

WI-DNR grant ACEI-141-13 final report
Crystal Lake Mixing Project
Jake Vander Zanden, Center for Limnology, UW-Madison

We tested an experimental Aquatic Invasive Species (AIS) control method in the Northern Highlands Lake District of Wisconsin and conducted primary research on ecosystem impacts resulting from treatment. This report provides a broad summary of our contributions over the course of the grant, with detailed findings to be found in the list of technical publications below. The project has trained (directly and indirectly) several graduate students, as well as a long list of undergraduates that have been involved in this research. Here we summarize our contributions to development of new AIS control and lake management approaches.

Whole lake mixing technology – We have engineered a novel lake mixing technology and successfully applied it to remove cold water habitat and exceed the thermal limits of the target AIS Rainbow smelt (RWS). This second generation of the Gradual Entrainment Lake Inverter technology (GELI) has demonstrated it can be scaled to mix larger lakes and the efficiency of this mixing can lead to considerable cost savings (Smith et al., *In review*). While questions remain about its utility in ameliorating water quality problems, we have provided valuable insights into the mixing dynamics and scalability of the technology, as well as technical documentation for its future development.

Managing the harmful invasive AIS Rainbow smelt – We have developed and tested a unique control method for selectively extirpating the cold water AIS RWS from a lake otherwise inhabited by warm water tolerant native species (Gaeta et al. 2012). Application of this method to Crystal Lake saw a dramatic reduction in the adult RWS population (ca. 90%) in the treatment years 2012 and 2013, however the remainder survived to spawn in the spring of subsequent years (Lawson et al. 2015). Treatment did not have a negative effect on the native Yellow perch population (YWP), which has increased in densities and size since the period of treatment (Tom Hrabik, *personal communication*). Although the YWP population grew, and the RWS have diminished in years immediately following treatment, it appears that the RWS is beginning to rebound (Tom Hrabik, *personal communication*). The full impacts of treatment on these populations will be better understood in the coming years. In addition to testing this novel AIS control method, we developed a tool to maximize the likelihood of successful stocking of Walleye in lakes invaded by RWS (Lawson and Carpenter 2014). Our work provides a valuable case study to formulating new approaches to controlling AIS, an area of management that has few options.

Effects of treatment on the ecosystem – We evaluated effects of treatment on select components of the Crystal Lake ecosystem. In terms of the high degree of water quality enjoyed by the numerous visitors and campers of Crystal Lake, we saw moderate increases in algal concentrations and reduced water clarity during the experiment, however these changes immediately reverted to normal after treatment. These changes in algal concentrations accord with changes to the underlying metabolism of the ecosystem during treatment. We found large

increases in gross primary production with an equal increase in respiration, resulting in no change to net ecosystem production (Smith et al., *In prep*). These findings indicate higher rates of primary production could have fueled secondary production, which is a food resource for the RWS. We investigated the spatial overlap between RWS and their zooplankton prey items and found the loss of stratification to have no effect on the coupling of these food web components (Heald et al. 2017). In addition to these investigations, there is currently genetics study underway to determine if the surviving portion of the RWS population is genetically different than the portion of the RWS population that was eliminated. These findings and ongoing studies shed light on our understanding of how thermal stratification controls ecosystem structure and function and provides additional information as to how a portion of the RWS population survived treatment.

Public education and outreach – We have provided a substantial amount of formal and informal public outreach on the project and the importance of AIS management more broadly. Our formal outreach efforts were conducted during the project (2010-2014) and was advertised to the more than 100,000 annual Crystal Lake campground visitors. Additionally, we provided interviews to local newspapers and radio stations, facilitating reach beyond the Crystal Lake site. Our informal outreach occurred daily with inquisitive lake users whom we would fully engage with their questions and concerns.

Training

This project supported Jereme Gaeta and Jordan Read, both PhD candidates at the time. Jereme is now an assistant professor at Utah State University, and Jordan is a data scientist at the USGS Center for Integrated Data Analytics. The project provided funding for Masters students Zach Lawson, and Colin Smith. Zach now works for WI-DNR as a fisheries biologist, and Colin works for the Environmental Data Initiative as an information manager. This project also indirectly supported the work of Emily Heald (National Parks Service), Jamie Dobosinski (M.S. Student at the University of Minnesota-Duluth). The project also provide training to 18 undergraduate students, many of whom have gone on or entered graduate study in the field.

Peer reviewed publications

Gaeta JW, RS Read, JF Kitchell, SR Carpenter. 2012. Eradification via destratification: Whole-lake mixing to selectively remove rainbow smelt, a cold-water invasive species. *Eco App.* 22(3): 817-827.

Lawson ZJ and SR Carpenter. 2014. A morphometric approach for stocking walleye fingerlings in lakes invaded by rainbow smelt. *N Am J Fish Manage.* 34: 998-1002.

Gaeta JW, TR Hrabik, GG Sass, BM Roth, SJ Gilbert, MJ Vander Zanden. 2015. A whole-lake experiment to control invasive rainbow smelt (*Actinopterygii*, *Osmeridae*) via overharvest and a food web manipulation. *Hydrobiologia*. 746: 433-444.

Lawson ZJ, MJ Vander Zanden, CA Smith, E Heald, TR Hrabik, SR Carpenter. 2015. Experimental mixing of a north-temperate lake: Testing the thermal limits of a cold-water invasive fish. *Can J Fish Aquat Sci*. 72: 926-937.

Heald E, TR Hrabik, Y Li, Z Lawson, SR Carpenter, MJ Vander Zanden. 2017. The effects of experimental whole-lake mixing on horizontal spatial patterns of fish and zooplankton. *Aquat Sci*. 1-14.

Smith CA, JS Read, MJ Vander Zanden. In review. Application of the “Gradual Entrainment Lake Inverter” (GELI) artificial mixing technology for lake and reservoir management. *Lake and Res Manage*.

Smith CA, JS Read, SR Carpenter, MJ Vander Zanden. In prep. Experimental mixing of a north-temperate lake: Effects on pelagic lake ecosystem metabolism. *Limnol Oceanogr*.

Data publications

The knowledge to be derived from the vast amounts of data generated during this project has yet to be fully realized. To preserve this value, and ensure its future use, several datasets have been compiled and submitted to the North Temperate Lakes Long Term Ecological Research Program data manager for processing and curation. These datasets include:

Crystal Lake Mixing Project: Spawning surveys: 2010-2014

Crystal Lake Mixing Project: Fish abundance: 2010-2014

Crystal Lake Mixing Project: Fish lengths and weights: 2010-2014

Crystal Lake Mixing Project: Fish growth rates: 2010-2014

Crystal Lake Mixing Project: Fish otolith images: 2010-2014

Crystal Lake Mixing Project: Fish diets: 2010-2014

Crystal Lake Mixing Project: Stable isotope samples: 2010-2014

Crystal Lake Mixing Project: Benthic invertebrates: 2010-2014

Crystal Lake Mixing Project: Instrumented buoy measurements of aquatic and atmospheric variables made at the deep hole: 2011-2014

Crystal Lake Mixing Project: Instrumented buoy measurements of aquatic and atmospheric variables made 400 m West of the deep hole: 2012-2013.

Crystal Lake Mixing Project: Microstructure temperature and conductivity profiles: 2010-2014

Crystal Lake Mixing Project: Full water column profiles of UV-A, UV-B, and PAR: 2010-2014

Representative media coverage

Table 1. Local and Regional media coverage of the Crystal Lake Mixing Project.

Date	News Source	Title
7/11/2011	WAOW (channel 9)	Crystal Lake Mixing Project aims to eradicate invasive species
7/6/2011	WXPR 91.7FM	Getting Rid of Rainbow Smelt in Crystal Lake
6/29/2011	WSAW (channel 7)	Students Try Groundbreaking Science Underwater
6/10/2011	The Lakeland Times	Water manipulation at Crystal Lake scheduled to begin within weeks: Goal is to eliminate invasive rainbow smelt
5/11/2011	NHAL State Forest Visitors Guide 2011	Crystal Lake Mixing Project: led by UW-Madison
4/2/2010	The Lakeland Times	Researchers to use revolutionary GELs in Crystal Lake invasives battle: Funding propels rainbow smelt elimination forward
11/1/2009	The Wisconsin Engineer	Tiny Invaders Spell Big Trouble for Wisconsin Walleye
8/21/2009	The Lakeland Times	Warming up: UW researchers look for ways to rid Crystal lake of smelt
12/13/2012	phys.org	Stirred, not shaken, lake mixing experiment shows promise
11/19/2012	The Daily Cardinal	Lake mixing possible solution to fighting invasive species
6/7/2012	For Your Information Northwoods	Lake Mixing and smelt eradication at Crystal Lake
6/26/2012	Vilas County News-Review	Lake mixing started at Crystal in experiment to eradicate smelt
6/15/2012	The Lakeland Times	Trout Lake Station researchers study anything 'lake'
8/11/2012	The Lakeland Times	UW Trout Lake Station hosts successful open house
5/11/2012	NHAL State Forest Visitors Guide 2012	UW-Madison researchers are mixing Crystal Lake
12/13/2012	Great Lakes Echo	Wisconsin scientists use lake mixer to drive out invasive species
12/13/2012	Physics.org	Stirred, not shaken, lake mixing experiment shows promise
7/25/2013	WXPR 91.7FM	How to Mix a Lake
6/17/2014	WXPR 91.7 FM	CLMP Update
7/13/2014	WXPR 91.7 FM	Mixing Experiment Helps Remove Ninety Percent of Invasive Smelt from Crystal Lake

Talks and other products for public audiences

Table 2. Public presentations made throughout the course of the Crystal Lake Mixing Project.

Date	Time	Audience	Location
7/31/2010	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Nature Center
8/19/2010	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Nature Center
9/13/2010	8 am - 1 pm	Arbor Vitae - Woodruff Middle School	Crystal Lake Nature Center and Crystal Lake
9/15/2010	7-8 pm	Local Boulder Junction public	Boulder Junction Library
11/3/2010	5-8 pm	Local Boy Scout Troop	Crystal Lake and Trout Lake Station
3/2/2011	12:00-3:00 pm	7th grade	AVW Middle School
3/3/2011	9:30 am - 2:00 pm	3rd graders	UW-TLS
6/1/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/8/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/15/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/16/2011	10:30-11:30 am	Lake Association Members	Vilas County Lakes Association Annual Meeting
6/22/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/29/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/6/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/13/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/20/2011	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/25/2011	5:30-7:00 pm	K-12 students at Conservation Camp	Trees for Tomorrow
8/5/2011	NA	Crystal Mix	YouTube
12/7/2011	10-11 am	9-10 grade Biology 1 Students	Wausau East High School
12/7/2011	11-12 am	11-12 grade Field biology students	Wausau East High School
12/7/2011	12-1 pm	9-10 grade Biology 1 Students	Wausau East High School
12/7/2011	1-2 pm	9-10 grade Biology 1 Students	Wausau East High School
12/7/2011	2-3 pm	11-12 grade Biology 2 Students	Wausau East High School
3/7/2012	12:00-3:00 pm	7th grade	AVW Middle School
3/8/2012	9:30 am - 2:00 pm	3rd graders	UW-TLS

4/11/2012	2:35 -3:15 pm	Lake Association Members lake managers	Wisconsin lakes partnership convention
5/22/2012	9:30-10:30 am	Department of Natural Resources Employees	Crystal Lake Nature Center
6/12/2012	3:30-5:00	Iron County Conservation Department Conservation School	Crystal Lake Nature Center
6/14/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/21/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/28/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/5/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/11/2012	3:30-5:00 pm	Wisconsin Leadership Class	Crystal Lake Campground and Beach
7/19/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/26/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/2/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/9/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/10/2012	10:30 - 11:45 am	Local public and Manitowish Discovery Center Visitors	Manitowish Discovery Center
8/16/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/23/2012	6-7 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
9/11/2012	NA	Update: Crystal Lake Mixing Project	YouTube
4/10/2013	2:35 -3:15 pm	Lake Association Members lake managers	Wisconsin lakes partnership convention
5/23/2013	12 am-2 pm	Purdue University class	UW-TLS
6/5/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/12/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/19/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/26/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/3/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/10/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground

7/17/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/24/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/31/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/7/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/14/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/21/2013	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
8/21/2013	NA	Crystal Mix 2013	YouTube
6/18/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
6/25/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/2/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/9/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/16/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground
7/23/2014	6:30-7:30 pm	Local public and Crystal Lake Campground visitors	Crystal Lake Campground

Academic talks featuring this work was presented to the following audiences

North American Lake Management Society (2012)

Joint Aquatic Sciences Meeting (2014)

Science in the Northwoods, Madison (2014)

University of Wisconsin, Madison (2015)

University of Wisconsin, Madison (2016)

Ecological Society of America (2017)

