water flea invaded Lake Mendota, leading to massive declines in water quality and a loss in ecosystem services valued at $140 million. [3, 8]

**Lakes are full of diverse microbes.** Although bacteria play a central role in processes affecting lake water quality, the taxa participating in these activities are largely undescribed. To address this knowledge gap, NTL LTER researchers have generated the largest freshwater microbial genome collection to date. These studies reveal a paradoxical pattern of large differences in community structure over time and among lakes, paired with the presence of specific taxa that are always present everywhere (the core lake microbiome), and communities that are surprisingly resilient to disturbance. [5, 6]
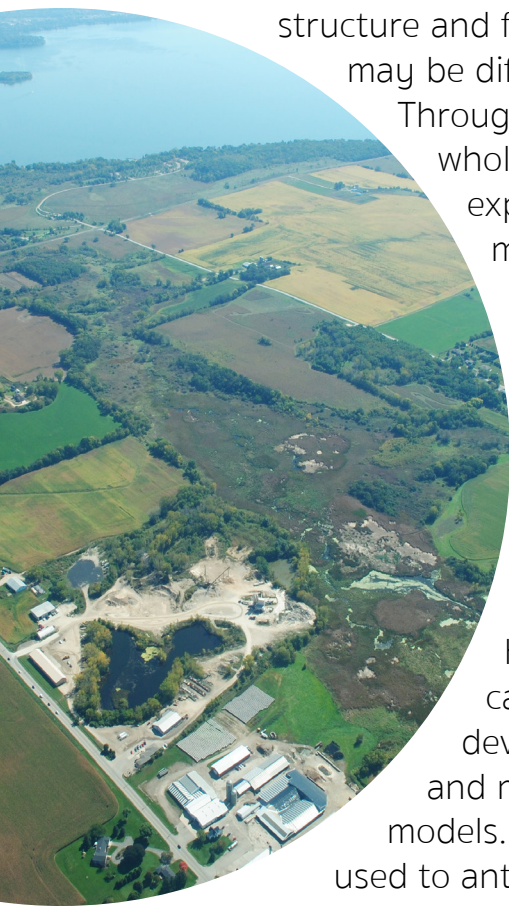
# Synthesis

**A global network of lake scientists.** North Temperate Lakes LTER researchers are leaders in the formation of, and active participants in, the Global Lake Ecological Observatory Network (GLEON), a grassroots network of researchers studying lakes in a changing global environment. Hallmarks of GLEON activities include collaborative synthesis and data sharing, traceable to practices of the LTER Network.

## Partnerships

UW-Madison's College of Letters & Sciences and Center for Limnology | AmeriFlux | NEON | GLEON | Wisconsin Department of Natural Resources | U.S. Geological Survey

**Continental and global patterns and consequences of long term lake ice dynamics.** As ice duration has shortened among NTL lakes over the past century, current and former NTL LTER researchers have led synthesis studies to provide context for local changes, generate forecasts of future changes in lake ice cover, and understand the ecological, social, and economic consequences of disappearing ice among lakes across the Northern Hemisphere [7].

## Data Accessibility

Excellence in information management was a founding principle of NTL LTER. The tradition of easy data access and data sharing is complemented by the development of new tools and technologies that are also widely shared. The NTL information management system focuses on linkages among the components of ecological and social systems, whether designing data collection systems, structuring centralized databases, or executing analyses. Core NTL LTER data is used for syntheses and cross-site analyses by both NTL and non-NTL researchers. Information managers from NTL LTER lead the Environmental Data Initiative.

# Broader Impacts

**Introducing the next generation to long term lake science.** The NTL Schoolyard LTER "Winter Limnology" program involves a long term partnership with five schools in the Trout Lake Station area to provide about 100 students per year (about 25% of whom are of Native American descent) with a hands on opportunity to learn about lakes and lake change. In Madison, NTL researchers and educators work with the Pre-College Enrichment Program for Learning Excellence (PEOPLE) to offer a limnology workshop for about 80 underrepresented middle and high school students per year.

**Art-science nexus.** Through the cross site LTER "Ecological Reflections" project, NTL's "Drawing Water" collaborative, and the Trout Lake Station Artists-in-Residence program, NTL LTER scientists are communicating science to diverse audiences and providing a novel perspective on lakes in the landscape.

**LTER science on campus.** Data and research from NTL LTER are routinely used in classrooms at UW-Madison and beyond, reaching approximately 1,200 students per year. Activities include acquiring and analyzing long term datasets in undergraduate limnology classes and performing time series analysis and biogeochemical modeling in graduate seminars.

**Communicating policy-relevant science.** Investigators from USGS and the Wisconsin Department of Natural Resources participate actively in NTL LTER research, which facilitates long standing and substantive partnerships with these and other natural resource agencies. Examples of NTL LTER research that has informed policy and practice include lake level management in flood prone Madison lakes, preventing the spread of invasive species, and management of highly valued northern Wisconsin fisheries.
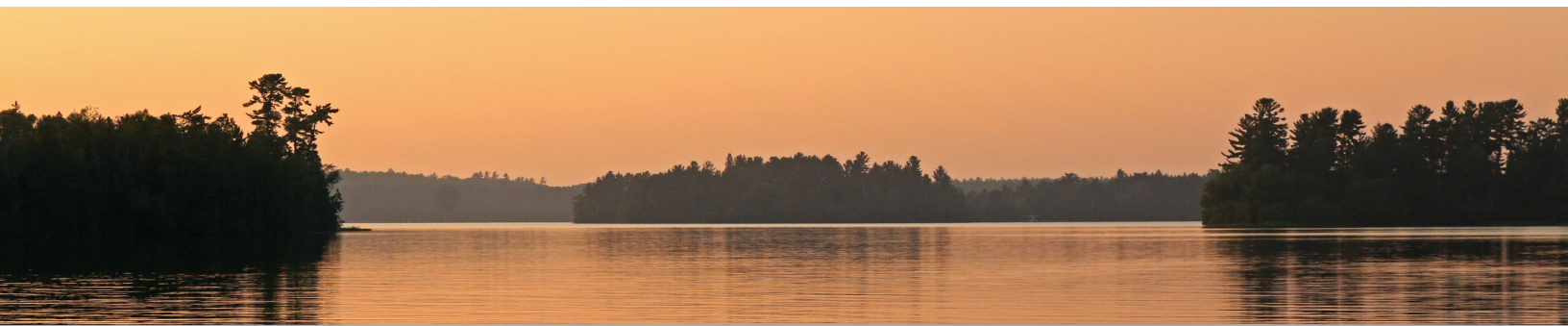
## Top Products

1. Biggs, RO et al. 2008. Turning back from the brink: detecting an impending regime shift in time to avert it. **PNAS.** doi: 10.1073/pnas.0811729106

2. Buffam, I et al. 2011. Integrating aquatic and terrestrial components to construct a complete carbon budget for a north temperate lake district. **Global Change Biology.** doi: 10.1111/j.1365-2486.2010.02313.x

3. Hansen, GJA et al. 2013. Are rapid transitions between invasive and native species caused by alternative stable states, and does it matter? **Ecology.** doi: 10.1890/13-0093.1

4. Hanson, PC et al. 2014. Quantifying lake allochthonous organic carbon budgets using a simple equilibrium model. **Limnology and Oceanography.** doi: 10.4319/lo.2014.59.1.0167

5. Kara, EL et al. 2013. A decade of seasonal dynamics and co-occurrences within freshwater bacterioplankton communities from eutrophic Lake Mendota, WI, USA. **The ISME Journal.** doi: 10.1038/ismej.2012.118

6. Newton, RJ et al. 2011. A guide to the natural history of freshwater lake bacteria. **Microbiology and Molecular Biology Reviews.** doi: 10.1128/MMBR.00028-10

7. Sharma, S et al. 2019, Widespread loss of lake ice around the Northern Hemisphere in a warming world. **Nature Climate Change.** doi: 10.1038/s41558-018-0393-5

8. Walsh, JR et al. 2016. Invasive species triggers a massive loss of ecosystem services through a trophic cascade. **PNAS.** doi: 10.1073/pnas.1600366113

9. Watras, CJ et al. 2014. Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: hydroclimatic implications. **Geophysical Research Letters.** doi: 10.1002/2013GL058679

10. Winslow, LA et al. 2015. Small lakes show muted climate change signal in deep-water temperatures. **Geophysical Research Letters.** doi: 10.1002/2014GL062325