THE UNIVERSITY OF NOTRE DAME ENVIRONMENTAL RESEARCH CENTER (UNDERC)

Sixty-Five Years of Whole-Ecosystem Manipulations and Counting

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Field stations are an essential component of limnology and oceanography. Some have argued field stations represent a crucible for serendipitous research discoveries (Michener et al. 2009). The place-based research conducted at field stations often diminishes traditional disciplinary boundaries paving the way to cross-disciplinary collaboration and innovation. Field stations also generate serendipitous moments in the life and career of young aquatic ecologists. Personally, a field station experience launched my career (and my marriage), and I know it has done the same for many of my friends and colleagues in ASLO, including a recent ASLO president (Elser 2016).

The University of Notre Dame Environmental Research Center (UNDERC) certainly embodies the magical features of any great field station. UNDERC has served as the origin and test bed for a number of important research discoveries in limnology and ecology. In addition, research and training at UNDERC has launched the career of many leaders in our society. The success of these individuals and UNDERC as a whole is owed in large part to a tradition of whole-ecosystem experimentation begun almost 70 years ago.

UNDERC is housed at the University of Notre Dame Land O'Lakes property—30 km^2 of land that straddles the border of Wisconsin and the Upper Peninsula of Michigan in the Midwest U.S. (Fig. 1). The property contains 30 glacial lakes and bogs totaling 5.5 km^2 in area. The university property is embedded within the larger Northern Highland Lake District (NHLD), which covers 5330 km^2, 13% of which consists of the almost 4000 glacial lakes contained in the district. The NHLD has experienced significant development in the form of lakeshore cottages and small urban centers over the last four decades, which provides an interesting contrast to the undeveloped lakes that support much of the research conducted at UNDERC.

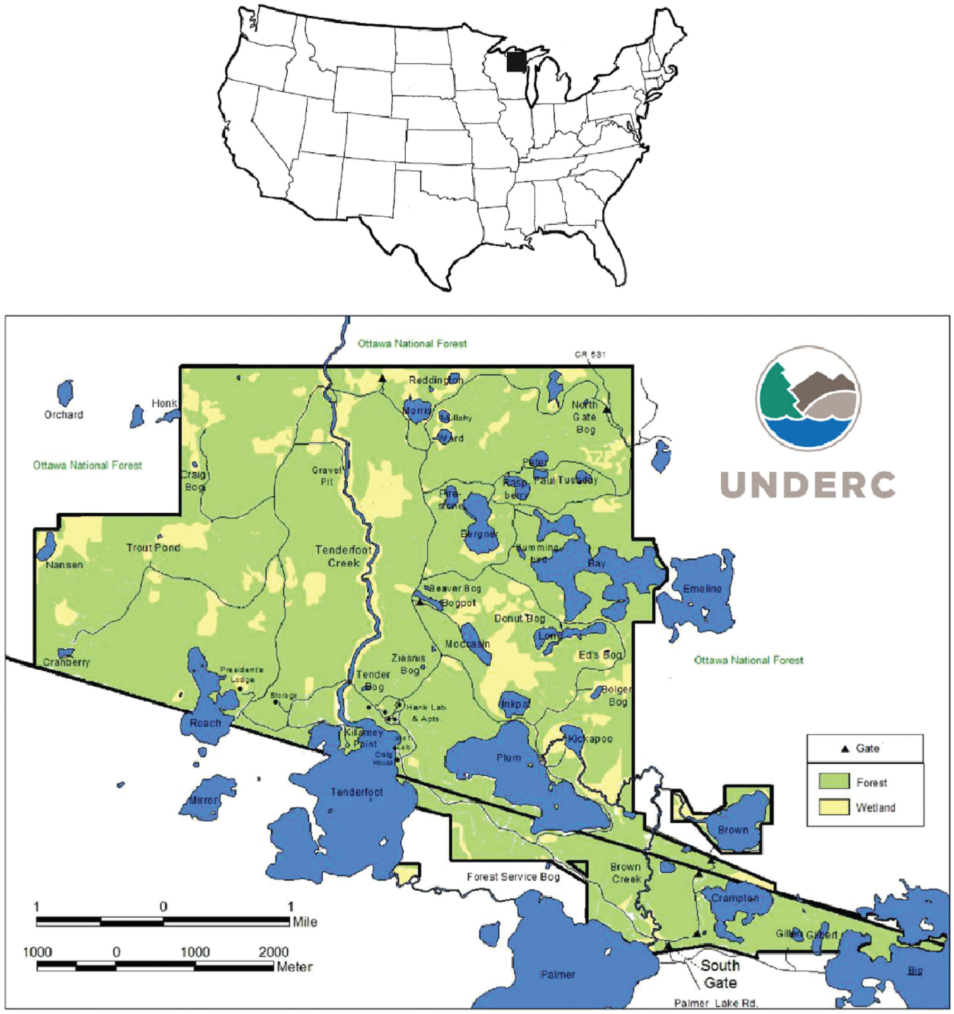

FIG. 1. Location and map of the University of Notre Dame Environmental Research Center (UNDERC) property.

High-quality, modern laboratory and housing facilities support research and education activities at UNDERC (Fig. 2). A combined 13,500 ft^2 of laboratory space is available in the lakeside Aquatic Laboratory and James B. Hank Research Facility. These laboratories house basic analytical chemistry equipment, including a gas chromatograph, molecular biology space, and mesocosm facilities. Apartment- and dorm-style housing is available for over 60 researchers and students.

The history of limnological research at UNDERC is nearly as long as that of North America. Prior to his 1936 gift of just over half of today's property to the University of Notre Dame, Martin J. Gillen provided research access to the pioneering limnologists Edward Birge and Chancey Juday who were conducting limnological surveys based at the nearby University of Wisconsin Trout Lake Station. Both terrestrial and aquatic research continued on the Land O'Lakes property following acquisition by the university, but formal development of a biological station did not begin until the late 1960s when it was initiated by Notre Dame Biology professors Robert E. Gordon and George B. Craig, Jr. and approved by University President, Father Theodore M. Hesburgh. Generous gifts from the family of Bernard J. Hank have constructed and supported much of the existing infrastructure and educational programming overseen by UNDERC administration and staff.

A legacy of whole-ecosystem manipulation experiments is UNDERC's greatest contribution to Limnology and Aquatic Ecology. From the early 1940s onward, Notre Dame faculty members and visiting researchers investigated diverse topics at UNDERC, including parasitology of fishes, mosquito ecology, wetland

FIG. 2. University of Notre Dame Environmental Research Center (UNDERC) facilities. The Hank and Aquatic Laboratories (upper panels), researcher apartments (lower left), and a common area in the student dormitory (lower right).

biogeochemistry, and invasion ecology. However, Arthur Hasler, the first Director of the Center for Limnology at the University of Wisconsin and early visiting researcher at UNDERC, demonstrated the utility of whole-lake manipulations afforded by the lake-rich, private property of UNDERC. In 1951, Hasler, who is a former ASLO president, initiated a series of liming treatments of Peter Lake to increase water clarity and replaced native fish populations with Rainbow Trout in both Peter and Paul Lake. Hasler's experimental approach, especially at the whole-ecosystem scale, contrasted strongly with observational and comparative studies that dominated limnological research at that time.

Following in the footsteps of Hasler, a multitude of researchers have advanced our understanding of diverse freshwater ecosystems through the use of whole-ecosystem experiments at UNDERC. In the early 1970s, Thomas Griffing (Notre Dame), Frank Hooper (University of Michigan), and William Cooper (Michigan State University) used radioactive tracers to study phosphorus cycling in acidic bogs. More recently, Notre Dame researchers, including Jennifer Tank and Gary Lamberti, manipulated large woody debris in streams flowing through the nearby Ottawa National Forest. Despite these important studies in wetlands and streams, lakes are by far the most common home for whole-ecosystem manipulations at UNDERC.

Since 1984, Steve Carpenter, Jim Kitchell, Jim Hodgson, Jon Cole, and Mike Pace, have more-or-less continually conducted whole-lake manipulative experiments at UNDERC. Beginning as a faculty member at Notre Dame and subsequently in his current position at the Center for Limnology at the University of Wisconsin, Carpenter worked closely with Kitchell and Hodgson to investigate cascading trophic interactions in lake food webs. The "Cascade" team then moved on to investigating the incorporation of terrestrial carbon into the biomass of aquatic consumers using innovative whole-lake additions of ^{13}C-bicarbonate. Most recently, this group has collaborated on a series of manipulative experiments using Peter and Paul Lake to evaluate the efficacy of early warning signs of ecosystem regime shifts.

A growing cast of researchers has expanded aquatic research at UNDERC over the past decade. Chris Solomon (Cary Institute of Ecosystem Studies), Brian Weidel (U.S. Geological Survey), and myself have investigated the implications of increased supply of terrestrial-derived dissolved organic carbon or "browning" for lake productivity using a whole-lake manipulation (Fig. 3) and a series of comparative studies. In 2013, UNDERC also initiated a lake monitoring program that collects seasonal baseline data on water chemistry, plankton and fish composition, and lake metabolism for thirteen of the lakes on the property, including a member site of the Global Lake Ecological Observatory Network (GLEON). Over that period, the monitoring program has also quantified annual hydrologic and elemental (carbon, nitrogen, and phosphorus) budgets for five UNDERC lakes. Construction of the National Ecological Observatory Network's

FIG. 3. The reference (left) and treatment (right) basins of Long Lake, located at UNDERC, after the terrestrial dissolved organic carbon concentration of the treatment basin was increased by ~ 50%. The difference in water color between the two basins can be seen with a pair of unofficial world's largest secchi disks (2.44 m diameter; upper panel). These secchi disks were constructed by Ph.D students Nikki Craig, Jake Ziegler, and Jake Zwart (lower left panel). The manipulation was achieved by trapping ~ 90% of the terrestrial DOC load in the treatment basin with a chemically impermeable curtain that was installed after a premanipulation period during which a mesh curtain separated the basins (lower right panel).

(NEON) Great Lakes region main site at UNDERC has provided complementary monitoring data. This includes terrestrial productivity and geospatial datasets, as well as NEON's aquatic site located on Crampton Lake. The presence of NEON has fostered collaboration with terrestrial ecologists, including Jason McLachlan (University of Notre Dame) who leads an effort to integrate pollen records from lake sediments, tree ring data, and eddy covariance flux data to infer forest composition and productivity since the last ice age (PalEON), and ongoing large-scale terrestrial experiments investigating tree gap succession (Michael Dietz, Boston University) and wolf-deer-plant trophic cascades (David Flagel & Gary Belovsky, University of Notre Dame).

Although the research described above has provided outstanding training opportunities for graduate and undergraduate students, UNDERC also sponsors more formal educational activities. Since the 1980s a multiweek field ecology course has been hosted at UNDERC each summer, http://underc.nd.edu/education/. The current iteration of this course includes 28 undergraduate students and consists of four week-long topical modules and a multiweek individual research project mentored by graduate students conducting research at UNDERC. The course draws students from across the United States, providing course credit, a generous stipend, and housing for all participants.

The research and education activities occurring at UNDERC over the past 70 years have had a profound influence on limnology and aquatic ecology. Although decades of research, including a multitude of whole-ecosystem experiments, have generated essential knowledge and understanding, UNDERC's most significant impact is reflected in the long list of leading researchers and ASLO members that spent a portion of their formative research years in "the northwoods." We welcome alumni and new visitors alike to visit us at UNDERC any time!

References

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NUTRIENT SENSOR CHALLENGE WINNERS ANNOUNCED AT ASLO CONFERENCE

The winners of the Nutrient Sensor Challenge were announced at a special awards session at the ASLO Aquatic Sciences Meeting in Honolulu, Hawaii, on Thursday, March 2.

Launched in December 2014, the Nutrient Sensor Challenge aimed to accelerate the development, production, and use of affordable, reliable, and accurate nutrient sensors. These sensors will enable automated and high-resolution nutrient monitoring in aquatic environments ranging from freshwater lakes and streams to the coastal ocean. Nutrient pollution is one of the nation's most difficult environmental challenges. While nutrients are essential compounds for functioning ecosystems and the production of food, fiber, and livestock feed, excessive nutrient levels can