DNR AIS grant final report
Smart prevention of AIS
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We conducted primary research relating to the *smart prevention* framework for invasive species prevention and management in Wisconsin. This report provides a broad summary of our specific contributions over the course of this grant, with the detailed findings to be found in the variety of technical publications listed below. We have also done a tremendous number of public talks, articles, and media interviews targeting general audiences, many of which are documented below. The project has trained (directly or indirectly) numerous graduate students and postdocs, as well as a long list of undergraduates that have been involved in this research. There are several key thematic areas from this project where we have made major contributions, which we summarize here.

Assessing lake vulnerability – We have developed a conceptual framework for assessing ecosystem vulnerability to invasion (Vander Zanden and Olden 2008). We have written about invasive species as a driver of change in Wisconsin (Vander Zanden and Maxted 2008), and conducted Wisconsin-level vulnerability assessments for zebra mussels (Papes et al. 2011), Chinese mystery snail (Papes et al. 2016), rusty crayfish (Olden et al. 2011), and Eurasian watermilfoil (Mikulyuk and Vander Zanden *in prep*). We have developed the foundation for a mechanistic population model that can be used for evaluating vulnerability to spiny water flea. Jake Walsh has developed a population model for this species that can be used as an ecological niche model to assess lake vulnerability to future invasion, which was a significant breakthrough (Walsh et al. 2016). In other work on vulnerability, we have found that impoundments are more vulnerable to species invasions (Johnson et al. 2008). Furthermore, we have demonstrated a tight link between species invasion and lakeshore development (Latzka et al. *in review*). A key output of this work has been a decision support tool for assessing vulnerability to invasive species: http://www.aissmartprevention.wisc.edu/. The tool currently has statewide vunerability assessments for zebra mussel, round goby, rainbow smelt, and rusty crayfish. In addition, we have developed an invasive species informational website for Wisconsin: http://www.jakevzlab.net/ais.html

Local impact – Understanding invasive species impacts is the largest knowledge gap in the implementation of the smart prevention framework for AIS management. Management is resource-limited, and efforts should be targeted to those species with the largest potential to cause harm. This project has contributed to our understanding of this phenomenon. We have found synergistic interactions among multiple invaders (Johnson et al. 2009), and documented relatively minor ecological effects of Chinese mystery snail (Solomon et al. 2010). We conducted a meta-analysis and provide a new framework for considering the ecological impacts of dreissenid mussels (Higgins and Vander Zanden 2010). We have documented the impacts of rusty crayfish on lake food web structure (Nilsson et al. 2012). Using a food web approach, we

were able to estimate the economic impact of spiny water in Lake Mendota to be on the order of $100 million due to loss of water quality (Walsh et al. 2016; Walsh et al. *in review*). Finally, we have conducted an extensive analysis comparing the ecological impacts of Eurasian watermilfoil to that of lakewide chemical treatment used in its control, and have found that impacts of chemical treatment exceed that of the invasive (Mikulyuk et al. *in prep*). Furthermore, the impacts of EWM on aquatic plant communities are similar to the impacts of native species. This work will inform our larger goals of aquatic plant management and allow us to explicitly consider the fundamental tradeoff inherent in balancing the goals of ecosystem protection and restoration with human goals of utilization and recreation.

Landscape level impact – As part of the smart prevention framework, our understanding of local impacts need to be scaled up to the broader landscape scale. There are a variety of factors that contribute to landscape level impacts. Landscape level impact is partially a function of local abundance – we have found that invasive species abundance is highly heterogeneous on the landscape, and is more often than not low (Hansen et al. 2013). Another key factor is site occupancy. We have developed estimates of site occupancy for a suite of species across the state of WI. Scaling up the results of randomized field survey reveals that lakes are much more highly invaded than indicated by previous data by a factor of ~ 5x. This work comprised Alex Latzka's PhD thesis (Latzka 2015) and a manuscript demonstrating their widespread distributions is currently in preparation (Latzka et al. *in prep*). Building on the above work, we have developed a conceptual framework for considering the heterogeneity of landscape level impacts for invasive species in Wisconsin (Latkza et al. 2016; Vander Zanden et al. 2017).

In sum, this project has supported our ongoing work aimed at conducting the science for a smart prevention framework for managing aquatic invasive species for the state of Wisconsin and beyond. The smart prevention approach requires understanding and knowledge of vulnerability, spread pathways, distributions, as well as local and regional impacts. Understanding these factors requires dedicated research, and this research was conducted with the support of this DNR grant. Moreover, we have trained the workforce, and shared this information with professional and public audiences through a wide range of talks, media outreach, web tools.

Training

This project supported Mona Papes, who was a postdoc at the start of the project. She is currently a professor at the University of Tennessee. This project also provided the main support for the PhD of Ali Mikulyuk, who is currently a researcher at the Wisconsin Department of Natural Resources. The project also indirectly supported the work of Erin Vennie-Vollrath (currently at The Nature Conservancy New York) and Jake Walsh (currently postdoc at the Center for Limnology). Gretchen Hansen (Research Scientist MN DNR), Alex Latzka (WI Sea Grant), Julian Olden (Professor, University of Washington), and Pieter Johnson (Professor, University of Colorado).

Peer-review Publications

Mikulyuk, A., M.J. Vander Zanden. *In prep*. Combining empirical estimates of invasion likelihood and invader abundance to identify high-priority management and prevention targets. **Ecological Applications**

Latzka, A.W. S. Van Egeren, M.J. Vander Zanden. *In prep*. How invaded are we? Estimating the prevalence of aquatic invasive species on landscapes **Biological Invasions**

Mikulyuk, A., M. Barton, J. Hauxwell, M. Nault, S. Van Egeren, K. Wagner, M.J. Vander Zanden. *In prep*. Is the cure worse than the disease? Comparing effects of Eurasian watermilfoil and large-scale herbicide treatments on aquatic macrophytes. **Ecological Applications**

Walsh, J.R., R.C. Lathrop, M.J. Vander Zanden *in review*. Invasive invertebrate predator, *Bythotrephes longimanus*, reverses trophic cascade in a north-temperate lake **Limnology and Oceanography**

Latzka, A.W., S. Van Egeren, M. Ferry, M.J. Vander Zanden *in review*. Roads and nearshore development as drivers of aquatic invasive species in lakes. **Diversity and Distributions**

Walsh, J.R., S.E. Munoz, M.J. Vander Zanden. 2016. Outbreak of an undetected invasive species triggered by a climate anomaly **Ecosphere** 7(12):e01628. 10.1002/ecs2.1628

Vander Zanden, M.J. Hansen, G.J.A., Latzka, A.W. 2017. A framework for evaluating heterogeneity and landscape-level impacts of non-native aquatic species **Ecosystems**

Latzka, A.W., G.J.A. Hansen, M. Kornis, M.J. Vander Zanden 2016. Spatial heterogeneity in invasive species impacts at the landscape scale. **Ecosphere** 7(3): e01311

Walsh, J.R., S.R. Carpenter, M.J. Vander Zanden. 2016. Invasive species triggers a massive loss of ecosystem services through a trophic cascade **Proc. Nat. Acad. Sci. USA** 113: 4081-4085

Papes, M., J. Havel, M.J. Vander Zanden. 2016. Use of maximum entropy to estimate the potential distribution of an invasive freshwater snail **Freshwater Biology** 61: 457-71

Hansen, G.J.A., M.J. Vander Zanden, M.J. Blum, M. Clayton, E.F. Hain, J. Hauxwell, M. Izzo, M.S. Kornis, P.B. McIntyre, A. Mikulyuk, E. Nilsson, J.D. Olden, M. Papes, S. Sharma,. 2013. Commonly rare and rarely common: comparing population abundance of invasive and native species **PLoS ONE** 8(10): e77415

Nilsson, E., C.T. Solomon, K.A. Wilson, T.V. Willis, B. Larget, M.J. Vander Zanden. 2012. Effects of an invasive crayfish on trophic relationships in north-temperate lake food webs **Freshwater Biology** 57: 10-23.

Olden, J.D., M.J. Vander Zanden, P.T.J. Johnson. 2011. Assessing ecosystem vulnerability to invasive rusty crayfish (*Orconectes rusticus*) **Ecological Applications** 21: 2587-2599.

Papes, M., M. Sallstrom, T.R. Asplund, M.J. Vander Zanden. 2011. Invasive species research to meet the needs of resource management and planning. **Conservation Biology** 25:867-872.

Solomon, C.T., J.D. Olden, P.T. Johnson; R.T. Dillon, M.J. Vander Zanden. 2010. Distribution and community-level effects of the Chinese mystery snail (*Bellamya chinensis*) in northern Wisconsin lakes. **Biological Invasions** 12: 1591-1605

Higgins, S.N. and M.J. Vander Zanden. 2010. What a difference a species makes: A meta-analysis of dreissenid mussel impacts on freshwater ecosystems. **Ecological Monographs** 80: 179-196.

Johnson, P.T.J., J.D. Olden, C.T. Solomon, and M.J. Vander Zanden. 2009. Interactions among invaders: Community and ecosystem effects of multiple invasive species in an experimental aquatic system. **Oecologia** 159:161-70.

Johnson, P.T., J.D. Olden, M.J. Vander Zanden. 2008. Dam invaders: impoundments facilitate biological invasions in freshwaters. **Frontiers in Ecology and the Environment** 6:357-63.

Vander Zanden, M.J. and Olden, J.D. 2008. A management framework for preventing the secondary spread of aquatic invasive species. **Canadian Journal of Fisheries and Aquatic Sciences** 65 (7): 1512-22.

Vander Zanden, M.J. and J.T. Maxted. 2008. Species invasions in Wisconsin lakes and streams. Pages 423-438 *In* **The vanishing present: Wisconsin's changing lands, waters and wildlife.** *Edited by* D.M. Waller and T.P. Rooney. University of Chicago Press.

Representative Media Coverage

Live & On Air Interviews - Larry Meiller Show (WPR 2016, 2013), Central Time with Rob Ferrett (WPR), Quirks and Quarks with Bob McDonald (CBC)

Wisconsin, Michigan, and Minnesota Public Radio – Interviews for on-air segments and articles – Chuck Quirmbach (WPR), Dan Gunderson (Minnesota PR), Ken Krall (WXPR)

National Print – Washington Post (Daryl Fears), New Scientist (Fred Pearce), El Confidencial (Sergio Ferrer), Weather Channel (Ada Carr)

Local & Regional Print – MinnPost (Ron Meador), Milwaukee Journal Sentinel (Lee Bergquist),

Television – NBC 15 (2016)

Talks and other products for public audiences

Vander Zanden, M.J. Invasive spiny water flea is making Lake Mendota murkier. 2015. Yahara Lakes Association newsletter

Vander Zanden, M.J. 2013. *Invasive species*. Wisconsin People and Ideas. Spring/Summer 2013.

Feature article about crayfish removal project in Sparkling Lake, Wisconsin Natural Resources. 2014

Walsh, University of Wisconsin - Whitewater Biology Colloquium, Lecture on economic impact of invasive species. 2016

Walsh, Minnesota Aquatic Invasive Species Summit II, Presentation on economic impact of spiny water flea - Calculating the ecosystem services cost of an invasive species. 2016

Walsh, Wisconsin DNR Aquatic Invasive Species Statewide Identification and Decontamination meeting, Led training to implement our spiny water flea detection method statewide. 2016

Walsh, Friends of the Pheasant Branch Conservancy, Presented on ecological and economic impact of Madison's aquatic invasive species. 2016

Walsh, Clean Lakes Alliance Limnology 101 Breakfast, Presented on ecological and economic impact of Madison's aquatic invasive species. 2016

Walsh, Upper Midwest Aquatic Invasive Species Conference, Massive ecosystem services impact by invasive spiny water flea in Lake Mendota, WI. 2016

Mikulyuk, Upper Midwest Aquatic Invasive Species Conference, LaCrosse, WI. The cost of the cure and the disease: understanding the ecological effects of in invader relative to large-scale herbicide treatments used in its control. 2016.

Vander Zanden, Upper Midwest Aquatic Invasive Species Conference, Measuring invasive species impact using comparative analyses. 2016.

Blog post for DNR website: http://lakes-l.blogs.govdelivery.com/2016/11/bringing-home-new-knowledge-on-aquatic-invasive-species/

Vander Zanden, Wisconsin AIS Coordinators meeting Spiny Water Flea Impact on Water Quality in Our Lakes' Oct. 2015

Vander Zanden, Dane County Lakes and Watershed Commission, How Spiny Water Flea Have Degraded Water Quality in Our Lakes Jun. 2015

Vander Zanden, Great Lakes Policy Workshop for Wisconsin Legislators, Great Lakes Legislative Caucus, Aquatic invasive species: A threat to the Great Lakes and Wisconsin' Feb. 2015

Vander Zanden, Clean Lakes Alliance, Yahara Lakes 101 Series, Lake Invaders: How Spiny Water Flea Have Degraded Water Quality in Our Lakes, Jun. 2015

Vander Zanden, Invasive Species Education Summit, Eau Claire, WI, Everywhere, or hardly there? Perspectives on invasive species in inland lakes of WI Jun. 2014

Mikulyuk, A. 2014. Preparing Wisconsin invasive species policy for a future of climate change. Wisconsin Lakes Convention. Stevens Point, WI. Invited talk.

Hansen, G. Invasive species abundance and impact. Northwest Wisconsin lakes conference 2013

Vander Zanden, Clean Lakes Alliance, Yahara Lakes 101 Series, Aquatic invasive species and water quality in the Yahara Lakes: are they connected? Jun. 2013

Vander Zanden, Wisconsin Invasive Species Council, Prevention of aquatic invasive species' Mar. 2012

Vander Zanden, Wisconsin Lakes Convention, Green Bay, WI, 2009 (Plenary)

Academic talks featuring this work was presented to the following audiences:
University of Canterbury, Christchurch, NZ (2016)
University of Otago, Dunedin, NZ (2016)
Waikato University, Hamilton, NZ (2016)
University of Michigan, Ann Arbor, MI, 2014
Intl. Conference on Aquatic Invasive Species, Niagara Falls, ON, 2013 (**Plenary**)
American Society for Limnology and Oceangraphy, New Orleans, LA, 2013

Forest and Wildlife Ecology, UW-Madison, Madison, WI, 2012
North American Lake Management Society, Madison, WI, 2012
University of Wisconsin–Milwaukee, Milwaukee, WI, 2010
University of California–Davis, Davis, CA, 2009
University of Notre Dame, South Bend, IN, 2009