III. Completed Research Projects

"a summary of any research project completed in the preceding biennium;"

The following documents include:

- Summaries of accomplishments for each appropriation year and short abstracts for all projects completed since the previous biennial report of January 15, 2021. Research projects have been marked as such in the description.
- Spreadsheet of all research projects completed between January 1, 2021 and December 31, 2022.

Additional information:

- The abstracts describe the general accomplishments of each completed project and are current as of 12/31/2022. See http://www.lccmr.mn.gov for additional project information, including Final Reports.
- 166 projects were completed with a total of $92,521,240.
- Legal citations for completed projects:
  1. M.L. 2019, First Special Session, Chapter 4, Article, 2, Section 2
  2. M.L. 2018, Chapter 214, Article 4, Section 2
  3. M.L. 2017, Chapter 96, Section 2
  4. M.L. 2016, Chapter 186, Section 2
  5. M.L. 2015, Chapter 76, Section 2
  6. M.L. 2014, Chapter 226, Section 2

1. **M.L. 2019 Projects Completed**
   January 15, 2021 – January 15, 2023

   MN Laws 2019, First Special Session, Chapter 4, Article 2, Section 2

M.L. 2019 Projects

MN Laws 2019, First Special Session, Chapter 4, Article 4 Section 2 (beginning July 1, 2015)

Visit the LCCMR website for the most up-to-date project information and reports

Subd. 03 Foundational Natural Resource Data and Information

Subd. 03b Restoring Native Mussels in Streams and Lakes - $500,000 TF (FY2020)

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Appropriation Language
$500,000 the first year is from the trust fund to the commissioner of natural resources to restore native freshwater mussel assemblages, and the ecosystem services they provide, in the Mississippi, Cedar, and Cannon Rivers and to inform the public on mussels and mussel conservation. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Reestablishing historical mussel assemblages through laboratory propagation began in 2016 at the MNDNR Center for Aquatic Mollusk Programs (CAMP). Since then, CAMP has released 9,541 sub-adult mussels from five species in three watersheds; restoring ecosystem services and enhancing Minnesota rivers with each mussel.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota's native mussels are critically important to aquatic ecosystems but have been lost or diminished in many water bodies. Harvest for pearls and buttons, pollution, dams, and destabilized waterways have caused mussel populations to decline dramatically, 80% of Minnesota's species are affected. Improvements from Clean Water Act implementation, stream restoration work, and protective laws are creating opportunities to reverse this trend. However, dams that limit fish movement are still hindering mussel recolonization, because mussels rely on fish as hosts to complete their life cycle. Thus, conservation methods such as laboratory propagation and reintroduction are needed to help mussel populations recover, and ultimately, restore ecosystem benefits. CAMP has implemented this work for three watersheds in Minnesota, which were chosen based on historical records, habitat, and fish communities. We constructed several propagation systems specifically designed for juvenile recovery and culture over time, improving our success along the way. Since 2016, CAMP has produced more than 1.5 million juvenile mussels. Due to the challenges of culture, survivorship varies between species and years. Juvenile survival after 90-days ranged from 0 – 84%. Newly metamorphosed juveniles were placed into various culture containers including a recirculating system, static system, or a flow-through system. Survival rates vary between systems, and within systems. Factors such as dissolved oxygen, ammonia, pH, and conductivity are monitored throughout growing period. Overall, survival is highest in the flow-through system, however, the system requires the most person-hours per juvenile. From July

2019 until June 2021, CAMP has released 7,038 sub-adult mussels from five species in three watersheds. Since our first ENRTF grant CAMP has released more than 9,500 sub-adult mussels. Mussels will enhance water clarity and improve habitat in the Cannon, Cedar, and Mississippi Rivers for years to come.

PROJECT RESULTS USE AND DISSEMINATION
CAMP's efforts to restore native freshwater mussels were featured in several news articles, including an Episode 1 of Season 3 on MN DNR Prairie Podcast. The Star Tribune and Cedar Watershed District discussed our efforts to reclaim stretches of the river with mussel populations. Moreover, CAMPs newsletters reach more than 5,000 users. Lastly, with the upcoming launch of Clam Counter App for IOS and Android platforms, a digital field guide and general information regarding mussels will be available to all smartphone users.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03c Quantifying Exposure of Minnesota's Raptors to Mercury and PFAS - Research Project - $250,000 TF (FY2020)

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Appropriation Language
$250,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Hawk Ridge Bird Observatory to quantify the exposure and health risk of two environmental neurotoxins to Minnesota raptors.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
These results are a first look at polyfluoroalkyl substances (PFAS) in Minnesota's Birds of Prey. Among vertebrates, birds appear to be most vulnerable to PFAS effects, which can result in reproductive failure. Birds of prey are vulnerable to PFAS because of their position atop both aquatic and terrestrial food webs.

OVERALL PROJECT OUTCOME AND RESULTS
Polyfluoroalkyl substances (PFAS) are a class of chemicals used in industrial processes and fire suppression. Mercury (Hg) enters the environment from point-source releases due to industrial processes and through combustion of coal for power generation. Both Hg and PFAS are present locally at highly contaminated sites and ubiquitously due to atmospheric deposition. Due to their predatory nature, birds of prey are at unique and elevated risk of exposure to both PFAS and Hg that concentrate in animal tissues; with each link in their food chain, predators consume and concentrate these toxicants contained in their prey. We collected blood and feather samples from 355 birds of prey at two

Minnesota locations, Hawk Ridge in Duluth, and The Raptor Center in St. Paul. We analyzed blood plasma for up to 40 PFAS chemicals and feathers for total mercury concentration. Our objectives were to (1) collect baseline data on exposure of MN raptors to Hg and PFAS and (2) to test specific hypotheses about patterns of exposure in relation to ecological variables such as diet, age, sex, and species identity. As expected, perfluorooctane sulfonate (PFOS) was the PFAS of highest concentration across all species and in each individual species, typically at concentrations ten or more times that of other PFAS. Bald Eagle (Haliaeetus leucocephalus) had the highest exposure, probably reflecting the greater representation of aquatic prey (fish) in its diet. However, Cooper's Hawks (Accipiter cooperii) had comparable exposures and they consume entirely terrestrial prey. Among ecological variables, species identity offered the greatest explanatory power, followed by a measure of species' tolerance of human activity, which may serve as a proxy for likelihood of exposure. These results will prove invaluable for understanding and managing both human and ecological exposures to PFAS and Hg in Minnesota.

PROJECT RESULTS USE AND DISSEMINATION
Dr. Etterson has presented results at internal meetings of the US Environmental Protection Agency's PFAS Working Group at the Great Lakes Toxicology and Ecology Division, Duluth, MN. Final PFAS results were received from the contract laboratory on 29 June 2022, just prior to the close of the project period and we expect dissemination activity to increase considerably over the next year. Dr. Ponder will present some results from this work at the upcoming International Ornithological Congress in Durban, South Africa, August 2022. We expect at least two manuscripts will be submitted to peer-reviewed journals for publication in the coming year.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03g Mapping Habitat Use and Disease of Urban Carnivores - Research Project - $500,000 TF (FY2020)

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Appropriation Language
$500,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to map habitat use and diseases of urban foxes and coyotes, evaluate risks these animals may pose to people and pets, and generate information needed to reduce human-wildlife conflicts.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This study provides information to residents and managers about coyotes and foxes. Our results reveal key insights, including about habitat requirements, the expansion of coyotes, and relationships between disease prevalence and free-roaming cats. They suggest outreach efforts to reduce free-roaming pets and management to increase natural vegetation in residential greenspaces.

OVERALL PROJECT OUTCOME AND RESULTS
Coyotes and foxes have not been studied in the Twin Cities Metro Area.

1. We captured, collared, and collected biological samples from 17 coyotes, 16 red foxes, and two gray foxes across the TCMA to assess space-use, survival, diet, and disease.
2. We found that coyote survival was greater than for red foxes, suggesting higher population growth. Canid attacks caused most fox mortalities, likely reflecting coyote population expansion and the presence of free-roaming dogs. Coyote and fox diets consisted of natural foods, with few individuals exhibiting diets associated with people. Toxoplasmosis gondii, a cat feces-transmitted a pathogen found in both coyotes and foxes, was especially frequent in red foxes, potentially due to fox selection of residential areas with more free-roaming cats. Higher heavy metal content in the hair of coyotes was likely a result of using industrial areas. Home range sizes suggest coyotes found resources more easily than red foxes. Den sites reflected the more general differences space-use; coyotes denned in non-residential areas while fox dens were in residential. We estimated 0.27 coyotes/km2 and 0.21 red foxes/km2; lower than in other cities.
3. Overall, our results suggest coyotes expanded into areas once occupied by red foxes, but both species rarely became nuisances. Outreach promoting leashing pets and keeping cats inside is likely to improve the health of pets, coyotes, and foxes. Communicating the smaller-than-expected weight (males=14.3 kg [31.5 lbs.]; females=11.9 kg [26.2 lbs.]) and low risk of attack should reduce negative perceptions of coyotes. Improving natural habitat in residential greenspaces is likely to benefit red foxes.
4. This study's results provide much-needed information to residents and wildlife managers about two charismatic species that are relatively unstudied in Minnesota.

PROJECT RESULTS USE AND DISSEMINATION
We delivered 17 presentations to colleges (e.g., Anoka Ramsey Community College and Macalester College), grade schools, and municipalities (e.g., Cities of Bloomington). We also provided 12 interviews to news outlets and podcasts (e.g., MPR, BBC, and Three Rivers Park District's "Wandering Naturalist" podcast), content for two Friends of the Mississippi River newsletters, and led over 60 volunteers into the field and coordinated with two UMN courses (60 students total). To further disseminate information, we created a University website, Facebook page, and iNaturalist page for the project, and we have drafted one scientific manuscript (set to be published this year).

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03i Den Boxes for Fishers and Other Nesting Wildlife - Research Project - $190,000 TF (FY2020)

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Appropriation Language
$190,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to build, install, and evaluate den boxes as habitat enhancement for fishers and other cavity-nesting wildlife in managed forests where a lack of large trees may be threatening population survival. The final outcome for the project must include guidelines and best practices for use of den boxes for fisher habitat.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Fishers used some den boxes, but it appears fishers find natural cavities to raise young. Den cavity availability alone is likely not causing the fisher population decline. Den boxes were used by many other wildlife species. Installing den boxes could be locally beneficial and increases public involvement with wildlife.

OVERALL PROJECT OUTCOME AND RESULTS
The fisher population in Minnesota declined by 50% from 2000-2015. Large cavity trees are critical habitat resources that female fishers use to raise kits. Previous research on fishers in Minnesota suggested that lack of large cavity trees could be one factor limiting the fisher population. We evaluated whether den boxes could provide critical habitat for fishers where natural cavities are rare. Our objectives were to build, install, and monitor fisher den boxes to describe use of den boxes by fishers and other wildlife, determine what factors influence whether fishers use den boxes, and to develop guidelines and recommendations for using den boxes to improve habitat. We built and installed 99 den boxes during fall and winter 2019-2020 and captured over 3 million images of wildlife visiting and using den boxes. Fishers visited 41% of den boxes and used 11% of den boxes on 43 different occasions. Use by fishers was lower than in other studies. Low use rates by fishers could indicate cavity availability is not limiting fishers, but additional work is needed to more fully understand why fisher use of den boxes was low and to evaluate other potential causes of the fisher population decline. Habitat suitability at den box sites was not associated with use by fishers. Fisher presence at den boxes increased over time, and fishers should continue to find and use den boxes in the future. Martens, red squirrels, gray squirrels, flying squirrels, and weasels also used den boxes to rest, store food, avoid predators, and care for young. Frequent use of den boxes by other wildlife demonstrates the value of den boxes to wildlife despite low use by fishers. Den box plans and guidelines we developed have allowed many members of the public to build and install their own den boxes, increasing public involvement with wildlife.

PROJECT RESULTS USE AND DISSEMINATION
We created den box building instructions and guidelines for den box installation. Throughout the project, we shared these documents directly with 120 members of the public and resource managers who requested information on the project. Project results were disseminated to technical and non-technical audiences through presentations, print and broadcast media, social media posts, and a Minnesota fisher den box project website we developed. Results are also summarized in a master's thesis. We are currently finalizing a technical report and three manuscripts using data from this project that will be submitted to scientific journals and shared with wildlife managers.

Project Completed: 6/30/2022
FINAL REPORT
Fisher Den Box Building Plans - 12 pgs
Fisher Den Box Instructions - 2 pgs

Subd. 03j Red-Headed Woodpeckers as Indicators of Oak Savanna Health - Research Project - $171,000 TF (FY2020)

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Appropriation Language
$171,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate red-headed woodpecker survival and habitat needs and to use this data to develop and disseminate a long-term oak savanna management plan that supports red-headed woodpeckers and other oak savanna habitat-dependent species.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our project results provide important information on the factors associated with red-headed woodpecker habitat use, survival, and productivity in savanna ecosystems, which can aid ongoing habitat management and conservation efforts intended to conserve and restore this species in Minnesota.

OVERALL PROJECT OUTCOME AND RESULTS
Red-headed Woodpeckers (Melanerpes erythrocephalus) are charismatic cavity-nesters that breed in savannas and open forest systems across the eastern and Midwestern United States and south central and eastern Canada. Historically, they were common across the Midwest, but populations have experienced dramatic regional declines. Habitat restoration initiatives have been challenged by a general lack of information on the factors that make savannas desirable for this species. With collaborators from the University of Toledo in Ohio, we studied red-headed woodpecker demography, habitat associations, and migration ecology from 2017 – 2020 in Ohio and Minnesota to elucidate critical periods, locations, life stages, and habitat characteristics associated with population growth rates and to provide habitat restoration and management recommendations for land managers and the public (separate funding sources for research in Ohio). Our results indicate that red-headed woodpecker productivity is higher in landscapes with both open and closed-canopy forest and that even in large stands of oak savanna, productivity near the center of those stands is predicted to be lower than in savanna closer to other forest types. GPS tracking data show detailed information on the migratory and overwintering locations and behaviors of adult red-headed woodpeckers, which, to our knowledge is the first reported data of its kind for this species in Minnesota. Our results provide information on snag density around nest trees, the importance of nest tree wood hardness, and habitat use by adult and fledgling woodpeckers. We have also gained considerable information on the community of predators that may impact red-headed woodpecker nest survival through our trail camera project, now hosted on Zooniverse. We have engaged with thousands of volunteers from around the world to share more about our research through our cavity camera project. Our best management practices are based on current results and we intend to update our recommendations in consultation with collaborators and other experts.

PROJECT RESULTS USE AND DISSEMINATION
We presented our research at professional conferences (the Annual meeting of the Minnesota Ornithologist's Union, the American Ornithological Society Annual Conference, and at the Toledo Museum of Natural History Forum on Local Natural History and Research). We also presented eight invited talks to public audiences through the University of Minnesota, Cedar Creek Ecosystem Science Reserve, multiple local Audubon Chapter organizations, and a Naturalist club in Brandon Manitoba in Canada. Our research project was featured in articles in the following newspapers and magazines: Terrain.org, University of Minnesota College of Biological Sciences, and the Minneapolis Star and Tribune.

We are also currently in the process of preparing three manuscripts for publication in the peer-reviewed, scientific literature focused on red-headed woodpecker nest survival and nest site selection, landscape productivity, and mating system:

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03n County Geologic Atlases - Part A, Mapping - $2,000,000 TF (FY2020)

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Appropriation Language
$2,000,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Minnesota Geological Survey, to continue producing county geologic atlases to inform management of surface water and groundwater resources. This appropriation is to complete Part A, which focuses on the properties and distribution of earth materials to define aquifer boundaries and the connection of aquifers to the land surface and surface water resources.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
County Geologic Atlases were completed in two counties and work continued in 17 counties. Based on the time spent, this is equivalent to "completing" about five atlases. Atlas maps and data provide foundational information that supports water management activities to the benefit of drinking water and aquatic habitat.

OVERALL PROJECT OUTCOME AND RESULTS
A Geologic Atlas provides the geologic framework of our state. It describes the materials and features at the land surface and extends all the way down to the bedrock surface. An atlas provides information useful for resource management and land-use planning. Each Atlas typically requires more than 7,000 person-hours of work. Some of that work is in the field: drilling test borings, examining, sampling, and

describing outcrops. Much of the work follows afterward: interpreting field measurements, recognizing and formally naming geologic units described in well records, and making maps. The result is a detailed account of the distribution and properties of the rock and sediment that lie below the land surface. These materials, and their ability to store or transmit water, determine where we can find water, and how we can protect and make wise use of that water. This includes our lakes and rivers as well as groundwater.

As part of this 2019 award, Rock and Nobles counties were completed. Over 8,000 well construction records, primarily located by County staff, were compiled into the database to support mapping, document water use in specific aquifers, and to help resolve well problems. Progress continued on mapping the bedrock and surficial geology, subsurface Quaternary stratigraphy, bedrock topography and glacial sediment thickness in 17 other counties. We've described hundreds of outcrops, taken thousands of hand samples, and drilled 13 continuous cores allowing us to sample rocks and sediment up to 300 feet deep.

Continuing under the M.L 2020 award, atlases for St. Louis, Aitkin, and Steele counties should be complete within the next three months. Lake, Ottertail and Lac Qui Parle counties should be finished within the next 12-18 months. Work on the remaining counties, Lincoln, Pipestone, Pennington, Cook, Yellow Medicine, Polk and Chippewa, will continue. The County Geologic Atlas program began in 1981 and continues with support of the Environment and Natural Resources Trust Fund as well as the Clean Water Fund, the Department of Natural Resources, and the U.S. Geological Survey. To date we have completed atlases for 46 counties, 29 are underway; and 16 have yet to be started. All of our mapping products and data are available in print or digital formats.

PROJECT RESULTS USE AND DISSEMINATION
Completed atlas products have been posted to the MGS website and linked to the University's Digital Conservancy as noted above. PDF products as well as all of the related GIS data are available on these pages. In addition, the MGS hosts an Open Data Portal on which many of our county geologic atlases are presented as "Story Maps" that allow for direct access of the data without any special software or interface.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03o County Geologic Atlases - Part B, Mapping Aquifer Hydrology - $2,400,000 TF (FY2020)

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Appropriation Language
$2,400,000 the first year is from the trust fund to the commissioner of natural resources to continue producing county geologic atlases to inform management of surface water and groundwater resources for drinking water and other purposes. This appropriation is for Part B, which uses the geologic formations mapped in Part A of the county geologic atlases to characterize the potential water yields of aquifers and the aquifers' sensitivity to contamination.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Groundwater Atlas provides foundational, science-based, information for use and management of Minnesota groundwaters. The atlas is valuable to government, industry, and for research. The grant supported work on nineteen atlases and publication of county groundwater atlases (County Atlas Part B) for Brown, Hennepin, Kanabec, Meeker, Morrison, Redwood, and Winona counties.

OVERALL PROJECT OUTCOME AND RESULTS
The Groundwater Atlas provides foundational, science-based, information for use and management of Minnesota groundwaters. The atlas is valuable to government, industry, and research. During the period of the grant, county groundwater atlases (County Atlas Part B) were published for Brown, Hennepin, Kanabec, Meeker, Morrison, Redwood, and Winona counties. Mapping activities also continued through the end of the grant in Aitkin, Becker, Cass, Dodge, Houston, Hubbard, Isanti, Kandiyohi, Nobles, Olmsted, Rock, and Wadena, with publication of completed groundwater atlases for Becker, Cass, Dodge, Houston, Hubbard, Isanti, and Wadena expected in 2023.

The following related reports were also published:

- The Karst Landscape Unit Map for Winona and Houston counties.
- Minnesota Groundwater Provinces 2021. This document is one of the most widely used reference documents from the Atlas Program.
- Groundwater Atlas Users Guide.

Groundwater sampling is a key element in the completion of an atlas. Sampling efforts necessarily slowed during the pandemic. However, groundwater sampling was completed in Dodge, Kandiyohi, Nobles, Olmstead, Rock, and Steele counties. Letter reports with all sampling results were provided to well owners for all wells sampled as part of this grant.

DNR Groundwater Atlas staff completed field work for the geophysical investigation of Pennington County as part of the atlas process. DNR Groundwater Atlas staff also completed planning for the geophysical investigations in fall 2022 of Douglas, Grant, Polk, and Red Lake counties.

As part of the atlas development process, DNR staff conduct reviews of draft County Geologic Atlases (Part A) prepared by the MGS. During the grant this included DNR reviews for Aitkin, Becker, Cass, Dakota, Lac qui Parle, Lake, Otter Tail, Steele and St. Louis.

Dissemination and outreach activities continued throughout the grant period including presentations, news releases, GovDelivery list serve (6,000 recipients) notifications, and virtual meetings with county staff and county boards, seminars, and presentations.

PROJECT RESULTS USE AND DISSEMINATION
Dissemination activities focused on notification of sampling activities and publication of atlases through

news releases and GovDelivery (6,000 recipient list serve), participation in seminars, presentations, and educational/technical field trips to a diverse set of stakeholders and resources managers including county SWCDs, county boards, the Clean Water Council, BWRS, MPCA, the Legislative Conference of Minnesota Counties, LCCMR events, and others. Dissemination also included workshops with counties, publication of summary articles, updated website and many personal contacts with users of the atlas. Atlas staff also worked closely with university staff to incorporate atlas materials in the classroom and to collaborate on projects.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03p Unlocking Science of Minnesota's Moose Decline - $199,000 TF (FY2020)

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Appropriation Language
$199,000 the first year is from the trust fund to the Minnesota Zoological Garden to develop educational displays, interactive exhibits, and engaging online programs that summarize and share scientific findings about moose decline in Minnesota. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Zoo gathered moose researchers to share their key scientific research findings about Minnesota's moose decline. The research findings were used to develop interactive interpretive features for the Zoo's moose habitat, an educational website, and an engaging online game that highlights the survival challenges influencing Minnesota's moose population.

OVERALL PROJECT OUTCOME AND RESULTS

The moose is an iconic Northwoods animal that has had an important presence in Minnesota and at the Minnesota Zoo. However, moose in Minnesota have experienced periods of dramatic population decline over the last 30 years. They have nearly disappeared from northwestern Minnesota. Since 2004, moose numbers have decreased by roughly 50% in the northeastern part of our state. Significant public resources have been invested in scientific research to understand Minnesota's moose decline. Many Minnesotans are keenly aware of the moose decline and want to know more about its causes and what can be done to help.

With ENRTF support, the Minnesota Zoo collaborated with researchers from across the state to identify key scientific research findings about Minnesota's moose decline and population dynamics. This project used those key research findings to develop interactive interpretive displays at the Minnesota Zoo's

moose habitat. A new, accessible, educational website was created to make the research findings available for broad virtual access. The website features basic moose natural history, information about moose research in Minnesota, and a custom, interactive game. The game encourages a user to experiment with habitat features to create a simulated environment where moose thrive. While the player attempts to manage for a healthy moose population over the course of a year, random, unexpected events occur. Players learn about some of the challenges wildlife managers (and moose) face in Minnesota.

The physical interpretive elements and online resources created from this project focus on complicated research findings in an engaging, accessible, and easily understandable fashion. These deliverables will be maintained by the Minnesota Zoo and will benefit learners of all ages for years to come.

PROJECT RESULTS USE AND DISSEMINATION
Through meetings, presentations and seminars, hundreds of Minnesota Zoo staff and volunteers have learned about Minnesota's moose decline and this ENRTF project. Thousands of guests have interacted with the interpretive elements created for the Zoo's moose exhibit. Thousands of people have also engaged with the virtual components resulting from this project.

Virtual components of this project include:

- Mission Moose website
- Aerial Moose Survey video
- Moose Research video

These online resources have been featured in professional newsletters, publications, listservs, websites and on social media platforms. The Dakota County Tribune also wrote an article about the Mission Moose website and game.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03q Forest and Bioeconomy Research - $2,200,000 TF (FY2020)

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Appropriation Language
$2,200,000 the first year is to the Board of Regents of the University of Minnesota for academic and applied research through MnDRIVE at the Natural Resources Research Institute to develop and demonstrate technologies that enhance the long-term health of Minnesota's forests, extend the viability

of current forest-based industries, and accelerate emerging industry opportunities. Of this amount, $500,000 is to support development of a forest optimization tool for Minnesota forest resources, $800,000 is for maintenance and expansion of the Natural Resource Atlas to statewide coverage, $400,000 is to the Minnesota Forest Resource Council for continued advancement of biochar development and application to forest health, and $500,000 is to advance emerging Minnesota technologies to produce clean syngas to drive high-value markets for forest biomass feedstocks.

Subproject 1 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Projections of Minnesota forest composition and associated ecosystem services were developed under different climate and management scenarios from 2020 to 2100. This information was made freely available through a custom website and interactive mapping tool, providing resource managers with critical information for planning.

Subproject 1 - OVERALL PROJECT OUTCOME AND RESULTS
Forest management is an increasingly complex discipline that requires the balancing of economics and ecology in the face of changing markets and climate. Beyond providing lumber, pulp, and other forest products, forests provide many additional goods and services that benefit society. Known as “ecosystem goods and services,” these include sequestering carbon, providing habitat for wildlife, maintaining water quality and quantity, and others. Understanding both how forests will change over time and how society values the goods and services they provide is critical to the successful management of Minnesota's forests.

This project was designed to provide projections of how forest composition and the goods and services that forests provide will change from 2020 to 2100 under different management and climate scenarios on 3,800,000 acres in northern Minnesota. It also helps users understand how Minnesotans value those forest goods and services. Foundational landscape change modeling was done using the LANDIS-II model, allowing for a better understanding of forest composition and carbon. Subsequent wildlife habitat and water quality and quantity modeling were done using the WHINGS and HSPF models, respectively. All models were run for each of the 12 unique combinations of our management and climate scenarios. Focus groups and surveys were used to quantify value.

Minnesota’s forest managers indicated that they would like to consider ecosystem services when making harvest and management decisions but lack the information to do so. The primary deliverable of this project is the Forest Change Assessment Simulation Tool, or ForCAST. This interactive mapping and decision support tool contains all of our projections of forest composition and associated ecosystem services and estimates of value, allowing for the development of informed, long-term management strategies that aren’t exclusively driven by the economics of timber markets.

Subproject 1 - PROJECT RESULTS USE AND DISSEMINATION
ForCAST, an interactive mapping and decision support tool developed as the main deliverable of this project, is freely and publicly available through the project website. The website also provides access to comprehensive project and methodology documentation. During development, awareness was raised about the project through presentations at the Minnesota GIS/LIS conference and a combined meeting of the Minnesota Society of American Foresters and the Sustainable Forests Education Cooperative’s (SFEC) Forestry and Wildlife Research Review. ForCAST was launched through a SFEC webinar in July 2022 with a subsequent training event scheduled through SFEC in September.

Subproject 2 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Natural Resource Atlas is an easy to use interactive mapping tool and spatial database that is freely available to all Minnesotans. It lowers or removes the barriers that prevent spatial data from informing the decisions that impact our state's natural resources.

Subproject 2 - OVERALL PROJECT OUTCOME AND RESULTS
Organizations and natural resources managers in Minnesota are often required to make decisions that impact our natural resources while using incomplete information. Spatial data contains valuable information that can improve decision making and outcomes. However, accessing it typically requires specialized software and advanced technical skills. The Minnesota Natural Resource Atlas was designed to be a statewide resource that improves access to spatial data and the information and insights that it contains.

The Atlas project was a statewide expansion and enhancement of an earlier version that served 27 counties in northeast and north central Minnesota. We worked closely with our original Atlas users, target users in the expanded geographic area, and our advisory committee to identify data and functionality needs. More than 500 additional data sets, with an emphasis on agriculture, forestry, and water resources, were developed or acquired. Functionality that allowed users to more easily visualize, analyze, and share data was developed, tested, and deployed. Improvements were also made to make the Atlas more robust, responsive, and reliable.

Training, outreach, and education were used to raise awareness of the project and expand Atlas users. Google analytics on the site indicate a growing user base with typical daily weekday unique visitors ranging from 60 to 100 and their locations distributed throughout the state, with the highest concentration in the Twin Cities metro area and Duluth. Internal software was developed that allows us to monitor which data is being requested and for which geographical area. This software indicates that water, natural and administrative boundaries, and biological data are the most frequently accessed and that users are viewing data for locations throughout the state.

The Minnesota Natural Resource Atlas is a valuable resource for the state. Ultimately, it is making spatial data more accessible for all Minnesotans.

Subproject 2 - PROJECT RESULTS USE AND DISSEMINATION
The Minnesota Natural Resource Atlas is freely and publicly available online. Dissemination through training, outreach, and education were key components of the project. Articles were contributed to relevant newsletters and publications to raise awareness, and free training sessions were offered to organizations throughout the state. Eight 15 to 30 minute project overview presentations that included Atlas demonstrations were also conducted. In total, 38 training or demonstration events were conducted with over 1000 individuals participating from conservation organizations, K-12 or post-secondary education, academia, and tribal, local, state, and federal governments.

Subproject 3 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Biochar is a material that can be produced from residual biomass that can improve soil health and reforestation while storing carbon for the long term in soils. This project demonstrated production and deployment of insect-damaged balsam fir and black ash as biochar to improve seedling regrowth and retain nutrients in sandy forest soils.

Subproject 3 - OVERALL PROJECT OUTCOME AND RESULTS

We demonstrated the concept of using Minnesota black ash and balsam fir as feedstocks for the generation of biochar for forest soil amendments to improve reforestation efforts. We produced biochars from both black ash and balsam fir wood chips at a variety of temperatures and characterized these by measuring different physical and chemical properties.

The fully-characterized biochar samples were evaluated in greenhouse plant growth studies. Biochars from black ash and balsam fir processed at 550°C were the most promising candidates for positive soil health improvements, as these products revealed a) the highest water holding capacities, b) minimization of potentially harmful mobile organics (extractives content), and c) greatest nitrogen and dissolved organic carbon retention. Field trials were then performed at the Cloquet Forestry Center to evaluate biochar impact on red pine and red oak seedling survival. Biochars were added to the soil surrounding newly-planted red pine and red oak seedlings using a randomized nested design with appropriate controls. Early results on photosynthesis and respiration rates from the field study are positive but conclusions on biochar's role on improving seedling survival will require long-term monitoring at the field site, extending beyond the end of this project.

We also produced two literature reviews. The first study examined net carbon sequestration potential of using biochar in forest regeneration projects and concluded that there is ample supply of black ash in Minnesota to support industrial-scale biochar production and that 20 years of biochar production in Minnesota, just from black ash, would sequester approximately 6.7 million tons of CO2. The second study was a techno-economic analysis performed by Dovetail Partners. This report concluded that the ecological and economical benefits of biochar implementation are best suited for revegetation efforts for jack and red pine in areas with sandy soils. This report can be found online: Dovetail Partners report.

Subproject 3 - PROJECT RESULTS USE AND DISSEMINATION

Toczydlowski, Alan JZ; Robert A Slesak; Rodney T Venterea; Kurt A Spokas. Effect of Biochar Feedstock and Pyrolysis Temperature on Nutrient Cycling in Forest Soil. 2021 ASA, CSSA and SSSA International Annual Meetings, Salt Lake City, Utah. Oral presentation November 7-10, 2021.

1. Reuling, Laura F; Alan JZ Toczydlowski; Robert A Slesak; Marcella A Windmuller-Campione. Effects of biochar on drought tolerance of Pinus banksiana seedlings. USFS National Silviculture Workshop, Kellogg, ID. Oral presentation July 12-14, 2022.
2. McFarland, Ashley; Fernholz,Kathryn; Groot, Harry. Biochar Potential in Minnesota's Forests. Commissioned Report 2021.
3. Singsaas, Eric. Engineering functional biochar for specific applications. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
4. Barry, Brian. A new approach for complete pore size distributions and regime-specific total pore volume determinations of biochars. North American Biochar & Bioenergy Conference, Morgantown, West Virginia. Oral Presentation August 8-11, 2022.
5. Singsaas E, Barry B, Kolomitsyna O, Kacharov O, Yemets S, Young M, Toczydlowski A, and Slezak R. 2022. Biochar from insect-damaged trees used as a forest soil amendment: production, characterization, and application. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/16.
6. Singsaas, E., Kolomitsyna, O., Kacharov, O., Young, M., and Barry, B. 2022. Biomass pretreatment to make clean syngas from Minnesota wood residuals. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/17

7. Wright, C. 2022. Biochar Production Scenarios in Minnesota Utilizing Ash (Fraxinus spp.) as a Feedstock. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/15

Subproject 4 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Synthesis gas (syngas) is a mixture of combustible chemicals that can be used to replace fossil fuels for industrial processes, hydrogen, and fuel production. This project demonstrated that forest residuals from insect-damaged trees can be pretreated to improve their conversion efficiency to make cleaner syngas.

Subproject 4 - OVERALL PROJECT OUTCOME AND RESULTS
Achievement of Minnesota's renewable energy transition and associated greenhouse gas (GHG) reduction goals requires development of non-fossil fuel alternatives for fuels and processes that are impractical to convert to electrical power. Key syngas applications include production of renewable diesel, jet fuel, and hydrogen, as well as direct use of syngas for production of iron and steel products. Our objective was to demonstrate that low-value forest biomass could be used to generate clean syngas for these markets in Minnesota by pretreating the biomass to improve its physical and chemical properties.

Our objective was to determine the best pretreatment conditions for one Minnesota biomass that would improve the yield of syngas components (H2, CO, CH4) relative to contaminants (tars) with the minimal processing temperature, time, and handling. Our results showed that addition of temperature and steam during pretreatment significantly reduced the tars produced during gasification, but with some loss in syngas yield. Therefore, we concluded that a mild steam treatment between 240-260°C with low residence time was optimal for pretreating black ash to make syngas.

Pilot-scale gasification trials on pretreated biomass was performed at the University of North Dakota Energy & Environmental Research Center, which ran pilot tests in their fluidized bed gasifier on eight different samples of black ash pretreated between 180 and 300°C and untreated biomass controls. The pilot results confirmed that pretreatment reduced tar production at the expense of reduced syngas yield. More importantly, however, the pilot tests showed that pretreatment improves the grindability of the biomass, making it easier to handle and feed to a gasifier.

These results demonstrate that renewable hydrogen, methane, or fuels can be made from Minnesota's biomass residuals by gasification, and low-temperature pretreatment will help.

Subproject 4 - PROJECT RESULTS USE AND DISSEMINATION
Singsaas E, Kolomitsyna O, Kacharov O, Yemets S, Young M, Barry B. 2022. Biomass pretreatment to make clean syngas from Minnesota wood residuals. Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2022/17.

Project Completed: 6/30/2022
FINAL REPORT
Subproject 1 Abstract
Subproject 2 Abstract

Subproject 3 Abstract
Subproject 4 Abstract

Subd. 03r Minerals and Water Research - $883,000 TF (FY2020)

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Appropriation Language
$883,000 the first year is to the Board of Regents of the University of Minnesota for academic and applied research through MnDRIVE at the Natural Resources Research Institute to develop and demonstrate technologies that enhance long-term Minnesota mineral opportunities. Of this amount:

(1) $300,000 is to support continued applied research to advance new technologies to improve water quality;
(2) $275,000 is to initiate the characterization of western Mesabi iron resources and development of next-generation Minnesota iron products;
(3) $158,000 is to develop emerging hydrometallurgy technology to support high-value mineral product development in Minnesota; and
(4) $150,000 is to support efforts of the Natural Resources Research Institute to accelerate demonstration of high-capacity, cost-effective energy storage using Minnesota's historical auxiliary mine lands.

This research must be conducted in consultation with the Minerals Coordinating Committee established under Minnesota Statutes, section 93.0015.

Subproject 1 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project provides a cost-effective process for treating wastewater to meet the wild rice sulfate standard of 10 mg/L. The data gathered from the field pilot trial at two wastewater treatment plants will help in implementing a full-scale treatment system to reduce sulfate level for protecting water resources in Minnesota.

Subproject 1 - OVERALL PROJECT OUTCOME AND RESULTS
The State of Minnesota adopted a sulfate standard of 10 milligrams per liter (mg/L) for wild rice waters in 1973. Compliance with this standard is a challenge for small industries and municipalities as membrane-based technologies typically require high capital and operation costs. The Natural Resources Research Institute (NRRI) has developed a mobile treatment system based on barite precipitation reactions to reduce sulfate levels. In this project, NRRI deployed the trailer-based modular

demonstration treatment system at two municipal wastewater treatment plants (WWTPs) in northeastern Minnesota to perform field pilot trials. The objectives of the field pilot trials were to:

1. Evaluate the efficacy of the chemical precipitation process at a flow rate of 1-2 gallons per minute with different wastewater sources (domestic and industrial wastewater);
2. Optimize the chemical reagent dosage levels; and
3. Estimate the chemical reagent costs.

The pilot tests were conducted using effluent from the Virginia WWTP and the Grand Rapids WWTP from June 2021 until October 2021. The Virginia WWTP treats domestic wastewater exclusively, and the resulting effluent has relatively steady sulfate concentrations of 60 mg/L. The Grand Rapids WWTP treats a mixture of domestic wastewater and industrial wastewater supplied from a regional paper mill with a sulfate level ranging from 85 to 115 mg/L. The pilot test results indicated that the chemical precipitation system consistently reduced the sulfate levels of both wastewaters to below 10 mg/L with optimal chemical dosage rates. The chemical costs were estimated to be $2.27 and $5.50 per thousand gallons of effluent from Virginia and Grand Rapids wastewater treatment plants, respectively. Information gained from the field trials was used to develop guidelines for the future design and operation of a plant-scale system.

Subproject 1 - PROJECT RESULTS USE AND DISSEMINATION
This project has produced materials of interest to a wide variety of stakeholders, including the researchers, city councils, wastewater treatment plant operators, and the community. Among these products are presentations, posters, and videos. Sulfate treatment research results were presented in three conferences (Minnesota Water Resources conference, The Society for Mining, Metallurgy & Exploration Inc. conference, and the International Mine Water Association conference), the Virginia City Council, and the University of Minnesota Duluth University for Seniors class. A YouTube video was created to describe the sulfate problem in Minnesota and our solution.

The full report is publicly available on the University of Minnesota Duluth Natural Resources Research Institute (NRRI) Website.

Subproject 2 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This study initiated a long-term characterization program of the iron resources in Minnesota. Analysis of two sections of the iron formation produced a better understanding of the variability and potential for developing new iron-based products. With continued support, this program will provide a foundation for the future iron industry in Minnesota.

Subproject 2 - OVERALL PROJECT OUTCOME AND RESULTS
Iron mining has been an important part of the economy of northern Minnesota for over a century. Today, mining companies process magnetite-rich taconite ore. Magnetite is important due to its chemical, magnetic, and thermal properties. All iron mining companies encounter magnetite that has been oxidized to various degrees. Minor amounts of oxidation can negatively impact the economic processing of iron ore, so oxidized material is either not mined or mined and stockpiled. Significant unoxidized parts of the iron formation are also stockpiled because they cannot be economically processed with current technology.

The purpose of this study was to initiate a long-term comprehensive characterization program of the

remaining iron resources of the Mesabi Iron Range to provide a foundation for future iron industry in Minnesota. This data is being used to direct research in the areas of reducing reliance on fossil fuels, reducing emissions, and to identify and develop value-added iron products that could be produced from under-utilized portions of Minnesota iron resources. This approach can also be applied to understanding and processing waste iron stockpiles. This study has been leveraged to obtain additional State and Federal support for other mineral related studies in Minnesota.

Two complete sections of the iron formation were analyzed in this study. The results have contributed to a better understanding of the mineralogical variability within the iron formation; the impacts of oxidation on iron product quality; the potential for new iron-based products; and the presence of trace elements. Furthermore, this study also indicated that there may be a significant resource of siderite, an iron carbonate mineral, on the Mesabi Range. While siderite is unlikely to be a primary source of metallic iron, there may be other applications for siderite. Future research will focus on opportunities to reduce environmental impact while creating value-added iron products in Minnesota.

Subproject 2 - PROJECT RESULTS USE AND DISSEMINATION
Presentations

- Minnesota Minerals Coordinating Committee 2021 Virtual Cloquet Workshop Agenda Lightning Talks (4/23/2021)
- SME Minnesota Conference 2022 Presentations (4/13/2022)
- Minnesota Iron Ore and the Green Economy webinar (3/16/2022)

- Articles
  - Business North: 'Iron of the Future' program looks to new iron making technologies, Lee Bloomquist Sep 16, 2021 Article.
  - Business North: A bright future for mining, Lee Bloomquist Dec 27, 2021 Article.
- Technical Report
  - Johnson, R.C., Mlinar, M.A., Spigarelli, B.P., Post, S. Western Mesabi Iron Resource of the Future. Natural Resources Research Institute. September, 2022. Report NRRI/TR-2022/11.

Subproject 3 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Based on outcomes of "voice of customer survey" and funding opportunities available through federal agencies, the project has identified emerging hydrometallurgical innovations with potential for processing Minnesota's in-situ and waste mineral resources with a reduced water, energy, and environmental footprint. The project has also identified bench-top hydrometallurgical research equipment required to initiate development of next generation value-added products from under-utilized and under-valued in-situ mineral and waste resources in Minnesota, specifically low-grade ores, waste tailings, metallurgical residues, incinerator ash, power plant combustion residues, and waste electrical and electronic equipment.

Subproject 3 - OVERALL PROJECT OUTCOME AND RESULTS
Minnesota has abundant in-situ mineral resources, including deposits of iron, iron manganese, copper-nickel-cobalt-platinum group elements, titanium-vanadium, copper-zinc, gold with and without silver, sand, and aggregate. Commercial and industrial byproducts such as mine tailings, industrial residues, and waste electrical and electronic equipment also contain valuable mineral resources. To address significant environmental impact concerns associated with mining, collection, and processing of these

materials, new processing technology approaches with reduced water and energy consumption and minimal environmental footprints are needed to support production of value-added products. Emerging hydrometallurgical processing technologies offer promising opportunities. To evaluate the technical, economic, and environmental benefits of emerging hydrometallurgical innovations, the Minnesota Legislative-Citizen's Commission on Minnesota Resources provided funding to the Natural Resources Research Institute (NRRI) to evaluate how to best support the development of emerging hydrometallurgical technologies in the state. The study highlights Minnesota's mineral and waste resources that have the highest potential for hydrometallurgical processing. The report also highlights key challenges anticipated by stakeholders during the commercial development of mineral and waste resources using hydrometallurgical technologies. The emerging hydrometallurgical innovations that may resolve various challenges are also identified by means of the stakeholder engagement survey and funding opportunities available through the federal agencies. The report summarizes research priorities that support development of emerging hydrometallurgical technologies in applications ranging from high-value materials to water remediation to carbon sequestration. The report shortlists key bench-scale and semi-pilot laboratory tools that will help NRRI to advance the readiness level of emerging hydrometallurgical technologies in Minnesota. The capital estimates for bench-top and semi-pilot laboratory prototypes range from $600,000 to $1.2 million. The personnel, installation, and collaboration costs range from $300,000 to $400,000.

Subproject 3 - PROJECT RESULTS USE AND DISSEMINATION
NRRI conducted a "Voice of Customer" survey through interviews with a broad range of stakeholders around the country. These included current or prospective mineral/metal producers, metal recyclers, hydrometallurgical R&D labs, engineering and technology providers, consultants, academia and educators, regulators, and federal agencies. The study produced a report of investigations of interest to wide variety of stakeholders, including regulators, mineral rights holder, federal agencies, prospective manufacturing and resource extraction companies, and the community.

Technical Report: Rao, S., Mlinar, M., Hudak, G., Kangas, K., and Peterson, D., 2022. Developing Emerging Hydrometallurgical Technologies: Report to the Legislative-Citizen Commission on Minnesota Resources. Natural Resources Research Institute, University of Minnesota Duluth, Report of Investigations NRRI/RI-2022/10. 179 p.

Subproject 4 - SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The purpose of this project was to provide a technology survey and a geographical recommendation of potentially feasible, non-battery, long-duration energy storage technology concepts that can utilize Minnesota's various topographies, geologies, and infrastructure to facilitate the state's renewable energy and greenhouse gas reduction goals. Numerous technology concepts with related siting recommendations are reported for consideration by state leaders.

Subproject 4 - OVERALL PROJECT OUTCOME AND RESULTS
Achievement of Minnesota's renewable energy transition and associated greenhouse gas reduction goals requires development and installation of both short- and long-term energy storage capability. Battery storage options (lithium batteries) readily provide 2-4 hour duration storage. Longer-term (>8hr), high-capacity (35-200 milliwatt) storage can better facilitate capture of available renewable energy and potentially eliminate the need for natural gas-based peaking plants to provide a more stable electrical supply when intermittent resources (e.g., solar or wind) cannot supply the necessary electricity. Non-battery options harnessing physical principles involving gravity, compressed gas, waste

heat and chemical processes can offer storage options with long lifetimes that do not require access to critical minerals and may offer safety improvements. Many of these options are in the development or demonstration phase and can take advantage of Minnesota's natural and man-made (former mine workings) topographical and geological features.

The project consisted of two parts. The first was a thorough survey of existing and emerging long-term, high-capacity, non-battery storage technologies with potential for applications in Minnesota. This entailed engagement with technology leaders, onsite concept evaluations and discussions with energy industry collaborators to characterize each technology. Identified technologies ranged from concepts that take advantage of mineland topographic features in northern Minnesota to others that could be deployed in municipalities or metropolitan areas. This information was collated into a summary format including industry contacts for each concept to facilitate follow-up by the state and/or industry.

The second part of the project entailed development of an interactive mapping tool to identify areas in the state where each identified technology might best be suited, considering the local topography, geology, and proximity to distribution infrastructure, industry, and applicable brownfield areas. This tool shows that there are multiple non-battery storage options in regions across Minnesota, primarily located in the vicinity of distribution infrastructure.

Subproject 4 - PROJECT RESULTS USE AND DISSEMINATION
The full report and three appendices are publicly available on the University of Minnesota Duluth Natural Resources Research Institute (NRRI) Website. NRRI:

- collaborated with Clean Energy Resource Teams (CERTs) personnel to organize two presentations to state stakeholders (agency, industry, academia, government) to communicate report findings and solicit feedback;
- presented to DER Energy Storage Workgroup meeting with Great River Energy and support from CERTs;
- was presented at a Minnesota House Climate and Energy Finance and Policy Committee hearing on renewable energy generation and storage; and
- Continues conversations with Minnesota Department of Commerce in conjunction with CERTs and University of Minnesota colleagues to model energy storage opportunities.

Project Completed: 6/30/2022
FINAL REPORT
Subproject 1 Abstract
Subproject 2 Abstract
Subproject 3 Abstract
Subproject 4 Abstract

Subd. 04 Water Resources

Subd. 04c Wastewater Nutrient Reduction through Industrial Source Reduction Assistance - $200,000 TF (FY2018)

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Appropriation Language
$200,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to provide technical assistance for industrial facilities to optimize their processes, reduce nutrient loads to wastewater treatment facilities, and improve water quality. The economic savings and water quality improvements achieved through this work must be documented.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project explored ways to keep Minnesota surface waters at high quality and make municipal wastewater treatment easier by reducing nutrient load sent to wastewater facilities by applying source reduction technical assistance at upstream industrial sites.

OVERALL PROJECT OUTCOME AND RESULTS
Nutrient pollution refers to the presence of excess nitrogen and phosphorus in water and is a major environmental concern. High nutrient levels promote plant growth that can result in eutrophication, algal blooms, or the creation of 'dead zones' in bodies of water where beneficial aquatic life cannot thrive. Wastewater treatment facilities are critical infrastructure sites purposed with reducing nutrient levels in wastewater to levels safe for the environment.

Wastewater treatment operations work hard to discharge high quality treated water. In areas of increasing community growth and industrial expansion, the wastewater infrastructure may not be able to keep up with treatment needs. When discharge exceeds the treatment capacity, communities have few choices: they can regulate load sent to the treatment plant limiting community growth or invest in costly new infrastructure.

The purpose of this project was to explore a third option to improve water quality by reducing nutrient pollution discharged by industrial facilities to municipal wastewater treatment facilities. This reduction is supported by source reduction technical assistance at the industrial site. The primary activities of this project included:

- Engaging industrial facilities in communities with high nutrient discharge;
- Providing technical assistance to identify and implement nutrient reduction; and
- Sharing strategies for industrial nutrient reduction with additional facilities.

By promoting strategies for upstream nutrient source reduction, the treatment intensity needed to meet wastewater discharge requirements may be reduced. This could reduce operating costs and possibly postpone or eliminate capital investment needs for treatment expansion projects. Key outcomes of this project include:

- Completed eight facility assessments that investigated nutrient reduction;
- Completed four intern projects with recommendations for nutrient reduction;

- Implemented 14,730 lbs of nutrient reduction or 67% of the identified opportunity;
- Developed a guide for wastewater operators to identify practical nutrient reduction options; and
- Delivered a webinar highlighting successful upstream nutrient reduction practices.

PROJECT RESULTS USE AND DISSEMINATION
Since nutrient pollution in wastewater can be a challenge for many treatment facilities and treatment costs can drain community resources, MnTAP created two resources to share the strategies developed and tested during this project. A webinar was created featuring wastewater sites and businesses that participated in activities to reduce discharge nutrient. Speakers provided perspectives on nutrient challenges and the value in collaboration. A guide was created to provide wastewater operators and community leaders with a framework for identifying and addressing opportunities to reduce nutrient pollution at the source and save of treatment costs. Four intern project summaries are posted on the MnTAP website for Kerry Ingredients, August Schell Brewing, Minnesota Specialty Yeast and Rochester Meats.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04d Quantifying Microplastics in Minnesota's Inland Lakes - Research Project - $200,000 TF (FY2018)

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Appropriation Language
$200,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to quantify the amount, type, and source of microplastics in the water, sediment, and fishes of a range of Minnesota lakes.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project has helped to determine the sources and fate of microplastics in inland lakes in Minnesota. This includes differences in loading between different watersheds and ecosystems, and differences in ingestion by different fish species.

OVERALL PROJECT OUTCOME AND RESULTS
When this project was funded, our goal was to determine the amount and fate of microplastics in a set of Minnesota lakes that represent a variety of different types of watersheds, degrees of human influence, and ecosystem characteristics. Our partnership with the MN DNR Sentinel Lakes program allowed us to target lakes that already had long-term study data available, including mapped watersheds, lake temperature and residence time, and known fish populations. This three-year project sampled water column particulates, sediments, and fish (cisco, bluegill, and perch) from four Sentinel lakes in Minnesota (Peltier Lake, White Iron Lake, Ten Mile Lake, and Elk Lake) over the course of two

summer field seasons. All four lakes contained microplastics in the water, sediments, and fish, indicating that like other locations throughout the world, microplastic pollution is widespread in the state. Our findings further indicate that the biggest drivers that increase microplastic loadings into lakes are more human infrastructure and building in the watershed, a longer water retention time, and more shoreline development. There appears to be little connection between concentrations of microplastics in the water column and sediments, though more research will be needed to confirm. Finally, filter feeding fish (like cisco) have increased gut microplastic concentrations with increased water column microplastic concentrations, though visual feeders (like bluegill and perch) do not and appear to be able to distinguish plastics from food in the water column. Taken together, these first results from Minnesota inland lakes provide clear information for scientist and managers and further give Minnesota residents vital information about the health of their inland lakes. All data from this project will be accessible on our project website once publications have been prepared.

PROJECT RESULTS USE AND DISSEMINATION
Results from this project have been disseminated to the scientific community through meeting presentations and scientific publications currently being prepared. We have maintained a project website that is available to the public, and which we have advertised in our outreach to the Lake Associations associated with our project lakes. Our website has information about our project, videos from public webinars, and will have data from our scientific publications once those are published. Our collaboration with scientists at the MN DNR has meant that the Sentinel Lakes program has access to our project data along with any interpretations or project publications.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04i Extracting Deicing Salt from Roadside Soils with Plants - Research Project - $360,000 TF (FY2018)

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Appropriation Language
$360,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to collaborate with the Department of Transportation to evaluate potential native plants that can be grown on roadsides to adsorb and remove toxic salts accumulated from deicing roads and assess uses for the harvested material.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project screened and evaluated several halophytic plants that can extract sodium chloride, the deicing salt, from soil, and accumulate it into the leafy biomass. The information can be used to develop

phytoremediation methods to address the environmental pollution caused by the application of roadside deicing agents.

OVERALL PROJECT OUTCOME AND RESULTS

Massive applications of road salts to melt the snow and ice on sidewalks and roads can negatively affect the health of surrounding ecosystem as the salts are leached into lakes, rivers, and groundwater, causing significantly increased salinity and high salt conditions can also negatively affect both plant growth and soil structure. Many agricultural fields have similar concerns over the growing salinity in the soil, especially under the conditions of prolonged drought and improper irrigations. We collaborated with the Minnesota Department of Transportation (MnDOT) to screen and evaluate several halophytic plants that can extract sodium chloride, the deicing salt, from soil, and accumulate it into the leafy biomass. The information can be used to develop phytoremediation methods to address the environmental pollution caused by the application of roadside deicing agents. The research detailed in this project showed that common sunflower and pitseed goosefoot so far are the most promising species for phytoremediation of deicing salt. It is recommended they be mixed in with perennials from MnDOT's seed mixes to improve soil structure and help prevent the salt from reaching the soil surface or the groundwater. Another high salt accumulating plant species, sugar beet and beets in the other cultivar groups, are more suited for agricultural and thus could be used to remediate salt from the growing number of salt-impacted agricultural fields. The harvest and utilization of each of these plants can provide additional value such as animal feed, oil, or reuse of salt in ash if burned for energy. This project and the following phytoremediation method developments can provide a long term sustainable solution to the de-icing salt pollution to our Minnesota environment.

PROJECT RESULTS USE AND DISSEMINATION

The detailed research results are in the final report, and we are drafting two manuscripts for possible publications. Leif was accepted for presenting this work at AIChE Annual Meeting in November 2022 in Phoenix, Arizona and he was invited to give a presentation at the MECA (Minnesota Erosion Control Association) Annual Conference in January 2023. We have been working at MnROAD site with support and help from MnDOT. Cindy Dorn, writer/producer with Prairie Sportsman, an outdoor show produced by Pioneer PBS that airs on all Minnesota PBS stations is drafting a story on absorbing deicing salts with plants.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04k Accelerating Perennial Crop Production to Prevent Nitrate Leaching - $440,000 TF (FY2018)

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Appropriation Language
$440,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Stearns County Soil and Water Conservation District to reduce nitrate leaching on sandy soils of central Minnesota by developing water-efficient production methods, supply chains, and end-use markets for three perennial crops: Kernza, prairie species, and alfalfa. Net income from the sale of products or assets developed or acquired through this project may be reinvested as described in the work plan approved by the Legislative-Citizen Commission on Minnesota Resources according to Minnesota Statutes, section 116P.10.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Perennial cropping systems that include Kernza and alfalfa are effective in reducing nitrate leaching in sandy soils of Central Minnesota. Improved Kernza value chains for food, beverage and non-food have increased interest from farmers, food processors and consumers. The potential for Kernza production to provide future ecosystems services is great.

OVERALL PROJECT OUTCOME AND RESULTS
The City of Cold Spring in Central Minnesota has long struggled with increasing nitrate concentrations in its public water supply. Perennial cropping systems may reduce the amount of nitrate leached into groundwater. In partnership with the University of Minnesota Forever Green the project measured nitrate leaching under three perennial plant systems: 1) native prairie, 2) intermediate wheatgrass (Kernza), and alfalfa under irrigation and dryland plots. This research was conducted at the Rosholt Research Farm in Pope County (managed by the Pope Soil and Water Conservation District). The site has similar sandy soils as in the Cold Spring area. The native prairie planting had limited growth during study because of its slow growth and weed pressure. The perennial cropping systems that included Kernza and alfalfa were effective in reducing the nitrate concentrations in groundwater. Kernza was slightly more effective than alfalfa. Averaged across the growing season, the concentration of nitrate in the soil water measured by lysimeters was 0.64 mg/L, which is consider very low and like other reports below Kernza. It was also discovered that Kernza grain yields were highly affected by drought conditions in 2021, even under irrigation, significantly reducing yields. In partnership with the Agricultural Utilization Research Institute (AURI) value chains for Kernza were explored which will ultimately increase demand for production by farmers. Local breweries and bakeries developed products that provided valuable feedback for new product development. Field day attendance indicated that farmers were interested in growing more Kernza if a market exists. Also, consumers in attendance were interested in Kernza food and beverage products. In addition, both food and non-food value chains will need additional investment to fully develop the market. Kernza production in drinking water supply management areas could reduce nitrate leaching. This could save cities millions of dollars in water treatment costs.

PROJECT RESULTS USE AND DISSEMINATION
The SWCD's final grant report is posted online. The full AURI report is also available online. University of Minnesota will be preparing a peer-reviewed report to be submitted as a future addendum to this report. Several field days and outreach events were completed during the project period, information about which are included in the SWCD final report.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04m Setting Realistic Nitrate Reduction Goals in Southeast Minnesota - Research Project - $350,000 TF (FY2018)

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Appropriation Language
$350,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to develop advanced water-flow and age-dating tools to improve the ability of state agencies to assess how well nitrate reduction best management practices are working in southeastern Minnesota.

Sound bite of Project Outcomes and Results
The long travel time of nitrate in groundwater negatively impacts our ability to assess the effectiveness of best management practices to reduce the nitrate contamination of groundwater resources. This project developed field monitoring and modeling tools to quantity nitrate travel time and enhance the ability to assess BMP effectiveness.

Overall Project Outcome and Results
Nitrate contamination of groundwater resources results from land management practices that ineffectively control the balance of nitrogen in the soil. This inadequate control leads to excessive leaching of nitrate from the soil, eventually loading the groundwater aquifers underlying the managed area. Best Management Practices (BMPs) have been developed to reduce the leaching of nitrate from the soil profile, and this should then have a positive impact on the quality of water in the groundwater aquifers located in the area of BMP presence. The response of the nitrate concentration at a given location in an aquifer, say for instance at a private or municipal well, will be affected by the history of landuse activity in the landscape upgradient (upstream) of the location of concern. The history is important because of the lag time, that is, the travel time (on the order of years to centuries) required for contaminated water to flow in the groundwater from the point of contamination to the well. This lagging of the response of the nitrate concentration at the well confounds the interpretation of the causes for the nitrate found in the well, thereby making it difficult to determine whether BMPs implemented in upgradient fields are actually working effectively. This project involved the development of methodologies to quantify the lag time for groundwater to flow from a landscape point to a well. The methods developed involved using chemical tracers to quantify the age of groundwater collected at wells, and development of models that can be utilized to calculate lag times. With this information, and a history of landuse practices on the landscape it is then possible to evaluate the effectiveness of BMPs in the landscape. It is also possible to identify, with some degree of certainty, the source of nitrate that is contaminating a given well.

Project Results Use and Dissemination

The project involved an ongoing collaboration with Mr. Kevin Kuehner, director of the Field-to-Streams Partnership in Preston. A complex groundwater model we developed for Trout Brook is being shared with the Dakota County SWCD to assist with the assessment of BMPs for reducing nitrate concentrations in Trout Brook. A simplified model of groundwater flow and chemical transport was developed to facilitate relatively easy assessment of the effect of landuse practices, and will be available to consultants, agency personnel, and academic institutions. The project has resulted in the submission of follow-up research proposals to one federal agency and one non-profit institution.

Project Completed: 6/30/2022
Work Plan

Subd. 04n Mapping Unprofitable Cropland for Water and Wildlife - Research Project - $100,000 TF (FY2018)

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Appropriation Language
$100,000 the first year is from the trust fund to the Science Museum of Minnesota for the St. Croix Watershed Research Station to conduct the first statewide analysis that maps the extent of Minnesota's unprofitable cropland and estimates both the water-quality and habitat benefits of converting these lands to perennial crops and vegetation. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project mapped an estimated 550,000 acres of unprofitable cropland in southern Minnesota. It was then estimated that converting 20% of these acres could significantly improve stream health and wildlife habitat.

OVERALL PROJECT OUTCOME AND RESULTS
Despite investing millions of dollars on agricultural conservation, the health of southern Minnesota's streams and rivers has not improved demonstrably. At the same time, increases in agricultural cropland have resulted in dramatic declines in grassland habitat critical for migratory birds, butterflies, and pollinators. An approach for improving both stream health and wildlife habitat lies in replacing portions of southern Minnesota's agricultural land with prairie and wetlands. However, most cropland is profitable and thus too costly for a farmer to take out of production. But what about parts of crop fields that often too wet or too dry to turn a profit - could these be replaced with prairie or wetlands more economically? This project set out to answer the following questions: 1) How much corn and soybean cropland in southern Minnesota is unprofitable? 2) What are the environmental benefits of converting portions of this unprofitable cropland to prairie or wetlands? Our project used county agricultural

financial data and detailed soil maps to pinpoint an estimated 550,000 acres of unprofitable cropland in a 40-county region of southern Minnesota. Next, the project estimated the improvement to streams and wildlife habitat if the most unprofitable of these acres located next to streams (114,000 acres) were converted to prairie or wetlands. The results suggest that targeting unprofitable croplands in this way would significantly improve stream health and wildlife habitat in southern Minnesota and provide a good bang for the buck. The project outcomes are intended to be useful for the public and policymakers to understand the amount and distribution of unprofitable cropland in southern Minnesota and its great potential for improving environmental health in an economical way.

PROJECT RESULTS USE AND DISSEMINATION
The project content was presented at several Science Museum member events over Zoom. And in October 2022, the work will be presented at the MN Water Resources Conference, a premier venue for this type of research.

The results of this project including the GIS files and attached fact sheet will be linked from this Science Museum website when our new web portal is up and running fall of 2022. Interested visitors will be able to download the GIS files and conduct their own analyses based upon those in the study. Announcements about these deliverables and about the key points and highlights of the project will be shared on the Science Museum's social media accounts in fall 2022.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04o Evaluating Locally Sourced Materials for Road Salt Reduction - Research Project - $162,000 TF (FY2018)

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Appropriation Language
$162,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to evaluate the effectiveness and benefits of using locally sourced wood chips, corncobs, and iron-bearing minerals as alternative abrasive materials to lower salt use for protecting Minnesota's water resources. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project evaluated local ecological abrasive materials for use as alternative materials to lower road

salt use in winter maintenance and consequent environmental impacts. The findings are useful for the development of the formulation and application practice for both water resource protection and safe winter roadway.

OVERALL PROJECT OUTCOME AND RESULTS

The use of chloride-based salt as a deicer for winter road maintenance has been a longstanding practice throughout the state of Minnesota and the country. However, once chloride enters the water, it is not naturally broken down, transformed, or removed from the environment, resulting in accumulation in the watershed and detrimental ecological and water quality impacts in freshwater systems. To protect freshwater resources and to prevent this issue from worsening with time, an alternative method for providing sustainable and effective winter road maintenance is needed. In some cold regions of Minnesota, sand is mixed with salt as an abrasive to provide additional traction to the roads; however, its effectiveness is not well established. This project investigated the potential of regionally available organic and inorganic industrial byproducts as alternatives to conventional sand and salts. Candidate materials include corn grit, timber waste, and taconite waste rocks local to Minnesota. Chemical and physical properties of the materials were characterized, including material elemental composition, morphology, particle size distribution, and specific gravity to establish a foundational understanding of the material. Skid resistance and deicing tests with environmental impact assessment were performed to evaluate traction effectiveness and material safety. The results showed potential for bio-based materials such as corn grit and bark mulch as a sorbent for salt brine deicer with less salt impact and for the waste iron-bearing minerals to be used as effective abrasives in the realm of winter road maintenance. The use of alternative materials for winter road maintenance show promise for lower environmental impact, lower/controlled chloride pollution, increased friction enhancement, and beneficial reuse of industry waste material. In addition, this work provided a streamlined method for evaluating potential abrasives/deicers which will be valuable for expediting future studies of alternative materials.

PROJECT RESULTS USE AND DISSEMINATION

The project findings have been disseminated via reports to LCCMR, master student's thesis, and presentations at regional conferences (Minnesota Water Resources Conference and UMD seminar series). The project findings were shared with the public through public outreach activities for 6th-12th graders and general audience: engineering discussion with middle school students of Arcadia Charter School, Northfield, MN and a video clip, Safe Roads and Healthy Water to present and discuss our project for achieving safe roads and healthy water using local materials for the UMD's STEM Discovery Day.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04p Minnesota Spring Inventory Final Phase - $71,000 TF (FY2018)

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Appropriation Language
$71,000 the first year is from the trust fund to the commissioner of natural resources to complete the Minnesota Spring Inventory that identifies, catalogs, and assists resource managers in monitoring, assessing, and protecting important and threatened statewide water springs. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Springs are natural points of groundwater discharge that provide flow for trout streams and cool water fisheries, base flow during to streams, and unique ecological habitats. Management of this resource is only possible when we know their location. The MSI project located and makes available information on over 7,200 springs.

OVERALL PROJECT OUTCOME AND RESULTS
Springs are natural points of groundwater discharge that provide flow for trout streams and cool water fisheries, base flow during to streams, and unique ecological habitats. Management of this resource is only possible when we know their locations and characteristics. The primary objective of this project was to find unmapped springs, add the location of those new springs to the existing Minnesota Spring Inventory (MSI) and field verify and characterize as many currently mapped but unverified springs as possible.

For the project, DNR conducted field investigations of targeted parts of the state to find, characterize and map new springs locations. The existing MSI database also held 'non-verified' spring locations added to the database from old maps and studies and from the MSI Citizens App. DNR conducted 'field verification' by traveling to many of those features to confirm their existence and update the database. Approximately 350 spring locations were added to the MSI through the Citizen App.

The Covid-19 Pandemic and Minnesota's Stay Safe at Home order limited MSI fieldwork for over twelve months of the two-year project. When restrictions were relaxed in 2021, fieldwork resumed for the MSI team and many springs and features were added the database.

Because of this project (all phases), Minnesotans benefit by having easy access to approximately 7,200 features in the MSI including a combination of field verified springs, and many likely, but non-verified spring locations. The MSI project resulted in a 76% increase in mapped springs and increased from holding verified springs in 22 counties, primarily in the southeast, to verified springs located in 71 counties.

The DNR established special MSI accounts for MPCA and SWCD field staff from the Duluth/ Northern MN region and provide guidance documents and training, allowing them to add springs directly to the MSI using the Survey 123 application.

PROJECT RESULTS USE AND DISSEMINATION
DNR conducts dissemination through individual contacts, presentations and news releases. One example is online at St. Croix 360. Another example came from an environmental consultant in a June 2021 email:

"Can (you) help assist with information gathering regarding seeps & springs in the St Paul area. I'm working with the Capitol Region Watershed District to identify springs within their boundary, and prioritize the springs in order of level of prevalence/risk to become a public comment or threat to infrastructure."

The spring data is accessible at Minnesota Spring Inventory and GIS files are at the Minnesota Geospatial Commons, and at Showcase.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04q Restoring Impaired Lakes through Citizen-Aided Carp Management - $106,000 TF (FY2018)

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Appropriation Language
$106,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Carver County Water Management Organization to quantify water quality improvements and the cost-effectiveness of a new citizen-aided carp management method for restoring impaired lakes in Minnesota.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 05 Technical Assistance, Outreach, and Environmental Education

Subd. 05a Expanding Camp Sunrise Environmental Program - $237,000 TF (FY2020)

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Appropriation Language
$237,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with YouthCare Minnesota to expand camp opportunities to more school districts and implement improved hands-on environmental education programs for economically disadvantaged youth.

Note: Dollars returned

Project Completed: 6/30/2022

Subd. 05c Mississippi National River and Recreation Area Forest Restoration - $199,000 TF (FY2020)

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Appropriation Language
$199,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Mississippi Park Connection to work with Conservation Corps Minnesota, local communities, and volunteers to address the loss of ash trees to emerald ash borer by planting approximately 15,000 native trees and plants in affected areas in the Mississippi National River and Recreation Area.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Mississippi Park Connection and its partners planted 15,069 native trees and shrubs in the Mississippi National River and Recreation Area to address tree canopy loss due to Emerald Ash Borer. The project also established a Mississippi River Crew with the Conservation Corps of Minnesota and Iowa and engaged volunteers.

OVERALL PROJECT OUTCOME AND RESULTS
Emerald ash borer (EAB) is a small insect without natural predators that is killing up to 99% of all native ash trees in the Twin Cities Metropolitan Area. In parklands with large natural areas, dying ash trees are creating hazardous conditions for park visitors and creating a gap in the canopy as they die. These canopy gaps are negatively impacting wildlife habitat along the Mississippi River. This project aimed to identify areas where ash trees were being lost to Emerald Ash Borer and support overall forest ecosystem health by planting a diverse set of native trees and shrubs to support the ash-elm-mixed-hardwood ecotype within the Mississippi National River and Recreation Area. Major outcomes achieved during the project include:

1. 15,069 native trees and shrubs were planted in the ash-elm-mixed-hardwood forests of the Mississippi National River and Recreation Area (MNRRA) in order to address tree canopy loss due to Emerald Ash Borer.
2. Trees were protected from herbivory through the installation of tree tubes. Additional measures to support establishment, like watering and the removal of encroaching understory, were also performed.
3. We conducted 246 plant surveys throughout the grant period and worked in 52 different parks within MNRRA. Working in those parks, we consulted with the land managers to identify where EAB infestations had occurred and, throughout the course of the grant, monitor the progression of the infestations. Dead ash trees in areas of high habitat value were kept when possible for habitat and removed as necessary in order to create gaps in the canopy for future plantings. Hazardous ash trees were also removed at the request of land managers. Protocols for working in forested areas with high levels of canopy loss due to EAB are currently being developed as a direct result of working in these late-phase infested forests.

PROJECT RESULTS USE AND DISSEMINATION
The work received recognition in a Star Tribune Article. We also talked about this work in Mississippi Park Connection's e-newsletters, which has 8,806 subscribers. We also celebrated this work in an Earth Day virtual event with over 70 registrants. Finally, we worked with thousands of volunteers who learned more about Emerald Ash Borer and forests and the support that LCCMR has provided to this project. This work is also highlighted on Mississippi Park Connection's website. We created a video describing the work of the Mississippi River Crew. A document regarding natural resource professional safety working in EAB-affected forests is forthcoming.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 06 Aquatic and Terrestrial Invasive Species

Subd. 06b Oak Wilt Suppression at its Northern Edge - $100,000 TF (FY2020)

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Appropriation Language
$100,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Morrison Soil and Water Conservation District to eradicate the northern-most occurrences of oak wilt in the state through mechanical means on select private properties to prevent oak wilt's spread to healthy state forest habitats.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Morrison SWCD partnered with DNR Forest Health Specialists and local DNR Foresters to suppress oak wilt at 18 sites within Morrison County through mechanical means. These sites are the northern-most occurrences of oak wilt in the state through on the edge of healthy state forest habitats.

OVERALL PROJECT OUTCOME AND RESULTS
Morrison SWCD partnered with DNR Forest Health Specialists and local DNR Foresters to suppress oak wilt at 18 sites within Morrison County. Control work was done by an experienced contractor using successful vibratory plow and tree destruction methods. Morrison County is at the leading edge of the known disease range in Minnesota. While the project was focused on private lands, the public good comes from controlling the spread to public forests of the state, and the continued habitat for turkey, grouse, deer and other wildlife.

The DNR Forest Health Specialist made numerous trips to the area to help train local resource professional staff on identification of oak wilt and confirm new spots and local DNR Foresters painted wilting trees throughout the season. At the time of grant execution, the number of known infection sites had jumped from ten to 65 triggering Morrison SWCD and DNR to prioritize work zones based on the proximity of the site to northern public forests. Highest priority sites were largely rural with large intact forests and lower priority sites were found near Little Falls, Minnesota in an actively developing residential area.

Landowners were approached by the SWCD to gain interest in oak wilt suppression activities on their properties. These property owners signed a Landowner Agreement that outlined program requirements, landowner and contractor responsibilities and timelines for treatment. The SWCD received overwhelming support from property owners, with 50 landowners signing on to be part of the program, and because of this, all the known oak wilt pockets in the high and highest priority zones were treated.

The SWCD and DNR continue to educate the public and work with landowners affected by oak wilt in the medium and low priority areas to guide them in properly addressing the disease on their properties until additional funding can be secured.

PROJECT RESULTS USE AND DISSEMINATION
The SWCD received overwhelming support from property owners, with 50 landowners signing on to be part of the program, and because of this, all the know oak wilt pockets in the high and highest priority zones were treated. The SWCD and DNR have both released articles to local newspapers, submitted articles for the Forest Health Unit newsletter and alerted landowners of the presence of Oak Wilt in Morrison County and grant opportunities through talk show programs on the local radio station. Both agencies have updated their websites to reflect current grant opportunities. Website addresses for both of these are located here: https://www.dnr.state.mn.us/treecare/forest_health/oakwilt/index.html ; https://morrisonswcd.org/gallery/fy2019-projects-events/oak-wilt-main. Both organizations will include this grant award and outcomes in their 2019 annual reports.

Informational packets were created to easily send in the mail or hand to interested landowners over the counter. These packets include a contractor list of certified arborists and experienced vibratory plow operators, handouts on how to identify oak wilt along with best management practices for suppressing oak wilt and links to additional resources and references. Landowners in the low and medium priority zones where oak wilt was not addressed with these funds were given or sent a packet and told they will be notified in the future if additional funds are secured. Morrison SWCD and DNR will continue to

provide technical support to these landowners so diseased pockets of oak are managed properly. The SWCD is also offering a 10% discount known affected property owners order trees through the office to help offset the cost of reforestation.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 07 Air Quality and Renewable Energy

Subd. 07a Development of Clean Energy Storage Systems for Farms - Research Project - $650,000 TF (FY2020)

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Appropriation Language
$650,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center at Morris to develop and test novel clean energy storage systems for farms using wind-generated ammonia to displace fossil fuels and reduce greenhouse gas emissions. This appropriation is subject to Minnesota Statutes, section 116P.10.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 07b White Earth Nation Community Solar for Economic Resilience - $500,000 TF (FY2020)

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Appropriation Language
$500,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Rural Renewable Energy Alliance to install a 200-kW White Earth community-owned solar garden to reduce greenhouse gas emissions, increase economic development through environmental education and solar workforce training, and improve energy resilience.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
200 kWs of solar community gardens were installed on the White Earth tribal reservation. This project will greatly reduce greenhouse gas emissions for years to come, in addition to providing energy resilience to the White Earth community. Furthermore, this project has increased economic development through environmental education and solar workforce training.

OVERALL PROJECT OUTCOME AND RESULTS
Five 40 kW ground-mounted solar arrays have been completed, were commissioned, and are now operating at 100% at each of the five chosen sites. Those sites are DOVE Shelter, Head Start Daycare Center, Maadaazizi Workforce Center, Naytahwaush Complex, and the Tribal College; all are located within the White Earth reservation tribal community.

Eight interns, in two rounds of four, completed a 45-hour paid internship at a rate of $15/hour. They each received a Minnesota Installers Certificate and a professional electronic instrument kit. Each student, as part of the 45 hours, spent 15 hours at the solar construction sites during installation. Rural Renewable Energy Alliance (RREAL) and the White Earth Tribal and Community College are expanding this program into a full Associate Degree program in 2022, including work experiences with Minnesota Power and several rural Habitat for Humanity affiliates.

PROJECT RESULTS USE AND DISSEMINATION
This project has directly led to a second year of Solar Tech Customized Education at the White Earth Tribal and Community College. It is also providing the tribal community with sustainable energy to promote energy independence and resiliency. RREAL is continuing to partner with the White Earth tribe to create long-lasting energy sustainability solutions. Please enjoy this video for further information on the collaboration between RREAL and the White Earth nation and how this project will continue to increase economic development and sustainability within the community.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 08 Methods to Protect or Restore Land, Water, and Habitat

Subd. 08c Sauk River Dam Removal and Rock Rapids Replacement - $2,768,000 TF (FY2020)

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Appropriation Language
$2,768,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the city of Melrose to remove an existing fixed-elevation dam, construct a rock arch rapids, and conduct in-stream and shoreline habitat restoration to improve water quality and native fish passage in the Sauk River. This project requires a match of at least $1,400,000 that must be secured before trust fund money is spent. At least $700,000 of this match must come from the city of Melrose.

City of Melrose expenses for the Sauk River dam removal and rock rapids replacement incurred before July 1, 2019, may be counted toward the match.

Note: Dollars returned

Project Completed: 06/30/2022

Subd. 09 Land Acquisition, Habitat, and Recreation

Subd. 09f Accessible Fishing Piers - $320,000 TF (FY2020)

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Appropriation Language
$320,000 the first year is from the trust fund to the commissioner of natural resources to provide accessible fishing piers in locations that have a high potential to serve new angling communities, underserved populations, and anglers with physical disabilities. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Nine (9) new accessible fishing piers have been installed in various locations around the state to improve fishing opportunities for people of all ages and abilities. The DNR worked with multiple sponsors and donors who brought funding and enthusiasm to the projects.

OVERALL PROJECT OUTCOME AND RESULTS
Accessible fishing piers make fishing safe, easy, and fun for all ages especially children, elderly, disabled, veterans, families, small and large groups, and anyone who doesn't own a boat. Fishing piers provide the "classroom" to teach fishing skills and outdoor education classes. Data shows that 40% of people with fishing licenses do not own a boat (approximately 480,000 anglers). The demand for fishing piers is increasing as more people want to fish close to home and from a safe location. Each fishing pier is expected to last 20 to 25 years with proper maintenance. Below are the nine new fishing pier locations:

- Duck Lake, Blue Earth County (Duck Lake County Park)
- Lake Koronis in Stearns County, City of Paynesville (Veterans Park)
- St. James Lake in Watonwan County, City of St. James (St. James Lake Park)
- Maple Lake, Polk County (Maple Lake East Boat Launch)
- Bingham Lake, Cottonwood County, City of Bingham Lake (Bingham Lake Park)
- Black Oak Lake, Stearns County (Black Oak Lake Public Water Access)
- Hoot Lake, Otter Tail County, City of Fergus Falls (Godel Park)
- Lake Frances (Francis), Le Sueur County, City of Elysian (Lake Frances Public Water Access)

- St. Croix River, Chisago County, City of Taylors Falls (South Lions Park)

PROJECT RESULTS USE AND DISSEMINATION
DNR now has approximately 364 public fishing sites; with 282 on partner owned and operated lands, and 82 on state-owned land. Since 1984, the fishing pier program has relied on funds from competitive capital funding sources to grow the program and add new fishing piers (and shore fishing sites) such as Bonding, Legacy and now LCCMR. In a typical year each existing fishing pier is checked and repaired as needed. Summer storms and winter ice are the most common causes for damage. Piers past their useful life are prioritized for rehabilitation or replacement at a rate four to eight each year. The program is hugely successful because of the many partnerships with local units of governments.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09g Mesabi Trail Extensions - $3,000,000 TF (FY2020)

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Appropriation Language
$3,000,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the St. Louis and Lake Counties Regional Railroad Authority for environmental assessment, permitting, right-of-way easements or other acquisition as needed, and engineering for and construction of four trail segments beginning and ending at the following approximate locations: Darwin Meyers Wildlife Management Area to County Road 21, Embarrass to Kugler, County Road 128 to the Eagles Nest Town Hall, and Wolf Creek to the Highway 169 underpass.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project was an important part on nearing the completion of a planned 162 mile long paved bicycle trail stretching from Grand Rapids to Ely, MN. The ENRTF funding along with other funds allowed for the completion of four (4) segments of the Mesabi Trail which are: Darwin Meyers Wildlife Management Area to County Road 21 (approximately 2 miles), Embarrass to Kugler Township (approximately 9 miles), County Road 128 to Eagles Nest Town Hall (approximately 2 miles), and Wolf Creek to the Highway 169 underpass (approximately 3 miles).

OVERALL PROJECT OUTCOME AND RESULTS
For Segment 1: Darwin Meyers WMA to CR 21, we completed about 90% (approximately 1.5 miles) of the trail construction for this segment by June 30th, 2022. We will be using funds from our IRRRB grant to complete the remaining construction management and trail construction for this segment. Segment 2: Embarrass to Kugler, this segment is 100% completed, approximately 9 miles. Our engineering and construction costs were under our original engineering estimates and finished favorable compared to

our budget for this segment. Segment 3: CR 128 to Eagles Nest Townhall, this segment is 100% completed, approximately 2 miles. Our engineering and construction costs were under our original engineering estimates and finished favorable compared to our budget for this segment. Segment 4: Wolf Creek to Highway 169 Underpass, this segment is 100% completed, approximately 3 miles. Typical challenges arose from designing and building these paved bicycle trail segments, such as land formations, wetlands and mitigation, land acquisitions, and rising material costs. To complete these four (4) segments, each required environmental assessments and permitting, engineering plans, services, management, right-of-way acquisition and construction. These key segments allow connections to various communities from the Giants Ridge Golf and Ski Resort in Biwabik through Embarrass and Kugler Township; Eagles Nest Township, Bear Head State Park and the Wolf Creek area towards Ely.

PROJECT RESULTS USE AND DISSEMINATION
The Mesabi Trail news and updates are provided through a variety of media, marketing and publications. Web site is: Mesabitrail.com. The following are some of the groups & organizations that disseminate Mesabi Trail information and typically include updates of newly completed trail segments and activities:

- Club Mesabi (10,000 maps & web site: Mesabitrail.com)
- Iron Range Tourism (30,000 brochures & web site)
- MN Office of Tourism
- amperes radio
- Parks & Trails, Home & Away, other private magazines
- Over 250,000 trail users per year
- Great River Energy/Mesabi Trail annual tour
- Named by the Star Tribune as “Best of Minnesota” in year 2013
- Named by Bicycle Magazine as” top 10 in the country”
- Information distributed at over 70 locations including Chambers of Commerce, visitor centers, businesses
- MN DOT/Pedal MN bikeways map
- “Second best trail in Midwest USA” Dubuque Iowa, 2017

The Environmental and Natural Resources Trust Fund is acknowledged as a funder for the Mesabi Trail with recognition posted in each kiosk along the trail.

The Minnesota Environment and Natural Resources Trust Fund (ENRTF) will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgement Guidelines.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 09l Vergas Long Lake Trail - $290,000 TF (FY2020)

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Appropriation Language
$290,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the city of Vergas to construct a bicycle and pedestrian bridge, trail, and floating boardwalk along Long Lake including shoreline restoration and stabilization with native plants. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 09m Glacial Edge Trail and Downtown Pedestrian Bridge - $600,000 TF (FY2020)

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Appropriation Language
$600,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the city of Fergus Falls to acquire easements for and construct a trail along the Otter Tail River in downtown Fergus Falls and a bicycle and pedestrian bridge crossing the river. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
On June 30, 2022, the City of Fergus Falls celebrated its 150th anniversary by unveiling a new segment of a shared use path enhancing the riverfront in downtown Fergus Falls.

OVERALL PROJECT OUTCOME AND RESULTS
This project, bolstered by the outcomes of a 2016 Downtown Riverfront Master Plan and colloquially referred to as Downtown Riverfront Improvements, has spanned multiple City Councils, elections, bonding bills, engineers, redesigns, and even a pandemic. Thanks to a shared vision and the strength of public- private partnerships, the City was able to unveil a segment of new shared use path and pedestrian improvements in downtown Fergus Falls at a community celebration on June 30, 2022.

The initial aims of the project included land acquisitions to complete two segments of new trail and a pedestrian bridge over the Otter Tail River. In 2020, land acquisition was removed to reflect an adjusted trail route. Due to impacts from COVID-19 and after additional engineering analysis, the project scope

was further reduced to reflect the community's ability to feasibly finance the intended project, focusing efforts on a first phase section of trail leading up to and crossing a pedestrian bridge. When it came time to finalize design and financing, resistance from the community (specifically and surprisingly to the proposed pedestrian bridge) further impacted project timeline and budget.

Consequently, the work completed by June 30, 2022 was a much reduced scope from the original work plan, but the project unveiled in celebration of the City's 150th anniversary remains impactful. Minnesotans benefit from the completion of a segment of trail that will connect to State and regional trails, the enhancement of a riverfront once flanked by crumbling parking lots and industrial sites, and the recreational and educational opportunities now available to local residents and visitors that increased access to pedestrian infrastructure and the river bring. The successful completion of pedestrian upgrades despite hurdles along the way strongly suggest that Minnesotans see the value in the natural beauty surrounding them and wish to preserve and enjoy that natural beauty.

PROJECT RESULTS USE AND DISSEMINATION
Project updates were shared periodically through a project website run by Bolton & Menk. More consistently, information about this project has been disseminated in in-person updates to City Council and in an unveiling speech given by Mayor Ben Schierer on June 30.

Though not posted before June 30, the kiosk in the project area will include attribution to the ENTRF based on ENTRF acknowledgment requirements.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 09o Restoring Five Sections of the Superior Hiking Trail - $191,000 TF (FY2020)

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Appropriation Language
$191,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Superior Hiking Trail Association to restore and repair the most damaged parts of five sections of the Superior Hiking Trail and restore an abandoned route to a natural footpath for hikers.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Superior Hiking Trail (SHT), which traverses the ridgeline of Minnesota's North Shore, was repaired in some its most damaged sections. A well maintained SHT keeps people on the trail and water off of it, the adjacent land and water are protected, and a human connection to nature is preserved.

OVERALL PROJECT OUTCOME AND RESULTS
The 310-mile Superior Hiking Trail (SHT), part of the larger North Country National Scenic Trail, is nationally recognized as a premier long trail in the United States. Almost the entire trail was built without application of modern trail-building standards. As a result, and due to the extreme popularity of the Trail, the SHT is in rough shape: decrepit built structures (boardwalks, bridges), severe erosion, and long stretches of muddy trail. With earlier assistance from LCCMR, we were able to complete multiple professional assessments of some of its most damaged sections, which came to known as "the Big Bad Five."

Using the assessments as a framework to identify distinct projects within those five sections of trail, we worked in partnership with land managers/owners to determine the project scope and type of trail renewal application. We rebuilt, replaced or rerouted trail segments to eliminate around a dozen dangerously built structures (e.g., stairways, small bridges); repaired 1.5 miles of the most eroded or degraded segments.; and replaced or built 1,500 feet of boardwalk.

Ability to maintain the Trail at a level that meets or exceeds industry standards has long-lasting impacts on both the critical role the Trail plays to connecting people to nature and to stewarding the land and water through which the Trail passes. Every year, thousands of Minnesotans utilize the unique access the Superior Hiking Trail affords, allowing people to interact with public lands otherwise not available to them and leaving them with the tenants of land stewardship and conservation that carries on after they return home.

PROJECT RESULTS USE AND DISSEMINATION
The project results (construction) are very tangible and can be seen and experienced. The processes we developed in the implementation, such as the development of design plan sets and identifying alignments through particularly challenging terrain are well documented so they can be used internally and by fellow trail organizations as a resource. Our Trail Maintenance Manual, which highlights many of the sustainable design and maintenance techniques used in our projects is available on our website for the public to access.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 10 Administration and Contract Agreement Reimbursement

Subd. 10a Contract Agreement Reimbursement - $135,000 TF (FY2020)

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Appropriation Language
$135,000 the first year is from the trust fund to the commissioner of natural resources, at the direction of the Legislative-Citizen Commission on Minnesota Resources, for expenses incurred for preparing and administering contracts for the agreements specified in this section. The commissioner must provide documentation to the Legislative-Citizen Commission on Minnesota Resources on the expenditure of these funds. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This appropriation was used to support the ENRTF contract management program, which ensured that ENRTF grantees expended grant funds in compliance with state law, session law, approved work plans, and Office of Grants Management grants policies.

OVERALL PROJECT OUTCOME AND RESULTS
This appropriation was used to support the ENRTF contract management program, which ensured that ENRTF grantees expended grant funds in compliance with state law, session law, approved work plans, and Office of Grants Management grants policies.

The DNR Grants Unit managed 78 grants active in FY 2020. In FY 2021, the Grants Unit managed 72 active grants.

Between 1/1/2020 when billing began and 12/31/2020 when it ended, the DNR Grants Unit:

- Made 136 reimbursements to grantees totaling $7,395,420
- Finished executing 18 project amendments due to COVID extensions, including implementation of electronic signature process
- Monitored all grants in compliance with Office of Grants Management policies.
- Billed 1,257 hours at the FY 2020 professional services rate of $66.00/hr and 754 at the FY2021 rate of $69/hr

PROJECT RESULTS USE AND DISSEMINATION
Project personnel were in frequent contact with appropriation recipients and LCCMR staff. Information was disseminated through manuals, training sessions, orientations, meetings, memos, letters, emails, newsletter, and phone.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 10c Legislative Coordinating Commission (LCC) Administration - $3,000 TF (FY2020)

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Appropriation Language
$3,000 the first year is from the trust fund to the Legislative Coordinating Commission for the website required in Minnesota Statutes, section 3.303, subdivision 10.

Project Completed: 06/30/2022

Subd. 11 Wastewater Treatment Recommendations

Subd. 11a Water Infrastructure Loans - $0 TF (FY2020)

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Appropriation Language
Up to $5,000,000 of the money in the trust fund is available to the State Board of Investment to invest in loans through the Public Facilities Authority's clean water revolving fund under Minnesota Statutes, section 446A.07. Notwithstanding Minnesota Statutes, section 446A.07, repayments of principal and interest and any investment income must be credited to the trust fund and are available for reinvestment in the clean water revolving fund.

Project Completed: 06/30/2022

Subd. 11b Optimization Local Mechanical and Pond Wastewater-Treatment Plants - $500,000 TF (FY2020)

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Appropriation Language
$500,000 the first year is from the trust fund to the commissioner of the Pollution Control Agency for the pilot program created under Laws 2018, chapter 214, article 4, section 2, subdivision 4, paragraph (a). This appropriation is available until June 30, 2021, by which time projects must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Wastewater treatment systems are critical infrastructure to manage waste effluent within hundreds of communities throughout Minnesota. Optimization means getting better results through existing infrastructure. This project determined that both mechanical and pond wastewater treatment systems can be optimized, and new effluent limits met, without adding substantial new infrastructure.

OVERALL PROJECT OUTCOME AND RESULTS
Achieving better nutrient treatment in wastewater treatment facilities serves to reduce the likelihood of algal blooms in Minnesota's water bodies resulting in cleaner lakes and rivers.

This project found that Minnesota's mechanical wastewater treatment plants can achieve better biological nutrient removal (BNR) through low-cost operational changes. These improvements were modeled using the Activated Sludge SIMulation Model (ASIM) in order to determine the specific plant operational parameters required to achieve BNR. On average, mechanical plants in this pilot were modeled to have average nitrogen reduction of 14.14 mg/L, average phosphorus reduction of 1.84 mg/L (most sites already treat phosphorus chemically to 1 mg/L) and chemical reductions of 886 lb chemical/Million Gallons (MGal) flow.

Wastewater ponds can achieve much better nutrient treatment by utilizing the 'Steady-State Primary' strategy developed during this project. This strategy involves holding the first pond at six feet, or the maximum depth permitted) with a slide gate. Raw influent continues flowing into pond 1, while treated effluent from pond 1 is used to fill pond 2. Meanwhile, pond 3 is also held full. This strategy maximizes treatment time and drastically improves nutrient treatment quality. The two developed case studies showcase a 69% reduction in phosphorus and 43% reduction in nitrogen when compared to the prior year's effluent. Secondary recommendations to wastewater ponds is to reduce inflow and infiltration, reduce fecal loading from waterfowl, and to encourage the growth of aquatic plants, with a specific emphasis on the growth of coontail.

By quantifying the role that optimization has in effective wastewater treatment, Minnesota's lakes and streams can meet standards in a more cost effective means.

PROJECT RESULTS USE AND DISSEMINATION
The project and its results have been presented in 17 different events and conferences by members of this team, including Minnesota Rural Water Association's annual conference, Minnesota Pollution Control Agency's annual conference, the Conference on the Environment, and many others. However, only one mechanical treatment plant has elected to move ahead with a pilot study, and one additional has expressed interest in doing so in the near future. The team has heard from staff and consultants of participating facilities that without a nitrogen standard as a driver, they feel little urgency to adopt optimization recommendations. Other facilities are meeting phosphorous limits under current flow, but would face difficulty at increased flow. Additionally, BNR design and operation is not a common treatment system in our Minnesota climate, and there may be some trepidation to moving toward that form of treatment until other facilities lead the way.

We have seen eight pond systems adopt the steady-state-primary flow regime in their operations, with more hoping to do so in the near future. Those that have done so already have reported roughly 50 percent reduction in nutrient discharge. The flow regime still needs additional validation. But, more discharge events will add more confidence with additional datasets from daily monitoring reports. Better flow management through infrastructure maintenance – making sure the control structures function as designed – is going to continue to be an area of importance in order to prevent short circuiting of the treatment in isolated pond cells.

The final report, the final work product of operator field guides for mechanical and pond treatment facilities, case studies of participating facilities, and additional findings, can all be found here, at the Minnesota Technical Assistance Program's wastewater webpages.

Project Completed: 06/30/2021
FINAL REPORT

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2. M.L. 2018 Projects Completed
January 15, 2021 – January 15, 2023

MN Laws 2018, Chapter 214, Article 4, Section 2

M.L. 2018 Projects

MN Laws 2018, Chapter 214, Article 4, Section 2 (beginning July 1, 2018)

Visit the LCCMR website for the most up-to-date project information and reports

Subd. 03 Foundational Natural Resource Data and Information

Subd. 03b Providing Critical Water-Quality Information for Lake Management - $250,000 TF

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Appropriation Language
$250,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a semiautomated system to acquire, process, and deliver new satellite-derived water-quality data in near real time on water clarity, algae, and turbidity for Minnesota lakes. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project created an automated system, which is capable of delivering satellite derived near real-time data and maps of key water quality measures (chlorophyll, clarity, CDOM), and updated the Minnesota LakeBrowser with new data and capabilities to visualize the water quality of all Minnesota lakes to improve data-driven resource management.

OVERALL PROJECT OUTCOME AND RESULTS
Using satellite imagery, we have been assessing lake water quality in Minnesota for over 20 years. For early assessments, we used analyst directed image processing techniques using remote sensing software and empirically calibrated each satellite overpass with in situ water clarity data. These assessments were at around five year intervals due to the effort required and availability of clear satellite imagery. Recent advances in satellite technology (improved spectral, spatial, radiometric and temporal resolution) and atmospheric correction, along with cloud and supercomputing capabilities have enabled the use of satellite data for automated regional scale measurements of water resource characteristics. These new capabilities provide opportunities to improve lake and fisheries management by measuring more variables (chlorophyll, colored dissolved organic matter (CDOM) and total suspended matter, the main determinants of water clarity) more often.

To utilize these capabilities this project developed field-validated methods and implemented them in an automated water quality monitoring system on University supercomputers. The system acquires satellite imagery, removes clouds, cloud shadows, haze, smoke, and land, and applies water quality models to deliver satellite-derived water quality products. Using this system we created statewide

monthly open water (May through October) pixel level mosaics and lake level data for each clear image occurrence. The lake level (2017-2020) data included 603,678 lake measurements of chlorophyll, clarity and CDOM (1,811,034 total) that were compiled into a database that was used to calculate water quality variables for different timeframes (e.g. monthly, summer (June-Sept)) and linked to a lake polygon layer that was used for geospatial analysis and included in a web map interface. The Minnesota LakeBrowser was updated with monthly chlorophyll, clarity and CDOM data from 2017 to 2020 and new capabilities for citizens, resource managers and researcher to easily access the data for specific lakes and regions.

PROJECT RESULTS USE AND DISSEMINATION
Communication of project results used a range of outlets. The primary mode of dissemination is the update and expanded Minnesota LakeBrowser. This website provides content for diverse users including citizen scientists, lake users, homeowners, classrooms, natural resource managers, researchers at agencies and academic institutions. The updates improved search and allow visualization of long term (1975-2020) and seasonal (May-October) trends for individual lakes in graphs, and for individual lakes or regions in pixel or lake level maps. Results were also disseminated through social media and in presentations made at conferences and state agencies and will be disseminated in peer reviewed literature.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03c Minnesota Biodiversity Atlas - Phase 2 - $350,000 TF

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Appropriation Language
$350,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to expand the biodiversity atlas project by adding more than 800,000 records and images of Minnesota wildlife, plants, and fungi, including observations from state agencies and other museum collections, to enhance research, guide field surveys, and inform conservation planning. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Biodiversity Atlas provides online access to 150 years' of natural history information by integrating and disseminating data from state agencies, museums, colleges, and universities. It enables the general public, natural resource managers, educators' and researchers to investigate past and present biodiversity patterns and make predictions about future directions.

OVERALL PROJECT OUTCOME AND RESULTS

This project expanded an online natural resource database situated at the University of Minnesota's Bell Museum to include data from multiple state agencies and museum collections. Extensive records of Minnesota biodiversity, past and present, are the product of ongoing biological surveys by agencies and organizations beginning with the Public Land Survey in 1848. As the official state museum of natural history, the Bell Museum is responsible for preserving and making available records of Minnesota plant and animal life. These records are the bellwether of informed responses to environmental change but literally millions of data points remain scattered among state agencies, museum collections and academic institutions.

The Minnesota Biodiversity Atlas serves to integrate and disseminate biodiversity data online. This second phase II of this project increased the size of the Atlas from 640,000 to 1,585,000 records of mammals, birds, fish, amphibians, reptiles, crustaceans, invertebrates, plants, and fungi. Additions included expert observations from the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency and also specimen records from the University of Minnesota Duluth, the Science Museum of Minnesota, the College of St. Benedict's/St. John's University, and Minnesota State University, Mankato.

Understanding biodiversity change in Minnesota and adapting to it are essential for cultural, economic, and environmental health. The Minnesota Biodiversity Atlas provides the historical baseline against which contemporary observations are compared to manage our natural heritage today and into the future. The Atlas is used by natural resource professionals, educators, and the public for species identification, distribution mapping, habitat assessment, restoration planning, management decision making, and learning. During the project, the Atlas grew to 500,000 digital images and 1.4 million mapped records. Software development needs for a mobile phone-friendly version of the Atlas were also identified.

PROJECT RESULTS USE AND DISSEMINATION

Online retrieval of data from the Minnesota Biodiversity Atlas grew from 76,000 page views in 2018 to 307,000 in 2021. Visitors to the Bell Museum also learn about the Biodiversity Atlas in the Minnesota Journeys gallery and it featured in a traveling exhibit that received over 70,000 in-person visitors. Two training workshops in using the Atlas were offered to over 30 natural resource professionals from across the state. In local media, it was twice featured on the "Grow with KARE" segment on channel 11 and in the Minnesota Daily.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03d Peatland Forest Management - $600,000 TF

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Appropriation Language
$600,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to identify management actions to maximize benefits to wildlife, water quality, timber production, and native plant communities in peatland forests. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project monitored 48 peatland sites for four years providing critical new information on hydrology during wet and dry years, boreal chickadee breeding habitats (some of the first data of its kind), and plant diversity. Data show regeneration harvests do not significantly impact the water table and vegetation responds quickly.

OVERALL PROJECT OUTCOME AND RESULTS
Peatlands provide critical ecosystem services for Minnesotans, which include helping to maintain clean drinking water, providing important forest products, serving as critical habitat for many wildlife species including the boreal chickadee, and storing huge amounts of carbon. However, these are very understudied systems and climate change and other forest health threats are impacting peatland forests. Over a four year period, we've monitored 48 sites that span four different age classes and three different forest cover types (eastern larch, productive black spruce, and stagnant black spruce) to understand how vegetation, hydrology, soils, and wildlife species interact within peatland forest communities. Over the course of the 48 years, we have measured thousands of trees and hundreds of different plant species to gain a fuller picture of plant species diversity and growth within peatland forest communities. We have some of the most robust data on boreal chickadee habitat use and early survival, which is critical for this species of great conservation need in Minnesota. Finally, we have hundreds of data points over multiple years on the daily hydrology within these systems to understand how water levels change over the growing season. All of this is critical base line data that can help information management practices within peatland forest communities. Results have been shared locally, regionally, and nationally through presentations and webinars, which include the basic data and sharing how to gather collectively across multiple disciplines to inform holistic management practices within forest ecosystems. Our results show that peatlands are not negatively impacted by harvesting in the vegetation and hydrology. Additional work is needed to consider how different harvest strategies may influence wildlife use within peatland forest ecosystems.

PROJECT RESULTS USE AND DISSEMINATION
We are currently working on final edits and submission for two peer reviewed papers with an additional two papers in progress that will continue outside of the granting program. Results have been shared through multiple forms including local news stories, including Scientists hang 500 birdhouses in Sax-Zim Bog to study boreal chickadees, presentations to forest managers at the Research Review hosted by the Sustainable Forest Education Cooperative, to a special symposium on wet forests which brought together researchers and managers to discuss opportunities and challenges within peatland forest communities.

Project Completed: 6/30/2022

FINAL REPORT

Subd. 03e Assessing Natural Resource Benefits Provided by Lichens and Mosses - Research Project - $213,000 TF

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Appropriation Language
$213,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to survey, map, and analyze mosses and lichens across the state, including their moisture-retention capacity, effects on hydrology, and ability to filter airborne pollutants. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We documented the potential impact of moss and lichen on the flow of water and pollutants through Minnesota forests. This impact varies across the state depending on the forest type but can reach more than 15% of each rain event. Pollutant filtering effects are smaller but not unimportant.

OVERALL PROJECT OUTCOME AND RESULTS
Moss and lichen are common in forests, and yet they are often overlooked. But this does not mean unimportant: they retain water and heavy metals, and so a mossy forest may function quite differently from a barren one. This project aimed to quantify how much moss and lichen is in Minnesota forests and to estimate their impact on water flows and pollutant retention.

To reflect the diversity of Minnesota's landscape, we established 83 plots in 30 counties across the stateto provide detailed and region-specific coverage of all of the major forest types recognized by the DNR. We recorded which species were present, their abundance (on forest floor, tree trunks and fallen branches), and collected the most abundant ones for lab analyses. 1650 unique specimens were collected.

The amounts vary greatly across the state, from less than one pound per acre to over 1,500 pounds per acre. These translate into sometimes considerable water storage capacity. With respect to heavy metals, contents were often quite low, at fractions of a pound peracre. We will follow up with future work on urban lichens to determine whether this is due to the lack of pollutants in forest sites. By combining our results with existing maps of forest coverage, we've been able to map these contributions across the state.

Another objective of the work aimed to test these estimates with experiments of how much water and elements are retained in the lab and field. Due to delays, these experiments were only installed in Spring 2022, and their continued monitoring and analysis will be funded from other sources.

Overall, our findings draw needed attention to an overlooked component of our forests, both in terms of diversity and impact on water cycles.

PROJECT RESULTS USE AND DISSEMINATION
The activities and findings in this project have been shared with the general public through a number of venues, including public presentations through Minnesota Master Naturalists, Minnesota Mycological Society, and the Bell Museum of Natural History; workshops attended by 30-50 people each at Minnesota Naturalists Association Annual Meeting (2019) and Cedar Creek Ecosystem Reserve (2019, 2022-115 participants!); a booth in the University of Minnesota pavilion at the MN State Fair and several other events. Scientific dissemination has so far included an undergraduate-led peer-reviewed publication and oral presentations at three international conferences. Further scientific publications are planned for late 2022.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03g Conserving Minnesota's Forest Birds of Management Concern - Research Project - $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to identify forest-management actions and guidelines to conserve birds in Minnesota's forests. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Golden-winged Warbler, Veery, and American Woodcock are species of conservation concern in Minnesota and have had significant population declines throughout their breeding ranges. We documented nest success and used radiotelemetry to study juvenile survival to identify habitat characteristics and management actions that maximize productivity and inform conservation efforts.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota’s forests provide critical breeding habitat for hundreds of resident and migrating bird species. Current land use practices and future modifications to Minnesota’s forests are likely to substantially transform native forest bird communities. Golden-winged Warbler, Veery, and American Woodcock are species of conservation concern in Minnesota and have had significant population declines throughout their breeding ranges. For breeding birds, conservation efforts are most effective when management plans include recommendations aimed at maximizing breeding season (nesting to post-fledgling) productivity. However, the period of time directly after young birds leave the nest and

before they disperse and/or migrate (i.e., the post-fledging period), remains an understudied life stage for most bird species. To address this knowledge gap, we documented nest success and used radiotelemetry to study juvenile survival and habitat use for Golden-winged Warbler, Veery, and American Woodcock in managed forests. Our results showed that nest success (one or more birds fledged per brood) was 47% for Golden-winged Warblers (n= 51), 39% for Veery (n= 43), and 67% for American Woodcock (n= 13). Documented nest failure for all species was due to predation and weather events. A total of 72 Golden-winged Warbler fledglings were tagged with a survival rate of 39%. Juvenile survival was highest for Veery fledglings (n= 35) at 83%. A total of 31 American Woodcock hatchlings were tagged during the study with a survival rate of 71%. Over 85% of mortality events occurred when birds were less than seven days post-fledge, indicating this as a high-risk time period for these species. Vegetation surveys were completed at all locations where birds were detected using handheld telemetry (Golden-winged Warblers (n= 620), Veery (n= 384), and American Woodcock (n= 281)). These data are being used to provide breeding cycle habitat recommendations for managing forested landscapes to maximize productivity and prioritize conservation efforts.

PROJECT RESULTS USE AND DISSEMINATION
The preliminary results of the research were presented at 13 conferences during the course of project; the study was featured on MPR; and four articles have been written about different aspects of the study. Data from this research was incorporated into a fact sheet "Managing for Birds of Conservation Interest in the Great Lakes Region", which features habitat and management recommendations for Golden-winged Warbler. Three peer-reviewed publications are expected to be published in 2023. The final results will be incorporated into the Golden-winged Warbler habitat management recommendations.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 03h Mapping Avian Movement in Minnesota - Research Project - $200,000 TF

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Appropriation Language
$200,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to pilot the establishment of a network of automated radio-telemetry stations to monitor bird migration and local movements and to develop strategic plans for using the infrastructure long term to monitor animal movement for conservation. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We used automated radio telemetry to understand habitat needs of Minnesota's birds. Specifically, we tracked birds across large and local-scales to document breeding, migratory and winter movements. Automated radio telemetry systems are useful for studying animal movements and can help to increase public awareness and impact for conservation efforts.

OVERALL PROJECT OUTCOME AND RESULTS
We explored the use of automated radio telemetry for tracking Minnesota's birds. We documented large-scale movements along the north shore of Lake Superior with Blue Jays and Northern Saw-whet Owls, colonial waterbird behavior on Interstate Island with Common Terns, local-scale migratory stopover in the St. Louis River Estuary with Rusty Blackbirds, and winter activity levels and movements in Hartley Park with Black-capped Chickadees. Each of these studies provided us with a greater understanding of the flexibility and adaptability of automated radio telemetry technology to answer a range of questions in different situations and seasons. Overall, we found the use of this technology to document small-scale movements of Rusty Blackbirds, Black-capped Chickadees, and Common Tern to be the most valuable and suggest it as a relatively low-cost way to study local movements while potentially enhancing migration studies simultaneously. For example, using an automated telemetry station at Interstate Island allowed us to obtain additional behavioral information on breeding Common Terns before the birds left and interacted with any foreign automated radio telemetry towers registered on the Motus system. We suggest researchers that are deploying VHF tags for the purposes of long-range migratory studies strongly consider deploying automated telemetry stations like those we developed for this project in strategic locations nearby tagging sites. In this way, researchers will be able to obtain potentially large amounts of local-scale data that can then be used to inform and enhance any large-scale detections after a bird migrates from the trapping site. Bird tracking research has broad public appeal, and stories of bird migrations provide an effective way to engage non-scientists and even non-birders in understanding the many threats small migratory landbirds face.

PROJECT RESULTS USE AND DISSEMINATION
The preliminary results of the research were presented at eight conferences during the course of project and the study was featured on MPR in 2019. Two peer-reviewed publications are expected to be published in 2022, one focusing on Common Tern and other on Rusty Blackbirds. We set up an additional Motus station at Sax-Zim Bog in 2020 to help facilitate research in this important area of the state. We established a website for the citizen science portion of the Black-capped Chickadee study in Hartley Park. A full report for this study is available on the Natural Resources Research Institute website.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03j Develop Sonar Data Mapping on Three Rivers to Assess Suitability for Native Mussel Habitat - Research Project - $200,000 TF

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Appropriation Language
$200,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the National Park Service to create high-resolution sonar data maps to identify critical native mussel habitat for the designated Lower St. Croix National Scenic Riverway and the Mississippi National River and Recreation Area including part of the Minnesota River.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Baseline information in the form of bathymetry and imagery were developed for the National Park Service for native mussel habitat suitability. These data have the analytic capabilities to be viewed and modeled in a digital environment to help understand mussel distribution, define preferred habitat parameters, and identify key habitat locations for restoring imperiled mussels.

OVERALL PROJECT OUTCOME AND RESULTS
The U. S. Geological Survey (USGS) collected depth information and sidescan imagery for areas of the National Park Service (NPS) Mississippi National River and Recreation Area (MISS) and the St. Croix National Scenic Riverway (SACN). For known locations of preferred mussel habitat, additional collection efforts of river flow velocities and underwater video of bed composition were collected. Prior to this project, MISS had no accessible bathymetry data above Pool 1, and SACN did not have any accessible bathymetry (other than a small area near Prescott, Wisconsin). The LCCMR ENRTF provided the opportunity to acquire bathymetry data where needed and make this information available to NPS resource management to help aid decision-making for the conservation of native mussels. Goals for this project were to collect high-resolution sonar data of three rivers where none previously existed. The data is delivered in digital format for modeling hydraulic variables related to native mussel habitat suitability. The USGS provided usable information in the form of bathymetry and topography (hillshades and sidescan imagery) for areas of full collection, and habitat measures of flow velocities and bed characterization for priority areas. Initially implemented as a two-year project, data collection was planned for each park in consecutive years. Due to the pandemic, some data collection was delayed a year. Bathymetric surveys for the lower SACN consisted of approximately 1,775 hectares (4,385 acres), and approximately 1,358 hectares (3,335 acres) were collected for MISS. Outcomes consisted of high-resolution bathymetry in the form of 0.5-meter digital elevation models, 3-D hillshade representations of the surface (using patterns of light and shadow), and sidescan images mosaics — which provide an underwater view of geomorphic features. Flow velocities and bed composition combined with bathymetry can be used to locate areas with similar features as the NPS priority areas. In order to provide complete coverage for MISS, the U.S. Corps of Engineers (USACE) main channel data were used for Pools 1, 2, and 3. The resulting merged bathymetry were generated at a lower resolution (5 meters) due to USACE collection parameters. This project is significant because it provides bathymetry where none previously existed for Minnesotans, and it provides valuable information to the NPS for imperiled mussel habitat modeling by locating other suitable areas for conservation efforts. Natural resource management and policy makers face an increasing number of environmental issues. These data combined with other river conditions can be used to help inform decision-making for aquatic invasive species, agricultural practices, riverfront development, erosion, sedimentation, and climate change.

PROJECT RESULTS USE AND DISSEMINATION
Dissemination included a formal USGS review for data and metadata, prior to release on the USGS data

repository. Datasets and metadata for the St. Croix National Scenic Riverway and the Mississippi National River and Recreational Area can be found online. This project was posted as a resource for current USGS projects at Develop Sonar Data Mapping on Three Rivers to Assess Suitability for Native Mussel Habitat (usgs.gov).

The information resulting from this project is currently being incorporated into a Freshwater Mussel Database (NPS Focused Condition Assessment) for MISS and SACN, which will further be linked to a Freshwater Mussel Decision Support System (USGS Natural Resource Preservation Program) for resource management. Furthermore, the NPS and USGS partnership plan to pursue additional funding for MISS to map untapped information that can be derived from the sonar data; and to collect additional bathymetry and flow data where none still exists on SACN.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03k Conserving Minnesota's Nine Species of Freshwater Turtles - Research Project - $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the Minnesota Zoological Garden to improve the long-term viability of Minnesota's imperiled turtle populations by researching threats, identifying mitigation strategies, implementing mechanisms to reduce threats and mortality, and creating related outreach and educational materials. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Zoo conducted research and implemented conservation actions including nest site protection and head-starting to bolster wood turtle populations. We studied methods to mitigate road mortality of turtles, with results suggesting that simple tube barriers may be effective. Our outreach efforts raised awareness and encouraged action to benefit conservation.

OVERALL PROJECT OUTCOME AND RESULTS
Native turtles are a key component of diverse, healthy, and resilient aquatic ecosystems, inspiring connections to nature for children and adults alike. However, populations of turtles in Minnesota face numerous threats, including habitat loss and degradation, high predation of incubating nests, and mortality on roadways. With this project, the Minnesota Zoo sought to improve the conservation of turtles by 1) collecting data to quantify two key threats – road mortality and nest predation – and

implement and evaluate mechanisms to mitigate these threats; and 2) building public awareness by developing educational and outreach materials for use during on- and off-site programming.

We outfitted imperiled wood turtles with radio and GPS transmitters, improving our understanding of their habitat needs and allowing us to identify and protect nesting sites. We reared hatchling wood turtles in captivity for their first year of life to improve their chances of survival in the wild and bolster depleted populations while other threats are addressed. To date, we have successfully released 68 one-year-old wood turtles back to the wild.

We also investigated strategies to mitigate mortality of turtles on Minnesota's roadways via cost-effective mechanisms including wildlife warning signs and small barriers. Although warning signs did not significantly reduce turtle mortality, corrugated pipe barriers were promising and yielded a decline in mortality of ~50%.

Finally, a variety of materials, including interpretive signage, a 3-dimensional snapping turtle model, and a children's book, were created to support educational and outreach programming and inspire public action to benefit the conservation of turtles. Healthy populations of turtles are an integral component of aquatic systems, and we anticipate that our results will inform effective management strategies that can benefit conservation at sites state-wide.

PROJECT RESULTS USE AND DISSEMINATION
Sharing information about the importance of turtles and their conservation was a key objective of this project. The Minnesota Zoo used a variety of platforms to disseminate significant findings and engage the general public in the conservation of Minnesota's aquatic resources, ranging from informal talks, public lectures and tabling events to media spotlights and distributing content on our social media channels. Media highlights include features on PBS's Prairie Sportsman, Kare 11's Minnesota Bound, a Minnesota Lottery commercial, and a variety of other print and television media outlets. This professionally produced video highlights the ecology and conservation of turtles in Minnesota.

Project Completed: 6/30/2022
FINAL REPORT
Reduce Vehicle-Animal Collisions with Installation of Small Animal Exclusion Fencing - 45 pgs
Poster - Mitigating Road Mortality
Poster - Builing Public Awareness
Poster - Tracking Imperiled Turtles

Subd. 04 Water Resources

Subd. 04a Pilot Program to Optimize Local Mechanical and Pond Wastewater-Treatment Plants - $700,000 TF

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Appropriation Language
$89,000 the first year and $611,000 the second year are from the trust fund to the commissioner of the Minnesota Pollution Control Agency, in partnership with the Minnesota Rural Water Association and the University of Minnesota's Technical Assistance Program, to implement a pilot program to optimize existing local mechanical and pond wastewater-treatment systems to increase nutrient removal and improve efficiency without requiring costly upgrades.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Wastewater treatment systems are critical infrastructure to manage waste effluent within hundreds of communities throughout Minnesota. Optimization means getting better results through existing infrastructure. This project determined that both mechanical and pond wastewater treatment systems can be optimized, and new effluent limits met, without adding substantial new infrastructure.

OVERALL PROJECT OUTCOME AND RESULTS
Achieving better nutrient treatment in wastewater treatment facilities serves to reduce the likelihood of algal blooms in Minnesota's water bodies resulting in cleaner lakes and rivers.

This project found that Minnesota's mechanical wastewater treatment plants can achieve better biological nutrient removal (BNR) through low-cost operational changes. These improvements were modeled using the Activated Sludge SIMulation Model (ASIM) in order to determine the specific plant operational parameters required to achieve BNR. On average, mechanical plants in this pilot were modeled to have average nitrogen reduction of 14.14 mg/L, average phosphorus reduction of 1.84 mg/L (most sites already treat phosphorus chemically to 1 mg/L) and chemical reductions of 886 lb chemical/Million Gallons (MGal) flow.

Wastewater ponds can achieve much better nutrient treatment by utilizing the 'Steady-State Primary' strategy developed during this project. This strategy involves holding the first pond at six feet, or the maximum depth permitted) with a slide gate. Raw influent continues flowing into pond 1, while treated effluent from pond 1 is used to fill pond 2. Meanwhile, pond 3 is also held full. This strategy maximizes treatment time and drastically improves nutrient treatment quality. The two developed case studies showcase a 69% reduction in phosphorus and 43% reduction in nitrogen when compared to the prior year's effluent. Secondary recommendations to wastewater ponds is to reduce inflow and infiltration, reduce fecal loading from waterfowl, and to encourage the growth of aquatic plants, with a specific emphasis on the growth of coontail.

By quantifying the role that optimization has in effective wastewater treatment, Minnesota's lakes and streams can meet standards in a more cost effective means.

PROJECT RESULTS USE AND DISSEMINATION
The project and its results have been presented in 17 different events and conferences by members of this team, including Minnesota Rural Water Association's annual conference, Minnesota Pollution Control Agency's annual conference, the Conference on the Environment, and many others. However, only one mechanical treatment plant has elected to move ahead with a pilot study, and one additional has expressed interest in doing so in the near future. The team has heard from staff and consultants of

participating facilities that without a nitrogen standard as a driver, they feel little urgency to adopt optimization recommendations. Other facilities are meeting phosphorous limits under current flow, but would face difficulty at increased flow. Additionally, BNR design and operation is not a common treatment system in our Minnesota climate, and there may be some trepidation to moving toward that form of treatment until other facilities lead the way.

We have seen eight pond systems adopt the steady-state-primary flow regime in their operations, with more hoping to do so in the near future. Those that have done so already have reported roughly 50 percent reduction in nutrient discharge. The flow regime still needs additional validation. But, more discharge events will add more confidence with additional datasets from daily monitoring reports. Better flow management through infrastructure maintenance – making sure the control structures function as designed – is going to continue to be an area of importance in order to prevent short circuiting of the treatment in isolated pond cells.

The final report, the final work product of operator field guides for mechanical and pond treatment facilities, case studies of participating facilities, and additional findings, can all be found here, at the Minnesota Technical Assistance Program's wastewater webpages.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04b Assess and Develop Strategies to Remove Microscopic Plastic-Particle Pollution from Minnesota Water - $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to assess, track, and develop methods to remove microscopic plastic particles that are dispersed and accumulating as pollution in Minnesota water bodies. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We performed a comprehensive study on the motions of microscopic plastic particles in water flows. Extensive experiments have been conducted utilizing innovative imaging techniques on laboratory apparatuses, assisted by state-of-the-art simulations on supercomputers. Valuable data have been collected and analyzed for addressing the plastic pollution in Minnesota water bodies.

OVERALL PROJECT OUTCOME AND RESULTS
The amount of plastic waste in lakes and rivers is projected to increase, driven by the rise in plastics

consumption. New federal and state legislation has banned the sale of certain products containing micro-beads, but thousands of tons of micro-plastic pollution are already in our waters and will take thousands of years to biodegrade. The objective of this project is to utilize the advanced facilities at the St. Anthony Falls Laboratory to carry out a series of experiments and use powerful computation simulations to investigate the motions of microplastics.

This project carried out extensive laboratory measurements of the motion of spherical and non-spherical particles (fibers and disks) in water channel flows. We also conducted the first-ever field measurements of particles transported on the water surface of a small river facility in the Outdoor StreamLab at the St. Anthony Falls Laboratory. Extensive analyses have been performed on the measurement data. We discovered that fibers tend to orient mostly in the streamwise direction while disks maintain their symmetry axis quasi-normal to the water bottom. The fibers undergo strong tumbling near the bottom in response to the mean shear and turbulent fluid velocity fluctuations, whereas the disks wobble about their preferential bottom-normal orientation. We also developed an advanced computer simulation method for the motions of plastic particles in water flows that can capture particle-particle interactions and particle-flow interactions with unprecedented realism and accuracy. We conducted numerical experiments using a supercomputer to study the effect of breaking waves on the surfaces of lakes and rivers on the transport of microplastics. Using computer simulation, we have also revealed the relationship between microplastic's preferential orientation in water waves and particle shapes. We have also elucidated the microplastics transport process through comparing the motions of spherical particles, oblate particles. and a mixture of both particles to quantify their transport characteristics in water bodies.

PROJECT RESULTS USE AND DISSEMINATION
In this project, substantial efforts have been put into sharing the knowledge gained from the research through presentations at national conferences, such as the annual meetings of the American Physical Society, Division of Fluid Dynamics and the Fall Meetings of the American Geophysical Union. A paper has been published in the Journal of Fluid Mechanics ("Experimental investigation of inertial fibres and disks in a turbulent boundary layer" by Lucia Baker and Filippo Coletti, vol. 943, A27), which is a leading journal in the field.

Project Completed: 6/30/2022
FINAL REPORT
Experimental investigation of inertial fibres and disks in a turbulent boundary layer

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Subd. 04c Reduce Chlorides in Minnesota Waters by Evaluating Road-Salt Alternatives and Pavement Innovations - $400,000 TF

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Appropriation Language
$400,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to investigate road-salt alternatives and pavement innovations to reduce lake, stream, and groundwater degradation caused by road-salt chlorides. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project produced background information, guidance and recommendations on the benefits and consequences of chloride-based road salt and non-chloride alternatives for de-icing and anti-icing Minnesota's roadways, which will assist road maintenance decision makers in reducing pollution from winter road management.

OVERALL PROJECT OUTCOME AND RESULTS
Over 100,000 tons of road salt are applied to Minnesota's roads each year to prevent or reduce snow and ice cover during the winter season. Sodium chloride is typically used because it is inexpensive and effective, but it can corrode vehicles, pavement, and metal structures (e.g., bridges), and it increases chloride concentration in surface and ground waters throughout the state. This results in additional costs for replacing roadway infrastructure and reduces water quality, habitat, and biodiversity in our natural resources. This project investigated alternatives to sodium chloride-based road salt that reduce snow and ice on roadways with less environmental impact. The project team reviewed scientific research papers, performed laboratory experiments, and used computer models to predict the potential environmental impacts of these chemicals on Minnesota's natural resources.

This project found several outcomes, including: 1) chloride-based road salt concentration can exceed the chronic and acute water quality standards during a typical year; 2) acetate-based alternatives only exceeded water quality standards for low flow rates (low dilution); 3) potassium-based chemicals can be toxic at low concentration, and toxicity thresholds are exceeded when potassium is applied over all roadways for all winter storms; 4) other alternatives such as formate, glycol, glycerol, and succinate have varying performance, application rate, and toxicity thresholds; 5) water-heated sand improves friction compared to bare ice or dry sand on bare ice and can be removed from the environment with simple grit collection chambers; and 6) non-chloride alternatives can reduce the bonding strength of ice to a solid surface. Thus, water-heated sand as an abrasive and organic or hydrophobic non-chloride alternatives can be used to reduce the use of chloride-based road salt and provide more winter benefit on Minnesota's roadways, but modeling predicts that some of these chemicals could exceed toxicity thresholds if applied for all conditions.

PROJECT RESULTS USE AND DISSEMINATION
The results from this project have been shared via presentations, interviews, reports, academic journals, and with stakeholders and decision makers during conferences and networking events. Some examples include a web article, two invited annual Minnesota Salt Symposium presentations (2019 & 2021), WCCO's 10 o'clock news "Good Question: How Does Salt Melt Ice?" with Jeff Wagner, the Transportation Research Board Annual meeting (2022), and several conference presentations and professional meetings. We believe sharing this information has enlightened decisions makers about the dangers of chloride road salts and non-chloride alternatives and how best to use each.

Project Completed: 6/30/2022
FINAL REPORT
Road Salt Alternatives and Pavement Innovations

Subd. 04d Protect Water Quality with Efficient Removal of Contaminants in Treatment Ponds for Storm Water - $325,000 TF

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Appropriation Language
$325,000 the second year is from the trust fund to the Board of Trustees of the Minnesota State Colleges and Universities system for St. Cloud State University to evaluate the effectiveness of best management practices in removing contaminants from storm water to safeguard aquatic habitats. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our study demonstrates that pharmaceuticals and pesticides are commonly found in urban stormwater and can impact aquatic life. Stormwater ponds, especially when augmented with iron-enhanced sand filtration, can often reduce these pollutants, and lessen their impact on Minnesota aquatic environments.

OVERALL PROJECT OUTCOME AND RESULTS
Urban stormwaters carry pollutants, including pharmaceuticals and pesticides, into Minnesota streams, rivers, and lakes. Stormwater ponds have not been studied to determine whether they are effective in removing these pollutants. The goal of this study was, therefore, to assess stormwater composition and treatment to inform natural resource managers to the best options for reducing urban stormwater related pollution to Minnesota waters. Our approach combined water chemistry analysis and assessment of biological toxicity in a range of species living in Minnesota waters. We sampled inflow and outflow of seven urban stormwater ponds across seasons and included traditional ponds and those augmented with additional iron-enhanced sand filters. Each water sample was analyzed for a range of pollutants and was also used to expose cells of animals living in Minnesota waters to assess the samples' toxic potential. Pharmaceuticals and pesticides were commonly found in stormwater. In nearly three-quarters of paired water samples (pond inflow and pond outflow), pharmaceutical concentrations were reduced in the outflow when compared to the inflow. Similarly, in about half of paired samples, pesticide concentrations were lower in the outflow sample. The measured reduction in pollutants was also reflected in improved cell health, but this effect was neither as pronounced nor as widespread as predicted by the water chemistry results. In some instances, exposed cells from some, but not all species did better in inflow water than outflow water and in some instances no changes in cell health were observed. The inconsistency in observed biological improvement may be the result of seasonal differences and/or conditions in specific stormwater ponds. This study demonstrates for the first time

that stormwater ponds are effective treatment options to reduce the impact of pharmaceuticals and pesticides on urban aquatic environments. Adding additional filtration, such as iron-enhanced sand filtration can further reduce stormwater pollutants.

PROJECT RESULTS USE AND DISSEMINATION
Despite the challenges associated with the Covid-19 pandemic, our team was able to give seven presentations related to this study. These include presentations to natural resource managers in Minnesota and to toxicologists at national and international scientific meetings. A St. Cloud State University graduate student completed a thesis on this project in 2020 which is currently being developed into a manuscript. Water chemistry data were integrated into a national USGS data base. Additional manuscripts are being prepared for future publication.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04e Develop Small and Inexpensive Purification System for Community Drinking Water - $425,000 TF

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Appropriation Language
$425,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a small and inexpensive purification-technology system for community drinking-water facilities to remove toxic contaminants, make water safe to drink, and improve drinking-water quality. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project designed a small water purification system for drinking water that can simultaneously remove the organic pollutants and heavy metal ions in the water. The system can be connected either to domestic drinking water taps or to water in lakes and rivers.

OVERALL PROJECT OUTCOME AND RESULTS
This project is dedicated to providing clean drinking water to the Minnesota community by designing and manufacturing a small water purification system and providing a possible solution for the water treatment of large water plants. A compact size prototype was first designed to verify the mechanism. Photocatalysis technology was used to remove the organic pollutants, and titanium dioxide was selected as the photocatalyst. Electrochemical reduction was applied to remove heavy metal ions in the water. Finally, the team innovatively combined photocatalysis and electrochemistry to develop a photoelectrocatalytic solution that can simultaneously remove organic matter and heavy metal ions from water. The result shows that the compact system can remove 91.6% percent of the 10-micrometer

methylene blue when the mass flow rate is 14.4 milliliters per hour (mL/h), and around 97.5% of 200 parts per million of copper(II) cations (Cu2+) can be removed at the same time. After the theory of photoelectrocatalysis was verified, standard-sized systems were designed and fabricated comprising an ultraviolet lamp, a chamber with active carbon, and a microfluidic system with immobilized photocatalyst. The standard-size system can remove nearly 100% of the 10-micrometer methylene blue and 96% of the Cu2+ in the water with a flow rate of 50 mL/h. The team conducted the field test with the drinking water from Commonwealth Terrace Cooperative, a community for University of Minnesota students and their families, and the water from Mississippi River. The testing results demonstrate the capability of using the designed system to remove organic pollutants and heavy metal ions in the water.

PROJECT RESULTS USE AND DISSEMINATION
On-site demonstration and tests as described in the activities at a student housing community and Mississippi river from May through June 2022. Communications with interested entrepreneurs have been ongoing with interested parties including local companies and individuals.

The following papers published in archived journals and prestigious conferences:

1. Zhou, P., & Cui, T. (2020). Enhanced photocatalytic efficiency by layer-by-layer self-assembly of graphene and titanium dioxide on shrink thermoplastic film. Microsystem Technologies, 26(12), 3793-3798.
2. Zhou, P., Zhang, T., Simon, T. W., & Cui, T. (2021). Simulation and Experiments on a Valveless Micropump With Fluidic Diodes Based on Topology Optimization. Journal of Microelectromechanical Systems, 31(2), 292-297.
3. Zhang, T., Zhou, P., Simon, T., & Cui, T. (2022). Vibrating an air bubble to enhance mass transfer for an ultra-sensitive electrochemical sensor. Sensors and Actuators B: Chemical, 354, 131218.

Professor Tianhong Cui presented five invited public seminars and talks on water sensors:
Invited Talk, University of Bath, July 4, 2022
Invited Talk, University of Cambridge, July 11, 2022
Invited Talk, EcoLab, May 4, 2022
Invited Talk, French-American Innovation Days, Water Management in Cities, April 8, 2021 (on-line)
Invited Talk, University of Texas at San Antonio, September 13, 2019

Project Completed: 6/30/2022
FINAL REPORT
Enhanced photocatalytic efficiency by layer-by- layer self-assembly of graphene and titanium dioxide on shrink thermoplastic film
Simulation and Experiments on a Valveless Micropump With Fluidic Diodes Based on Topology Optimization
Vibrating an air bubble to enhance mass transfer for an ultra-sensitive electrochemical sensor

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Subd. 04f Evaluate Emerging Pathogens in Lakes, Rivers, and Tap Water to Keep Drinking Water Safe - Research Project - $325,000 TF

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Appropriation Language
$325,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to evaluate emerging pathogens including Legionella and mycobacteria to ensure that surface water used for drinking water and tap water is safe to drink. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Seven full-scale drinking water systems were investigated for the presence of Legionella and Mycobacteria, opportunistic bacterial pathogens of health concern. This research demonstrates these organisms are commonly found in drinking water during the late summer/early fall; water utilities are encouraged to sustain a residual disinfectant to help suppress these pathogens.

OVERALL PROJECT OUTCOME AND RESULTS
The goal of this project was to investigate the presence of opportunistic pathogens at seven public water utilities within the State of Minnesota that treat surface water (i.e., lakes and rivers), as those water sources are expected to be at greater risk of pathogen contamination than deep groundwater wells. Samples were collected from the water prior to treatment (i.e., the water supply), the water immediately after treatment (i.e., finished water), and at two locations from within each drinking water distribution system. Each of the seven utilities was sampled from one to five times at the four locations for a total of 94 unique sample events.

This project demonstrated that known opportunistic pathogens (e.g., Legionella species) can be routinely detected throughout the year in surface water supplies in Minnesota and that water treatment is effective at removing them by 99% or more in most cases. The most concerning opportunistic pathogens that we tested for, Legionella pneumophila and Mycobacterium avium complex (MAC), were rarely detected and all the observed concentrations in tap water were well below the levels whereby these organisms would be of direct concern (i.e., none of our research results suggest a direct concern with respect to human health). Our results, however, are of indirect concern because these organisms could multiply within a drinking water distribution system should the conditions become favorable for their growth. Hence, our recommendation is that water utilities meticulously maintain a residual disinfectant throughout their distribution systems, particularly in the late summer/early fall when the warmer water creates conditions where Legionella species and MAC are most likely to multiply in the system and to be detected.

PROJECT RESULTS USE AND DISSEMINATION
Dissemination activities related to this project were severely hindered by the COVID-19 pandemic. We were, however, able to make two different presentations of our preliminary results to the Minnesota Section of the American Water Works association; these presentations were titled “Emerging Pathogens in Lakes, Rivers, and Tap Water” (September 24, 2020) and “Opportunistic Pathogens in Lakes, Rivers, and Tap Water” (September 16, 2021). We are currently writing three different manuscripts for

publication in the peer-reviewed literature that will include the results from this study. We will also share our results with Minnesota Department of Health personnel.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04g Characterize Unregulated Contaminants in Source Water and Drinking Water - $1,000,000 TF

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Appropriation Language
$1,000,000 the second year is from the trust fund to the commissioner of health to establish monitoring networks of public water-system wells and surface-water intakes to determine if contaminants persist after standard public water treatment. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Analysis of drinking water resources reveals the presence of a range of unregulated contaminants at low levels. Most of these levels are below health-based guidance, if available. Results are being used to inform development of new health-based guidance and to perpetuate drinking water ambient monitoring.

OVERALL PROJECT OUTCOME AND RESULTS
This project sampled water from 105 public water systems statewide for a wide spectrum of drinking water contaminants. Participating public water systems were organized into three groups: systems that use surface water, systems that use groundwater potentially influenced by wastewater, and systems that use groundwater potentially affected by agricultural land uses. Depending on the group, samples were analyzed for as many as 600 different contaminants, including pharmaceuticals, per- and polyfluoroalkyl substances (PFAS), organic wastewater indicators, and pesticides.

Results for individual systems showed that most contaminants analyzed were not detected in drinking water, but some contaminants were present at low levels. The detections included 84 pesticides, 51 pharmaceuticals, 43 wastewater indicators, 15 PFAS, eight benzotriazoles, and one inorganic compound. Some contaminants were detected at multiple systems. Results were compared against health-based guidance values, if available, although most contaminants analyzed lack health-based guidance values. A few results exceeded available guidance values. In those instances, Minnesota Department of Health staff coordinated with the public water system to validate results and take action where appropriate.

There were detections of contaminants from most classes analyzed, but pesticides and PFAS were the most commonly detected. The most frequently detected contaminants across the study included lithium, pesticides (metolachlor, atrazine, deethylatrazine), PFAS (PFBA, PFHxS, PFOS, PFOA), and tribromomethane. Differences in occurrence or concentration were observed in source versus finished water samples for some groups (e.g., pharmaceuticals, benzotriazoles) but not for others (e.g., PFAS, pesticides). Samples collected in geologically vulnerable settings generally showed higher contaminant concentrations than those collected from non-vulnerable sites.

Results have been used to prioritize and nominate contaminants for the development of health-based guidance. Also, the project has led to creation of a permanent drinking water ambient monitoring program. This ongoing work will help mitigate and manage the exposure to unregulated contaminants through Minnesota's drinking water.

PROJECT RESULTS USE AND DISSEMINATION
The project and associated materials are described on the MDH website. This project has spurred creation of risk communication resources for public water systems and MDH staff.

A project summary report has been prepared and will be available on the MDH website by October 2022.

Preliminary results from the project have been presented at the University of Minnesota's Water Resource Conference (October 2020). A complete analysis of the results is forthcoming and will be prepared for publication.

A professional paper describing the ELISA methodology used in this project is in press for publication. (Krall, Aliesha L., et al, 2022)

Project Completed: 6/30/2022
FINAL REPORT
Comparison of the Results of Enzyme-Linked Immunosorbent Assay (ELISA) to Mass-Spectrometry Based Analytical Methods for Six Unregulated Contaminants in Source Water and Finished Drinking-Water Samples
MN Department of Health - Monitoring Plan - Unregulated Contaminants Monitoring Project

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Subd. 04h Mapping Antibiotic Resistance in Minnesota to Help Protect Environmental, Animal, and Human Health - Research Project - $750,000 TF

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Appropriation Language
$750,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota

to quantify and map antibiotic and antibiotic-resistance gene contamination in Minnesota waters and soils to identify locations in need of mitigation to protect environmental, animal, and human health. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Our project mapped and quantified antibiotics and antibiotic resistance genes in Minnesota waters and soils. These findings are now used to target hotspots to better understand their fate and transformation in waterbodies. Ultimately, this information will be used for antimicrobial resistance mitigation strategies to protect environmental, human, and animal health.

OVERALL PROJECT OUTCOME AND RESULTS

Antimicrobial resistance (AMR) threatens human, animal, and ecosystem health. Antibiotic use in hospitals, long-term care facilities, and animal husbandry operations (point sources) play a major role in AMR emergence. Discharges and runoff from these point sources which may include AMR and antibiotics enter the natural environment, especially waterbodies, in some cases after going through a treatment system at the point source itself or at a wastewater treatment plant. The project goals included a) developing an "antibiotic footprint" map of Minnesota's natural environment that would predict areas where antibiotics, resistant bacteria, and antimicrobial resistance genes (ARG) are most likely to accumulate; b) quantifying concentrations of antibiotics and ARG at sites variably impacted by anthropogenic activities; and c) validating the prediction maps with the data collected across the state to develop a risk-based surveillance system that will aid in statewide AMR mitigation efforts in the natural environment. To achieve the overall project goals, an iterative holistic approach was used which included sampling different environmental matrices at different spatial scales, and the use of diverse statistical and spatial methods to map and predict both antibiotics and ARG. The highest antibiotic concentrations were found near human populated areas, while ARG did not present any specific spatial pattern. The macrospatial approach identified hotspot areas of ARG and antibiotic contamination, and the microspatial approach revealed an influence of wastewater on ARG abundance. The maps and predictions created for waterbodies were useful to identify antimicrobial AMR and antibiotic hotspots areas throughout the state, while the maps created for soil can be used for targeted field surveillance of antibiotics. The environment plays a key role in the dissemination and persistence of AMR, which affects human, animal, and environmental health; therefore, these findings are critical to continue developing mitigation strategies of AMR spread in Minnesota.

PROJECT RESULTS USE AND DISSEMINATION

This project has produced two peer-reviewed publications (Bueno, I., et al., 2021; and Bueno, I., et al., 2022), and there will be two others submitted soon summarizing the data for the 2020-2021 field seasons. This project has been presented at nine international and domestic conferences both as poster and oral presentations, and during at least two teaching courses. Also, a graduate student used data from this project to conduct her Master's. One of the dissemination goals was to engage the general public at the state fair, but the COVID-19 pandemic halted that.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04i Farmer-Led Expansion of Alfalfa Production to Increase Water Protection - $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a farmer-led, market-based working-lands approach to increase water protection in agricultural areas by targeted expansion of alfalfa production and development of methods to convert alfalfa to high-value bioproducts. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Farmers working together in watersheds can build the base of supply chains for new crops that provide continuous living cover of farmland, thereby providing healthy soil, clean water, and abundant wildlife. These supply chains will meet demand for sustainably produced commodities, providing a market-driven pathway to clean water.

OVERALL PROJECT OUTCOME AND RESULTS
We advanced a novel prevention-based strategy for protecting water resources, based on market-driven integration of alfalfa—and other perennial and annual crops that provide continuous living cover (CLC) of farmland—into corn/soybean-based farming operations. Integration of CLC crops will protect water resources, improve soil health, support wildlife, and enhance agricultural production and profit. Specifically, we 1) tested a farmer-led working lands approach for using alfalfa and other CLC crops to improve agricultural effects on water, and 2) did R&D to open new markets for alfalfa. Under 1), we worked with farmers in the Rogers Creek watershed near St. Peter, MN to develop and implement a watershed-scale protection plan based on adoption of alfalfa and other CLC crops, including on-farm implementation plans, and supported pilot-scale production of several novel CLC crops. We monitored water quality, showing that current farming systems are releasing relatively high levels of nutrients. Simulation modeling showed that increased production of alfalfa and other CLC crops can efficiently produce significant improvements in water quality. Economic analyses showed that integrating alfalfa and other CLC crops had good potential to support profitable production. Under 2), we assessed advanced processing and storage practices to reduce moisture-related spoilage and nutrient leaching of alfalfa, identifying eviable practices that reduce these historical impediments to profitable alfalfa production; we developed and assessed new applications for alfalfa, which revealed multiple promising options: biochemicals, nutraceuticals, and high-value sustainably-produced animal and aquaculture feeds; and developed supply-chain connections and identified market opportunities, via development of pilot projects, outreach and knowledge sharing, and novel collaborations. Overall, the project illuminated methods for building new production systems and supply chains needed to support increased production of alfalfa and other CLC crops as a scalable, non-regulatory approach for improving agricultural effects on water resources.

PROJECT RESULTS USE AND DISSEMINATION
We have disseminated results in reports, provided as appendices to the final project report (available in

the Research Reports section here), and many presentations as detailed in the project's reports. These include the 2019 Minnesota River Congress meeting on "Profitable Farming in Time of Climate Change" meeting, a February 2020 industry meeting on alfalfa utilization, a February 2021 exhibition on value-added alfalfa applications at the Midwest Forage Association's Symposium, a July 2021 field day at a Kernza® field attended by 75 industry stakeholders, and a June 2022 "Fields of Opportunity" webinar in June that presented an overview of project findings to a large internet audience.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 04j Using Perennial Grain Crops in Wellhead Protection Areas to Protect Groundwater - $250,000 TF

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Appropriation Language
$250,000 the second year is from the trust fund to the commissioner of agriculture to establish demonstration plots of Kernza, a new intermediate perennial grain crop, to evaluate the potential to profitably reduce nitrate contamination of groundwater in vulnerable wellhead protection regions of Minnesota. Any income generated as part of this appropriation may be used to expand the project.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This study established demonstration fields of Intermediate wheatgrass (Kernza®) within wellhead protection areas in central and southeast Minnesota and research results showed the nitrate reduction potential of targeted placement of perennials in areas with vulnerable groundwater.

OVERALL PROJECT OUTCOME AND RESULTS
Nitrate-nitrogen is one of the most common pollutants in Minnesota's groundwater. In some areas of the state, public and private wells have elevated nitrate levels. Groundwater is most vulnerable to nitrate contamination in central and southeast Minnesota. Areas in central are vulnerable because of widespread sandy soil and in southeast because of shallow bedrock, sinkholes and other geologic features. Intermediate wheatgrass (IWG) is a perennial grass that produces a novel grain, Kernza® and has the potential to reduce nitrate leaching compared to common annual row crop production. This study 1) established demonstration fields of IWG within wellhead protection areas in central and southeast Minnesota and 2) conducted an experiment that compared grain yields, biomass yields, soil nitrate, soil water content, and root biomass under IWG and a corn-soybean rotation for three years on a sandy soil in Central Minnesota. We also 3) conducted grain testing to determine optimum processing of Kernza for various end-use products (crackers, bread, beer, etc). Outcomes included targeted planting of 68 acres of IWG in wellhead protection areas near Chatfield and Verdi. A field day was held at both

sites, engaging over 60 people. Results from Activity 2 found that the mean soil nitrate was 77 to 96% lower under IWG than an annual rotation of corn and soybean. Total soil water content did not differ among cropping treatments. Root biomass was 82% lower under soybean than under IWG. Results from Activity 3 include the development of multiple Kernza cleaning and dehulling process workflows that include equipment needs, costs, and Kernza grain quality outcomes. The results from this project show that IWG effectively reduces the risk of nitrate leaching when grown on wellhead protection areas, and that the farming and food community is eager to continue exploring IWG as a new crop for water protection.

PROJECT RESULTS USE AND DISSEMINATION
Field days at two locations with ~60 participants on site. Events highlighted in newspaper articles. Case study/ project summaries written by Green Lands Blue Waters. Master's student research is in process of being submitted for publication in a peer-reviewed journal. Deliverable for Activity 3 includes a technical report on cleaning intermediate wheatgrass (Kernza) as well as resources for food processors to integrate it into their business operations.

The research supported by this grant is part of a larger network of research and implementation efforts around Kernza. Resources are compiled on a Kernza website, including resources for the cleaning and dehulling process.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04k Implement a Pilot Credit-Trading System for Storm Water in Shell Rock River Watershed to Improve Water Quality - $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Shell Rock River Watershed District to develop and implement a pilot water-quality credit-trading program for storm water that provides voluntary and cost-effective options to reduce pollution on a watershed scale.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This pilot project developed a water management framework plan along with associated appendices to submit an overlay permit for water quality credit trading to the Minnesota Pollution Control Agency. This work may provide water quality solutions to MS4 permittees bound by funding constraints.

OVERALL PROJECT OUTCOME AND RESULTS
This project was a collaborative effort between the SRRWD, the City of Albert Lea and utilized a technical advisory committee that consisted of Minnesota Pollution Control Agency (MPCA), Board of Water and Soil Resources, and Department of Agriculture staff.

Stormwater credit trading begins when an upstream landowner, or discharger, reduces pollution or nutrients below levels that are required by law. Those nutrient reductions are then verified, and measured by third party scientists and translated into "credits" that are sold to a credit bank. Downstream towns or cities could then purchase those credits instead of spending multi-million dollars in stormwater system retrofits.

The outcome of this project is the Fountain Lake Phosphorus Stormwater Water Quality Trading Management Plan. This document includes the regulatory requirements, policies, trade ratio, credit transaction value, and program administration behind stormwater credit trading. Attached to this plan are the appendices that support the management plans reasoning and forms that could be used to establish a credit trading program. The end result is a set of documents that are ready for an MS4 entity to submit to MPCA for possible approval of stormwater credit trading to take place. Please note the MPCA would have the authority to approve, modify or deny a stormwater credit trading program in the State of Minnesota. A working credit trading program such as this can provide water quality benefits at a reduced cost, contributing to the fishable, swimmable, drinkable waters initiative.

PROJECT RESULTS USE AND DISSEMINATION
Documents that are available for dissemination include the Fountain Lake Phosphorus Stormwater Water Quality Trading Management Plan and the cost effectiveness for water quality trading report. These documents will be sent to the Minnesota Pollution Control Agency, the Board of Water and Soil Resources, and Department of Agriculture. Both documents can also be found on the Shell Rock River Watersheds District website and submitted to LCCMR staff.

Project Completed: 6/30/2021
FINAL REPORT
Fountain Lake Stormwater Water Quality Trading Management Plan, including template forms and letters

Subd. 05 Technical Assistance, Outreach, and Environmental Education

Subd. 05b YES! Students Take on Minnesota Water-Quality Challenge - $213,000 TF

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Appropriation Language
$213,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Prairie Woods Environmental Learning Center to expand the Youth Energy Summit (YES!) model to improve local waterways by training and mobilizing over 20 youth-led teams in Minnesota communities to complete 30 or more projects related to water quality including monitoring and reporting.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our project, YES! Students Take on Water Quality Challenge, brought water quality and conservation knowledge and expertise to over 800 students from 126 communities across Minnesota. In 3 years, 81 hands-on water quality and prairie/habitat restoration projects were completed, and 20 waterbodies were improved while engaging with 30 resource experts.

OVERALL PROJECT OUTCOME AND RESULTS
Our project goal was to engage Minnesota's youth in taking on the challenge to improve our state's water ways. We accomplished this goal by:

- Supporting 54 youth-led YES! teams, with over 800 students, in 126 Minnesota communities
- Completing 81 new student-driven water quality and prairie/habitat restoration projects
- Providing 3 Fall Summit events and 27 regional workshops
- Leveraging the expertise and kindness of 6,564 volunteer hours including 3,125 hours of YES! student volunteer hours and $75,000 in community funds
- Awarding the Water Quality Stewardship award in 2019 and 2020

Our aim was to help students to better understand the interconnectedness of their daily actions and water quality. We accomplished this through leveraging the expertise of 30 water quality experts who educated and trained our students about local water quality challenges, techniques to improve and conserve water quality and then assisted them in doing related student-driven projects.

YES! student-driven projects benefited Minnesota communities by improving waterways, cleaning up shorelines, restoring native prairies and establishing new native plantings and habitats. Other projects included Aquatic Invasive Species (AIS) monitoring, assessing drinking water, installing hydration stations, storm drain stenciling (Adopt-a-Drain), water usage tracking and water-related events and peer education.

As one YES! student from Minnewaska said, "I enjoy YES! because of the positive interactions-people taking time out of their day to teach you things. It's something for yourself and it's something to do for your community." Another student from Carlton stated, "It feels really rewarding to know that we are actually making a difference!" Resource expert Phil Votruba commented, "You guys serve as an inspiration for youth across the state and across the country!"

A Sleepy Eye Student remarked "As a part of YES! team I got to participate in River Watch which consists of monitoring Minnesota's rivers and helping to keep them safe. I was able to learn more about what makes the rivers healthy or unhealthy and was able to help in the monitoring process."

PROJECT RESULTS USE AND DISSEMINATION
During this project (July 1, 2018, to June 30, 2021) YES! staff have tabled or presented at 20 events. YES! was featured in 22 outside articles, radio broadcasts and videos. They are listed on our website and can

be accessed here at YES! in the News. In addition, staff posted 86 blog posts to our YES! website which were shared on our social media pages including Facebook, YouTube, and LinkedIn.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 05d Connecting Students with Water Stewardship through Hands-on Learning - $400,000 TF

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Appropriation Language
$400,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Minnesota Trout Unlimited to engage students in classroom and outdoor hands-on learning focused on water quality, groundwater, aquatic life, and watershed stewardship and providing youth and their families with fishing experiences. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project connected approximately 10,000 Minnesota youth with their local watersheds. Through a combination of habitat site explorations, field studies, classroom learning, and outdoor recreation, students gained an appreciation for the natural world and understanding of how their decisions can positively impact water quality and watershed health.

OVERALL PROJECT OUTCOME AND RESULTS
In today's technology-based society, youth are increasingly becoming disconnected from the natural environment. This disconnect can foster apathy about the environment, natural resources, and outdoor recreation, and impact their ability to make well informed decisions about the environment as adults. The program countered this by using tangible education tools and getting students outdoors for hands-on learning activities that connected them to aquatic ecosystems. It utilized classroom aquariums where students studied the development of trout from egg to juvenile. This served as a springboard for field trips to streams and as a focal point for reinforcing learning about water, watersheds, and ecology. Introductions to outdoor recreation were offered to encourage lifelong, tangible connections to aquatic ecosystems.

The number of schools and nature centers participating in this outdoor education program doubled from 29 during the 2018-2019 school year to 60 during the 2021-2022 school year. The program expanded from Twin Cities metropolitan area to schools in Duluth, Bemidji, Alexandria, Willmar, Winona, and other outstate communities. Despite the serious challenges that the COVID-19 pandemic

created for conducting in-person field day and classroom learning, our education team conducted more than 260 hands-on environmental education programs for nearly 9,000 students. In addition, we developed remote learning lessons for teachers, students, and parents to extend learning outside the classroom. We reinforced learning about watershed health with a recreational component that creates lifelong interest in waters through fishing and conservation. Minnesota Trout Unlimited's (MNTU) instructors led nearly 70 introductory fishing skills programs for over 1,000 youth and their families. These clinics were made possible by partnerships with local governments and civic organizations, and numerous Trout Unlimited volunteers.

Approximately 10,000 students developed greater understanding of, and connections to, aquatic ecosystems, which will help them to make well informed decisions that positively impact water quality and watershed health.

PROJECT RESULTS USE AND DISSEMINATION
Our website was revamped with updated information about educational opportunities, including Trout in the Classroom and fishing skills programs. The Facebook and Instagram pages were started in 2018 and gained hundreds of followers during this project. A suite of youth educational videos and other resources were developed and are available online. Our team wrote education updates and youth series articles for all three MNTU newsletter editions publish each year. Thousands of hard copies of the newsletters were distributed to teachers for classroom use and/or to send home with students.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 05e Expanding River Watch Program on the Minnesota River With High School Teams - $100,000 TF

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Appropriation Language
$100,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Friends of the Minnesota Valley to expand a River Watch program on the Minnesota River to recruit at least 15 additional teams of high school students in monthly monitoring and reporting of water quality.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
With funding from the ENRTF, we were able to expand River Watch from four high school teams to 14 teams and recruited at least two additional teams to participate in future years. Through the program, approximately 250 students learned how to conduct water quality monitoring, the pollutants that affect water quality, how to operate monitoring equipment, and to report the data. Students learned sources of pollution and actions that can be taken to reduce future water pollution.

OVERALL PROJECT OUTCOME AND RESULTS

The River Watch program engaged high school students from18 high schools in lessons about surface water quality, students learned how to operate sophisticated electronic equipment to test water quality. Data collected was submitted to the Minnesota Pollution Control Agency through the Citizen Water Quality Monitoring program.

Although data collection is an important purpose of the River Watch program, providing students with a meaningful experiential learning opportunity that teaches them the importance of water quality is the primary purpose. River Watch participants learn more than just facts, they develop understanding about water quality they will carry with them for their entire lives. Based on student feedback, River Watch achieved this goal of a meaningful educational experience.

Another goal Friends of the Minnesota Valley hoped to accomplish with ENRTF funding was to grow our River Watch program from a trial program working with four teams to a program working with 15-20 teams. Through the use of ENRTF funding, Friends was able to develop high quality informational brochures, a website, and other supporting materials to promote the River Watch program. We succeeded by working with 18 different high schools and will begin the 2021-2022 school year with 16 teams participating in River Watch and other teams considering joining. Covid limitations significantly reduced our ability to take students directly to rivers for sampling during the 2021 school year, but desired program growth did occur.

A third objective was to raise public awareness of the River Watch program and public awareness of the water quality problems facing the Minnesota River. On several occasions, local news media covered student monitoring events. Public awareness of River Watch is well established and the program is set to continue in future years due to the foundation built during the three years that the program was funded by LCCMR.

The Minnesota River is widely seen as one of the most polluted rivers in Minnesota. Teaching today's high school students(tomorrows adult citizens and leaders) the seriousness of this problem, giving them the knowledge and understanding of the problem, and inculcating a desire to solve the problem will benefit the State of Minnesota as these young people move into positions in which their personal actions and the public decisions they make or influence lead to river water quality protections. As the River Watch program grows, an ever-growing number of young people will be motivated and equipped to "clean up" the Minnesota River.

The data collected to date and in the future will enable policy makers at the local and state level to make better informed decisions that will improve and protect water quality in the Minnesota River basin and downstream in the Mississippi River.

PROJECT RESULTS USE AND DISSEMINATION

Each time a River Watch Team conducted a water quality monitoring event, local news media including radio, newspapers, and television was informed and invited to provide coverage. Several local newspaper articles covering such events were published and at least one television story was broadcast.

The very process of recruiting River Watch teams involved communication with every secondary school administrator in the Minnesota River basin. These communications were often shared with local school boards as part of the participation approval process. Students and staff in River Watch have been invited

to speak at local service group meetings. Each communication included reference to LCCMR/ENRTF funding.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 05f Pollinator Ambassadors Program for Gardens - $250,000 TF

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Appropriation Language
$250,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to increase knowledge of pollinators in gardens and yards and improve pollinator habitat by expanding outreach, training, and tools for Minnesota communities as part of the Pollinator Ambassadors program. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Pollinator Ambassadors for Gardens program broadened pollinator education access across Minnesota, particularly to traditionally underserved audiences, through training 43 youth Pollinator Ambassadors and distributing 250 Pollinator Education Toolkits. Broader adoption of pollinator conservation action-steps will help Minnesotans conserve pollinator diversity, which will support food production, water quality, and healthy ecosystems.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesotans are aware of the importance of pollinators to healthy food systems and ecosystem health but lack prepared educators and education materials to provide action steps for pollinator conservation. The Pollinator Ambassadors Program for Gardens aimed to 1) provide direct training to youth to engage their communities in pollinator education and 2) create a Pollinator Education Toolkit with expert-designed materials that educators state-wide can use to teach pollinator conservation action steps. We have successfully trained 43 Pollinator Ambassadors between the ages of 14 and 18 through in-person and virtual workshops. Pollinator Ambassadors have directly engaged approximately 3,000 Minnesotans. We distributed 250 Pollinator Education Toolkits across Minnesota to 53 nature centers, 91 classroom educators, 33 Master Gardeners and Master Naturalists, 42 non-profits, 14 federal, state, or municipal agencies, and 17 University of Minnesota Extension programs. These Pollinator Education Toolkit holders estimate reaching 100,000 people annually. Many organizations receiving Pollinator Education Toolkits prioritize service to or primarily serve low-income audiences (40%), recent immigrants (15%), Latinx communities (15%), African American communities (13%), Asian American communities (9%), and Native American communities (9%). Toolkits are also available publicly through Inter Library Loan and check out at four University of Minnesota Extension and Outreach Centers across

Minnesota. Over 400 educators across the world have accessed the Digital Pollinator Education Toolkit with an estimated annual reach of 180,000. The Pollinator Ambassadors Program for Gardens has increased capacity to reach a broad geographic range of audiences in Minnesota, with youth trained in Big Stone, Hennepin, Ramsey, Wright, and Olmsted counties and toolkits with educators in 60 of Minnesota's 87 counties, as well as increasing reach to traditionally underserved audiences. Broader adoption of pollinator action steps by Minnesotans will help conserve pollinator diversity, which in turn will support food production, water quality, and healthy ecosystems.

PROJECT RESULTS USE AND DISSEMINATION
We have several resources that should be shared broadly. A summary of the impact of the Pollinator Ambassadors for Gardens program is available on the Bee Lab YouTube channel. The University of Minnesota Bee Lab website has a page dedicated to the Pollinators Ambassadors program. Pollinator Education Toolkits are available for checkout out through Interlibrary Loan and at the University West Central, North Central, Southwest and Rosemount Research & Outreach Centers. Digital Pollinator Education Toolkit resources are available to everyone who fills out our application form. We have created a "Learn to Use Pollinator Education Toolkits" video playlist to provide extra background, and a "Pollinator Ambassadors" video playlist to complement activities from the Toolkits. The Habitat Assessment Guide for Yards and Gardens is available as a pdf document.

Project Completed: 6/30/2022
FINAL REPORT
Habitat Assessment Guide for Pollinators in Yards, Gardens, and Parks - 12 pgs
Checklist of Actions - To Promote Pollinators In Yards, Gardens & Parks
A Bee Nest Round The Year
Bees or Wanna-Bees?
Four Actions to Help Pollinators
How are the Pollinators Doing?
Rare Minnesota Bees
Myths and Realities for Polinators
Abejas O Mimicas
Como Les Esta Yendo A Los Polinizadores
Cuatro Acciones Para Ayudar A Los Polinizadores
Mitos Y Realidades Sobre Los Polinizadores

Subd. 05g Morris Prairie Pollinator Demonstration Area and Education - $550,000 TF

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Appropriation Language
$550,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota

for the West Central Research and Outreach Center at Morris to restore 17 acres of native prairie for pollinators and to construct wayside shelters and kiosks along an existing trail to provide information to visitors on the importance of pollinators and native prairie ecosystems. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project restored 17 acres to a native prairie habitat to enhance the local ecosystem for beneficial pollinators and native species of plants. The project site also provides educational opportunities for visitors on how to protect or enhance native habitats and beneficial pollinators.

OVERALL PROJECT OUTCOME AND RESULTS
The Pomme de Terre River watershed area in west central Minnesota was once a sprawling prairie, home to beneficial pollinator species and prairie vegetation. Now, however, we've seen a devastating decline of beneficial pollinator species and a disruption to the remaining native prairie ecosystem due to land conversion to other uses. To address this concern, we worked with prairie restoration specialists to restore a 17-acre habitat in Morris, Minnesota. All non-native vegetation was removed, and a diversity of prairie plant seeds were seeded throughout the site to offer food sources for pollinators known to our region. Fifty Bur Oak trees were planted to create an oak savannah for improved wildlife habitat. Regular maintenance was conducted on the site to control both perennial and annual weeds, which allowed the prairie species to establish. The outcome was an improved landscape that supports bees, butterflies, and other beneficial pollinators as well as an enhanced ecosystem. The addition of native plants sequesters carbon and other air pollutants and filters runoff entering the watershed. Since restoration, biodiversity of plant and wildlife species has visibly increased. The native plant species are beginning to dominate over unwanted vegetation and attract a multitude of pollinator species.

Educational interpretation was installed throughout the demonstration site to encourage visitors to connect with the prairie habitat and learn how to create or enhance habitats on their own properties. We partnered with University of Minnesota Morris faculty and students to design, develop, and evaluate an interactive educational activity on pollinators and prairie restoration. The local high school uses the restoration site as an outdoor classroom to learn about beekeeping, pollinator health, and pollinator habitats.

PROJECT RESULTS USE AND DISSEMINATION
Two educational kiosks were installed on the site, along with two interpretive signs. Information available to the public at the kiosks includes why we need pollinators, the steps we've taken to restore the area, and the types of native pollinators in our region. A pamphlet from the Minnesota Department of Agriculture is available at the northern most kiosk. Interpretive signs along the trail include information about pesticide use in a pollinator friendly way and the environmental benefits of prairie restoration. Updates and articles about the project are available on the West Central Research and Outreach website.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 05h Expanding Nature Knowledge and Experience with New Interactive Exhibits at North Mississippi Regional Park - $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Minneapolis Park and Recreation Board to develop new interactive exhibits at North Mississippi Regional Park to encourage the approximately 326,000 annual visitors to better understand and explore the river and surrounding natural area.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The new Nature in the City exhibit at North Mississippi Regional Park features compelling design with interactive components that spark curiosity about Nature, increase knowledge about Nature, entice visitors to explore the outdoors, and become better stewards of the environment.

OVERALL PROJECT OUTCOME AND RESULTS
Nestled between I-94 and the Mississippi River in north Minneapolis, North Mississippi Regional Park serves more than 300,000 annual visitors. Located within the park is the Carl Kroening Interpretive Center which featured an outdated and worn educational exhibit focused on human relationships to the Mississippi River as drinking water, transportation corridor, and job source. However, park staff discovered that what visitors really wanted was to learn more about the natural resources found in the park - the land, the water, animals, birds and insects - and connect with Nature in a hands-on, immersive way.

The overarching objective of the project is to educate and inspire park visitors so they can make better decisions to positively impact the natural world. Minneapolis Park & Recreation Board staff worked with Split Rock Studios (SRS) to imagine and develop content and components for a new educational exhibit titled Nature in the City. SRS then designed, fabricated, sculpted, and installed the landforms, interactives, super graphics, taxidermy, technology, signs and more. The exhibit features current research, compelling interpretation and visuals, and interactive components to spark wonder and curiosity about the Mississippi River, stormwater runoff, native plants and pollinators, wildlife and their adaptations to city living, plus migration, the Mississippi flyway, and more. Designed to foster repeat visitation, parts of the exhibit can change out seasonally, while others provide space to add stories and information in response to park visitor interests. The exhibits, along with programs led by staff, promote ways people can take action to benefit land and water. Park visitors are also encouraged to apply their new knowledge while exploring the park and contribute to citizen science field work.

PROJECT RESULTS USE AND DISSEMINATION
Due to the pandemic, the Kroening Interpretive Center remains closed to the public. When restrictions are lifted, staff look forward to welcoming the estimated 326,000 annual visitors to North Mississippi Regional Park to explore the new Nature in the City exhibit.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 05j Expanding the State's Reuse Economy to Conserve Natural Resources - $275,000 TF

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Appropriation Language
$275,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with ReUSE Minnesota to provide outreach and technical assistance to communities and small businesses to create and expand opportunities for reusing, renting, and repairing consumer goods as an alternative to using new materials so solid-waste disposal and its impacts are measurably reduced and more local reuse jobs are created. Net income generated as part of this appropriation may be reinvested in the project if a plan for reinvestment is approved in the work plan.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
ReUSE MN connected businesses and consumers to organizations providing reuse, repair, and rental services through two conferences and 24 educational events. Research conducted revealed the Minnesota reuse sector makes up 1/3 of the retail economy. By avoiding new products, reuse saves 67 billion gallons of freshwater from being used each year.

OVERALL PROJECT OUTCOME AND RESULTS
Current practices of throwing away usable items and unnecessarily producing new goods depletes finite natural resources and pollutes our environment at an unsustainable pace. Reuse helps slow this process and keeps materials and products in use longer. The goal for this project was to promote the benefits of reuse, repair, and rental, including the organizations providing these services. Encouraging consumers to reuse results in more sustainable consumption patterns and supports the local economy.

LCCMR funding allowed ReUSE MN, a small, volunteer-run non-profit, to hire a management company to streamline organizational processes, update our website, and improve our membership structure.

Over the past two years, we hosted two conferences that highlighted reuse innovations, programs, policies, and research. The 2019 conference was the state’s first reuse-focused conference, and welcomed 118 attendees. The 2020 virtual national conference saw 212 attendees representing 23 states and 3 Canadian provinces. ReUSE MN also hosted 20 webinars and educational sessions, and staffed booths/presented about reuse at 17 partner-hosted events.

The organization grew its reuse network of nonprofits, businesses, policymakers, educators, and consumers with paid memberships increasing to 205 – a nearly 7-fold increase over the grant period.

Using survey responses and purchased business data, ReUSE MN created a report summarizing the environmental, economic, and social impacts of reuse. Minnesota's reuse sectors:

- make up 1/3 of the retail economy, generating $5.8 billion (2017).
- avoid over 2.7 million metric tons of greenhouse gas emissions and 67 billion gallons of freshwater extraction per year (ground or surface water sources) from products that would have been newly manufactured.

Reuse organizations play an important role in communities, keeping money and services local, offering spaces for learning and skills-building, and bringing like-minded individuals together around shared goals. Data and stories gathered throughout this grant will help advocate for Minnesota reuse organizations and show the importance of extending the life of our belongings and protecting the state's resources.

PROJECT RESULTS USE AND DISSEMINATION
ReUSE Minnesota provides regular updates and resources through monthly e-newsletters and social media. We reached more than 2,100 people through 36 educational sessions, member meetings, and two conferences. The ReUSE MN website acts as a directory for rental, repair, and reuse businesses as well as a resource for events and news about the reuse economy.

The final measurement and methodology report is housed on the ReUSE MN website. The new Reuse Impact map provides an interactive look at how reuse benefits the economy and environment across the state and by county. Nearly 100 listeners heard about the impact study results on a webinar. Results have already helped start conversations in counties that want to boost their reuse business sector to reduce waste.

Project Completed: 12/31/2020
FINAL REPORT

Subd. 05k Expand Materials Reuse and Recycling Jobs Program - $800,000 TF

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Appropriation Language
$665,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Better Futures Minnesota, in cooperation with the Northwest Indian Community Development Corporation, and $135,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Natural Resources Research Institute in Duluth to expand building deconstruction and material-reuse practices and jobs in partnership with counties, tribes, and

municipalities statewide and to document the environmental, health, and economic benefits of these practices. Net income generated by Better Futures as part of this or a previous related appropriation from the environment and natural resources trust fund may be reinvested in the project if a plan for reinvestment is approved in the work plan.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

This project funded: the deconstruction of 29 properties; 10.5 FTE jobs; transitional employment of 200 people; a reuse project at a county landfill; and the promotion of deconstruction and material reuse throughout the State. The project generated close to net zero emissions by diverting 80% of 8,000,000 pounds of material from landfills.

OVERALL PROJECT OUTCOME AND RESULTS

This project supported the growth of building material stewardship, an essential and viable alternative to burying 70% of the State's building waste in landfills. Practical alternatives to dumping are needed to avert the serious health, financial, and environmental costs of landfill use.

Three activities were completed. First, by providing advice and assistance to counties, a deconstruction incentive grant program for homeowners in Hennepin County was implemented and a diversion/reuse program at the Becker County landfill was established.

Second, through presentations and outreach the partners made significant progress in making the reuse and recycling of building materials a preferred practice statewide. One result is the Sustainable Building Materials stakeholder group with staff support from the MPCA. This work group is focused on informing rule changes for landfills, expanding deconstruction work in the State, and expanding the marketplace for the reuse of materials.

This outreach was combined with deconstructing 29 properties in 22 communities, launching a diversion and reuse program at a county landfill, and training and offering transitional employment for 200 people. The results of this effort - types and value of materials harvested and reused; jobs created; and the benefits for our air, water, and land - demonstrated to many audiences the value of this project.

The third activity focused on documenting that 80% (3,117 tons or 6,234,000 pounds) of the 4,000 tons collected was diverted from landfills. The most beneficial environmental outcome is that 346 tons or 9% of the material was reused.

Overall, the benefits of the deconstruction and reuse, as an alternative to demolition, are broad and generous. Project data shows deconstruction generates 70% less emissions than demolition. This project also approached net zero emissions per ton of material collected: .63 metric tons of CO2 for deconstruction compared to 2.23 metric tons of CO2 for demolition.

This project can inform economic development and healthy environmental practices Statewide. The formula is practical: take apart and reuse buildings rather than dumping them in landfills and begin diverting reusable materials at landfills. These new methods create more jobs, provide quality materials for consumers, and dramatically reduces harmful pollutants.

PROJECT RESULTS USE AND DISSEMINATION

The highlights of the partners' many and varied dissemination efforts included: an opportunity to introduce building material stewardship and deconstruction practices to more than 150 government,

tribal, and business owners during statewide MPCA stakeholder meetings; an opportunity to describe this projects' value and impact to an international audience during a "virtual" conference sponsored by the Ellen McArthur Foundation in London, England; and, a presentation at the 2021 Environmental Initiative awards ceremony (Better Futures and Becker County received the 2021 Rural Innovation Award).

The partner's deconstruction pilot with St Louis County generated opportunities to promote the benefits and impact of deconstruction and material reuse.

Articles on this project were included in the Duluth Monitor, WDIO Radio, Duluth News Tribune, FOX21, and KBJR6.

Becker County staff created a significant number of followers (over 2500) on Facebook Marketplace. This site along with Craig's List are effective venues for promoting the reuse pilot and promoting sales events. Staff also promote reuse on a local weekly radio show.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 06 Aquatic and Terrestrial Invasive Species

Subd. 06b Palmer Amaranth Detection and Eradication Continuation - $431,000 TF

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Appropriation Language
$431,000 the second year is from the trust fund to the commissioner of agriculture to continue to monitor, ground survey, and control Palmer amaranth primarily in conservation plantings and to develop and implement aerial-survey methods to prevent infestation and protect prairies, other natural areas, and agricultural crops.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Palmer amaranth is an aggressive weed that is expensive and damaging to control. It was found as a contaminant in a small number of conservation planting seed mixes sold in Minnesota. Rapid response to the situation resulted in Palmer amaranth eradication from impacted conservation plantings.

OVERALL PROJECT OUTCOME AND RESULTS
Palmer amaranth is an invasive plant that threatens row crop production and prairies. In 2016, it was found in a small number of conservation planting seed mixes. There were concerns that Palmer amaranth would spread to nearby crop fields and cause high yield losses, up to 91% in corn and 78% in soybeans. Palmer amaranth can be resistant to multiple herbicides making it difficult to control. There

was a lot of concern about the conservation planting pathway for Palmer amaranth and it was declared an agricultural emergency by the commissioner of agriculture.
This project enabled rapid response to the situation as it unfolded.

- Palmer amaranth was controlled in the field by Conservation Corps Minnesota using propane torches, prescribed fire and hand pulling. As a result, Palmer amaranth was eradicated from all impacted conservation plantings. There were 92 infestations (some in crop fields) of which 67 were eradicated, 13 were negative (no Palmer found in field planted with contaminated seed mix) and 12 are active infestations in crop fields that MDA will continue to monitor.
    - Intensive infestation monitoring was required to achieve this successful outcome.
- Drones were utilized to help look for Palmer amaranth in large fields. This work with drones was experimental and led by the University of Minnesota's UAV Lab. We learned much that can be applied for future aerial survey efforts.
    - MDA now uses a drone for aerial survey.

Palmer amaranth control efforts were so effective that some Conservation Corps Minnesota funding could be diverted to control other priority target species infestations including black swallow-wort, common teasel, cutleaf teasel, Japanese hops, oriental bittersweet, poison hemlock and knotweeds.

PROJECT RESULTS USE AND DISSEMINATION
Presentations, articles, and a paper were the primary dissemination means. There were 40 presentations, trainings or updates about Palmer amaranth and this project. In trainings, we used resources developed for the ENRTF project Elimination of Target Invasive Plant Species including 3D printed models of Palmer amaranth seedlings, pressed plant samples, and large format printed displays. Two popular press articles were written and sent to outstate media. Our paper Timeline of Palmer amaranth invasion and eradication in Minnesota was open access published in Weed Technology. To date, it was accessed via HTML by 741 and via PDF by 4,580.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 06c Evaluate Control Methods for Invasive Hybrid Cattails - Research Project - $131,000 TF

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Appropriation Language
$131,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Voyageurs National Park to evaluate the effectiveness of mechanical harvesting and managing muskrat populations to remove exotic hybrid cattails and restore fish and wildlife habitat in

Minnesota wetlands. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Invasive hybrid cattails can be effectively controlled by mechanical treatments, creating space for native plants like wild rice and other native aquatic plants, and enhancing habitat for wetland-loving wildlife like muskrats, mink, otters, bitterns, rails, grebes, and more.

OVERALL PROJECT OUTCOME AND RESULTS
Invasive hybrid cattails are rapidly expanding throughout Minnesota's wetlands. Hybrid cattails grow in dense stands that crowd out native plant species and create single species stands that can degrade both fish and wildlife habitat and negatively impacts biodiversity and wetland function. Starting in 2016, Park staff, securing both state and federal funding, initiated the Voyageurs Wetland Restoration Project to restore wetlands within the large lakes of the park that have been infested by invasive hybrid cattails. Through this LCCMR grant, we documented that we achieved reductions of invasive hybrid cattail cover from all six mechanical treatments that were tested. Lethal treatments showed the greatest reduction in cattail coverage with all treatments, showing approximately a 90% reduction in cattail cover up to 3-years post-treatment. Treatment of cattails increased cover and diversity of native wetland plants across all treatment types, which we lumped into 4 functional plant groups: rushes, sedges, grasses, and herbaceous plants. Our project represented the first attempt to translocate muskrats and assess post-translocation survival and movements. Additionally, our project was the first to experimentally investigate feeding preferences of muskrats and also quantify immediate foraging effects of translocated muskrat populations on T. x glauca coverage in wetlands. We found that translocated muskrats quickly established home ranges and that survival of post-translocated muskrats was similar to reported survival estimates of other established muskrat populations. Overall, our results suggest that muskrat translocations may be a viable option to re-establish or temporarily increase abundances of muskrat populations, especially in areas with a healthy beaver population. Even though we showed that muskrats do eat invasive hybrid cattails, we do not believe that muskrat densities in our area can be elevated to a high enough density for multiple years to where stands of invasive hybrid cattail can be eliminated or even noticeably reduced in abundance.
PROJECT RESULTS USE AND DISSEMINATION
This collaboration between the National Park Service's Voyageurs Wetland Restoration Project and Kansas State University produced five scientific papers and other reports. Our findings, though many are still preliminary, have influenced wetland restoration techniques throughout the U.S. and Canada through our presentations at local, state, and national scientific conferences; through our outreach efforts via print and online media; and through one-on-one consultations with others working on wetland restoration.

Project Completed: 6/30/2022
FINAL REPORT
Supplementary Materials for "Evaluate Control Methods for Invasive Hybrid Cattails" - 85 pgs

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Subd. 06d Developing RNA Interference to Control Zebra Mussels - $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the United States Geological Survey to develop a genetic control tool that exploits the natural process of RNA silencing to specifically target and effectively control zebra mussels without affecting other species or causing other nontarget effects. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project did not occur due to challenges the entity encountered receiving state funds.

Project Completed: 6/30/2021

Subd. 06e Install and Evaluate an Invasive Carp Deterrent for Mississippi River Locks and Dams - $998,000 TF

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Appropriation Language
$998,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota in cooperation with the United States Army Corps of Engineers and the United States Fish and Wildlife Service to install, evaluate, and optimize a system in Mississippi River locks and dams to deter passage of invasive carp without negatively impacting native fish and to evaluate the ability of predator fish in the pools above the locks and dams to consume young carp. The project must conduct a cost comparison of equipment purchase versus lease options and choose the most effective option. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project discovered that even when equipped with a sound-light deterrent, Lock and Dam 8 has little promise to stop invasive carp but that Lock and Dam 5 could stop over 99% of all carp if equipped with a sound-light deterrent that includes a bubble curtain.

OVERALL PROJECT OUTCOME AND RESULTS
The purpose of our project was to determine how to stop invasive carp. Because all carp must pass through locks-and-dams we focused on these structures, focusing on Lock and Dam 8 (LD8) near the Iowa border. We specifically examined whether and how carp could be stopped at LD8 by adjusting its spillway gates, installing a sound-light deterrent in its lock, and managing native fish predators in its vicinity. While we found that this combination has little promise at LD8, nearly all carp could be stopped upstream at LD5 using a variant of it, sparing Lake Pepin and most of the state. Insight came from several aspects of our research. First, by releasing acoustically-tagged common carp at biweekly intervals and tracking their movements upstream through LD8, we discovered that carp passage through spillway gates only occurs at high discharges as predicted by a fish passage model -- proving that LD8 is a poor location to stop carp because its gates open infrequently, but that LD5 is an excellent location because its gates do. Second, we found that carp passage through locks is predictably low, meaning that the lock at LD5 is an excellent location to install a deterrent because of this LD's low spillway passage rates. Third, while we found that a sound-light deterrent was ineffective at blocking carp, a sound-light-bubbling system (BAFF) is. An engineering analysis supported using a BAFF at LD5. Fourth, when we examined whether native predatory fishes might control invasive carp, we discovered no support: no common predator feeds on fish (carp) eggs and floodplain predators do not favor their young. Finally, we created a numeric model which showed that a BAFF at LD5, coupled with spillway optimization, and carp removal at that site would stop 99.6% of all carp in Minnesota – a solution has been identified.

PROJECT RESULTS USE AND DISSEMINATION
Our findings on carp deterrents are being used by the US Fish and Wildlife Service to test a bioacoustic fish fence. Our findings have been widely disseminated. A recent summary of the project was presented at a carp forum: Carp Forum. In addition, we presented our findings at several public (ex. 2019 Stop Carp Forum), scientific (ex. Midwest Fish and Wildlife meetings) and agency level meetings (ex. annual Mississippi River ANS Task Force Meetings). We have published 3 scientific peer-reviewed articles and have 2 in review. The StarTribune covered our project twice in front page articles as did Minnesota Outdoors.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 06f Determining Risk of a Toxic Alga in Minnesota Lakes - Research Project - $200,000 TF

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Appropriation Language
$200,000 the second year is from the trust fund to the Science Museum of Minnesota for the St. Croix

Watershed Research Station to determine the historical distribution, abundance, and toxicity of the invasive blue-green alga, Cylindrospermopsis raciborskii, in about 20 lakes across Minnesota and inform managers and the public about the alga's spread and health risks. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

This project produced the first systematic survey of Minnesota's Sentinel Lakes for the toxic invasive algae Cylindrospermopsis raciborskii (Cylindro). Cylindro was contained to the 2 lakes where it was initially found and did not produce toxins in measurable amounts. Sediment records indicated that Cylindro has appeared in the last 10 years and has not spread statewide.

OVERALL PROJECT OUTCOME AND RESULTS

Cylindro is a subtropical invasive species of Cyanobacteria that has been invading lakes in the Upper Midwest since the early 2000s. Cylindro is of particular concern because it is known to produce a potent liver toxin and the presence of its blooms can be difficult to identify. Cylindro was first discovered in two Minnesota lakes in 2013, and that discovery led to the design of this statewide survey of the Minnesota Sentinel Lakes to better understand the spread and invasion history of this species. Our monitoring results, based on DNA and microscopy, show that Cylindro is currently limited to the two lakes where it was initially found, and sediment cores indicate that it has been present in those lakes for under 10 years. Additionally, even in lakes where Cylindro was present, there was no evidence of toxin production in detectable amounts, minimizing the public and wildlife health threat of this species. Thankfully, these results suggest that the threat of Cylindro invasion in Minnesota lakes is currently low, though continued monitoring for this species is important given the trend of warming lake waters across the state.

PROJECT RESULTS USE AND DISSEMINATION

We have shared the progress and results from this project widely over the duration of the project. This includes both articles written by our staff, shared with traditional and social media, and peer reviewed papers. These efforts are summarized below in chronological order:

- Invisible" species of exotic algae threatens to poison Minnesota lakes, posted to SMM.org on 11/6/2018, (PDF attached in supplemental materials)
- "Conditions ripe for a record number of algae blooms", Minnesota Public Radio Climate Cast segment on 7/19/2019
- "Why good algae go bad", talk at the Marine Community Library by Adam Heathcote on 7/14/2019, picture of event on Twitter
- Adam Heathcote Co-chaired special session on Harmful Algal Blooms at the Minnesota Water Conference and organized a panel of experts to take questions from conference attendees in St. Paul, MN on 10/16/2019
- During the pandemic we provided information on harmful algal blooms for the public on the Science Museum website in our "Learn From Home" section, posted on 7/7/2020
- Preliminary results from this study were presented to the Minnesota Inter-agency HABs group at their Winter Workshop on 1/25/2021. Attendees includes representatives from the Minnesota DNR, MPCA, MDH and the MVMA
- Results from this study were published in the peer-reviewed journal PLOS ONE on 3/21/2022. PDF of paper is attached in the supplemental materials

Project Completed: 6/30/2022

FINAL REPORT
Diversity and distribution of sediment bacteria across an ecological and trophic gradient - 20 pgs

Subd. 07 Air Quality and Renewable Energy

Subd. 07a Develop Solar Window Concentrators for Electricity - $350,000 TF

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Appropriation Language
$350,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop, evaluate, and optimize thin film silicon-based luminescent solar window concentrators in order to produce inexpensive, clean energy and reduce air pollution. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project demonstrated the potential of semi-transparent “solar windows” based on silicon nanocrystals to produce carbon-free, renewable electricity. Greenhouses were identified as an attractive application. As greenhouses are becoming more widespread in Minnesota, this project will contribute to reducing their environmental footprint in terms of energy and water usage.

OVERALL PROJECT OUTCOME AND RESULTS
This project focused on exploring inexpensive “solar windows” that are transparent and produce clean electricity. Solar windows are based on solar concentrators using highly luminescent nanometer-sized silicon crystals, a technology developed at the University of Minnesota. The silicon crystals, embedded in or coated onto the windowpane, absorb harmful-to-humans ultraviolet and blue light and turn it into red light, which is guided by internal reflection to the edge of the window pane, where it is concentrated onto a small-area solar cell.

Over the course of this project, the project team learned that these solar windows are of particular interest to greenhouses. While being partially transparent, they can produce electricity while not impeding or even enhancing plant growth. The project team initially focused on exploring experimental prototypes of the technology. Based on characterization of these prototypes, models were developed that allow us to predict the performance of larger scale devices. These models were extended into a comprehensive simulation tool that can describe the renewable electricity produced by a solar greenhouse, the light available for plant growth, as well as the overall energy balance of a greenhouse.

For Minnesotans, results of this research may have significant future benefits. Greenhouses allow us to produce certain crops locally that are hard to grow in open-field farming in Minnesota. Locally grown

produce is fresher and reduces the emissions associated with shipping of produce across the county. Greenhouses also only use a fraction of the water and fertilizer that is required in open-field farming. While generally energy-intensive, this research project has pointed the way to reduce the energy consumption of greenhouses through solar windows.

PROJECT RESULTS USE AND DISSEMINATION
Results of this research have been published in the scientific literature and presented at conferences. Three scientific papers were published related to:

- The influence of scattering on the performance of silicon luminescent solar concentrators
- The demonstration of silicon thin film luminescent solar concentrators
- The application of silicon luminescent solar concentrators to agrivoltais

Among the conference presentations presented by graduate students working on this project, one was chosen for the "best presentation" award.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 07b Demonstrations for Community-Scale Storage System for Renewable Energy - $550,000 TF

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Appropriation Language
$550,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to install, demonstrate, and evaluate three community-scale storage systems for renewable energy and develop a guidebook on storing renewable energy for statewide use. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The University of Minnesota's Institute on the Environment with Renewable Energy Partners, Red Lake Tribal Government Center, and University of Minnesota-Morris, demonstrated community-scale storage for renewable energy, including microgrids and battery systems. This project expanded our knowledge of leading-edge technology, shared lessons learned on battery acquisition, permitting, and installation, and advanced energy justice.

OVERALL PROJECT OUTCOME AND RESULTS
More cities, campuses, nonprofit entities, and businesses across Minnesota are using wind and solar technology to produce cleaner energy. To reach high levels of renewable energy, significantly reduce their emissions, and achieve energy independence, they will need to include energy storage in their energy systems. Currently there are few examples of "community scale" energy storage projects, and

often these entities lack the technical knowledge needed to select and optimize the best energy storage system. The overall goal of this project is to expand community-based, locally-produced renewable energy and reduce air emissions to improve the environment, under the LCCMR's funding priority "Air Quality, Climate Change, and Renewable Energy".

This project included three activities. First, we produced an "Community-Scale Energy Storage Guide" that describes both the operation of the US electricity grid with renewable energy and battery storage and different battery storage technologies and installation steps, using the sites as case studies. Second, we selected sites - Renewable Energy Partners, Red Lake Tribal Government Center, and University of Minnesota-Morris - and worked with them, using the guidebook research, to identify and acquire the optimal battery technology to meet site needs and provide technical assistance on design, permitting, and battery installation. At this stage, Renewable Energy Partners has a fully functional and tested battery - it will be complete when insurance is registered with Xcel Energy; Red Lake Tribal Government Center is completed; and University of Minnesota-Morris has the battery and installation components finalized and will proceed with installation once it receives permits. Third, given COVID-19, this project pivoted to develop a virtual site that includes highlights of the three demonstration sites, interviews on the benefits of battery storage, and webinars on battery storage lessons learned. Overall, this project expanded our knowledge of leading-edge technology, shared lessons learned on battery acquisition, permitting, and installation, and advanced energy justice.

PROJECT RESULTS USE AND DISSEMINATION
The project team created a "virtual site visit" that highlights the three demonstration sites and and presents interviews with the Project Partners to get the full scope of how the storage system was implemented.

We created a two part webinar that took a deep-dive into battery storage by conducting a panel discussion with industry experts, seminars and workshops.

We published an Energy Storage guidebook and highlighted this downloadable, user friendly publication at the CERTS events, Energy and Equity workshop, and with the Energy Storage Advisory Committee.

Published Videos on the IonE YouTube page:
Community-Scale Battery Energy Storage in Minnesota https://www.youtube.com/watch?v=RpNs6rvGKCI
Community-Scale Energy Storage: How does it work? https://www.youtube.com/watch?v=QjTjuJAtrxA

Project Completed: 6/30/2022
FINAL REPORT

Subd. 07c Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing - $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop inexpensive, high-efficiency solar energy with simple roll-to-roll advanced manufacturing technology, using new materials such as perovskite to make solar cells. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Perovskite solar cells and modules were fabricated via two-step deposition method, hybrid chemical vapor deposition and air blade deposition, to produce electricity from free clean solar energy, which could reduce the dependency on the non-renewable energy usage and provide green environment and habitats for both residency and wildlife of Minnesota.

OVERALL PROJECT OUTCOME AND RESULTS
Perovskite material is a promising candidate for the next generation of solar cells with high efficiency and significantly lower cost than silicon solar cells. Potential use of thin film perovskite solar cells may revolutionize the current solar industry to produce clean renewable energy. We met the final objective of this project by developing methods for roll-to-roll manufacturing, including hybrid chemical vapor deposition and air blade deposition. More specifically, chemical vapor deposition processes were optimized, and air blade coating system was developed based on a 3D printer. Perovskite solar cell compositions, structures, and additives were also investigated and optimized to enhance the performance. We developed flexible perovskite solar cells on PEN substrates, which are compatible with the roll-to-roll process, and which show an efficiency of 13.3% via chemical vapor deposition method. We also produced a device with power conversion efficiency of 13.82% via air blade and chemical vapor deposition methods, and we fabricated and field tested 5 cm x 5 cm perovskite solar modules with an active area of 18 cm2square centimeters. The outcomes from this project contribute to the development of next generation photovoltaic industry and help researchers better understand the nature of the perovskite solar cells. By utilizing clean solar energy more efficiently via perovskite solar cells, the dependency on non-renewable energies and pollution may be reduced. Cheap and clean electricity produced from perovskite solar cells via the developed roll-to-roll compatible methods demonstrated during this project may further benefit the residents of Minnesota. By harvesting green solar energy more efficiently and economically.

PROJECT RESULTS USE AND DISSEMINATION
The findings were disseminated through the following publications in archived journals.

1. Rui Zhu, Xiangyang Wei, Gongnan Xie, Terrence Simon, and Tianhong Cui. "Numerical simulation of vapor deposition process of perovskite solar cells: The influence of methylammonium iodide vapor flow to perovskite growth." Journal of Solar Energy Engineering 143, no. 1 (2021).
2. Xiangyang Wei, Yangke Peng, Gaoshan Jing, Terrence Simon, and Tianhong Cui, “High Performance Perovskite Solar Cells Fabricated by a Hybrid Physical-Chemical Vapor Deposition”, ASME Journal of Solar Energy Engineering, Vol. 143, No. 4, 2021: 041006

3. Wei, Xiangyang, Yanke Peng, Gaoshan Jing, and Tianhong Cui. "Planar structured perovskite solar cells by hybrid physical chemical vapor deposition with optimized perovskite film thickness." Japanese Journal of Applied Physics 57, no. 5 (2018): 052301.

Project Completed: 6/30/2022
FINAL REPORT
Numerial Simulation of Vapor Deposition Process of Perovskite Solar Cells: The Influence of Methylammonium Iodide Vapor Flow to Perovskite Growth
High-Performance Perovskite Solar Cells Fabricated by a Hybrid Physical-Chemical Vapor Deposition

Subd. 08 Methods to Protect or Restore Land, Water, and Habitat

Subd. 08a Nongame Wildlife Program Acceleration - $220,000 TF

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Appropriation Language
$220,000 the second year is from the trust fund to the commissioner of natural resources to accelerate the nongame wildlife program including rare wildlife data collection, habitat management, collaborative land protection, conservation education, and a new emphasis on promoting nature tourism to benefit wildlife, visitors, and rural communities.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Funds from this grant helped us prioritize collaborative efforts in our Conservation Focus Areas. We successfully conducted 10 habitat improvement projects on over 200 acres for multiple Species in Greatest Conservation Need including: bottomland forest songbirds, prairie pollinators, Blanding's turtles, and oak savanna dependent species.

OVERALL PROJECT OUTCOME AND RESULTS
Results of this project can be broken down into three separate categories: habitat work, monitoring efforts and research. We surpassed our goals for the habitat restoration piece of this grant mainly due to the partnership aspect of Conservation Focus Areas. We were able to provide partial funding that leveraged broader participation in conservation actions. In total, this project enabled us to:

- plant 765 sapling trees in bottlomland forest habitat to help with reforestation efforts,
- plant 6,000 oak saplings in oak savanna habitat on 17 acres at Meadow Brook WMA,
- conduct prairie forb inter-seed plantings on 45 acres of prairie grassland at three different locations,
- contribute to 102 acres or prescribed fire management to reduce succession and overgrowth of woody vegetation in grasslands,

- restore a sandy shoreline for turtle nesting habitat.

All activities took place in at least one of the four activated CFAs (see map: Conservation Focus Areas (CFA) Status 2015-205 MN Wildlife Action Plan).

An important component of conducting habitat improvement work is monitoring the species response to management. These efforts were focused primarily on prairie habitat restoration activities in the southwest and southeast potion of the state. Both flora and fauna response has been measured prior to the restoration activity, during the establishment of the restoration and post management. These data will provide managers with information on ways to potentially adapt their management practices to better accommodate the species the habitat restoration is meant to benefit.

Research and monitoring are a top priority for the Nongame Wildlife Program, which uses status and trend data to determine the protection status of many nongame species. This grant helped us to conduct a pilot study for a new research project to better understand the recent declines of American kestrels. The pilot efforts resulted in a full scale project proposal for a federal grant which was awarded in spring of 2021.

PROJECT RESULTS USE AND DISSEMINATION
Conservation Focus Areas are one of the main implementation tools in our State Wildlife Action Plan and we celebrate the work being done throughout the CFA network in many of our communications. Our Nongame Wildlife Program Facebook page has featured some of the CFA habitat projects as well as the kestrel research. We have also created a 34 page, Wildlife Action Plan 5-year Report, featuring highlights on how the plan is funded and the work we do. This report will be available to the public as well as our supporters to provide a fun "behind the scenes" look at how our program operates.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 08b Develop BioMulch to Replace Plastic Soil Covering in Vegetable and Fruit Production to Increase Yield and Reduce Waste - $310,000 TF

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Appropriation Language
$310,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop and test the performance of biodegradable biomulch to increase yield, conserve water, suppress weeds and pests, add nutrients to the soil, and replace large amounts of nonrecyclable and nondegradable plastic used in vegetable and fruit production. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project was used to develop a biodegradable product that can be used to replace plastic mulch used in vegetable production. The results of research showed that the current formulation of BioMulch worked as expected for watermelon and zucchini; and underperformed (yield was reduced) for tomatoes, peppers, and strawberry.

OVERALL PROJECT OUTCOME AND RESULTS
This project was used to develop a biodegradable product, BioMulch, that can be used to replace plastic mulch used in vegetable production in MN. Plastic mulch cause environmental pollution as it slowly breaks down and creates pollutants such as micro and nanoplastics. Micro and nanoplastic have been proven to be endocrine disruptors and also cause severe health issues to human, animals, and aquatic life. Our intent with this project was to develop a biodegradable product which would replace plastic. Field trials were set up at the University of Minnesota Research and Outreach center at Lamberton. The BioMulch was tested on bell peppers, tomatoes, strawberry, watermelon, and zucchini. Our main goals with this project were to test the efficacy of BioMulch on preventing weeds from emerging and growing and keep the soil moist in comparison with plastic mulch. The results of our project showed that a biodegradable product can be safely created and used to replace plastic mulch used in vegetable production. Yield for watermelon and zucchini were similar between plastic cover and BioMulch; however, yield of tomatoes, peppers, and strawberry were reduced with the use of BioMulch. This management practice should minimize the agricultural footprint on the environment by minimizing the amount of waste being produced in Minnesota by vegetable producers. The use of a biodegradable soil cover means that at the end of the season a simple tillage practice can incorporate the soil cover into the soil and eliminate the waste currently being produced with plastic. Therefore, Minnesotans could benefit from this project by having lower amounts of plastic being used in vegetable production, lower amounts of micro and nanoplastic being created as plastic covers brake-down, and as a result cleaner air, soil, and water. In addition to, healthier Minnesota grown foods.

PROJECT RESULTS USE AND DISSEMINATION
The results of this project have been disseminated to growers that have attended Extension events at the Southwest Research and Outreach Center (SWROC) from 2021 to Summer 2022. The last phase of the research project was completed in June 2022 and now we are working on Extension materials which will be posted on the SWROC nutrient management website. Technology commercialization efforts continue at AURI.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 08c Develop Market-Based Alternatives for Perennial Crops to Benefit Water Quality and Wildlife - $150,000 TF

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Appropriation Language
$150,000 the second year is from the trust fund to the Science Museum of Minnesota for the St. Croix Watershed Research Station to design and evaluate at least six market-based scenarios for perennial cropping systems in Minnesota, including technological and economic feasibility, and estimate their potential to improve water quality and provide wildlife habitat. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project researched using different types of market incentives to develop policies and programs to fund putting more perennial lands in Minnesota's agricultural areas to benefit water quality and wildlife habitat.

OVERALL PROJECT OUTCOME AND RESULTS
Although as a state we've spent millions of dollars on conservation, the health of our streams and lakes has not improved in most of Minnesota's agricultural areas. At the same time, populations of songbirds, pheasants, bees, and monarch butterflies have continued to decline because of a loss of grassland habitat. The main reason for these issues is the continued loss of grassland to planting row crops like corn and soybeans. Reversing this loss is very difficult because of the high cost required to take profitable cropland out of production without affecting a farmer's bottom-line. In this project we researched new ways to restore our waterways and habitat by economically replacing typical row crops with grass and perennial crops by creating new market incentives. For example, what if a solar company could be paid an incentive by a publicly funded program to place solar arrays on small areas of corn fields near the edges of streams? A subsidy would be paid to the solar companies to install the array and the farmer could grow forage grass for grazing sheep underneath them. This way the farmer gets paid a fair rental rate for having the array on their property and could collect additional income from the livestock, while the solar company has an incentive to spend more to install and maintain the array. Our objective in this project was to research solutions such as these, estimating how much they would cost, and how a program or a policy would have to be structured to pay for them. We investigated several incentive programs and found that economically practical programs are possible right now with the right policies to support them. Our research provides a valuable starting point for policy makers to start thinking about new creative, economical ways to help restore the health of our waterways and grassland habitats.

PROJECT RESULTS USE AND DISSEMINATION
The work has been presented to agencies such as the Minnesota DNR and at several Science Museum member events. Finally, the project team was instrumental in organizing and leading the highly successful AgroEcology Summit in Windom, MN in August 2019, where the project work was presented over several hours to more than one hundred attendees. The concepts of using markets to drive adoption of perennial crops/cropping systems generated considerable interest, and follow-up meetings have been scheduled with several environmental advocacy groups to discuss next steps.

Following the completion of the project, the fact sheet created for this project and link to LCCMR and the final report will be shared via Science Museum social media platforms.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 08d Agricultural Weed Control Using Autonomous Mowers - $750,000 TF

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Appropriation Language
$750,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center at Morris to design, integrate, and field-test new technology mowers to control weeds, reduce herbicide use, reduce energy costs, and improve native vegetation and forage quality on agricultural lands. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
An autonomous electric mower, along with a solar powered charging trailer, was successfully developed and demonstrated to control weeds in cow pastures. The “Cowbot” eliminates the need for pesticides in conventional pastures and provides a carbon-free solution for organic pastures.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota farmers and land managers are engaged in an annual battle to control weeds. Each year, significant amounts of herbicide, diesel fuel, labor, and money are expended to stay ahead of weed infestations. Our project team developed an autonomous mowing robot, we call Cowbot, that can design a path to mow a pasture given the GPS coordinates of the pasture corners. The Cowbot can then accurately follow this path and return to its starting point when mowing is completed. A specially designed solar charging trailer is placed at the starting point to recharge the Cowbot when its batteries are low. Widespread adoption of the technology we demonstrated could lead to:

- Significant reductions in the use of herbicides on agricultural and natural lands,
- Replacement of fossil fuel with clean energy produced locally,
- Protection of water resources by preventing surface and ground water contamination with herbicides,
- Reducing the impact of herbicide on wildlife, desired native plant species, and the evolution of herbicide tolerant ‘super’ weeds.

The project team consisted of researchers at the University of Minnesota from several departments working together to develop a robotic pasture mower in partnership with a Minnesota manufacturing company, The Toro Company. Safety protocols were developed for field testing and safety implications of autonomous farm vehicles in general were researched. The Cowbot was field tested in pastures at the U of MN West Central Research and Outreach Center (WCROC) comparing its performance to a conventional mower deck pulled by a diesel tractor. The Cowbot successfully mowed three, two-acre pasture paddocks demonstrating three different path strategies. It returned to the charging trailer after

mowing each paddock and was successfully recharged. A dairy producer reviewed the mowed pasture and judged the Cowbot mowed paddocks to offer equivalent or better control of weeds than the tractor mowed paddocks.

PROJECT RESULTS USE AND DISSEMINATION
Several academic papers were published relating to technology used to design mowing paths and control the Cowbot. The Cowbot was demonstrated to farmers and land managers at several events like the Midwest Farm Energy Conference at the WCROC in 2019 and 2022. It was also featured in an episode of the PBS television show "The Prairie Sportsman" along with interviews with several project team members airing in March 2021. The Cowbot was a featured live demonstration at a state-wide expo in August 2021 called FarmFest. Finally, the Cowbot appeared in several print media articles including the Star Tribune and AgWeek.

Project Completed: 6/30/2022
FINAL REPORT
Cowbot: System Design and Field Evaluation of an Autonomous Weed Mowing Robot for Cow Pastures - 7 pgs

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Subd. 08f Develop Strategies for Timber Harvest to Minimize Soil Impacts to Maintain Healthy and Diverse Forests - Research Project - $200,000 TF

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Appropriation Language
$200,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop strategies and practical tools to minimize soil compaction and other impacts across a range of conditions during timber harvest to maintain timber availability, improve regeneration of diverse forests, and benefit wildlife habitat. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Reduced snowfall predicted with climate change is likely to increase the amount of soil frost during winter, increasing the times when forest harvesting can safely occur. We developed tools that will allow managers to predict when and where optimal soil conditions occur to minimize impacts of forest harvesting.

OVERALL PROJECT OUTCOME AND RESULTS
Soils and forest health can be impacted during forest harvesting depending on how much frost is present during winter and how wet the soils are in summer. Climate change is expected to change these

conditions, creating challenges for managers to determine when the optimal harvest time will occur. Our objectives were to determine how 1) snow cover influences the rate of frost development; 2) soil moisture influences soil strength; and 3) each of those relationships vary across areas that span a range of soil drainage (relative wetness). We conducted snow removal and rainfall reduction treatments in three aspen forests and monitored soil temperature and moisture, frost development, and soil strength for a period of three years. Treatments were conducted across a range of drainage classes that were expected to influence the treatment response and which could be readily identified by managers in the field (to improve application of any findings). We determined that snow removal causes significant increases in frost development and that the relationship is dependent on relative soil wetness of the forest: wetter, more poorly drained soils had lower frost development compared to drier, well-drained soils. Rainfall reduction had limited and inconsistent effects on soil moisture, possibly because of the small plot size. The relationships between soil moisture and soil strength were also inconsistent, hindering identification of the optimal soil moisture content where soil strength is optimal to reduce harvest impacts under non-frozen conditions. Based on our findings and previously developed metrics, we developed a map of harvest suitability for all forested areas in Minnesota under two scenarios, which can be used by managers and landowners to identify the season when forest harvesting is likely to have the smallest impact on soil and forest health. The results provide managers with tools that support sustainable forest management and the benefits it provides.

PROJECT RESULTS USE AND DISSEMINATION

We summarized the primary project findings into peer-reviewed journal articles that highlight key relationships and considerations that managers can use when determining the optimal time to conduct forest harvests. The information was also shared with resource managers at the annual Research Review conducted annually by UMN's Sustainable Forestry Education Cooperative. The journal articles are still in publication, but a graduate student thesis is available here that outlines the primary findings. In addition, we created a map of harvest suitability by season for the forested region of Minnesota that can be accessed here. These two references are missing their hyperlink info.

Project Completed: 6/30/2022

FINAL REPORT

The effects of combined throughfall reduction and snow removal on soil physical properties across a drainage gradient in aspen forests of northern Minnesota, USA - 10 pgs

Limited Effects of Precipitation Manipulation on Soil Respiration and Inorganic N Concentrations across Soil Drainage Classes in Northern Minnesota Aspen Forests - 15 pgs

The effects of combined throughfall reduction and snow removal on soil physical properties across a drainage gradient in aspen forests of northern Minnesota, USA - 47 pgs

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Subd. 08g Restoring Wetland Invertebrates to Revive Wildlife Habitat - Research Project - $400,000 TF

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Appropriation Language
$400,000 the second year is from the trust fund to the commissioner of natural resources to assess invertebrate amphipods in wetlands and explore stocking them as a valuable food source for ducks and other wildlife in the Prairie Pothole Region of the state. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our research showed amphipods are particularly sensitive to their wetland environments. High abundances of amphipods useful as wildlife food requires wetlands with high plant diversity and abundance, low concentrations of pesticides, and few fishes. Our work suggests many ways to manage and protect amphipod populations and their high biodiversity habitats.

OVERALL PROJECT OUTCOME AND RESULTS
Amphipods (shrimp-like aquatic invertebrates) are found in a variety of Minnesota's wetlands and are important food for many species of waterfowl, amphipods, and fish. Two species of prairie amphipods (Gammarus lacustris and Hyalella azteca) have declined in recent decades and have been linked to decline in the continental population of Lesser Scaup (Aythya affinis) ducks. Our project had two objectives: (1) to learn what wetland conditions support high abundances of amphipods, and (2) to assess whether "stocking" amphipods in seemingly high-quality wetlands was successful at establishing new populations.

We surveyed 66 wetlands across western Minnesota for amphipod abundance, fish, aquatic plants, water quality, and surrounding landcover. Key findings included a positive relationship between amphipod abundance and aquatic plant biodiversity, and negative relationships to pyrethroid pesticide levels and several fish species, especially black bullheads (Ameiurus melas).

We also collected G. lacustris amphipods and stocked them into wetlands at 19 sites. We surveyed amphipods before and up to 3 years after stocking to assess survival and reproduction. G. lacustris were detected in only one stocked site after stocking, suggesting that our stocking methods did not create sustained new populations.

Our results will inform management actions to support wetland quality and wildlife populations of interest to Minnesota's waterfowl hunters, birdwatchers, and other wetland enthusiasts. Our results suggest amphipods will benefit from actions that increase aquatic plant diversity, remove and prevent black bullhead and other fish invasions, and reduce impacts of high intensity agriculture. Management might include drawdowns, fish barriers, upland riparian buffers, and reduced agricultural pesticide use. Further, results from Objective 1 can be used to better target stocking wetlands where G. lacustris are likely to thrive and spread on the Minnesota landscape. We are sharing results with natural resource managers and the public via publications, presentations, and depositing data in publicly-accessible repositories.

PROJECT RESULTS USE AND DISSEMINATION
We trained, mentored, and provided paid work experience to two successful master's students and 23 undergraduates, producing two theses and five capstone projects. We shared information via MNDNR Research Summaries, two open-access scientific publications describing invertebrate sampling methods and amphipod-aquatic plant relationships, and 16 oral and poster presentations at professional conferences (see YouTube and ResearchGate). We have drafted a third paper and planned four more.

Additional outreach included a MNDNR virtual presentation, Minnesota Conservation Volunteer article, Minnesota Public Radio podcast and article, KSTP-TV broadcast, and informal communication with curious members of the public in the field, site managers, and landowners.

Project Completed: 6/30/2022
FINAL REPORT
High abundance of a single taxon (amphipods) predicts aquatic macrophyte biodiversity in prairie - 21 pgs
High abundance of a single taxon (amphipods) predicts aquatic macrophyte biodiversity in prairie wetlands - 21 pgs
Protocols for Collecting and Processing Macroinvertebrates from the Benthos and Water Column in Depressional Wetlands - 32 pgs

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Subd. 08h Preserving Minnesota's Native Orchids - Phase 2 - $259,000 TF

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Appropriation Language
$259,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Minnesota Landscape Arboretum to expand collection and preservation efforts to enable long-term conservation of at least 25 of the 48 native orchid species in Minnesota and to continue propagation and cultivation research. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Native orchid populations across the state have been stored in a long-term seedbank at the Minnesota Landscape Arboretum, preserving these native jewels. This project also preserved many of the fungal partners that orchids need to survive and establish in the wild.

OVERALL PROJECT OUTCOME AND RESULTS
This project worked to bank the seed of more of Minnesota's native orchid species, a complex and difficult plant family to conserve because of their complex biology. As part of this seed banking effort, there is a wealth of research that must be done with each species, to determine how best to store seed and propagate them and what the soil fungal partners are and how those fungi can be used to establish these notoriously difficult species, either in display beds for visitors to enjoy or in the wild to establish, augment or protect their presence in or landscapes. There are about 46 native orchid species in Minnesota and understanding how to propagate them and store their seed had not previously been well-established for nearly all of them. This project sought to develop that information for as many of those species as possible. Overwhelmingly successful, multiple populations of these plants were banked for nearly all species and research on nearly all 46 species has been successful and continues. A fungal

bank of nearly 500 specimens was also established to grow and work with the fungal partners that orchids need.

This work will not only benefit visitors to the Arboretum, it is already being used by groups across the state, region and country for a variety of projects that would have previously been unthinkable or unsuccessful, including outplantings of native orchids in restored or protected landscapes and transplants and rescues of plants under immediate threat from development or construction. The resulting information we have produced, and continue to produce, is invaluable for any groups wanting to work with these species.

PROJECT RESULTS USE AND DISSEMINATION
Orchids brought into the seedbank and propagated at UMLA have been displayed in existing and new display beds with a series of educational brochures. Displaying orchids at UMLA allows visitors to see many species that they would likely never see in person otherwise. We give talks, in person or virtually, and have been able to reach out in a variety of media formats, including a website. Finally, we have been able to use the techniques, infrastructure and expertise developed during this project to assist a variety of groups in a variety of conservation-aimed projects related to native orchids.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 09 Land Acquisition, Habitat, and Recreation

Subd. 09a Grants for Local Parks, Trails, and Natural Areas - $2,000,000 TF

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Appropriation Language
$2,000,000 the second year is from the trust fund to the commissioner of natural resources to solicit, rank, and fund competitive matching grants for local parks, trail connections, and natural and scenic areas under Minnesota Statutes, section 85.019. The appropriation is for local nature-based recreation and connections to regional and state natural areas and recreation facilities and does not include athletic facilities such as sport fields, courts, and playgrounds. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Provide approximately 14 matching grants to local units of government for local parks, acquisition of locally significant natural areas and trails to connect people safety to desirable community locations and

regional or state facilities. Park development includes nature-based recreation facilities and does not include playgrounds, sports courts or sport fields.

OVERALL PROJECT OUTCOME AND RESULTS
The primary project results include,

- Six Outdoor Recreation grants to provide nature based outdoor recreation opportunities including park trails, natural resource interpretive opportunities, boating and fishing facilities in Andover, Brooklyn Park, Princeton, St. Peter, Wright County and Zumbrota.
- Four Natural and Scenic Area grants to help protect 139.5 acres of significant natural and scenic areas in Bayport, Wright and Washington Counties through fee title and permanent conservation easement.
- Four Local Trail Connection grants to provide safe, accessible trails to parks, schools, and other significant locations within the communities of Austin, Canby, Luverne and Moose Lake.
- Project administration for the grants was completed for $50,000. Two application cycles were completed, applications reviewed and selected for grants. Active projects were monitored, financial review completed, grantees reimbursed, final site visits completed as needed, projects close, land acquisition report filed.

The Outdoor Recreation (Local Parks), Natural and Scenic Area and Local Trail Connections Grant Programs provide competitive matching grants for local parks, natural areas and trails to local governments for land acquisition and improvements related to parks and trails. Many projects include renovation of existing facilities to improve safety and accessibility, acquisition of locally significant natural and scenic areas, completion of trail linkages to safely connect where people live to desirable locations within the community and/or connecting local trails to regional or state facilities.

PROJECT RESULTS USE AND DISSEMINATION
A Request for Proposal is announced for the programs in December of each year through our park and trail contacts e-mail list and regional and statewide organization. Regional and statewide organizations are encouraged to forward to their members. Program information and applications are available to download on the DNR Recreation Grants webpage under each specific program. A list of the awarded projects is posted on the program webpages under recent grants.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 09b Develop Mesabi Trail Segment From County Road 88 to Ely - $600,000 TF

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Appropriation Language
$600,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the St. Louis and Lake Counties Regional Railroad Authority for environmental assessment, permitting, right-of-way easements or other acquisition as needed, engineering, and construction of an approximately three-mile-long bituminous surface section of the Mesabi Trail between Ely and the intersection of Highway 169 and County Road 88. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Mesabi Trail is a project to build a paved trail from Grand Rapids to Ely. At the conclusion of this phase of the project, approximately 150 miles of the trail are complete. With this appropriation, permitting and engineering was completed, and construction began for this segment of the trail from County Road 88 to the City of Ely.

OVERALL PROJECT OUTCOME AND RESULTS
The funds for this project have been spent toward the development of Mesabi Trail segment from County Road 88 to Ely. Engineering design, specifications, environmental and permitting have all been completed. Construction has started. We will now use the funds from our M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 09b – Mesabi Trail: CSAH 88 to Ely ($1,650,000) to complete the Construction Engineering Management and Construction for this 3.0 mile trail segment.

PROJECT RESULTS USE AND DISSEMINATION
The Mesabi Trail news and updates are provided through a variety of media, marketing and publications. Web site is: Mesabitrail.com. The following are some of the groups & organizations that disseminate Mesabi Trail information and typically include updates of newly completed trail segments and activities:

- Club Mesabi (10,000 maps & web site)
- Iron Range Tourism (30,000 brochures & web site)
- MN Office of Tourism
- amperes radio
- Parks & Trails, Home & Away, other private magazines
- Over 240,000 trail users per year
- Great River Energy/Mesabi Trail annual tour
- Named by the Star Tribune as "Best of Minnesota" in year 2013
- Named by Bicycle Magazine as "top 10 in the country"
- Information distributed at over 70 locations including Chambers of Commerce, visitor centers, businesses
- MN DOT/Pedal MN bikeways map
- "Second best trail in Midwest USA" Dubuque Iowa, 2017

ENRTF Acknowledgement is provided in these dissemination activities per the Acknowledgement Requirements.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 09d Mississippi Blufflands State Trail - Red Wing Barn Bluff to Colvill Park Segment - $550,000 TF

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Appropriation Language
$550,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the city of Red Wing to be used with other funds to construct an approximate three-quarter-mile-long hard-surfaced segment of the Mississippi Blufflands State Trail along Red Wing's Mississippi River riverfront from Barn Bluff Regional Park to Colvill Park. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project was intended to enhance Minnesotans experience of the natural beauty of the state through the development of 0.75 miles of trail. While much design and planning were completed for this trail, the actual trail could not be built due to land acquisition problems.

OVERALL PROJECT OUTCOME AND RESULTS
This project proposed to construct an approximate a 0.75-mile-long segment of the Mississippi Blufflands State Trail along Red Wing's riverfront from Barn Bluff Regional Park to Colvill Park. A portion of the trail required the purchase of fee interest of a right-of-way held by the Canadian Pacific Railway. Early in the project, the City of Red Wing achieved agreement with the CP Railway to acquire this ROW, and trail planning was underway. Unfortunately, during the project period, CP Railway's director of real estate abruptly left. This, followed by the COVID epidemic, essentially stalled acquisition negotiations. While the project was granted a one-year COVID extension through the legislature, the railway continued to be non-responsive until after the grant expired.

Over the late spring and early summer of 2022, the Canadian Pacific Railway has been responsive to our need to the fee interest in the railroad ROW necessary to build the project. The ENRTF appropriation ended on June 30, 2022. In July the CP Railway agreed to sell the needed ROW. The CP Railway amount needed was identified as approximately 25,473 square feet with approximately 5,248 square feet identified for temporary construction easement needs. CP Railway staff agreed to maintain the price of $3.55 per square foot to acquire right of way necessary for the project, approximately 25,475 square feet or $90,429.15, using non-ENRTF funds. No other costs will be associated with the agreement.

On Monday, August 22, 2022, the purchase agreement was approved and executed by the City Council. Although this process took multiple years and required the return of grant funding the city remains committed to seeking full funding for this important Mississippi riverfront trail segment.

We expect the closing for the property to be completed within 90 days.

PROJECT RESULTS USE AND DISSEMINATION
While desired results of this project—0.75 miles of trail built—were not ultimately completed during this appropriation period, the City of Red Wing diligently updated the city council as to progress of this trail, including tours of the proposed trail route. The city also provided press releases regarding ENRTF funding. At the City Council meeting of August 22, 2022, it was stated during the project period no progress was gained on the property acquisition and the ENRTF grant had expired. The project is at 65% design with level three cost estimates completed.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 09e Swedish Immigrant Regional Trail Segment within Interstate State Park - $2,254,000 TF

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Appropriation Language
$2,254,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Chisago County Environmental Services to construct an approximate one-half-mile regional county trail segment within Interstate State Park from the end point of the existing trail at the park boundary to city hall including a trail bridge over the ravine and parking and trailhead improvements and to conduct a natural and cultural review to determine the feasibility and route of a future section of the trail through the park. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Swedish Immigrant Regional Trail within Interstate Park was designed and constructed to protect the natural resources within the State Park Land while preserving rare plants, native tree species and wetlands. The Interstate State Park trail enhances Minnesota's air, water, and wildlife by avoidance and mitigation of many natural resources that were present. Resulting trail is a 10 ft. wide bituminous surface with a 160 ft. long bridge crossing a ravine.

OVERALL PROJECT OUTCOME AND RESULTS
The Swedish Immigrant Regional Trail project was constructed within Interstate Park State Park and into the City of Taylors Falls. This segment of trail has a ten-foot-wide bituminous trail surface and is approximately .60 miles in length that was designed as an ADA compliant multi-use and non-motorized trail. The main goal of this project was to expand the Swedish Immigrant Regional Trail further east to allow a safe route for pedestrians and bicyclist to travel. The project will benefit many local communities and Minnesotans alike by connecting multiple cities along this trail corridor. The trail will likely attract new visitors each year to enjoy the majestic views of Interstate State Park while also providing health

and wellness benefits.

The overall project was implemented years prior to construction through the vision and involvement of many organizations, stakeholders, cities and residents to construct a County Regional Trail within a State Park and along a historic rail corridor to Taylors Falls. During the construction phase many accomplishments were achieved by excellent planning and cooperation, some of these included a beautiful 160 ft. bridge over a ravine and a trailhead that incorporated many great landscaping features that are prevalent in the region. Throughout the entire construction project one of the main challenges was to find the perfect trail alignment that meet all necessary trail compliances while also minimized impacts to many of the Interstate State Park environmental, natural, and cultural resources.

PROJECT RESULTS USE AND DISSEMINATION
The Minnesota Environmental and Natural Resources Trust Fund (ENRTF) acknowledgement has be very prevalent throughout the entire project. The use of the trust fund logo and attributed language have been printed in newspaper publications and Environmental Services Newsletters, social media platforms and signage along the Swedish Immigrant Regional Trail corridor. Throughout the project we have created several documents and other online resources to help communicate and receive public outreach. Some of these include the use of electronic public surveys and mailing for community input and involvement.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 09g Protecting Mississippi River Headwaters Lands through Local, State, and Federal Partnership - $700,000 TF

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Appropriation Language
$700,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the city of Baxter, in cooperation with Brainerd Public Schools and the Camp Ripley Sentinel Landscape Program, to acquire about 200 acres of forested land on the upper Mississippi River adjacent to Mississippi River Overlook Park for multiple public benefits, including being an outdoor classroom for local schools. To be eligible for reimbursement, costs for real estate transactions must be specific to this acquisition and documented as required in subdivision 15, paragraph (k).

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project preserved 200 acres of forest on the upper Mississippi River. After the grant was awarded, the project grew to ultimately preserve 1,338.4-acres locally. Of this total, Baxter now has 880-

contiguous acres (including the project 200 acres) of high-quality natural resource property preserved within Baxter.

OVERALL PROJECT OUTCOME AND RESULTS

The 200-acres targeted for this protection project were at risk of being sold for development along the city limits of Baxter and the scenic rolling hills of the Mississippi River. Another downfall of development of the land beyond the conservation impacts are the encroachment that hinders training of soldiers at Camp Ripley. Camp Ripley has prioritized protecting lands near the military base to continue their important training mission without negatively impacting citizens near the base. The major project objective was to purchase and permanently protect the 200-acres that are directly adjacent to Baxter Overlook Park to the west. This land would also become part of Forestview Middle School's outdoor classroom.

After discussions with Potlatch, as well as Sylvan Township, Cass County, and Crow Wing County, it became apparent that this project could utilize more funding and have broader local government support and protect more forestland in a larger context. This Baxter Overlook Park project appraised less than anticipated at the project outset, and utilized $400,000 in Department of Defense funding, and $330,322 in LCCMR funding for a total cost of $730,322 (55% DoD funding; 45% LCCMR funding). Additional non-federal funding was needed for match in the larger project, and the increased LCCMR match allowed for $2.1 million in DoD funding and $1.29 million in LSOHC to be applied over the entire project scope of 1,546.84-acres.

This protection project will grant Minnesotans the ability to recreate, hunt, and enjoy the public lands that encompass the entire project area, even beyond the City of Baxter. It will also allow for hundreds of middle school students to learn about Minnesota's forests each year, and perhaps inspire future generations to cherish and continue to protect our shared natural resources.

The project was completed, and the property was purchased by the City of Baxter on June 30, 2020. Along with this 198.5-acre Baxter Overlook Park addition, TCF, Baxter, and Camp Ripley partners were also able to protect 1,338.4-acres of additional forestlands from Potlatch in this area in this same negotiation to also be permanently protected utilizing LSOHC and Department of Defense funding, totaling more than $3,700,000. Multiple public partners, including Baxter, Cass County, Crow Wing County, and Sylvan Township now hold those properties for public use and wildlife habitat benefits. The scope of the project grew over time and achieved a greater outcome than the partners anticipated in 2018. Additional non-federal funding was needed for match in the larger project, and the additional LCCMR match allowed for $2.1 million in DoD funding to be applied over the entire project scope.

PROJECT RESULTS USE AND DISSEMINATION

The City notified the public of the environmental, educational, open-space recreational opportunities of the property with an article in the local Baxter newsletter, which is sent to all residents. City staff also joined Camp Ripley Environmental staff, and The Conservation Fund staff by going on-air on WJJY radio to discuss the environmental project and opportunities. Lastly, on November 2, 2021, the City Council authorized City staff to execute a contract with SRF Consulting to guide the City through an Open Space Master Plan study. A significant portion of the study is public outreach and civic engagement to help the City develop an open space master plan for the property.

Pieces about this project were published in MinnPost, the Brainerd Dispatch, and the Conservation Fund website and a Conservation Fund press release.

Project Completed: 6/30/2020
FINAL REPORT

Subd. 09k Minnesota State Parks and State Trails - $2,500,000 TF

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Appropriation Language
$2,500,000 the second year is from the trust fund to the commissioner of natural resources to acquire about 163 acres of high-priority in holdings from willing sellers within the legislatively authorized boundaries of state parks and trails in order to protect Minnesota's natural heritage, enhance outdoor recreational opportunities, and improve the efficiency of public land management. Priorities include but are not limited to Tettegouche, Sibley, and Minneopa State Parks and the Goodhue Pioneer State Trail. A list of proposed acquisitions is required in the work plan. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 10 Emerging Issues Account

Sub-Project 01: State-wide Reconnaissance of SARS-CoV-2 in Drinking Water Supplies - $59,297 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
There were concerns that SARS-CoV-2, the virus that causes COVID-19, could contaminate drinking water supplies. In this study, we investigated 30 drinking water samples from homes around the State of

Minnesota supplied by either a private well or a public water system, testing for SARS-CoV-2. To date, we have not been able to detect SARS-CoV-2 in any Minnesota drinking water samples.

OVERALL PROJECT OUTCOME AND RESULTS

Soon after the COVID-19 pandemic began, it was observed that the SARS-CoV-2 was detectable in the feces of infected individuals and thus was likely to be present in raw sewage. With this knowledge, researchers developed techniques to monitor the extent of COVID-19 spread in communities by quantifying the virus in untreated municipal wastewater. Given the presence of this virus in raw sewage, concerns were expressed that it could contaminate our public and private drinking water supplies, either from leaky sewer pipes, municipal wastewater effluent, or septic systems. Although well-functioning public water and wastewater facilities are typically very good at preventing the spread of disease via the fecal-to-oral route, this project was undertaken to confirm that SARS-CoV-2 was not contaminating our drinking water. Because SARS-CoV-2 is a pathogen that infects the lungs, the risk of exposure from water supplies is via inhalation of water droplets while showering or other uses. We therefore used filters to collect the microorganisms from 30 high-volume drinking water samples (sample volume: 500-1000 liters) from various locations within the State of Minnesota. These samples were obtained from homes supplied by private wells that do not employ any treatment as well as from homes supplied by public water systems that treat the water, including but not necessarily limited to, disinfection with chlorine. We were unable to detect SARS-CoV-2 in any of these samples; positive-control sewage samples collected from a municipal wastewater treatment plant, however, confirmed that our assays were working and could detect SARS-CoV-2 in water samples. Our results, therefore, provided evidence to suggest that, at the time of our study in the spring and summer of 2020, SARS-CoV-2 was not present in our public and private water supplies and that drinking water was not a likely route of exposure to SARS-CoV-2.

PROJECT RESULTS USE AND DISSEMINATION

We have shared our results with LCCMR staff and with Kirsti Marohn from Minnesota Public Radio (MPR) and Greg Stanley from the Minneapolis Star Tribune. We also presented our research results at the annual meeting of the Minnesota section of the American Water Works Association (September 24, 2020) and during an online seminar hosted by the Minnesota Pollution Control Agency (December 9, 2020).

Subproject 01 Completed: 06/30/2021
FINAL REPORT

Sub-Project 03: Environmental Assessment of CWD Prions at the Beltrami County Deer Carcass Dump Site - $108,232 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

We confirmed CWD-positive deer remains within the dumpsite and that the positive remains came from the neighboring cervid farm. We recommend: 5 years of CWD surveillance in the region, monitoring water runoff, routine CWD-testing of deceased cervid-farm fawns, monitoring wild mammal health in the area due to documented CWD risks.

OVERALL PROJECT OUTCOME AND RESULTS

In April 2021 we were notified by the DNR that deer carcasses from a CWD positive deer-farm in Beltrami County had been dumped on public land and were asked to help with CWD-testing of the remains. Our initial tests confirmed some remains were CWD positive. CWD-prions remain infectious within the environment for years. Therefore, the goals of our project were to complete testing of deer remains, collect samples of soil, water, and plants for future testing, and perform a CWD-prion risk assessment. We used RT-QuIC testing to identify CWD-prions in biological and ecological samples, and we performed DNA analyses to see if the dump-site carcasses came from the neighboring cervid farm. We collected deer remains, soil, plant, fungi, and water samples from the ~12-acre site. At least 11 deer were deposited, with carcasses subsequently pulled apart by scavengers. Forty-four locations had white-tailed deer remains and 58 carcass samples were suitable for RT-QuIC testing. Of these, 14 were statistically positive for CWD. Fly larvae and soil associated with the positive remains also tested positive for CWD. DNA analyses confirmed positive remains originated from the neighboring cervid farm. Based on our findings we recommend the state: conduct a total of 5 years of CWD surveillance in the region, perform routine testing of deceased fawns in cervid farms, and support research monitoring wildlife health in the region (e.g., recent data show raccoons and voles are susceptible to CWD-prions). Our team will continue monitoring water runoff from the site, as well as soil, plants, and fungi to help monitor CWD-prion contamination in the region. Our recommendations are based on the latest CWD science and will improve CWD monitoring of both wild and captive deer in Minnesota. Our research will ultimately help Minnesotans better understand the environmental risk of CWD prion contamination throughout the state.

PROJECT RESULTS USE AND DISSEMINATION

We presented a poster describing the biological sample-collection and assessment at the dumpsite during the 70th Annual International Conference of the Wildlife Disease Association in Madison, WI. A manuscript was published reporting results of our engagement with Tribal Nations in the region (available here) and a second paper reporting our research findings is to be submitted to a peer-reviewed journal in October 2022. Updates of the project have been made to the MN Legislature, three public information meetings, the MN Board of Animal Health work conference, and two University of Minnesota events. Additional updates will be provided to our state and tribal nation partners and at MNPRO outreach events in 2023 as well as on the MNPRO website.

Subproject 03 Completed: 06/30/2022

FINAL REPORT

3. M.L. 2017 Projects Completed
January 15, 2021 – January 15, 2023

MN Laws 2017, Chapter 96, Section 2

M.L. 2017 Projects

MN Laws 2017, Chapter 96, Section 2 (beginning July 1, 2017)

Visit the LCCMR website for the most up-to-date project information and reports

Subd. 03 Foundational Natural Resource Data and Information

Subd. 03a County Geologic Atlases – Continuation - $2,000,000 TF (FY2017)

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Appropriation Language
$2,000,000 in fiscal year 2017 is from the trust fund to the Board of Regents of the University of Minnesota, Minnesota Geological Survey, to continue acceleration of the production of county geologic atlases for the purpose of sustainable management of surface water and groundwater resources. This appropriation is to complete Part A of county geologic atlases, which focuses on the properties and distribution of earth materials in order to define aquifer boundaries and the connection of aquifers to the land surface and surface water resources. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Geologic atlases provide maps and databases essential for management of water resources. Of the 16 county atlases covered by this grant, 5 are complete and 6 are past the halfway mark.

OVERALL PROJECT OUTCOME AND RESULTS
The grant funds have been completely expended. This grant funded work in 16 counties including: Lake and St. Louis ($583,175), Kandiyohi ($225,315), Hennepin ($117,254), Hubbard ($100,206), Aitkin ($227,156), Isanti ($37,780), Cass ($110,692), Rock and Nobles ($261,732), Steele ($60,389), Pennington ($27,824), Lac Qui Parle ($53,801), Lincoln and Pipestone ($18,167), and Otter Tail ($106,227) counties. An additional $36,000 supported initiation of work in new project areas and $34,277 was spent to characterize glacial sediments using geochemistry. Atlases for Kandiyohi, Hennepin, Hubbard, Isanti, and Cass are complete. At this time bedrock and surficial mapping in Lake and St. Louis counties is about 75% complete. Good progress has been made on associated databases. Federal cost-sharing has been applied to this work each year. Effort on Olmsted and Dodge counties have been shifted to another funding source, and both should be complete by the end of the summer. In Aitkin County, the bedrock map is nearly ready for review; the bedrock topography is about 75% complete. The Aitkin surficial map is nearly complete, and work on the cross sections and sand models is underway. For the Rock and Nobles CGAs the bedrock maps are about 85% complete and the bedrock topography is nearly ready for review. The surficial geology for both counties is complete, and the work on the cross sections and sand

models is underway. Similarly, in Steele County all bedrock and surficial maps are near completion and work on the cross sections and sand models is underway. The work in Pennington, Lac Qui Parle, Lincoln and Pipestone, and Ottertail counties is still in the early stages with mostly field work underway to support maps. We will conduct rotary sonic drilling in all of these counties (underlined) starting this fall. Counties that are not yet complete have been shifted to the LCCMR18 contract funding.

PROJECT RESULTS USE AND DISSEMINATION
Completed atlas products have been posted to the MGS website and linked to the University's Digital Conservancy as noted above. PDF products as well as all of the related GIS data are available on these pages.

In addition, the MGS hosts an Open Data Portal on which many of our county geologic atlases are presented as "Story Maps" that allow for direct access of the data without any special software or interface.

The Hennepin County workshop was held on April 22 at the County Library in Ridgedale. An article about the atlas and related workshop was published by the SWNewsMedia. Formal presentations for Cass and Hubbard counties were held on March 6 in Backus and Park Rapids, respectively. An update to the Cass County Board was held last summer and written up by the Echo Journal.

Project Completed: 6/30/2020
FINAL REPORT

Subd. 03b Assessment of Public Benefits of Protecting Source Water - $320,000 TF (FY2018)

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Appropriation Language
$320,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to map and quantify source water risks, determine ecosystem service valuation of clean water, and provide analyses of equity and community capacity to improve decisions about the protection and management of groundwater and surface water. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Source Water protection is associated with multiple economic, environmental, and social benefits. We created new spatially-explicit datasets representing multiple socio-economic benefits of source water protection for all 821 drinking water management units in Minnesota. Our work gives practitioners a more complete picture of the outcomes of source water protection statewide.

OVERALL PROJECT OUTCOME AND RESULTS

The goal of the project was to collect and synthesize economic, social, and environmental data relevant to source water protection in Minnesota. We created new spatially-explicit datasets representing multiple socio-economic benefits of source water protection for all drinking water supply management areas in Minnesota. Project outcomes include:

1. Mapping land use change and land protection costs for all 821 drinking water management areas.
    - Estimated trends in land use change in each DWSMA in order to identify potential threats to source water from increasing agricultural expansion or development.
    - Obtained new spatial data based on estimated market values of hundreds of thousands of parcels in the state in order to quantify the opportunity costs of source water protection in each DWSMA.
2. Valuation of the multiple public benefits of land protection for clean water.
    - Applied best-available estimates for drinking water treatment to calculate potential costs of contamination in each DWSMA as a function of population served.
    - Implemented a methodology for estimating the potential health damages and associated monetary costs of drinking water contamination.
    - Generated 19 spatially-explicit environmental benefit maps that can be used to assess the potential for co-benefits of protection or restoration in each DWSMA.
3. Assessing the equity implications of source water protection and community capacity to protect land and improve water quality.
    - Developed a technique for linking source water protection areas to municipalities served, allowing us to relate census data and demographic characteristics to each DWSMA.
    - Administered and analyzed data from a statewide survey of water values in order to identify perceived threats to water quality and preferences for different water-quality related values and uses.
    - Completed a series of participatory water valuation exercises using a Q-sort methodology to understand stakeholder preferences for water-related expenditures and tradeoffs among water quality objectives.

PROJECT RESULTS USE AND DISSEMINATION

We presented our work at venues targeting academic and state agency audiences, and held meetings with specialists at MDH and the interagency GRAPS team exploring application of the work in MN agency work. We shared findings with state agencies including MPCA, MDH, DNR, and BWSR, along with external stakeholders and advocacy groups such as Freshwater Society and the Environmental Working Group. Our work contributed to multiple students' master's theses and is being written up for publication in a peer-reviewed journal. Our work is summarized in a report (available on our website) and includes appendices with data useful for further analysis.

Project Completed: 6/30/2021

FINAL REPORT

Minnesota Water Values

Assessment of Public Benefits of Protecting Source Water

Communicating Risk and Increasing Civic Engagement in Water Protection in Minnesota

Nature in the Urban Century

Source Water Protection Challenges and Co-Benefits

Subd. 03c Preserving Minnesota Prairie Plant Diversity - Phase II – Research Project - $900,000 TF (FY2018)

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Appropriation Language
$900,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to continue collecting and preserving germplasm of plants throughout Minnesota's prairie region, study the microbial effects that promote plant health, analyze local adaptation, and evaluate the adaptive capacity of prairie plant populations. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We gathered seeds of prairie plants and shared them with producers who are expanding seed availability for restorations. We collected, identified and studied many microbes that prairie plants harbor, documenting their effects on their hosts. Our experiments have clarified the geographic scale of plant adaptation and genetics underlying ongoing adaptation.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota prairies harbor extraordinary diversity of plants and microbes, while also nurturing wildlife, retaining water and topsoil, and beautifying landscapes. Yet habitat loss threatens the persistence of the once vast prairies and their stunning biotic diversity. Limited understanding of this diversity and insufficient seed availability hinder sustainable management of this iconic Minnesota biome. We conducted Healthy Prairies (HP) Phase II to expand availability of seeds for prairie restorations and study approaches to increase success of restorations. Building on our prior accomplishments under ENRTF funding, we have:

1. Preserved diverse seed from 57 rarer prairie species, gathering them from widely separated locations.
2. Obtained, archived, and studied 2,600 naturally occurring microbial partners from two species.
3. Gathered data to assess the geographic scale important to plant survival and reproduction in MN.

Our extensive collections of source-identified seeds and microbes across a wide range of MN's prairie region help to conserve the diversity of MN prairies. We have provided seeds to seed producers, who have, in turn, used them in establishing fields and are seeking certification of the seeds that they obtain from them.

Our studies of effects of microbial associates on prairie plants have indicated that the bacteria providing

nitrogen to prairie clover (Dalea purpurea, D. candida) disperse widely across MN prairies. Consequently, we can recommend to growers an inoculum that need not be site-specific. In contrast, the communities of fungi associated with roots of S. scoparium are spatially restricted, indicating that a regionally-based inoculum may be preferable.

We continued our large-scale experiment to elucidate the geographic scale of adaptation of six prairie species. We gathered extensive data from this experiment and began analyses of the data. We implemented experiments to investigate genetic structure of two populations of little bluestem (Schizachyrium scoparium), including genetic variance for fitness and the fitness consequences of inbreeding and of crossing between populations.

PROJECT RESULTS USE AND DISSEMINATION
HP team members have participated in varied opportunities to disseminate findings from this project. These include informal events to communicate with members of the public who are not all well-versed in science and may not be aware of prairies (Market Science), as well as workshops involving other scientists and land managers (Nature Conservancy 'Science Slams', Local Adaptation Workshop, held at UM-TC, March 2019, discussions of seed sourcing guidelines led by staff of MN DNR).

A paper providing an overview of the Local Adaptation Workshop has been published in New Phytologist (2020) 225:2246–2248. A manuscript reporting findings about geographic scale of local adaptation has been submitted to Restoration Ecology and has received positive reviews. A second manuscript reporting on a study that used focus groups to identify impediments to use of source-identified seeds for prairie restorations has been submitted to Restoration Ecology and has received positive reviews. Both manuscripts are under revision and will be resubmitted soon.

Project Completed: 6/30/2021
FINAL REPORT
Latitude of Seed Source Impacts Flowering Phenology and Fitness in Translocated Plant Populations
Factors Limiting the Availability of Native Seed for Reconstructing Minnesota's Prairies: Stakeholder Perspectives
Evolutionary Approaches to Seed Sourcing for Grassland Restorations

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Subd. 03d Minnesota Biological Survey – Continuation - $2,900,000 TF (FY2018)

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Appropriation Language
$2,900,000 the first year is from the trust fund to the commissioner of natural resources for continuation of the Minnesota biological survey to provide a foundation for conserving biological diversity by systematically collecting, interpreting, monitoring, and delivering data on plant and animal

distribution and ecology, native plant communities, and functional landscapes. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

The Minnesota Biological Survey (MBS) collects, interprets and delivers foundational data on native plants, animals, plant communities and functional landscapes. These data help prioritize actions to conserve, manage and restore Minnesota's biological diversity and ecological systems.

OVERALL PROJECT OUTCOME AND RESULTS

MBS baseline terrestrial plant field surveys occurred in Lake of the Woods, St. Louis and Koochiching counties within the Border Lakes, Littlefork-Vermilion Uplands, and Agassiz Lowlands subsections. MBS baseline aquatic lake plant surveys occurred in lakes in central Minnesota counties. Plant surveys documented numerous rare and notable terrestrial and aquatic vascular plant species. Native plant community surveys occurred in areas that are either representative of the native vegetation in these counties and subsections or are rare, unique or unusual for these areas. MBS field surveys were also targeted in other northern Minnesota counties to address questions stemming from GIS mapping of native plant communities and sites of biodiversity significance.

Pollinator surveys in MBS sites of biodiversity significance focused on native and rare moths and butterflies in far northern, northwest, and southeast Minnesota. Over 3,000 specimens of at least 900 species were collected, some of which have potential to be new state records.

Targeted surveys occurred in southeast, east-central, and northern forests in MBS sites of biodiversity significance to update and expand MBS data from surveys that occurred in the 1990s and early 2000s. Likewise, similar surveys occurred in the Prairie Province to document new sites or expand on previous MBS surveys from the 1980s. This work resulted in the documentation of many new and updated records of rare species and high quality native plant communities.

Updates and improvements to the DNR Rare Species Guide continued that rely heavily on MBS data and technical expertise arising from this a previous MBS ENRTF appropriations. The book, Sedges and Rushes of Minnesota, was published by the MN Press and the final manuscript for the book, Minnesota Red River Valley and Aspen Parkland - A Guide to Native Plant Communities, was submitted to the UMN Press for publishing.

PROJECT RESULTS USE AND DISSEMINATION

MBS data are stored in the DNR's Natural Heritage Information System and biological specimens accessioned to the UMN Bell Museum of Natural History. This includes information on rare species, native plant communities, sites of biodiversity significance. MBS distributes survey results on the MBS website, DNR GIS QuickLayers, and MN Geospatial Commons. Presentations, technical guidance, biological reports, and published books are delivered that describe and interpret MBS results for use by local government units, conservation groups, citizen advisory groups, scientists, land managers, and students. MBS data, products, and staff expertise are used throughout the state to assist conservation decisions.

Project Completed: 6/30/2021

FINAL REPORT

Subd. 03f Assessment of Microbes for Improving Wild Rice Restoration – Research Project - $334,000 TF (FY2018)

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Appropriation Language
$334,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Natural Resources Research Institute, to evaluate the microbial communities and nutrients associated with wild rice and competing vegetation, with the goal of enhancing restoration success to increase the abundance of wild rice. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project improved our understanding of microbial and nutrient associations with self-sustaining wild rice wetlands. This information will be useful to develop management strategies for wild rice restoration success, which will improve long-term protection of native species and aquatic biodiversity, and support management of Minnesota's culturally and ecologically important natural resource.

OVERALL PROJECT OUTCOME AND RESULTS
Wild rice (Zizania palustris), a native emergent aquatic plant, has a multitude of ecological functions and high cultural and economic value in Minnesota. Wild rice was historically abundant in northern Minnesota but its abundance and distribution have been reduced due to various factors. There have been collaborative efforts to restore wild rice wetlands for improved wildlife habitat and increased opportunities for wild rice harvest. Despite ongoing efforts, restoration has been met with mixed success. Much research was conducted on surface water and sediment chemistry that is conducive to wild rice growth. However, one ecological component of the wild rice ecosystem that remains under-explored is microbial communities that are involved in processing key nutrients. This project characterized microbial communities associated with wild rice wetland. Wild rice and coexisting plant samples were collected from 7 wild rice wetlands along with water and sediment. High-throughput DNA sequencing analyses indicated that wild rice-associated microbial communities were distinct from those found in water and sediment. Moreover, the influence of surface/porewater chemistry and nutrients on the microbial communities were evaluated. The project outcomes will allow the restoration partners to understand why restoration efforts are successful or not and can be immediately transferable to restoration managers for the development of applicable restoration practices. Likewise, if beneficial microbial groups associated with self-sustainable wild rice beds were identified from this project, the methods to encourage their abundance and functions for wild rice growth are needed through seeding with inoculants derived from successful wild rice stands and sediment amendments. If coexisting or invasive species alter nutrients and microbial community structure unfavorable for wild rice fitness by imposing some degree of selective pressures, targeted species control is essential prior to current

restoration efforts. This will be useful to for the partners to develop effective management strategies for wild restoration goals.

PROJECT RESULTS USE AND DISSEMINATION
The project findings have been disseminated via reports to LCCMR, publications, and regional and national presentations at conferences. We held four meetings with wild rice managers and the project partners for field sampling plan, project progress, consultation and outcomes. The project findings were shared with the public through the university's news article, public outreach activities (e.g. Lake Superior Youth Symposium), and student stories. Moreover, microbial DNA sequences of environmental samples collected from wild rice wetlands were archived at National Center for Biotechnology Information.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03i Landslide Susceptibility, Mapping, and Management Tools - $500,000 TF (FY2018)

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Appropriation Language
$500,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to create landslide susceptibility maps using a landslide inventory and quantitative analysis of LiDAR to provide tools and data for mitigation and restoration to reduce impacts on water resources. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Landslides in five regions across Minnesota were mapped and inventoried to identify geologic and topographic conditions vulnerable to slope failures providing resource and emergency managers with better predictive tools to guide land-use decisions. Landslides are a dominant source of sediment to regional waterways, occurring frequently along steep valley walls.

OVERALL PROJECT OUTCOME AND RESULTS
In June 2014, widespread landslides occurred in south-central Minnesota; a similarly rainy period in 2012 caused two deaths. In June 2012, a two-day rain event in Duluth generated hundreds of landslides, extensively damaging Jay Cooke State Park and surrounding areas. In August 2007, a year's worth of rain fell in 36 hours in southeastern Minnesota causing extensive landsliding. Weak clay soils in the Red River valley frequently fail, undermining homes and roads. All of these eroding, hazardous slopes present an acute natural resource and emergency management challenge, yet until now, the state lacked landslide hazard maps. Because mass wasting processes vary with geology, we defined five study areas in which we documented the distribution, failure mechanisms, and frequency of landslides in order to help resource managers make sound mitigation decisions.

Each region was mapped by a different partner institution using established data standards and protocols through: 1) historical research, 2) mapping known slides onto high-resolution lidar base maps, and 3) identifying additional landslides using lidar data; topographically-derived maps (slope, hillshade, and red relief); and aerial imagery. Slide sites were field-checked where possible for geology, hydrogeology, vegetation cover, and land use.

In northeastern Minnesota, where repeat lidar data were available, additional work was done. Repeat lidar data collected before and after a major 2012 storm event were properly aligned to allow erosion and deposition to be quantified, and Object-Based Image Analysis was used to define and classify types of change (erosion, deposition in different settings) across the landscape.

Landslide susceptibility modeling in that same, well documented area illuminated which landscape parameters were most important to slope stability: slope, distance to stream, and depth of glacial deposits overlying competent bedrock. The method developed in northeastern Minnesota can be applied to the other four areas of the state.

PROJECT RESULTS USE AND DISSEMINATION
Project results were disseminated to local and regional stakeholders through presentations at meetings and to the scientific community through conference presentations. The full inventory database is being released through the U. S. Geological Survey with an accompanying U. S. Geological Survey Fact Sheet on Landslides in Minnesota. These products will be available to assist with emergency management planning and natural resource assessments of sediment loading in watersheds across the state. Details on landslide mapping methodologies and results across the state, and multitemporal lidar correction and Object-Based Image Analysis research in northeastern Minnesota will be published through publicly-available scientific papers.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03k Cedar Creek Natural Area Wolf Recolonization Assessment – Research Project - $398,000 TF (FY2018)

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Appropriation Language
$398,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Cedar Creek Ecosystem Science Reserve, to assess wolf recolonization impacts on wildlife, biodiversity, and natural resources and provide educational opportunities at Cedar Creek Ecosystem Science Reserve.

This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Minnesota's wolves are expanding southward. A new pack recently recolonized Cedar Creek Ecosystem Science Reserve, which is one of the best-studied ecosystems worldwide. Our project assessed costs (e.g., unwanted impacts on pets and livestock) and benefits (e.g., impacts on biodiversity and ecosystem functioning, educational opportunities) of this unassisted wolf recolonization.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota's wolves (Canis lupus) are expanding southward. A new pack recently became established at Cedar Creek Ecosystem Science Reserve (henceforth Cedar Creek), which is one of the best-studied ecosystems worldwide, located just north of the Twin Cities. The goals of our project were to assess costs (e.g., unwanted impacts on pets or livestock) and benefits (e.g., potential enhancement of biodiversity and ecosystem functioning, educational opportunities) of this unassisted wolf recolonization. Our project achieved the following outcomes: (1) determine wolf movements inside and nearby Cedar Creek; (2) experimentally test the impacts of wolves on wildlife, biodiversity, and ecosystem functioning; and (3) provide educational programming to K-12 students and adults. We achieved these goals and outcomes by establishing a network of trail cameras, establishing a new experiment to assess wolf impacts on plants and soils, and bringing K-12 students to Cedar Creek for field trips and developing a website for engagement by citizen scientists. We found that wolf pack produced three litters of pups and grew to include up to 19 wolves, but was then lethally removed by federal trappers after preying on livestock and dogs (Mech et al. 2019). We also found that wolf cues shifted when, but not where, deer used the landscape (Palmer et al. 2021). Deer used risky areas at relatively safe times of the day, when wolves are typically less active, attenuating any cascading effects of wolves on plants or soils. Our Eyes on the Wild citizen science website has thus far engaged 12,625 registered citizen scientists who have provided 7,636,071 classifications of 4,153,218 images generated by our network of trail cameras. These data are being included in several national and global studies of wildlife (e.g., Suraci et al. 2021). More than 7,000 K-12 students and adults engaged in programming related to the project.

PROJECT RESULTS USE AND DISSEMINATION
Project results have been widely disseminated. The Eyes on the Wild website has engaged 12,625 registered users (and thousands more non-registered users), who provided 7,636,071 classifications of 4,153,218 images from our cameras. Project information and results have been widely shared through in-person and online lectures, K-12 school programs and field trips, summer camps, community events, art shows, educational curricula, and local workshops which reached more than 7,000 community members over the lifetime of the project. Additionally, the project has generated four scientific publications, and regular coverage by local print, radio and television outlets.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03l Effects of Wolves Predation on Beaver, Moose, and Deer – Research Project - $293,000 TF (FY2018)

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Appropriation Language
$293,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Voyageurs National Park to assess the effects of wolf predation on beaver, moose, and deer in the Border Lakes region. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our studies of how, where, and when wolves prey on beavers, moose, and white-tailed deer shed exciting new light on the interactions of these iconic denizens of Voyageurs National Park, Minnesota's only National Park.

OVERALL PROJECT OUTCOME AND RESULTS
Gray wolves are widely known to prey on adults and fawns/calves of white-tailed deer and moose. Beavers also make up a large portion of wolf diet in areas where beavers are plentiful. Scientists have long pondered how the abundance of beaver prey can affect wolf predation on moose and deer. Voyageurs National Park - Minnesota's only National Park – and the surrounding area offers the perfect natural laboratory to learn about wolf hunting behavior and how that affects deer and moose in an area of high beaver densities, as densities can be 2-10x higher here than anywhere else in the state. We captured and GPS-collared 42 wolves in at least 12 different wolf packs to follow their movements and find sites where they killed their prey during the spring-summer-fall period. We identified >1,045 kills, including kills of 335 beavers, 192 adult and 444 fawn white-tailed deer, 1 adult and 1 calf moose, and 65 kills of ≥12 other species including snowshoe hare, bears, muskrats, raccoons, swans, geese, ducks, and other birds. Some of our key findings include understanding how wolf predation can affect beaver abundance, pond creation, and even water storage; better understand how wolves use ambushing behavior and cooperative hunting techniques to hunt and kill beavers; how wolves use roads and trails and areas of recent timber harvest to target and kill deer fawns; and how wolves use a variety of other food sources such as fish and berries to persist in an environment where food can often be scarce. While issues surrounding management of wolves, deer, and moose tend to generate a variety of opinions, better understanding the summer ecology of wolves, especially in a relatively pristine environment such as in Voyageurs National Park, can only improve the ability for Minnesotans to better co-exist with wolves and their prey.

PROJECT RESULTS USE AND DISSEMINATION
This collaboration between Voyageurs National Park and the University of Minnesota produced 15 scientific papers and other reports. Our findings have influenced the understanding of wolf behavior and the importance of beavers to forested landscapes in the U.S. and beyond. Research about charismatic species like wolves, beavers, moose, and deer are often very interesting to the general public. We capitalized on that interest by engaging the public through several social media outlets, most notably

through a popular Facebook page created by the University of Minnesota. Check out the University of Minnesota's Voyageurs Wolf Project website for project information.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 03m Mapping Taxonomy and Environmental Toxicology of Minnesota Freshwater Sponges – Research Project - $258,000 TF (FY2018)

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Appropriation Language
258,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Crookston, to determine freshwater sponge distribution, identify and quantify accumulated contaminants, and provide educational research opportunities to undergraduate students. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our project identified freshwater sponges are widely distributed throughout Minnesota's lakes and rivers. Sponges are thought to be bio-indicators of good water quality, suggesting many rivers and lakes in Minnesota are of relatively good quality. We identified new species of freshwater sponges not described previously, so there is likely significant amounts of biological diversity not described in the state. As filter feeders, it doesn't appear that freshwater sponges are accumulating pollutants that can be passed through the food chain.

OVERALL PROJECT OUTCOME AND RESULTS
Freshwater sponges are the simplest animals and play a vital role in the aquatic ecosystem by functioning as a filter feeder and providing habitat and nutrients for other aquatic life. As filter feeders, freshwater sponges could potentially accumulate pollutants and transfer them through the food chain to game fish and other economically important aquatic and terrestrial organisms. Furthermore, despite their importance, information on the distribution of freshwater sponges in Minnesota lakes and rivers is very limited. The primary goals of this project were to **(1) determine the diversity and distribution of freshwater sponges in Minnesota's water basins and watersheds and to (2) determine if these freshwater sponges are accumulating toxic pollutants.**

From our sampling of freshwater sponges, we found freshwater sponges are widely distributed throughout the state of Minnesota. We sampled over one hundred locations and found freshwater sponges at over 75% of the locations sampled, resulting in a total of 169 individual freshwater sponges collected. The majority of the freshwater sponges collected are species that have previously been identified in the state. We identified one new species of freshwater sponge from this project, while

potentially identifying a few more after additional follow-up analyses.

From the chemical analysis of collected sponges there does not appear to be an accumulation of pollutants within the sponge that could be passed through the food chain. Our chemical analysis did identify interesting and unique chemical compounds in the freshwater sponges that has the potential for having bioactivity and could be used for human purposes.

The results of this project showed that freshwater sponges are widely distributed in the state of Minnesota, supporting the notion that these animals are important for the freshwater ecosystem. We have identified new species of freshwater sponges, and importantly, it doesn't appear that sponges are accumulating pollutants that could remain in the ecosystem. We were also able to train 18 undergraduate students in biological and chemical research. Many of these students have gone on to be scientists, nurses, doctors and other important jobs in Minnesota.

PROJECT RESULTS USE AND DISSEMINATION
The dissemination of the project has occurred through multiple mediums. This project was highlighted in the Minnesota DNR's Minnesota Conservation Volunteer Magazine. The project has also been shared with the general public by being added to the Minnesota State Parks and Trails Geocaching Aquatic Quest. An important aspect of this project was providing research opportunities for our undergraduate students at the University of Minnesota Crookston. The research involvement by students was highlighted in a number of publications. This results of this project were also presented at multiple scientific and non-scientific conferences by faculty and students.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04 Water Resources

Subd. 04a Assessment of Household Chemicals and Herbicides in Rivers and Lakes – Research Project - $236,000 TF (FY2018)

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Appropriation Language
$236,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to quantify environmental levels of household chemical and herbicide ingredients in rivers and lakes and assess their potential to form toxic by-products.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The levels of quaternary ammonium compounds (QACs), which are used widely as disinfectants and for

other purposes, were measured in Minnesota wastewaters and sediments. The QACs are present at microgram per liter levels in wastewater. While the QACs are slowly degraded in surface waters by bacteria and light, they accumulate in sediments. The QACs form specific suspected carcinogens during water disinfection in very low yield, and QACs are likely less important than other precursors for these toxins. The results provide information on current QAC levels and provide insights on how to lower them if desired.

OVERALL PROJECT OUTCOME AND RESULTS

Quaternary ammonium compound (QACs) are ingredients in personal care products, fabric softeners, disinfectants, and herbicides. QACs, which are biologically active molecules, are unintentionally and intentionally released into the environment. QACs kill bacteria and may affect microbial communities in wastewater treatment and algal communities in surface waters. In this study, the levels of QACs in the effluent from 12 wastewater treatment plants were determined. Plants with more advanced treatment processes had lower levels of QACs. Sediment samples in a lake demonstrated potential inputs from both municipal wastewater effluent and agricultural sources for QACs. In sediment cores taken from lakes, two distinct trends over time were observed. In lakes with large watersheds and mixed domestic and industrial wastewater sources, peak concentrations of QACs were found at depths corresponding to deposition in the 1980s and decreases after this time are attributed to improved wastewater treatment and source control. In a smaller lake with predominantly domestic wastewater inputs, concentrations of QACs increased slowly over time. In surface waters, QACs were found to degrade by reaction with reactive species (hydroxyl radicals) generated by sunlight and by microbial processes. Even with these loss processes, QACs likely persist from days to weeks in the water, leading to their deposition in the sediments. QACs were found to form low levels of a carcinogenic class of compounds (nitrosamines) when reacted with a drinking water disinfectant (chloramine), but this would be of greatest concern in wastewater potable reuse scenarios. The overall results of the work indicate that QACs are being released by wastewater treatment plants. Once in the environment, degradation by bacteria and by sunlight can occur in surface waters, but accumulation in sediments, where the QACs are persistent, is likely the main removal process. During the wastewater disinfection process QACs can form a carcinogen, but QACs are not as important as other chemicals known to form nitrosamines. The findings allow more robust assessment of potential impacts of QACs and insight into wastewater treatment processes that lead to removal, which is important given the increasing use of QACs during the COVID-19 pandemic.

PROJECT RESULTS USE AND DISSEMINATION

Three papers were published: 1) the detection of QACs in wastewater and sediment (the paper and data set are available online); 2) Photolysis of QACs; and 3) Potential environmental impacts of elevated QAC usage during the COVID-19 pandemic (available online through ACS Publications or PubMed Central). A public lecture that incorporated data for the project was also given at the U of MN, and it is available on YouTube.

Project Completed: 6/30/2019
FINAL REPORT

Subd. 04b Wastewater Nitrogen Removal Technology to Protect Water Quality – Research Project - $450,000 TF (FY2018)

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Appropriation Language
$450,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to develop a technology for inexpensive low-energy nitrogen removal in wastewater. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
A group of bacteria ("anammox") have received attention for their potential in wastewater treatment, transforming harmful reactive nitrogen into harmless dinitrogen gas. However, anammox perform poorly in typical wastewater environments. In this project we developed new materials to selectively enhance anammox growth/retention, supporting more sustainable removal of harmful nitrogen.

OVERALL PROJECT OUTCOME AND RESULTS
Anammox bacteria have received attention for their ability to completely transform harmful reactive nitrogen compounds in wastewater into harmless dinitrogen gas. In addition, when using anammox bacteria, much less oxygen and no supplemental carbon is needed for nitrogen removal, and there is little production of excess biomass in the form of sludge. This reduces costs and energy use for nitrogen removal. It is estimated that the anammox process saves 60% of the energy used in conventional nitrogen removal. Unfortunately, this process has been difficult to implement in typical wastewater systems. Anammox bacteria are slow growing and the ammonium and carbon concentrations in wastewater result in low anammox activity and competition from faster growing bacteria. This leads to the washout of anammox bacteria. In this collaborative research project, our goals were to develop new polymeric materials that could concentrate ammonium to create localized niches for anammox enrichment and retention. We developed two different materials in this project: (1) a porous polymer carrier and (2) a gas-permeable alumina membrane. Both materials were able to concentrate ammonium, while the membrane could also transfer low quantities of oxygen to the surrounding solution. Both materials were also able to enrich and retain anammox when added to a wastewater environment. Further optimization of these materials is needed to enable scale-up and deployment. Nevertheless, given that in the US, the energy used for wastewater treatment costs approximately $2B a year, the predicted energy savings if this technology was implemented would be significant. The impact within the state of Minnesota would also be large, saving millions of dollars and providing more complete removal of harmful nitrogen species. A patent was awarded and the University of Minnesota is exploring commercialization and licensing options. Three peer-reviewed manuscripts were published from this work and have been submitted to the LCCMR.

PROJECT RESULTS USE AND DISSEMINATION
Information from this project has been shared with several water technology companies who may be able to assist in optimizing and eventually deploying this technology. As stated above, three peer-

reviewed manuscripts were published from this work and have been submitted to the LCCMR. Multiple presentations about the research have been given to both regional and national/international conferences. Additional funding is being sought from a large infrastructure company. We anticipate submitting a proposal to the National Science Foundation for additional funding. The University of Minnesota Technology Commercialization Office is working with us to further the technology.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04c Rearing Native Mussels for Reintroduction and Expanding Water Quality Awareness - $591,000 TF (FY2018)

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Appropriation Language
$591,000 the first year is from the trust fund to the Minnesota Zoological Garden in cooperation with the Department of Natural Resources to accelerate the reintroduction of native mussels into Minnesota rivers and streams through expanded mussel rearing, research, and statewide educational activities promoting mussel conservation and water quality. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Zoo increased capacity for rearing mussels to more than 10,000 individuals and researched methods to improve husbandry, enabling us to better support efforts to recover depleted populations. The Show Us Your Mussels challenge engaged >2,200 students, with student-created content reaching >150,000 citizens and encouraging action to benefit conservation.

OVERALL PROJECT OUTCOME AND RESULTS
Native mussels are aquatic engineers, providing important ecosystem services such as water filtration and creating habitat for fish and other wildlife. However, many populations are depleted in Minnesota due to factors such as overharvest and pollution. With this project, the Minnesota Zoo sought to support state-wide recovery efforts led by the DNR and improve mussel conservation by 1) increasing our capacity to rear juvenile mussels for reintroduction; 2) advancing our understanding of mussel husbandry to improve the growth and survival of individuals in our care; and 3) raising public awareness about and encouraging action to benefit our aquatic resources.

We constructed a new mussel rearing and research facility on the Zoo's campus and installed associated systems for housing mussels. These improvements significantly increased our capacity for rearing mussels; we currently have space to accommodate >65,000 newly transformed mussels, surpassing our

target of 10,000 individuals. This expansion significantly increases our conservation impact and positions us to better support ongoing recovery efforts that will restore ecosystem services.

We also conducted experiments to evaluate how substrate affects growth and survival of juvenile mussels. Our research documented that the presence of fine sand in rearing pans significantly increases growth rates for some species. As such, we have modified our husbandry methods to incorporate this finding, which will yield larger individuals more suitable for reintroduction and ultimately may accelerate reintroduction efforts.

To encourage local communities to take action on behalf of water quality, we established the Show US Your Mussel Challenge. This project engages middle and high school students in the creation of social media campaigns to expand communications efforts throughout local communities. To date, >2,200 students have participated in the challenge, sharing information about the importance of mussels, Minnesota's aquatic resources, and actions the public can take to protect Minnesota's waterways with >150,000 residents.

PROJECT RESULTS USE AND DISSEMINATION
Communicating the importance of native mussels and water quality was a key goal of this project. The Minnesota Zoo engaged with Minnesotans to share information about mussels, their conservation, and stewardship of aquatic resources via a variety of platforms, ranging from in-person and virtual presentations at schools, camps, and other forums to free school curriculum and teacher professional development in association with the Show Us Your Mussels challenge. We developed an interpretive area on Zoo campus, outfitted with signs, videos, and a water quality activity, shared research findings at scientific meetings and hosted Smart Salt workshops to reduce salt use.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04d Water Quality Monitoring in Southeastern Minnesota Trout Streams - $500,000 TF (FY2018)

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Appropriation Language
$500,000 the first year is from the trust fund to the Board of Trustees of Minnesota State Colleges and Universities, Winona State University, to develop a system of biological monitoring for water quality protection of trout streams in southeastern Minnesota. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Strobin fungicides were detected in most water samples from the Whitewater River in southeastern Minnesota. Many citizen scientists were trained and continue to monitor stream sites. Stream habitats and fish and aquatic invertebrate communities ranged from excellent to poor, based largely on upstream versus downstream location and adjacent land uses.

OVERALL PROJECT OUTCOME AND RESULTS
Water quality in many trout streams in southeastern Minnnesota has been compromised by rain-event runoff, exposing sensitive trout to mixtures of eroded soils, pesticides, urban stormwaters/wastewaters, and animal wastes. The main goal of this project was to better protect at-risk streams by developing an improved water-quality monitoring infrastructure and network within the Whitewater River system. This was achieved by:

- Automated Water Sampling - establishing both continuous and rain-event sampling throughout 3 at-risk trout stream reaches (North, South, Middle Forks of the Whitewater River),
- Citizen Scientists - training an action network of citizen scientists to respond to episodic run-off events and to monitor water quality and aquatic life in these and additional trout stream reaches, and
- Baseline Surveys - conducting inclusive biotic inventories of fish and aquatic invertebrate communities throughout entire at-risk watersheds for broader, complete delineation of baseline conditions.

Water sampling detected various strobin fungicides in >80% of rain event and low-flow samples, with some concentrations above toxic levels for aquatic life. Strobin concentrations were higher in rain-event samples, but concentrations could not be predicted by rain volume or season. Increased monitoring and better chemical management are needed in these and other watersheds to protect our coldwater ecosystems.

More than 30 citizen scientists have been trained to monitor stream water quality and aquatic invertebrate communities with the Whitewater River and nearby stream systems. They assess their chosen stream sites four times per year, and upload their findings directly to the Izaak Walton League's Save Our Streams web portal. In addition to regular seasonal monitoring, citizen scientists can respond to sudden events (e.g., floods, fish kills) to gather additional information as needed.

Based on surveys at 62 sites, stream habitats and biotic communities ranged from excellent to poor, influenced largely by upstream/downstream location, adjacent land uses, and proximity of springs.

PROJECT RESULTS USE AND DISSEMINATION
Results from our project were the basis for two MS theses completed at Winona State University, and a chapter of a PhD dissertation completed at the University of Minnesota. At least two papers reporting our findings will be published in the peer-reviewed scientific literature.

Our 30+ trained citizen scientists have reported and will continue to report their stream monitoring data to the Izaak Walton League's Save Our Streams web portal, where they are continually available to the public.

Project results also have been reported to the scientific community at seven different state, regional, and national science meetings.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 04e Reassessing Toxicity of Petroleum Spills on Ground and Surface Water – Research Project - $300,000 TF (FY2018)

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Appropriation Language
$300,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the University of St. Thomas to reassess long-term effects of oil spills through the analysis of chemical parameters related to oil degradation and evaluate the impacts on aquatic species, groundwater, and surface waters. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The groundwaters contaminated with chemicals from the decades-old crude oil spill and/or their breakdown products can adversely affect development and hormone and liver functioning if vertebrates were to be exposed to them sufficiently. This project advanced understanding of oil spill remediation and will help protect Minnesota's natural resources/drinking water sources.

OVERALL PROJECT OUTCOME AND RESULTS
A fundamental issue in protecting ecosystem health in Minnesota is the degree to which waters impacted by, relatively common, petroleum releases (e.g., oil or gasoline spills) are toxic, both initially and over time as the oil breaks down into new chemicals. This study was the first to comprehensively screen the toxicity of groundwater from an aged crude oil spill site. The National Crude Oil Spill Fate and Natural Attenuation Research Site near Bemidji, MN is the site of a 1979 pipeline rupture that released 10,000 barrels of crude oil. This site has been extensively studied for over 40 years offering a unique opportunity to study the toxicity of groundwaters impacted by crude oil. Groundwater samples (collected 2016-2019) were analyzed for over 90 different chemical and toxicity parameters using cutting-edge techniques where living cells were exposed to water samples and screened for potential toxic effects. Analysis of the molecular/toxicity targets that were activated in cells indicated that (even 40+ years after the spill) the groundwaters contaminated with chemicals from the original spill and/or chemicals resulting from the breakdown of the oil compounds have the potential to cause adverse impacts on development, endocrine, and liver functioning if vertebrates (fish, turtles, birds, mammals) were to be exposed to them sufficiently. This work clearly shows the need to improve understanding of the identity and toxicity of oil breakdown products. Furthermore, this work shows that commonly used

sampling and analysis methods (including sample extraction and clean-up protocols) can exclude or under-represent oil breakdown products and thus may underestimate risks from these chemicals. This finding is of importance to remediation managers and regulators in Minnesota and nationally because there is an active debate as to which methods and protocols are most suitable for hazard and risk assessment at petroleum spill sites.

PROJECT RESULTS USE AND DISSEMINATION
We published three research manuscripts, presented at numerous research conferences, and raised awareness of the issue with Minnesotans statewide (reached circa 1200 individuals at the State Fair exhibits). We introduced oil industry, and managers and regulators in MN and nationally to a new toolbox of novel cell and artificial intelligence approaches that can streamline hazard assessment and facilitate identification of chemicals/hazards of concern and enhance oil spill remediation monitoring. Results of our work are relevant to Minnesotans as the analyses conducted herein advance an understanding of oil spill remediation and will help protect Minnesota's natural resources/drinking water sources.

Project Completed: 6/30/2021
FINAL REPORT
Toxicity Assessment of Groundwater Contaminated by Petroleum Hydrocarbons at a Well-Characterized, Aged, Crude Oil Release Site - 7 pgs
Biological Effects of Hydrocarbon Degradation Intermediates: Is the Total Petroleum Hydrocarbon Analytical Method Adequate for Risk Assessment? - 9 pgs

Subd. 05 Environmental Education

Subd. 05a Connecting Youth to Minnesota Waterways through Outdoor Classrooms - $1,200,000 TF (FY2018)

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Appropriation Language
$1,200,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Wilderness Inquiry to provide place-based environmental education science water experiences to approximately 20,000 middle- and high-school students. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Floating Classroom served more than 25,000 Minnesota youth by creating opportunities to engage in environmental science through accessing Minnesota waterways and public lands. Youth assessed

natural resources, collected scientific data, developed a stewardship ethic, and learned about outdoor employment opportunities, becoming Minnesota's next generation of natural resource protectors.

OVERALL PROJECT OUTCOME AND RESULTS
All told since the beginning of the project in June 2017, Wilderness Inquiry's Floating Classroom connected more than 25,714 Minnesota youth to environmental science and Minnesota's abundant waterways and public lands.

On live outdoor events, Wilderness Inquiry's Floating Classroom served 24,421 diverse Minnesota youth through placed-based, educational experiences, creating opportunities to engage in environmental science through accessing Minnesota waterways and public lands. Of these youth, 23,600 youth engaged in hands-on exploration, recreation and assessment of said waterways and public lands and 821 youth participated in a multi-day expedition, learning to restore and maintain public lands and discover pathways into outdoor-related employment.

When COVID-19 forced Minnesota schools into distanced learning and limited the gathering of groups, the Floating Classroom quickly pivoted to meet the needs of educators and families educating and learning from home. Wilderness Inquiry's Online Learning Resources were created and this website has been visited by 1,254 unique visitors. Some highlights include pages dedicated to Environmental Science and Natural Resources (visited by 353 visitors) and Jobs in the Outdoors (visited by 126 visitors). The full scope of these resources goes much further with downloadable activities and additional pages being shared among virtual classrooms.

As COVID-19 continued to impact the Floating Classroom's ability for in person programming through summer 2020, Wilderness Inquiry and the National Park Service partnered together to create a free virtual summer camp to connect youth to the mysteries of the Mississippi River. 39 Minnesota Youth took part in this camp focused on the ecology of the Mississippi River.

PROJECT RESULTS USE AND DISSEMINATION
While participating in Floating Classroom activities, students collected water quality data and this data was reported back and disseminated through a citizen science online portal Canoe Quest via GLOBE, a national database for citizen science.

Wilderness Inquiry worked with the University of Minnesota's Center for Applied Research and Educational Improvement (CAREI) to evaluate the project. CAREI produced two reports over the course of the three years which were shared directly with partners and stakeholders, presented at conferences, and can be found on the Wilderness Inquiry website.

Lastly, many local media outlets covered the Floating Classroom's arrival throughout the state. Many of these are included in the Wilderness Inquiry blog, including this story from MPR.

Project Completed: 6/30/2020
FINAL REPORT

Subd. 05b Increasing Diversity in Environmental Careers - $487,000 TF (FY2018)

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Appropriation Language
$487,000 the first year is from the trust fund to the commissioner of natural resources in cooperation with Conservation Corps Minnesota and Iowa to encourage a diversity of students to pursue careers in environment and natural resources through internships and mentorships with the Department of Natural Resources, the Board of Water and Soil Resources, and the Pollution Control Agency. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

Project due to be completed: 6/30/2022
FINAL Abstract

Subd. 05c Interactive Water Resource Programs for Planetariums Minnesota - $500,000 TF (FY2018)

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Appropriation Language
$500,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Bell Museum of Natural History, to create an interactive planetarium program on water resources, reaching approximately 400,000 citizens statewide through the Bell Museum Planetarium, St. Paul Public Schools, Mayo High School, Mankato East High School, Southwest Minnesota State University, Minnesota State University Moorhead, and University of Minnesota Duluth. This appropriation is available until June 30, 2022, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Water flows out of Minnesota in three directions, and our personal and public choices have impacts far beyond our borders. With Minnesota Water Stories, citizens tour Minnesota in planetariums across the state, to learn about issues in each region and understand what they can do to protect this natural resource.

OVERALL PROJECT OUTCOME AND RESULTS
The planetarium dome is an ideal place to provide an immersive venue for citizens to understand

complex topics such as time, scale, and geographic perspective as they relate to water. The shape of a dome fills our peripheral vision and mirrors the way our eyes see the world around us, which allows the audience to feel they are part of the story, connected to the decisions made by themselves and others. A skilled presenter can tailor the show to the needs of the audience, so each experience is unique. *Minnesota Water Stories* includes a mixture of animation and live-action video from a dozen locations around the state including Park Rapids, Halstad, Breckenridge, Redwood Falls, Waseca, Wabasha, and Tofte.

The outcomes for citizens attending *Minnesota Water Stories* were to increase awareness of challenges facing our waters, understand the challenges' relations to the larger system, and becoming aware of community resources to work toward addressing these problems. Due to the pandemic, we were not able to do a full-scale evaluation of the show in planetariums around the state. We created an online version with similar content as the planetarium show to measure how it meets these outcomes. According to the evaluation report, "general audience and student participants increased their understanding of challenges facing Minnesota waters."

Almost 1,000 Minnesotans saw the interactive and audience participatory experience of *Minnesota Water Stories* in its initial run at the Bell Museum's Whitney and Elizabeth MacMillan Planetarium, and 231 students and public reviewed the web-based version. Over the next few years Minnesota Water Stories will show to thousands of people at planetariums in Baxter, Duluth, Hibbing, Mankato, Marshall, Moorhead, Rochester, St. Cloud, and St. Paul.

PROJECT RESULTS USE AND DISSEMINATION
This project produced a planetarium show and an online StoryMap that all Minnesotans can access. To date, over 900 Minnesotans have seen the show at the Bell Museum. In fall 2022 it will be available for audiences in planetariums in nine cities around the state and can travel to any region with the University of Minnesota's portable planetarium system. In the years to come, thousands of Minnesotans will view *Minnesota Water Stories*.

Project Completed: 6/30/2022
FINAL REPORT

Subd. 05e Local Planning and Implementation Efforts for Bird Habitat - $280,000 TF (FY2018)

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Appropriation Language
$280,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the National Audubon Society, Minnesota office, to engage approximately 60 communities and 400,000 citizens in bird habitat improvement through local planning and implementation efforts using

the National Audubon Bird City program. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Through Bird City Minnesota, Audubon Minnesota has engaged communities in improving the habitat and protecting birds. Nine communities completed the certification program, while many more have been using this conservation roadmap to leverage resources and achieve results in making their communities friendly for birds and wildlife.

OVERALL PROJECT OUTCOME AND RESULTS

Bird City Minnesota has worked to enhance conservation efforts to protect birds and habitats in Minnesota communities. A total of nine communities have received the Bird City Minnesota designation, while many other communities have showed interest and start working to complete the requirements of the program. Bird City Minnesota requirements lead communities in taking steps to accomplishment conservation efforts that improve habitat through restoration, reduce threats to birds, and engage local citizens through projects, training and birding events. Many of the communities that participated made substantial progress in protecting habitat in local parks and engaging citizens in hands-on conservation work that creates a healthier environment for birds. By focusing on these efforts, local communities have engaged their residents in citizen science and conservation. Through public events, residents have learned how to take simple actions that result in improving the landscape for birds and ensuring appropriate habitat.

During the course of this project, the COVID-19 pandemic significantly disrupted the progress that communities were making in attaining Bird City Minnesota recognition. Staff have been flexible to support communities as necessary, made adjustments where appropriate, and encourage continued work towards completing the program event after the funding of this project has ended. Minnesotan's have benefited from this work by learning simple steps that they can take in their own communities to make a difference for birds, and what they have learned in this process will benefit communities and birds for decades to come.

PROJECT RESULTS USE AND DISSEMINATION

While the project was significantly affected by the COVID-19 pandemic, we have been able to successfully promote the achievements of communities through significant local news media coverage for cities who have achieved the Bird City Minnesota recognition. Additionally, signage and flags are now displayed in each of the communities that have completed the Bird City Minnesota requirements and were awarded recognition. Application materials have been shared with communities to assist in their continued fulfillment of program requirements, as well as to serve as historical records of the conservation efforts taken.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 05f Developing Youth Watershed Stewardship in Northwest Minnesota - $121,000 TF (FY2018)

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Appropriation Language
$121,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Headwaters Science Center to accelerate a multiyear environmental science club for middle-school students focused on water quality, watershed evaluation, and aquatic invasive species in northwestern Minnesota. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project entitled Developing Youth Watershed Stewardship in Northern Minnesota established the Environmental Science Club. Goals were established, pursued and met:
skill development, enhanced understanding, recognition of relationships between actions and outcomes, provided positive experiences, shared similar information through presentations, and demonstrated deeper understanding of ecosystems.

OVERALL PROJECT OUTCOME AND RESULTS
Environmental Science Club was established in early 2019 for 10 to 18 students led by HSC staff in each of 2-hour club sessions. Members came to HSC from two sources: Boys & Girls Club of Bemidji with students from fifth grade to eight grades along with HSC's youth participants. Students explored ground-water, examined rivers & built models of watersheds; culminating with a lakeshore clean-up. The club was expanded into summer where Voyageurs Expeditionary High School students participated in a four-day outdoor ecological study as part of their summer school course curriculum requirements.

Club activities resumed heading into the fall and winter of 2019. Specimens from area water were gathered and examined. Eighteen students participated in Environmental Science Club.

With the turn of the new year, HSC headed into 2020 with twelve more club sessions in January, February, and early March. Then Covid-19 struck & we were soon surrounded by uncertainty with hybrid models for students attending class & afterschool activities virtually. In this phase we co-opted our "Daily Live Science Show" -once a week- with labs testing for chloride & then showing E. coli sampling & lab technique for various local stream studies.

Our hybrid approach shifted again to macroinvertebrate assays, crowd sourced, demonstrating how to gather, sort, classify & count organisms for our pollution intolerance index. With this scale we were able to determine water quality by presence, or lack thereof, pollution intolerant organisms, as well as diversity. This scale allowed us to determine, and present electronically degree of ecological integrity. Despite most environmental news being dire and even depressing, we are pleased to present our

findings of excellent condition for many streams and even found pollution sensitive organisms in places way downstream. We are thankful that this LCCMR grant allowed us to share these insights.

PROJECT RESULTS USE AND DISSEMINATION
Club participants always focused on results -via exploration & the scientific method- utilizing various skills learned for water examination. In the first thirty months of the project, participants presented knowledge they had gained at science fairs & peer-to-peer feedback sessions. Student field journals, notes & posters accompanied project presentations. Final professional production of posters was not completed. Funding for this portion of the project was remains unspent and this portion of the grant should be returned to the ENRTF.

During the last six months of the grant cycle the pandemic overtook us, so we shifted to a hybrid virtual model. Our 3:30 show became a regular afternoon session on three platforms: YouTube, Facebook and Twitch TV with final selected videos appearing on the hscbemidji.org Website.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 06 Aquatic and Terrestrial Invasive Species

Subd. 06a Aquatic Invasive Species Research Center - Phase II – Research Project - $2,700,000 TF (FY2017)

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Appropriation Language
$2,700,000 in fiscal year 2017 is from the trust fund to the Board of Regents of the University of Minnesota to support the Minnesota Aquatic Invasive Species Research Center in finding solutions to Minnesota's aquatic invasive species problems through research, control, prevention, and early detection of existing and emerging aquatic invasive species threats. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

Sub-Projects M.L. 2017, Subd. 06a:

- *4.3: Social Learning and Carp Removal - Przemek Bajer* - $189,475
- *8.2: Impacts of Invader Removal on Native Vegetation Recovery - Daniel Larkin* - $119,034
- *12.2: Historical Analyses of Spiny Water Flea Invasion Patterns - Donn Branstrator* - $53,795
- *15: Determining Highest Risk Vectors of Spiny Water Flea Spread* - Valerie Brady* - $26,581

- *16.2: AIS Impacts on Walleye Populations and Mercury Concentrations - Gretchen Hansen* - $199,862
- *18.2: Genetics to Improve Hybrid and Eurasian Watermilfoil Management - Raymond Newman* - $236,423
- *20: A Novel Technology for eDNA Collection and Concentration* - Abdennour Abbas* - $96,264
- *21.2: Field validation of mulitbeam sonar zebra mussel detection (Year 1)** - Jessica Kozarek* - $14,247
- *22: Copper-Based Control – Zebra Mussel Settlement and Non-Target Impacts* - James Luoma* - $152,090
- *23: Public Values of Aquatic Invasive Species Management* - Amit Pradhananga* - $110,245
- *24: Genetic Method for Control of Invasive Fish Species* - Michael Smanski* - $140,004
- *25: What's in Your Bucket? Quantifying AIS Introduction Risk* - Nicholas Phelps* - $84,094
- *28: Evaluating Innovative Coatings to Suppress Priority AIS - Mikael Elias* - $51,234
- *30: Managing Midwestern Aquatic Invasions in a Changing Climate - Ranjan Muthukrishnan* - $39,000

*Subproject is split between M.L. 2013 and M.L. 2017 funding, only M.L. 2017 funds are reflected.
**Subproject is split between M.L. 2017 and M.L. 2019 funding, only M.L. 2017 funds are reflected.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

This project continued MAISRC's work to develop research-based solutions that can reduce the impacts of aquatic invasive species in Minnesota. Through this appropriation, MAISRC has supported 15 subprojects on many of Minnesota's most important AIS, significantly advanced our scientific understanding and ability to manage AIS and engaged thousands of stakeholders and partners.

OVERALL PROJECT OUTCOME AND RESULTS

The Minnesota Aquatic Invasive Species Research Center (MAISRC) continued to develop research-based solutions that can reduce the impacts of AIS in Minnesota and advance AIS knowledge among natural resources managers, the research community, and the public. In total, 15 subprojects were supported from this project – significantly advancing our scientific understanding and ability to manage AIS. New tools have been developed and knowledge gaps filled on many of Minnesota's most important AIS, including zebra mussels, spiny water flea, bigheaded and common carps, and starry stonewort. The results of this work have been broadly disseminated via research reports, peer-reviewed manuscripts, fact sheets, white papers, news media, newsletters, social media, and direct stakeholder engagement through presentations, workshops/trainings, and public events. Highlights of project outcomes include identifying the highest risk methods of introduction and spread of spiny water flea and baitfish viruses, advancing innovative control tools for established AIS like zebra mussels and common carp, and defining the impact of AIS on ecosystems and sportfish populations. Throughout this project, MAISRC has continued to serve as a global leader in the field of AIS research and a go-to resource for managers, researchers, and members of the public.

This project also supported MAISRC's work to ensure the effectiveness and efficiency of a center-based research model. Progress in this area included an ongoing, comprehensive process for prioritizing research needs; stronger collaboration and coordination between researchers and managers; a competitive, peer-reviewed annual proposal competition; and increased communications and outreach capacity to help managers and community members translate research findings into on-the-ground management.

MAISRC continues to advance Minnesota's resiliency and ability to address AIS issues facing our state through research, collaboration, and stakeholder engagement. This project will continue with Phase II and III appropriations awarded in 2019 and 2021.

PROJECT RESULTS USE AND DISSEMINATION
The MAISRC website has become a resource for AIS stakeholders across the state with an average of 40,000 users visiting the site each year. MAISRC and the AIS Detectors program also have active social media accounts on Twitter, Facebook, and YouTube. MAISRC and AIS Detectors' videos on YouTube, including webinars and project spotlights, have collected nearly 94,000 views, totaling an estimated 2,700 hours of watch time. MAISRC's Twitter account has grown into a popular means of connecting researchers, legislators, community organizations and nonprofits, and other AIS stakeholders. Social media posts continue to disseminate research findings, highlight behind-the-scenes project activities, promote MAISRC events and AIS Detectors workshops, and share invasive species news. In addition, the MAISRC e-newsletter delivers in-depth stories about MAISRC research and management tools to more than 5,300 people and growing.

Project Completed: 06/30/2022
OVERALL FINAL REPORT

Sub-Project 4.3: Social Learning and Carp Removal - $189,475 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
A new method for removing common carp to improve water quality and habitat was developed. It uses bait to attract carp and remove them. It is very selective and easily scalable. While its efficacy is being improved, it is already being used by lake managers in Minnesota.

OVERALL PROJECT OUTCOME AND RESULTS
Common carp is a widespread, invasive fish that negatively impacts habitat and water quality in lakes. Practical and selective removal strategies are needed for carp. Previous research showed that bait can be used to selectively attract large numbers of carp in lakes. In this experiment, we documented how the carp are attracted to the bait (Objective 1; social structure) and whether they could be removed using nets (Objective 2). In a lake with multiple baiting sites (8 sites in a 258-acre lake) and 300 carp tagged with electronic tags, 54% of carp (164 tags) were attracted to the bait over the whole summer, and ~ 20% of population were attracted daily (60 tags). Some carp ("Superfeeders") visited baited sites

nearly every day, while others only every few days. The Superfeeders were significantly larger than other carp. The carp visited the bait mainly at night. Feeding aggregations were very dynamic – individual feeding bouts included 2-9 tagged carp, lasted <1 minute to over 30 min, and continuously formed and dissolved for several hours each night. We attempted three removal events at the baited sites, on 3 separate nights, collectively capturing 27% of the population (3,602 carp). Native fish bycatch was <1% (released).

Our results indicated that carp foraging is social, easily induced by species-specific bait, dominated by large-bodied individuals, and predictable (nightly). However, only a fraction of carp attracted to the bait were removed because individual feeding groups visited that bait at different times of the night. We suggest that next steps should address how to synchronize carp aggregations at the bait to increase removal efficiency (starts in January 2022 using acoustic conditioning). This line of research resulted in carp removal methods that are already being applied in Minnesota, often involving volunteers to bait the carp. Future optimizations will increase the efficacy of this new management method.

PROJECT RESULTS USE AND DISSEMINATION

To disseminate the results of this work we have presented two talks at scientific conferences focusing on invasive species and lake management:

Bajer P. G. et al. 2019. A new approach to manage common carp: Citizen-aided carp management. International Conference on Aquatic Invasive Species ICAIS, Montreal, Canada.

Hundt, P. J., Bajer P. G. 2020. Common Carp Feeding Aggregations: Responses of Invasive Carp and Native Fish to Corn Baiting, North American Lake Management Society, Minneapolis, MN.

We have published two peer-reviewed manuscripts:

Hundt, P. J., Amberg, J., Sauey, B., Vacura, K., & Bajer, P. G. (2020). Data from: Tests in a semi-natural environment suggest that bait and switch strategy could be used to control invasive Common Carp. Management of Biological Invasions.

Hundt PJ, While LA, Craft ME, Bajer PG. In review. Social associations in common carp: Insights from induced feeding aggregations for targeted management strategies. Ecology and Evolution.

We were featured in a Star Tribune article from January 30, 2021: Corn, Conveyor Belts and a Virus show promise in removing invasive carp from Minnesota Waters. We were also featured in a Minnesota Bound episode on common carp management in Lake Parley https://www.youtube.com/watch?v=3sS-Ej3VU4w.

We have also presented twice at the MAISRC Research & Management Showcase and conducted a webinar on common carp management that included 150 participants from several states. https://youtu.be/zNXcB1IfhqM.

Subproject 4.3 Completed: 06/30/2021

FINAL ABSTRACT

FINAL Graphic

Sub-Project 8.2: Impacts of Invader Removal on Native Vegetation Recovery - $119,034 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project adds to the growing understanding that invasive species are often only one of multiple stressors that drive declines in the health of our lakes. Controlling invasive plants is not a silver bullet for restoring turbid, degraded lakes—we have to think more holistically about what's dragging down our lakes' health.

OVERALL PROJECT OUTCOME AND RESULTS
Controlling dominant invasive aquatic plants is a common goal of many stakeholders around the state. These invader-reduction efforts are often motivated as ways to promote the health or recovery of native plant communities—but the potential for these efforts to actually meet those goals is uncertain. We hypothesized that, in addition to potential competitive effects of invasive species, insufficient water clarity and native plant recolonization can also be "rate-limiting" components of restoring lake vegetation. If so, these limitations must be addressed and invader control alone will be inadequate for restoration. We addressed this issue in two ways: (1) By evaluating responses of native plants to actual, on-the-ground management efforts in invaded lakes in MN through synthesis and analysis of monitoring data. This can tell us how management is working across the state at scales relevant to lake managers. (2) We compared those conclusions to results of field experiments designed to untangle how invaders, light limitation, and reproduction can hinder native plant recovery. Overall, our work resulted in the aggregation of more than 4,000 surveys that will be used to evaluate responses of native plants to curlyleaf pondweed, Eurasian watermilfoil, and the management of each of these AIS. The funding supported the completion of all experimental fieldwork, bringing four years of work to a conclusion. In short, our experiments and data synthesis reveal that native plant recovery following invader control is a realistic outcome—but only under certain conditions, i.e., where water clarity and propagule availability are sufficient to foster native plant recovery. In addition, our results show that Eurasian watermilfoil exerts a stronger negative effect on native plants than curlyleaf pondweed. Thus, control of Eurasian watermilfoil is more likely to foster native recovery than is control of curlyleaf pondweed. If lake management is to restore native macrophytes, it must target the factors that are limiting native species recovery, and we show that invasive species are one of multiple limiting factors in Minnesota lakes.

PROJECT RESULTS USE AND DISSEMINATION
This project has produced materials of interest to a wide variety of stakeholders covering a wide breadth of the work the project entailed. Among these products are peer-reviewed publications, videos, presentations, posters, databases, and a data dashboard. Videos include a webinar on the statewide plant survey database, an instructional video describing point-intercept and delineation plant-survey

methods for student and extension audiences, and two short presentations—one describing analysis of statewide data for management evaluation, and another describing ecological work using statewide data to define the niches of macrophytes. A poster and a presentation detail much of the work that went into developing aquatic plant revegetation methods. The statewide database is available as a database and through a beta-version dashboard. Multiple publications will detail the work as it pertains to contributions to the state of knowledge on the ecology and management of aquatic plants. All of these materials are available upon request.

Peer-reviewed publications:

Verhoeven, M. R., D. J. Larkin, and R. M. Newman. (2020). Constraining invader dominance: Effects of repeated herbicidal management and environmental factors on curlyleaf pondweed dynamics in 50 Minnesota lakes. Freshwater Biology, 65(5), 849–862. https://doi.org/10.1111/fwb.13468

Verhoeven, M. R., W. J. Glisson, and D. J. Larkin. (2020). Niche models differentiate potential impacts of two aquatic invasive plant species on native macrophytes. Diversity, 12, 162. https://doi.org/10.3390/d12040162

Published datasets and R code:

Verhoeven, M. R., D. J. Larkin, and R. M. Newman. (2020). Complete data and analysis for: Constraining invader dominance: Effects of repeated herbicidal management and environmental factors on curlyleaf pondweed dynamics in 50 Minnesota lakes. Data Repository for the University of Minnesota. https://doi.org/10.13020/aw92-e606

Verhoeven, M. R., W. J. Glisson, and D. J. Larkin. (2021). Complete data and analysis for: Niche models differentiate potential impacts of two aquatic invasive plant species on native macrophytes. Data Repository for the University of Minnesota. https://doi.org/10.13020/cwqe-ge69

Subproject 8.2 Completed: 06/30/2021
FINAL ABSTRACT
FINAL Graphic

Sub-Project 12.2: Historical Analyses of Spiny Water Flea Invasion Patterns - $53,795 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
After spiny water flea was first recorded in North America in the 1980s, sediment core analysis was heralded as a method to document the timing of lake invasions with implications for understanding and

managing spread and threats. Our study casts concern on the method, revealing limitations to pinpoint early detection.

OVERALL PROJECT OUTCOME AND RESULTS

Spiny water fleas threaten Minnesota's lakes, including walleye health, but we do not understand how many years it takes for the threats to manifest once they invade. This project was a continuation of Subproject 12 where we sought to use evidence in lake sediments to determine the timeline of first presence and growth of spiny water fleas in Lake Kabetogama and Lake Mille Lacs. The results of Subproject 12 demonstrated that spiny water fleas have been present in both lakes continuously since the early 1900s. This timeline conflicts with data on first sightings that do not place spiny water fleas in either lake until the early 2000s. This gap of about 100 years suggests that our sediment analysis methods are biased. With Subproject 12.2, our main objective was to conduct two additional lines of inquiry to determine the suitability of our methods by 1) measuring natural rates of mixing in surface sediments of Lake Kabetogama and Lake Mille Lacs, and 2) searching sediment cores that were collected before first sightings of spiny water fleas in Lake Kabetogama. The results demonstrate that 1) natural rates of sediment mixing are not sufficient to explain the early presence of spiny water flea body remains in Lake Kabetogama or Lake Mille Lacs sediments, and 2) there is no evidence in historical core material that places spiny water fleas in Lake Kabetogama before their reported year of first detection in the water. We combined our results with results from scientists at Queen's University (Canada) who have recently used similar methods to ask similar questions, into a forthcoming publication in the Journal of Paleolimnology. In that publication we review our findings and caution the use of our methods to pinpoint early detection of spiny water fleas in lakes until further study of the methods is conducted.

PROJECT RESULTS USE AND DISSEMINATION

We widely disseminated the results of Phase I of Subproject 12 (M.L. 2013) but we have not thus far disseminated any of the results in Phase II for two reasons. First, the COVID pandemic limited our opportunities. Second, the controversial nature of our results led to a hesitancy among us to share them until we had fully analyzed all evidence and lines of inquiry, both in our data set and the data set contributed by our collaborating scientists at Queen's University. Peer-reviewed publications are in process and presentations on results will be given as a part of the MAISRC Showcase.

Subproject 12.2 Completed: 06/30/2021
FINAL ABSTRACT
FINAL Graphic

Sub-Project 15: Determining Highest Risk Vectors of Spiny Water Flea Spread - ML2013 $92,932/ ML2017 $26,581 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Spiny water fleas are an invasive zooplankton that threaten Minnesota lakes. In tests of recreational fishing gear, fishing lines entangled the most spiny water fleas and should be the focus of cleaning efforts. In addition, all water should be removed from bait buckets and livewells to prevent spreading this invader.

OVERALL PROJECT OUTCOME AND RESULTS

Spiny water fleas are a predatory non-native zooplankton that threatens the ecology and recreational value of Minnesota lakes. Estimates are that >40% of northern Minnesota lakes are vulnerable to invasion. These invaders are primarily spread by human recreational activity, but we do not know exactly how this is happening. Our project goals were to 1) determine which types of recreational fishing gear would entangle (and thus spread) spiny water fleas, and 2) widely disseminate our results and gear-cleaning tips. We conducted 7 sampling events on Lake Mille Lacs, collecting 718 samples including zooplankton tows and spiny water flea counts on fishing gear and anchor ropes. We found that fishing lines accumulated the most spiny water fleas and thus should be the focus of angler cleaning efforts. In addition, it is critically important that all water be removed from bait buckets and livewells to prevent spread. To help recreational anglers clean their fishing gear, we printed and/or coordinated the distribution of over 20,000 cellulose dish cloths that were printed with cleaning instructions. 8,000 cloths were printed and distributed to 18 community partners (lake associations, AIS prevention staff, agency partners) as a part of this project and an additional 12,000 were printed and distributed through coordination with partner organizations and additional funders. Cloths were distributed to recreational anglers, focusing on those who move between spiny water flea infested lakes and uninfested lakes. In addition, we launched the stopspiny.org website to disseminate research findings and share prevention resources and created three PSA videos that demonstrated how to use the cloth to clean fishing lines. The videos played on YouTube, Facebook, Twitter, and TV in the Lake Superior, Lake of the Woods, Mille Lacs, Twin Cities markets. Facebook advertising was used to extend the stop spiny PSAs, reaching over 208,000 individual people and resulting in 442,000 impressions. PSA ads were also placed in local, online and print publications with an estimated reach of 103,000 readers. The research team also wrote one scientific manuscript and presented their results 19 times to about 1,500 people.

PROJECT RESULTS USE AND DISSEMINATION

All outreach was done with strong collaboration and support from MAISRC staff.

Stop Spiny Cloths: To help recreational anglers clean their fishing gear, we printed a simple image of a spiny water flea and what they look like when ensnared on fishing lines, along with cleaning instructions and funder logos, on 8,000 cellulose dish cloths. These cloths look like a steam-rolled sponge. Use of these cloths (or any cloth) to wipe fishing line prior to leaving an infested lake will help prevent the spread of spiny water flea from lake to lake. In testing, we found that these cloths are easy to use to clean fishing lines (and a more useful product than our original idea of a sticker). These cloths were distributed this spring to about 18 partners (lake associations, AIS spread prevention staff, agency partners, etc.). In addition, we facilitated the Minnesota Lakes and Rivers Advocates to help about 25 other groups (mostly lake associations and conservation districts) order over 9,000 more spiny wipe cloths for distribution. In total, we have or are in the process of facilitating distribution of over 20,000 cloths (3,000 of these were part of our companion project funded by St. Louis County) to wipe spiny water fleas from angler fishing lines.

To support distribution of the cloths and assist those distributing them, MAISRC staff worked with us to create an outreach campaign that we called the "Stop Spiny" campaign.

Website: The Stop Spiny campaign was chiefly hosted on the MAISRC website at stopspiny.org, which redirects to www.maisrc.umn.edu/stopspiny. The web page was created in Fall 2020 by MAISRC staff. Since its creation, the Stop Spiny campaign page has been viewed over 4,721 times. The average time a visitor spends on the page is nearly two minutes and thirty seconds. The Stop Spiny campaign webpage, as of Jan. 2022, is the seventh most popular page on the entire MAISRC website over the last year and a half.

The Stop Spiny campaign page gives an overview of spiny water flea invasion history and impacts and explains how water recreationists can help prevent the spread of spiny water fleas. A video about the project results is linked on this page. Additional information includes an interactive map showing current spiny water flea invaded lakes in Minnesota and links to additional spiny water flea research and species pages.

MAISRC staff also created a Stop Spiny campaign resources web page. This page hosts a variety of Stop Spiny factsheets, images, videos, fliers, and more for the free use and distribution of educators, resource managers, lakeshore associations, and/or any others hoping to help prevent the spread of spiny water fleas. The average time spent on this page by users was six minutes, which is very long by web page viewing standards and indicates that visitors are taking the time to read and download the information on this webpage.

Videos: To help share the Stop Spiny message in a visually interesting format, we worked with MAISRC and UMD to produce multiple high-quality videos. Three different video lengths were created—15 seconds, 30 seconds, and a full length (~2:30 min). The videos were shared on multiple social channels, including MAISRC's Facebook and Twitter accounts. The videos were also used in different combinations for Facebook advertisements and a television advertisement. On YouTube alone, the videos have accumulated over 850 views.

Advertisements: The Stop Spiny campaign included a combination of digital and print advertising. Print advertising included placements in the Lake Country Journal (based near the spiny water flea-infested Lake Mille Lacs), the Ely Summer Times (distributed along the Minnesota Iron Range, in the heart of spiny water flea-infested lakes), and Northern Wilds Magazine (another Northern Minnesota distributor). The estimated reach, per outlet, as provided by their respective company websites are as follows; Lake Country Journal—40,000; Ely Summer Times—28,000; Northern Wilds Magazine—18,000.

Northern Wilds Magazine, which also has an online edition and active online community, was contracted for Stop Spiny banner ads. The ads were placed on the Northern Wilds Magazine website at the top column of their side bar. The company estimates that their web pages see roughly 17,000 page views per month. Stop Spiny advertisements were placed on the top side bar for three consecutive months, from June to August 2021.

In addition, extensive Facebook advertising was used to enhance the Stop Spiny campaign. Multiple rounds of advertisements were planned to coincide with time of year and spiny water flea population increases. Since the launch of the campaign in spring 2021, Stop Spiny advertisements on Facebook reached over 208,000 individual people and resulted in 442,000 impressions. Included in all the advertisements were hyperlinks to the Stop Spiny campaign website for additional information and

resources. In total, over 1,500 people clicked from the advertisement to the Stop Spiny campaign page.

On average the amount of time an individual person will watch a video on Facebook is six seconds. Engaging users to watch more than six seconds is a huge engagement success. By the end of the Stop Spiny campaign, over 29,000 users watched the Stop Spiny video they were served to completion (15-30 seconds) and over 60,000 users watched over 50% of the video they were served (7-15 seconds).

Finally, we have had numerous radio and print articles about our project and how to stop the spread of this invasive species, including an outreach article by MAISRC personnel in a Minnesota angling magazine (Activity 2, Outcome 4). Additional outreach has included working with Lake Minnetonka local government staff to use their lighted electronic boards to promote Stop Spiny messages, creating Stop Spiny factsheets and handouts, and sidebar online advertisements on the Northern Wilds website. Our Stop Spiny website hosts all these videos, factsheets, an interactive map, the radio scripts, and presentations for watercraft inspectors. The PIs published one scientific manuscript, and gave 19 presentations to over 1,500 people in total.

Peer-Reviewed Publications

• Donn K. Branstrator, Joshua D. Dumke, Valerie J. Brady & Holly A. Wellard Kelly (2021): Lines snag spines! A field test of recreational angling gear ensnarement of Bythotrephes, Lake and Reservoir Management, DOI: 10.1080/10402381.2021.1941447

Presentation Recordings/Videos

• 2021 MAISRC Research & Management Showcase Presentation
https://z.umn.edu/2021ShowcaseSpiny
• 2020 MAISRC Research & Management Showcase Presentation
https://z.umn.edu/2020ShowcaseSpiny
• AIS Detectors Webinar: Lines Snag Spines! Preventing the Spread of Spiny Water Flea
https://z.umn.edu/DetectorsWebinarLinesSnagSpines
• MAISRC Video: Preventing the Spread of Spiny Water Flea
https://z.umn.edu/MAISRCPreventingSpinySpread

Select Media Coverage

• Minnesota Opinion: Avoid catches you don't want this fishing season – West Central Tribune
https://www.wctrib.com/opinion/editorials/ minnesota-opinion-avoid-catches-you-dont-want-this-fishing-season
• New ways to stop spiny water flea spread – Mesabi Tribune
https://www.mesabitribune.com/opinion/columnists/new-ways-to-stop-spiny-water-flea-spread/article_daea21e8-bca9-11eb-ae17-0b26c8aa0317.html

Subproject 15 Completed: 12/31/2021
FINAL ABSTRACT
Manuscript
Map
Visual

Sub-Project 16.2: AIS Impacts on Walleye Populations and Mercury Concentrations - $199,862 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Invasive zebra mussels impact lakes supporting walleye in Minnesota. Our research demonstrates that zebra mussels are associated with lower recruitment (reproduction and survival) of walleye in their first year. Furthermore, walleye and yellow perch alter their feeding habits in lakes with zebra mussels, which is associated with increased mercury concentrations.

OVERALL PROJECT OUTCOME AND RESULTS

Invasive zebra mussels profoundly affect lake ecosystems, but their impacts on walleye are not well understood. We used a multi-pronged approach to understanding zebra mussel impacts on walleye in Minnesota lakes. First, we evaluated how walleye recruitment (reproduction and survival) to their first fall was affected. We used statistical models applied to data collected by the Minnesota Department of Natural Resources to quantify changes in walleye recruitment. Walleye recruitment declined by ~41% following zebra mussel invasion. Additionally, lakes with zebra mussels supported the highest walleye recruitment prior to invasion, suggesting that zebra mussels invade high quality walleye lakes. Next, we evaluated how zebra mussels influence food webs supporting walleye and yellow perch, and how food web changes influence mercury concentrations in fish tissue. Using stable isotope analysis, we found that walleye and yellow perch in zebra mussel invaded lakes use 36-50% more nearshore food resources compared to those in uninvaded lakes. Mercury concentrations in fish were also influenced by zebra mussels; mercury in fish tissue was 66% higher for adult walleye and 91% higher for adult yellow perch in lakes containing zebra mussels compared to those in uninvaded lakes. On average, mercury concentrations in 16-inch walleye from lakes containing zebra mussels were 0.28 ppm, above the 0.2 ppm threshold triggering human consumption advisories by the Minnesota Department of Health. Zebra mussel-induced changes have important implications for walleye in Minnesota lakes. Lower walleye recruitment in invaded lakes may influence abundance at later life stages, which could influence harvest and stocking plans. Walleye were able to persist on nearshore food resources following zebra mussel invasions, but mercury concentrations were higher in these fish with important implications for human consumption. Given the significance of the impacts of zebra mussels documented in our study, preventing zebra mussel invasions into additional walleye lakes is critical.

PROJECT RESULTS USE AND DISSEMINATION

We have provided regular updates of our progress to scientists, managers, and the public via oral presentations and posters. PI Hansen and graduate student Kundel are members of the MN DNR Walleye-Zebra Mussel task force, and our research on the effects of zebra mussels on walleye recruitment has been critical for informing their approach to monitoring and managing for zebra mussel invasions. We have presented our results directly to MN DNR fisheries staff, at the MAISRC showcase, and at a national conference, as well as through several public virtual sessions. Progress on each objective was delayed due to the Covid-19 pandemic, and we are in the process of preparing

manuscripts describing our results for peer-reviewed publications.

Presentation Recordings
• 2020 MAISRC Research & Management Showcase Presentation
https://z.umn.edu/2020ShowcaseZMWalleye

Factsheets/Informational Documents
• Zebra mussel impacts on walleye populations and mercury concentrations: A collaborative project investigating the connections between zebra mussels, changes to lake food webs, and walleye success
https://z.umn.edu/HansenWalleyeFactsheet

Subproject 16.2 Completed: 12/31/2021
FINAL ABSTRACT
Factsheet
Map
Visual

Sub-Project 18.2: Genetics to Improve Hybrid and Eurasian Watermilfoil Management - $236,423 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Invasive Eurasian and native northern watermilfoil can hybridize and we identified hybrid watermilfoil in 39 lakes across the state. Hybrid watermilfoil is genetically more diverse than Eurasian watermilfoil and has potential to be more invasive and resistant to herbicides; several potentially problematic genotypes have been identified for further study.

OVERALL PROJECT OUTCOME AND RESULTS
Invasive Eurasian and native northern watermilfoil can hybridize and some genotypes of hybrid watermilfoil have been shown to be more invasive or resistant to herbicidal control. Our aim was to determine the occurrence and distribution of hybrid watermilfoil in Minnesota, assess the response of different genotypes to herbicidal management, identify potentially problematic genotypes and assess the response of some of these genotypes to herbicide in controlled laboratory conditions. We assessed watermilfoil genetic composition in 81 waterbodies in Minnesota; 55 lakes had pure Eurasian, mostly one widespread genotype that was found in 52 lakes. Eight other Eurasian genotypes were found. We identified hybrid watermilfoil in 39 lakes across the state, mostly, but not entirely, in the Twin Cities

Metro. Hybrid watermilfoil is genetically more diverse than Eurasian watermilfoil and 82 genotypes were found. Most lakes have one unique genotype of hybrid but multiple genotypes were found in several lakes and 26 have been identified in Lake Minnetonka. One hybrid genotype has been found in 10 lakes. No clearly problematic genotypes have been identified in Minnesota but we did find changes in genotype frequency with management in an assessment of 5 managed waterbodies and 3 reference waterbodies over 3 years. Several hybrid genotypes have expanded while Eurasian decreased and two hybrids from Lake Minnetonka have persistently rebounded after control. We also identified one genotype of northern watermilfoil that may be less affected by herbicide treatment. We conducted laboratory performance and herbicide challenge tests with the widespread Eurasian genotype and 4 hybrid genotypes. Additional experiments are needed but preliminary results suggest that two hybrid genotypes may be more tolerant of 2,4-D than the widespread Eurasian and two other hybrid genotypes. Continued identification of hybrid genotypes and response to management will improve milfoil management by allowing manager to appropriate controls for their particular populations.

PROJECT RESULTS USE AND DISSEMINATION

We presented our insights and results and interacted with stakeholders at the MAISRC Showcase in 2019 and 2020 and held two in person and two virtual meetings with stakeholders to discuss observations and interest in genetic testing. We provided information to update the MAISRC website and hybrid watermilfoil fact sheet and developed a genotyping fact sheet for distribution by MAISRC and the DNR. We gave 8 presentations at regional and national scientific meetings and published three papers: Eltawely et al. 2020, Pashnick and Thum 2020, and Thum et al. 2020. In addition, two Masters projects, Eltawely 2019 and Gannon 2021 were completed.

We are in regular contact with the DNR, consultants and applicators about our results, which have been used to inform management actions.

Peer-reviewed publications:

Eltawely, J. A., R. M. Newman, and R. A. Thum. 2020. Factors Influencing the Distribution of Invasive Hybrid (Myriophyllum Spicatum x M. Sibiricum) Watermilfoil and Parental Taxa in Minnesota. Diversity 12(3):120. https://doi.org/10.3390/d12030120

Pashnick, J., and R. A. Thum. 2020. Comparison of molecular markers to distinguish genotypes of Eurasian watermilfoil, northern watermilfoil, and their hybrids. Journal of Aquatic Plant Management 58(1):61-71. http://www.apms.org/wp/wp-content/uploads/japm-58-01-61-full.pdf

Thum, R.A., Chorak, G.M., Newman, R.M., Eltawely, J.A., Latimore, J., Elgin, E., and Parks, S. 2020. Genetic diversity and differentiation in populations of invasive Eurasian (Myriophyllum spicatum) and hybrid (Myriophyllum spicatum × Myriophyllum sibiricum) watermilfoil. Invasive Plant Science and Management 13(2): 59-67. https://doi.org/10.1017/inp.2020.12

Masters' theses:

Eltawely, J. A. 2019. Distribution of Eurasian and hybrid watermilfoil in Minnesota. Water Resources Science Masters Plan B Paper, University of Minnesota, St. Paul, MN. https://hdl.handle.net/11299/211341

Gannon, K. A. 2021. Integrating DNA fingerprinting of invasive watermilfoil strains into aquatic

vegetation monitoring and assessment. Plant Sciences Masters of Science Thesis, Montana State University, Bozeman, MT.

Subproject 18.2 Completed: 06/30/2021
FINAL ABSTRACT
Graphic

Sub-Project 20: A Novel Technology for eDNA Collection and Concentration - ML2013 $94,599 / ML2017 $96,264 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The development of a novel filter capable of efficiently extracting Environmental DNA (eDNA) from water, and enabling rapid filtration of large volumes of samples at a reasonable cost, is expected to help convert the eDNA technology from a research curiosity into a routine tool for ecosystem protection and monitoring, and evidence-based management of invasive species.

OVERALL PROJECT OUTCOME AND RESULTS
Background/Context: Environmental DNA (eDNA) is the genetic material (genomic DNA) obtained directly from environmental samples such water. Collection and analysis of eDNA has the potential to provide actionable information on the presence and distribution of aquatic invasive species.

Challenge: The major challenge is that the results obtained from eDNA techniques currently do not always correlate with traditional netting data due to the size and quality of sampling. Unlocking the potential of eDNA requires disruption in sampling methods and tools.

Objectives: This project aimed to develop a novel aquatic eDNA collection and concentration technology for more efficient, reliable and cost-effective screening for not only invasive aquatic organisms and pathogens but also native and endangered species. The technology would significantly enable and empower aquatic ecosystem survey and management programs in Minnesota. Specifically, we aimed to 1) develop an eDNA nanofilter that specifically and rapidly captures nucleic acids (DNA, RNA) from water and enable the processing of large volumes of samples within a short period of time, 2) Verify increased eDNA sampling efficiency of the new nanofilter in field settings (proof-of-concept)

Results and Accomplishments: We have successfully developed a new eDNA filter that captures 50-100% of eDNA within 10 seconds. Commercial kits are incapable of capturing free eDNA. The loading capacity of the new filter is up to 5 mg/g, meaning that 1 g of filter can capture up to 5 mg of DNA. This is a

record-breaking capacity that enables the filtration of large volumes of water with one filter, knowing that surface water contains usually 10 ng/L of eDNA.

Following the COVID-19 pandemic, we have adapted the nonfilter to develop an RNA extraction kit for SARS-CoV-2. The new kit was evaluated by the University of Minnesota COVID-19 Diagnostic Laboratory on 80 patient samples, and it showed that our kit has a 100% specificity and 94% sensitivity, which is respectively 12.8% and 5.4% higher than the widely used Qiagen kits

Significance and Impact to Minnesota: Ecosystem conservation managers have been relatively reluctant to use eDNA as a routine tool for ecosystems monitoring. The results obtained here can have a significant impact on the widespread adoption of eDNA technology, which will help the State enhance the accuracy and quality of the data and improve decision making for the management of invasive species. This work has also led to starting a new company, which is expected to accelerate the transfer of the technology to the market, and enhance the industry capacity to respond to the State's need for AIS management.

PROJECT RESULTS USE AND DISSEMINATION

The results obtained in this project have been presented at three conferences and meetings and will be published through four scientific publications that are currently in process. The work has also been highlighted by the University of Minnesota news service and more media coverage is expected after manuscript publication. The work conducted in this project has also led to the foundation of a new technology company that is expected to take the eDNA filter technology to the market during 2021.

Presentations:

• Zarouri, A., A. Abbas. September 2019. Enhancing fish surveys: A novel technology for environmental DNA capture. MAISRC Research and Management Showcase. Saint Paul, MN.

• Quichen, D., A. Zarouri, A. Abbas. September 2019. A Novel Technology for Environmental DNA Collection and Concentration. American Fisheries Society and The Wildlife Society Conference. Reno, NV.

• Zarouri, A., Q. Dong, A. Abbas. October 2019. A Novel Technology for Environmental DNA Collection and Concentration. 2019 Department of Bioproducts and Biosystems Engineering Research Poster Session. Saint Paul, MN.

Media:

• Detection connections. CFANS News. 9 July 2020. https://cfans.umn.edu/news/abbas-lab-covid-19-update

Attachments:

• Photo of the eDNA nanofilter that was developed as a part of this project.

Subproject 20 Completed: 06/30/2020

FINAL ABSTRACT

Photo

Sub-Project 21.2: Field validation of mulitbeam sonar zebra mussel detection (Year 1)** - $14,247 TF

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Subproject 21.2 Completed: 06/30/2020

Sub-Project 22: Copper-Based Control – Zebra Mussel Settlement and Non-Target Impacts - UMN ML2013 $54,438 / ML2017 $30,300 and USGS ML2013 $12,428 / ML2017 $121,790 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

A 10-day low-dose copper treatment of an enclosed bay in Lake Minnetonka (Minnesota) was highly effective at reducing the abundance of zebra mussel veligers and preventing zebra mussel settlement success. The treatment did cause some nontarget effects including, but not limited to, reductions in native zooplankton and benthic invertebrate abundance.

OVERALL PROJECT OUTCOME AND RESULTS

This study evaluated a low-dose copper treatment for zebra mussel (Dreissena polymorpha Pallas 1771) suppression by maintaining a mean copper concentration of 60 µg/L in waters above the thermocline for 10 consecutive days in St. Albans Bay (66.3-ha) of Lake Minnetonka, Minnesota. Robinson Bay (37.2-ha, Lake Minnetonka) was a control site. The volume of EarthTec QZ applied during five every-other-day applications was determined using copper concentrations measured in the field.

Treatment effects on zebra mussels lifestages were evaluated by analyzing changes in veliger abundance, juvenile settlement, benthic abundance, and adult survival. Treatment effects on nontargets were evaluated by analyzing changes in water chemistry properties, chlorophyll a, native fish (4 species) survival, native mussel (1 species) survival, native zooplankton abundance and richness, and native benthic invertebrate abundance and richness.

The copper concentration was maintained above 60 µg/L during the treatment period and returned to background levels between 60 and 90 days after treatment. The treatment adversely affected all life stages of zebra mussels throughout the study period. In the treated bay, veliger density was near zero

14 days after treatment, a strong reduction in juvenile settlement was observed, zebra mussel benthic density was sparse after treatment, and the odds of adult survival was substantially reduced. Detectable nontarget treatment-related effects included reductions in zooplankton abundance, chlorophyll a, and fathead minnow survival. Elevated copper residues in fish and mussel tissues were also observed. Decreases in benthic invertebrate abundance, secchi disk readings, and dissolved oxygen concentration were also observed after the treatment.

The data from this study can be used to assist in assessing if low-dose copper treatments are an appropriate zebra mussel management strategy for a waterbody. Any use of trade, firm, or product names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Government.

PROJECT RESULTS USE AND DISSEMINATION

Publications:

• Luoma J.A., Barbour M.T., and Severson T.J. (2020). Data Release: Copper-based control: zebra mussel settlement and non-target impacts. U.S. Geological Survey. Data Release. https://doi.org/10.5066/P9B9NUQM.

Presentations:

• Barbour M.T., Luoma J.A., Severson T.J., Wise J.K., and Dahlberg A. (2019). Low-dose copper-based control: zebra mussel settlement and non-target impacts. MAISRC Research and Management Showcase, University of Minnesota Continuing Education and Conference Center, Saint Paul, Minnesota.

• Dahlberg A., Phelps N., Waller D., Luoma J., and Barbour M. (2020). Low-dose copper-based control: zebra mussel settlement and non-target impacts (webinar). AIS Detectors Program, August 26, 2020, https://www.maisrc.umn.edu/ais-detectors/webinars.

• Dahlberg A., Phelps N., Waller D., Luoma J., and Barbour M. (2020). Low-dose copper-based control: zebra mussel settlement and non-target impacts (webinar). Invasive Mussel Collaborative, August 27, 2020.

Media:

• UMN Driven to Discover video: Guardians of the Lake (2019). https://twin-cities.umn.edu/discover/guardians-lake

• Zebra mussels research project planned for Lake Minnetonka this summer. Melissa Turtinen, Southwest News Media. 23 April 2019. https://www.swnewsmedia.com/lakeshore_weekly/news/local/zebra-mussels-research-project-planned-forlake- minnetonka-this-summer/article_750497a4-a492-5020-868b-6d752887fa0b.html

• St. Alban's, Robinson's bays will be site of zebra mussel research project. Sabina Badola, Sun Sailor. 16 April 1029. https://www.hometownsource.com/sun_sailor/free/st-alban-s-robinson-s-bays-will-be-site-of-zebra-musselresearch-project/article_fe8a1ea4-607c-11e9-aafc-63c0878d1728.html

Attachments:

• Zebra Mussel Control with Low-Dose Copper (handout)
• Photos from field work
• Effects Map

Subproject 22 Completed: 06/30/2020

FINAL ABSTRACT

Graphic

Sub-Project 23: Public Values of Aquatic Invasive Species Management - ML2013 $131,845 / ML2017 $110,245 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Minnesotans hold great value for Aquatic Invasive Species Management, both to lakes they visit and to waterbodies in the state as a whole and are willing to pay significantly for it. Minnesotans are concerned about AIS and are generally supportive of AIS management actions and policies.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota hosts a number of aquatic invasive species (AIS), which have far-reaching impacts on Minnesota's waterbodies, and subsequently its population. However, little was known about how Minnesotans value AIS, as well as costs associated with AIS management. To address this, we collected data on aquatic invasive species management and costs, public perceptions, values, knowledge, and willingness to pay for aquatic invasive species management via several surveys of different types spanning 2019 to 2021. Surveys of watershed districts and soil and water conservation districts provided data from 92 lakes across 12 counties, showing that carp management is a priority in Minnesota. We also were able to collect data on costs and types of management employed. On the individual side, an onsite survey of approximately 1000 people visiting lakes in the summer showed us visitors are willing to pay for AIS management at the lakes they are visiting and hold significant value for Minnesota's water resources, though individual AIS species present are not impactful for these social values. We also collected data through a mail survey of about 300 people, which confirmed Minnesotans' intrinsic value for water resources. Many residents are willing to pay for AIS management statewide, meaning they do not have to directly visit or use a lake to find value in it. This project is important as it provides data to support the viewpoint that Minnesotans do in fact have great value for AIS management and are willing to pay to expand management across the state.

PROJECT RESULTS USE AND DISSEMINATION
This project's findings have been disseminated through nine oral and poster presentations to researchers, resource professionals (e.g., Minnesota Department of Natural Resources), lake associations, policy makers, and the general public (e.g., lakeshore residents) at professional conferences (e.g., Minnesota Water Resources Conference), Minnesota Aquatic Invasive Species Research Center (MAISRC) Research & Management Showcase, and invited seminars (e.g., Minnesota DNR, AIS Detectors' Aquatic Invasive Species Webinar Series). We have published one open access article in a peer-reviewed journal (PLOS ONE). We have developed a fact sheet highlighting findings from the statewide survey conducted with Minnesota residents. In coordination with MAISRC, we developed a handout of findings from the survey conducted with recreationists at four Minnesota lakes. We plan to

continue to disseminate study findings through presentations and peer-reviewed journal articles. We have submitted two abstracts to the International Association for Society and Natural Resources Conference and Universities Council on Water Resources Annual Conference to be held in June, 2022 and are currently preparing three additional manuscripts for submission to peer-reviewed journals.

Peer-Reviewed Publications
• Levers, L., & Pradhananga, A. (2021). Recreationist Willingness to Pay for Aquatic Invasive Species Management. PLOS ONE. https://doi.org/10.1371/journal.pone.0246860

Presentation Recordings/Videos
• 2021 MAISRC Research & Management Showcase Common Carp Panel
https://z.umn.edu/2021ShowcaseCommonCarpPanel
• AIS Detectors Webinar: Recreationists' Willingness to Pay for Aquatic Invasive Species Management
https://z.umn.edu/DetectorsWebinarWillingnessToPay
• MAISRC Video: Valuing Aquatic Invasive Species Management
https://z.umn.edu/MAISRCValuingAISManagement

Subproject 23 Completed: 12/31/2021
FINAL ABSTRACT
Factsheet
PLOS ONE Manuscript
Statewide Resident Survey Factsheet

Sub-Project 24: Genetic Method for Control of Invasive Fish Species - ML2013 $110,112 / ML2017 $140,004 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
MAISRC has laid the groundwork to develop innovative genetic biocontrol approaches to be used in the fight against invasive carp.

OVERALL PROJECT OUTCOME AND RESULTS
Invasive fish species present an estimated $5.4 billion burden on our domestic economy, and much of that extends to the lakes and rivers of Minnesota. For example, the foraging habits of the invasive common carp, Cyprinus carpio, diminishes water quality, reduces vegetative cover and waterfowl numbers, and reduce the ability of lakes to absorb nutrients that enter water systems through agricultural runoff. Current control methods have not been able to stem the tide of invasive carp and other fish species, so improved strategies are needed. The overall goal of this project is to demonstrate

a novel approach for controlling aquatic invasive species using invasive carp species as proof-of-concept. Success of this project would lead to its implementation in other aquatic invasive species (AIS), including Asian carp and zebra mussels.

Several major obstacles had to be overcome on this project to lay the foundation for genetic biocontrol of invasive carp. These included (i) Developing husbandry for year-round carp spawning in the MAISRC Containment Lab, (ii) Demonstrating transgenesis of C. carpio, (iii) Testing genetic reagents in a model laboratory fish that will be needed to engineer carp, and (iv) Performing a survey to gauge public perceptions of carp genetic biocontrol. We accomplished these project goals within a one-year no-cost extension to the project funding.

The impact of our results is that we are now primed to engineer carp genetic biocontrol agents in the lab during the next phase of this award, which will begin January 2022. There is still substantial work to be done before this will directly benefit Minnesotans. Specifically, we need to demonstrate a proof-of-concept carp biocontrol system in the laboratory; perform safety/efficacy testing; obtain permits for field trials; and eventually work with key stakeholders to use this new tool in the fight against invasive carp. The overall process is expected to take 10-15 years.

PROJECT RESULTS USE AND DISSEMINATION
Data generated from this subproject is expected to be included in three peer reviewed publications. These include results from the public survey (expected submission Summer 2021), results from the carp husbandry/transgenesis procedure (expected submission Winter 2021), and agent-based modeling results (waiting for accompanying wet-lab experimental confirmation).

In addition to these primary research reports, one book chapter that describes the techniques developed under this subproject has already been published:

Bajer P, Ghosal R, Maselko M, Smanski MJ, Lechelt JD, Hansen G, Kornis M (2019) Biological control of invasive fish and aquatic invertebrates: a brief review with case studies. Management of Biological Invasions. 10: 200-226.

Subproject 24 Completed: 06/30/2021
FINAL ABSTRACT
Graphic

Sub-Project 25: What's in Your Bucket? Quantifying AIS Introduction Risk - ML2013 $111,642 / ML2017 $84,094 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Live baitfish are popular among Minnesota anglers, but their illegal release is a known risk factor for spreading harmful diseases to wild fish populations. Our research identified high-risk pathogens in Minnesota, estimated the number of times anglers release an infected baitfish each year, and identified opportunities for strategic management intervention.

OVERALL PROJECT OUTCOME AND RESULTS

In Minnesota, the illegal release of live baitfish by anglers has been identified as a weak point in our efforts to prevent the spread of aquatic invasive species and pathogenic microbes, however the magnitude of the risk and evidence-based opportunities for intervention had not been well studied. The purpose of this project was to assess the risk of fish pathogen introduction via illegal release of live baitfish by Minnesota anglers to inform strategic management strategies to reduce that risk. First, we created a semi-quantitative framework to evaluate the threat of baitfish pathogens in Minnesota and used it to rank pathogens so managers can prioritize resources. We then conducted a statewide survey of anglers to quantify risky behaviors and used those data to parameterize a risk assessment model for high-risk pathogens to estimate the number of risky trips that occur in a given year under a variety of scenarios. Our results were variable, indicating a wide range of outcomes depending on current management strategies and pathogen prevalence. For example, with strong surveillance and controls in place for the viral hemorrhagic septicemia virus, the number of risky trips is limited in most scenarios. However, for high-risk pathogens (Ovipleistophora ovariae, Asian fish tapeworm) for which no controls are in place, the large number of anglers, frequency of illegal release, and the popularity of susceptible baitfish species, can result in hundreds of thousands of risky trips each year, even in low-prevalence scenarios. Ensuring a safe, pathogen-free bait supply and decreasing the percentage of anglers who release their baitfish can reduce pathogen introduction risk while preserving the important cultural and economic benefits of recreational angling. Our project provides evidence-based tools for prioritizing scarce resources and identifying weak points in our management strategies so we can improve them to protect our valuable fish and fishing resources.

PROJECT RESULTS USE AND DISSEMINATION

Throughout this process we have communicated and collaborated with technical experts, managers, and members of the public alike. In addition to the three manuscripts either published or in prep for this project, we have presented this material in a variety of settings. Results from this project have been shared via presentations to local (UMN Ecosystem Health Group, MAISRC Research Showcase, MNDNR AIS Working Group meetings, Minnesota Lakes and Rivers Advocates), statewide (MN Chapter of the American Fisheries Society, UMN Extension Webinars), regional (Upper Midwest Invasive Species Conference), and national (North American Invasive Species Management Association, American Fisheries Society Fish Health Seminar) audiences and hundreds of individual participants. We have also maintained close contact with DNR Fisheries and AIS staff who have periodically served as unfunded collaborators and advisers on the project, and we worked with a number of AIS Detector volunteers in implementing the survey portion of the project.

Subproject 25 Completed: 12/30/2020

FINAL ABSTRACT

Graphic

Sub-Project 28: Evaluating Innovative Coatings to Suppress Priority AIS - $51,234 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Biofouling is a natural phenomenon that includes the adhesion of Zebra mussels to structures or boats and contribute to their spread in Minnesota waters. Current antifouling coatings are environmentally toxic. We demonstrate the efficacy of an eco-friendly coating technology that could help mitigate the spread of sessile invasive species, while minimizing non-target impacts.

OVERALL PROJECT OUTCOME AND RESULTS
Biofouling is a natural phenomenon that sticks on structures or boats. It is a vector for the spread of numerous invasive species in Minnesota waters. A current way of fighting biofouling involves using metals that are harmful to the environment. We successfully evaluated a new generation of coatings containing a non-toxic, antifouling, biological molecule, and demonstrate that it reduces the adhesion of invasive species. These coatings could help mitigate the spread of sessile invasive species not only in coastal and inland waterways but also on recreational and industrial equipment surfaces, while minimizing non-target impacts.

Problem: Replace current toxic antifouling coatings with coatings containing a non-toxic, antifouling, biological molecule to mitigate the spread of sessile invasive species while minimizing non-target impacts.

Methodology: We took advantage of our unique technical and scientific edges to evaluate the potential of this technology to replace toxic biocides currently used to limit biofouling. Coated samples were submerged in the field in three different sites in Minnesota, including infested sites, and samples were analyzed using microscopies, organisms were quantified and measured, and surface microbial communities determined.

Results and Significance: Biofouling is a main vector for the spread of aquatic invasive species. Current antifouling solutions are both partly effective and highly toxic to the environment. In this proof-of-concept project, we demonstrate that our non-toxic enzyme technology can prevent the adhesion of AIS on submerged surfaces. We show that in three different Minnesotan field sites that enzymatic coatings can outperform coatings containing biocides, and prevent Zebra mussels adhesion to polycarbonate surface over the course of two summer months. This enzyme-based coatings could help mitigate the spread of sessile invasive species in Minnesota and beyond. These results evidence that this novel technology has the potential to replace toxic antifouling coatings and help mitigate the spread of AIS in Minnesota and beyond.

PROJECT RESULTS USE AND DISSEMINATION
We have disseminated our findings to stakeholders to increase awareness of our technology and allow us to learn about market landscape and end-users needs. In particular, we discussed with lake owner associations leaders at and representative of the Legislature at the AIS Research and Management Showcase. We also have communicated via seminars and presentation with other stakeholders, including Dupont, the MN DNR, the Bureau of Reclamation, and presented our results at the iPrime meeting, an academic-industrial meeting where key stakeholders were present, including 3M, BASF, Evonik and Ecolab. We also used communication services at the Biotechnology Institute to disseminate our results to the public in the form of a blog article and we are preparing two research articles to communicate to the scientific community.

Presentations:
• Huang, Hicks, Elias. Suppressing Microbial Communication to Mitigate the Spread of AIS. 9/18/2019. MAISRC Research and Management Showcase.
• Elias. Interference in Microbial Signaling: a powerful way to control microbes and study their languages. 12/3/2019. Presentation to the bureau of Reclamation.
• Elias. Interference in Microbial Signaling: a powerful way to control microbes and study their languages. 11/18/2019. Presentation to Dupont.
• Elias. New Advances in Controlling Microbial Behaviors by Interfering in Microbial Speech. 8/6/2020. iPrime national meeting.

Media:
• Enzyme-based coatings developed at the University of Minnesota help protect port infrastructure by disrupting the signals underwater bacteria use to communicate. Nick Minor and Kristal Leebrick, Gateway: Signal and Noise. 18 May 2020. https://gateway.bti.umn.edu/2020/05/18/signal-and-noise/

Attachments:
• Figure of results of coupons coated with paint containing control protein.

Subproject 28 Completed: 06/30/2021
FINAL ABSTRACT
Graphic

Sub-Project 30: Managing Midwestern Aquatic Invasions in a Changing Climate - UMN $16,238 / IU $22,762 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Managing AIS in Minnesota's water requires integrating ecological science to understand invaders' impacts and how they respond to different management strategies, climate science to understand changes under changing conditions, and social science to understand the preferences of communities and how they make decisions. This project helps us understand all three.

OVERALL PROJECT OUTCOME AND RESULTS
Nitellopsis obtusa (starry stonewort) is a freshwater alga that is a key emerging invader in Minnesota and the upper Midwest that displaces native aquatic plant communities and restructures lake ecosystems. We conducted an interdisciplinary project to evaluate how starry stonewort will respond to climate change and to understand community decision-making about management options incorporating both ecological and social factors. We did this by utilizing a latitudinal gradient in the range of starry stonewort, from Indiana to Minnesota, as well as inter-annual variability as proxies for potential climate change. Across the region we monitored invasions to evaluate community effects of starry stonewort and conducted interviews with stakeholders to evaluate perceptions of starry stonewort impacts and management preferences. We found that starry stonewort can expand rapidly, but invasion dynamics were highly variable and influenced by climatological conditions. In some particular circumstances expansion was very limited and, in some years, native species were able to recover in areas where starry stonewort abundances decreased. From stakeholder interviews we learned that current management strategies, perceptions about the importance of addressing invasive species, and stakeholders' goals differed between states and stakeholder types. We also found that there were two distinct sets of values that motivated stakeholders, where individuals either viewed lakes as a public good or an exclusive resource.

This information can help predictions of further spread of starry stonewort and of the potential impacts of starry stonewort invasions once established. Additionally, our results can help local stakeholders understand invasion dynamics and impacts to inform their decisions about management options. At the same time our social science efforts can help inform state and regional resource managers about how they can best assist stakeholders in their decisions and our ecological efforts can help develop standards (such as monitoring protocols) that should be included in permitting for treatments.

PROJECT RESULTS USE AND DISSEMINATION
We have presented results from this project in a number of academic, governmental, and public presentations including at the MAISRC Showcase, a MAISRC detectors webinar, the Indiana Invasive Species Council, the Indiana University Environmental Resilience Institute Symposium, Hoosier Flyfishers, Boston University, and the University of Buffalo. We are also currently drafting a policy brief based on our social science efforts (in coordination with a manuscript about to be submitted) that will be shared with MAISRC.

Presentation Recordings/Videos

- 2021 MAISRC Research & Management Showcase Presentation https://z.umn.edu/2020ShowcaseStarryClimate
- AIS Detectors Webinar: Understanding Starry Stonewort Invasions in a Changing Climate https://z.umn.edu/DetectorsWebinarStarryClimate

Subproject 30 Completed: 06/30/2022
FINAL ABSTRACT

Subd. 06b Emerald Ash Borer Biocontrol - Phase III - $729,000 TF (FY2018)

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Appropriation Language
$729,000 the first year is from the trust fund to the commissioner of agriculture in cooperation with the Board of Regents of the University of Minnesota to implement biocontrol of emerald ash borer using a newly approved parasitic wasp, assess the impact of the statewide program, and engage citizen volunteers. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Biological control has been effectively implemented, which has led to increasing recoveries of parasitoids over time. Cold tolerance testing of Spathius galinae resulted in a forecasting model of survival in North America. The Buprestidae of Minnesota guide was created and provides baseline data on jewel beetles present in Minnesota.

OVERALL PROJECT OUTCOME AND RESULTS
We have successfully completed all activities. We are pleased to report that the effective implementation of EAB biocontrol has led to increasing recoveries of the larval parasitoid Tetrastichus planipennisi and the egg parasitoid Oobius agrili through time based on data analysis in Activity 2. We produced several peer-reviewed scientific publications (with full credit to LCCMR) on Activities 3 and 4. For Activity 3, we evaluated the cold hardiness of the larval parasitoid Spathius galinae and published a study forecasting its survival in North America (Wittman, Aukema, Duan, and Venette (2021) Forecasting overwintering mortality of Spathius galinae in North America. Biological Control. 160: 104694). The insect will survive best in areas where winter temperatures remain above -20 Fahrenheit. For Activity 4, we published two journal articles detailing a checklist of buprestids found in Minnesota (Hallinen, Steffens, Schultz, Aukema (2021) The Buprestidae (Coleoptera) of Minnesota, with a discussion of the emerald ash borer, Agrilus planipennis Fairmaire. The Coleopterists Bulletin 75: 173-190) as well as a study on their habitat features (Hallinen, Wittman, Aukema (2020) Factors associated with diversity and

distribution of buprestid prey captured by foraging Cerceris fumipennis (Hymenoptera: Crabronidae) (Environmental Entomology 49: 1363-13763). These works provide critical information on what is here, now, so we have a basis of comparison for when a new invasive wood-boring beetle in the same family as emerald ash borer arrives in the future. We then published, from the scientific checklist, a free and accessible guide (The Buprestidae of Minnesota) that can be downloaded from permalink. This latter guide contains not only specimen photos but also maps of the distribution record and dates of last collection by decade. All four publications are submitted with this final report.

PROJECT RESULTS USE AND DISSEMINATION

Throughout the duration of the project, results were disseminated through a variety of venues. A wide and diverse audience was reached through interviews with local press, informational webinars, outdoor training sessions held throughout the state, and at academic and natural resource professional conferences and meetings. Parasitoid release and recovery results from activity 1 and 2 can be viewed through an interactive online map. Through the work on activity 3 of this project, models have been created and published forecasting the expected overwintering mortality of the introduced larval parasitoid Spathius galinae. This information is of vital importance to the successful implementation of EAB biological control throughout North America (Wittman, Aukema, Duan, and Venette (2021) Forecasting overwintering mortality of Spathius galinae in North America. Biological Control. 160: 104694). Activity 4 of this project produced tremendously valuable baseline data on the buprestids found in Minnesota. Two journal articles were published detailing a checklist of buprestids found in Minnesota (Hallinen, Steffens, Schultz, Aukema (2021) The Buprestidae (Coleoptera) of Minnesota, with a discussion of the emerald ash borer, Agrilus planipennis Fairmaire. The Coleopterists Bulletin 75: 173-190) as well as a study on their habitat features (Hallinen, Wittman, Aukema (2020) Factors associated with diversity and distribution of buprestid prey captured by foraging Cerceris fumipennis (Hymenoptera: Crabronidae) (Environmental Entomology 49: 1363-13763). A free and accessible guide was created from these publications called The Buprestidae of Minnesota and can be downloaded from the permalink.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 06c Invasive Bighead Carp and Silver Carp and Native Fish Evaluation - Phase II - $500,000 TF (FY2018)

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Appropriation Language
$500,000 the first year is from the trust fund to the commissioner of natural resources to continue invasive bighead and silver carp monitoring in the Mississippi River and tributaries through advanced acoustic telemetry and assess food chains to determine how native species might prevent invasive bighead and silver carp establishment. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Over the past four years, this project tested new capture methods, learned locations where invasive carp are vulnerable to capture, and removed over 150 fish. Our goal in learning how best to remove invasive carp is to disrupt the potential for spawning that could lead to their establishment in Minnesota waters.

OVERALL PROJECT OUTCOME AND RESULTS
Invasive carp have caused severe ecological damage to the Illinois, Missouri, and lower Mississippi River ecosystems, and threaten to do the same if they become established in Minnesota. Increased monitoring by the Minnesota Department of Natural Resource (DNR), funded in part by ENRTF, has found invasive carp becoming more numerous and widespread in Minnesota in recent years. However, our mulit-year monitoring of larval fish has not documented any reproduction in Minnesota waters to date, indicating they are not yet established. ENRT funding has led to significant gains in our understanding of where, when and how to capture and remove these fish and disrupt their establishment.

An array of receivers used in tracking tagged fish has been instrumental in identifying movement patterns and season habitat preferences of invasive carp and native species. We are learning the seasonal use of invasive carp habitats, which has proven useful in removal and management efforts. Tracking of a radio-tagged invasive carp allowed us to know when and where to target removal efforts, and has directly led to the capture of six invasive carp. Applying what we have learned to places where we don't have tagged fish, ENTRF funded staff conducted 364 days of field sampling, including over 139,000 feet of gill net deployed, over 7,300 minutes of electrofishing and over 134 days of monitored/contracted commercial fishing. This resulted in the removal of over 150 invasive carp during the grant period.

Our tracking tagged native fish assessing their habitat use through stable isotope analysis will be useful in the future to learn what effect invasive carp have on the native species.

PROJECT RESULTS USE AND DISSEMINATION
MN DNR invasive carp staff have provided a yearly Invasive Carp Sampling Report in which all sampling data is shared for anyone to view. MN DNR invasive carp staff also shares data with other state and federal agencies as well as Universities. In addition, numerous news outlets have covered the work done by the invasive carp crew over the last four years. Those articles and news stories can be located by doing a quick google search of Invasive carp in Minnesota.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 07 Air Quality, Climate Change, and Renewable Energy

Subd. 07b Assessment of Urban Air Pollution - $700,000 TF (FY2018)

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Appropriation Language
$700,000 the first year is from the trust fund to the commissioner of the Pollution Control Agency to set up and operate a network of 250 air pollution sensors at 50 sites to monitor fine particles, ozone, nitrogen oxides, sulfur dioxide, and carbon monoxide in each zip code for the cities of Minneapolis and St. Paul to assess variability of urban air pollution. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Air pollutant concentrations cannot be assumed to be the same across all zip codes in the cities of Minneapolis and St. Paul. There are local differences observed and these can influence quality of life where one lives. Monitor placement is very important in being able to detect these differences in neighborhoods.

OVERALL PROJECT OUTCOME AND RESULTS
Understanding small-scale differences in air pollution in urban areas is important for minimizing exposure to harmful air pollutants, particularly for vulnerable communities. This project is using new air-monitoring sensor technology to broaden our knowledge about air quality in Minneapolis and St. Paul. A total of 47 AQMESH air monitors were installed in the study area. 10 of these were co-located with existing MPCA regulatory monitors in order to more closely evaluate the use of sensor technology for accuracy. 14 monitors were located on parking lot light poles, in St. Paul public schools. 23 monitors were placed on Xcel light poles in Minneapolis in residential areas. Pollutants monitored were CO, NO, NO2, SO2, O3, PM2.5 and PM10. Data was collected from June 2019 to June 2021. In addition to the overall goal of seeing small scale differences in urban neighborhoods, this project had 3 main goals:

- Are there significant differences in pollutant concentrations between ZIP codes in the urban core?
- Are there areas with unusually high pollutant concentrations?
- Is this technology suitable for measuring small differences in air quality?

To investigate the last question, data from collocated sensors was compared to the regulatory monitoring data and it was found that there is a reasonably moderate confidence in the sensor data as they compare to the regulatory grade monitors. A strong relationship was also found between the sensor pods themselves, indicating that these would be a good tool for highlighting the differences in pollutant concentrations across the study area.

To further investigate the first 2 questions, data collected from all the sensors for all zip codes was analyzed using R (v 1.4.1717). Data was divided by region into North Minneapolis, South Minneapolis and St. Paul, based on the sensor location. Basic data statistics were computed, pollutant level charts were plotted and a generalized additive model was applied to look for trends and differences across the entire study area.

The analysis showed that although minimal, there are indeed micro level differences that can be observed. A very clear seasonal pattern can be seen for CO and O3 concentrations across all regions. Local events like the wide spread fires in May/June 2020 and July 4th fireworks tend to slightly increase the particulate counts for a short period. Sensor placement is very important as it affects the measurements.

Residents can use this data to be more cognizant about activities that happen around them in their neighborhoods, especially on days with bad AQI, which adds more particulates into the air making it unhealthy, and make appropriate changes for a healthier lifestyle. In St. Paul, monitoring was done in school parking lots, making these results suitable for education purposes and to understand how idling cars and buses effects short term air quality. Results specific to outdoor activities coinciding with drop off and pick up times can be useful. Extensive monitoring along roadways was not part of this project but some monitors along busy roads did show higher NOx levels. Overall, the air quality in Minneapolis and St. Paul is good but depending on where you live and any preexisting health conditions, it may affect ones quality of life. This study can inform future monitoring projects, specific areas where traffic could be examined more closely and looking at other local neighborhood sources of pollution.

PROJECT RESULTS USE AND DISSEMINATION
Over the past two years, various efforts were made to communicate results as and when they were analyzed. A project website was developed which is available on the MPCA's website. A tableau workbook is available with all the monitoring sites and data for all the pollutants being monitored. These can be filtered by site, pollutant and dates if desired.

Six month quarterly updates were provided to the LCCMR. In fall of 2018, project presentations were made in Minneapolis and St. Paul to solicit feedback on monitor placement. In Fall/winter 2019-2020, one year study results were presented at several meetings in Minneapolis and St. Paul to give residents an overview of what the monitors were showing in their respective zip codes. These results were also presented to the Metropolitan Council and other stakeholders.

Presentations will be made to community groups, stakeholders and interested parties. Community concerns, comments and additional analysis done, will be incorporated in the final report and published on the MPCA project webpage.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 07c Generation, Storage, and Utilization of Solar Energy - $500,000 TF (FY2018)

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Appropriation Language
$500,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, West Central Research and Outreach Center, Morris, to develop and demonstrate an integrated facility to generate electricity, shade dairy cattle, and provide energy storage and utilization from solar technologies at the West Central Research and Outreach Center, Morris. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The project benefited lakes and streams through the development of novel methods to reduce energy usage on farm and integrate cattle grazing and solar systems. We evaluated technology that that will reduce the carbon footprint through energy reduction from dairy farms in Minnesota that will improve environmental impact.

OVERALL PROJECT OUTCOME AND RESULTS
The work conducted at the University of Minnesota West Central Research and Outreach Center in Morris was were to investigate electrical energy use on dairy farms located in west central Minnesota and to evaluate the effects of shade use by cattle from solar photovoltaic systems. Measurements of baseline fossil fuel consumption within dairy production systems are scarce. Therefore, there is a need to discern where and how fossil fuel-derived energy is being used within dairy production systems. Baseline energy use data collection is the first step in addressing the demand for a reduced carbon footprint within dairy production systems. Energy use on five Midwest dairy farms was evaluated from July 2018 to June 2021. Through in-depth monitoring of electricity-consuming processes, it was found that electricity use can differ quite drastically in different types of milking systems and farms. Electricity on an annual basis per cow ranged from 400 kWh/cow in a low-input and grazing farm to 1,145 kWh/cow in an automated milking farm. To reduce electrical energy consumption as well as reduce the effects of heat stress in pastured dairy cows, producers may investigate using an agrivoltaic system. Biological effects of internal body temperature, milk production, and respiration rates and behavioral effects of activity, rumination, fly avoidance behaviors, and standing and lying time of the solar shade were evaluated. Results of this agrivoltaic system suggested that grazing cattle that have access to shade had lower respiration rates and lower body temperatures compared to cattle that do not have access to shade. This project suggests that improvement in Minnesota waterways and environment may be achieved through reduced use of fossil energy through integrating livestock and solar energy production systems.

PROJECT RESULTS USE AND DISSEMINATION
We have provided tours of the agrivoltaic system at the WCROC to legislators, farmers, and industry representatives. We have also hosted dairy field days and the Midwest Farm Energy Conference at the WCROC that have shown the results and solar system to the public as well. Over 10,000 people have viewed the solar system and have responded with favorable interest in the system. A graduate student

on the project presented an abstract at the ADSA Meeting and Waste to Worth conference. So far, 3 peer reviewed papers have been published with more to follow. The WCROC website provides the results of the project and YouTube videos for promotion of the project. A presentation was made at the global Virtual AgriVoltaics conference in 2021. This applied dairy energy and agrivoltaics projects was the Master's thesis of Kirsten Sharpe in the Department of Animal Science at the University of Minnesota and she defended her thesis in 2020.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 07d District Heating with Renewable Biomass at Camp Ripley Training Center - $1,000,000 TF (FY2018)

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Appropriation Language
$1,000,000 the first year is from the trust fund to the commissioner of military affairs to install a 5,000,000-BTU centralized biomass boiler system utilizing the forestry management at Camp Ripley. This appropriation must be matched by at least $900,000 of nonstate money and must be committed by December 31, 2017. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The scope of this project was to install a biomass heating plant that would service 7 Buildings including mechanical and distribution systems. We received an architect estimate and the base cost for the project in total was $7,122,035.

OVERALL PROJECT OUTCOME AND RESULTS
Due to these headwinds, Current Project estimates (Steel prices, metal prices in particular; (Piping), and lumber prices, etc), we lowered the scale of the project to just the biomass heating plant and underground piping and connections to just 2 facilities, and that bid estimate came in at $4,407,008.

National Guard Bureau and DMA leadership requested that we reassess the Life Cycle Cost Analysis (LCCA's) numbers on this project. The Saving's to Investment Ratio (SIR) changed from 2.31 during the planning phase to .32 currently. Again, this is largely due to the current cost of construction and the reduction in buildings being included. Since we only have $2.5 million available from federal sources and $1 million in state LCCMR funds, we legally can no longer implement this project. We will be crossing budget thresholds. Only the design of the biomass facility has been completed.

PROJECT RESULTS USE AND DISSEMINATION
The funds spent for the Biomass project enabled the MNARNG to design a 5,000,000-BTU centralized biomass boiler system that was intended to heat 2 building on Camp Ripley. The design process started with 7 buildings but due to increase in material cost we had to decrease the scope to only 2 buildings.

The design is complete and on the shelf and available to others.

No information or the project design has been disseminated.

Project Completed: 12/31/2023
FINAL REPORT

Subd. 07e Geotargeted Distributed Clean Energy Initiative - $800,000 TF (FY2018)

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Appropriation Language
$800,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Center for Energy and Environment. Of this amount, $600,000 is for analysis of community-distributed clean energy investments as alternatives to utility capital investments for transmission and distribution upgrades to meet forecasted electrical loads, and $200,000 is to conduct pilot programs using energy efficiency and other distributed energy resources to achieve forecasted electric energy loads in communities. The appropriation for pilot programs is contingent on a $200,000 match of an equal or greater amount of nonstate money. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project demonstrated that energy efficiency can be used to reliably offset utility infrastructure expansion, thereby saving money and decreasing the amount of air pollutants from Minnesota's electricity generation.

OVERALL PROJECT OUTCOME AND RESULTS
This pilot project demonstrated that energy efficiency and demand response are cost-effective tools to increase the use of clean electricity technologies while reliably deferring investments in grid expansion. While Minnesota has relatively low distribution grid expenditures today, peak demand is predicted to increase due to population growth, electrification of end uses like transportation and space heating, and warmer temperatures. This pilot demonstrated that adopting longer time horizons and multiple scenarios for planning forecasts will allow distribution planners to integrate non-wires alternatives, therefore saving money and advancing clean energy throughout the state.

This pilot successfully saved 576 kW of peak electricity across two small communities, higher than the pilot goal of 500 kW. This was the result of enhanced incentives, increased and geotargeted marketing, as well as a higher than average baseline participation in commercial lighting programs. Participation was also boosted by smart thermostat incentives which were available upon enrollment in a demand management program. The pilot cost (incentives + direct labor) came to $163,000, within the estimated

value of a one-year deferral.

Minnesota has a modest technical potential for non-wires alternatives, but this is expected to increase. With current growth forecasts and distribution system expenditures, we calculated a low to modest potential for non-wires alternatives in Minnesota, estimated at between one and four million dollars per year. This will save between 4,000 and 17,000 tons of carbon per year, or the equivalent of the annual pollution caused by 800-6,000 passenger vehicles.

Additional information is included in the final technical report for this project on the CEE website.

PROJECT RESULTS USE AND DISSEMINATION
This pilot is summarized in a technical report and project summary document that outlines the process, major findings, and recommendations for policymakers and stakeholders. Results have been included in policy processes at the Public Utilities Commission to help inform regulatory decisions. Pilot outcomes have been presented at multiple conferences of industry professionals and to Minnesota utilities.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 08 Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Subd. 08a Optimizing the Nutrition of Roadside Plants for Pollinators - $815,000 TF (FY2018)

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Appropriation Language
$815,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota in cooperation with the Departments of Agriculture, Natural Resources, and Transportation and the Board of Water and Soil Resources to produce site-specific recommendations for roadside plantings in Minnesota to maximize the nutritional health of native bees and monarch butterflies that rely on roadside habitat corridors. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This research shows that, from a nutritional perspective, Minnesota roadsides are promising habitat for native bees and monarchs. To minimize the negative effects of roadside pollutants on insect pollinators, managers should prioritize low- to moderate-traffic roads for restoration, mow a buffer strip, and support efforts to ban the pesticide chlorpyrifos.

OVERALL PROJECT OUTCOME AND RESULTS

Insect pollinators have suffered steep declines over the last two decades. Roadsides are a promising opportunity for pollinator conservation, potentially providing millions of acres of habitat, and acting as dispersal corridors. However, roadside habitat also contains pollutants such as heavy metals from car wear and past leaded gasoline use, sodium from road salt application, and pesticides from adjacent agriculture. In this research, we combined surveys of roadsides across Minnesota, with controlled lab and field experiments, to test how such roadside pollution impacts insect pollinators, and implications for restoring roadside habitat for monarch butterflies and native bees. Our results suggest that plants alongside the majority of Minnesota roadsides have sodium and metal content below which is worrisome to bees and monarchs. However, plants along very high traffic roads, especially those right next to the road, likely have negative effects on pollinator health. Our data also suggest that pesticides may be a significant concern for 5-10% of roadside plants. This research suggests roadside restoration efforts should focus on roads with low to moderate traffic volumes (<20K cars daily) and that mowing a buffer on the road edge should eliminate the most toxic plants. Recent national efforts to ban the pesticide chlorpyrifos would also be beneficial for Minnesota roadsides as this was the most commonly detected insecticide. Finally, this research suggests benefits to planting a diversity of roadside plants as species accumulate different toxins to different degrees, although on higher traffic roads, managers may want to avoid a handful of high accumulating species (e.g., yellow coneflower). Overall, from a nutritional perspective, Minnesota roadsides are promising habitat for insect pollinators, for instance, potentially producing 14M migratory monarchs annually. Future work should consider management methods that may minimize vehicle collisions, as currently pollinator mortality from collisions likely far exceeds that from plant toxicity.

PROJECT RESULTS USE AND DISSEMINATION

This project directly led to six publications in print and twelve in progress. Data are publically available on either DRYAD or Mendeley. This work was presented in over 25 seminars, conference presentations, and webinars presented locally, nationally and internationally. The conclusions of the work are available in online talks, such as the Cedar Creek "Lunch with a Scientist" series and the Rights-of-Way working group research series on pollinator habitat. This research will be featured in a popular science book on road ecology and resulting management recommendations shared as a brief report to relevant agencies later this year.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 08c Evaluating the Use of Bison to Restore and Preserve Savanna Habitat – Research Project - $388,000 TF (FY2018)

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Appropriation Language
$388,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, Cedar Creek Ecosystem Science Reserve, to research combined bison grazing and fire management strategies to restore Minnesota's oak savanna ecosystems. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Oak savanna is Minnesota's most threatened ecosystem, but effective approaches for protecting and restoring savannas remain elusive. Our project reintroduced bison to one of Minnesota's largest remaining oak savannas. We found that bison grazing helped increase oak regeneration and stimulated plant productivity, providing a promising new strategy for savanna conservation.

OVERALL PROJECT OUTCOME AND RESULTS
Oak savanna is Minnesota's most threatened ecosystem, but effective approaches for protecting and restoring savannas remain elusive and prescribed fire, alone, is not maintaining oak savannas. Fire helps old oaks with thick bark that can survive its intense heat, in part by preventing other trees from growing and shading the oaks. However, fire also kills young oak seedlings, which prevents oak trees from regenerating. Thus, fire is a necessary, but insufficient strategy for maintaining oak savannnas. We tested whether bison are essential for savanna preservation and restoration. Bison preferentially graze the most abundant native prairie grasses, which compete with young oaks and supply fuel for fires that kills them. Our project achieved the following outcomes: (1) discover better restoration and preservation practices for savanna remnants; (2) determine how these practices impact the full range of savanna biodiversity; and (3) educate Minnesotans about the ecological heritage of their state, including the roles that bison, fire and biodiversity play in the functioning of savannas and other Minnesota ecosystems. Specifically, we restored seasonal bison grazing to more than 200 acres of oak savanna, experimentally tested savannna restoration using bison grazing by establishing experimental plots and planting 660 oak seedlings, and disseminated results to more than 19,000 members of the public, in part by establishing a bison viewing gazebo. For many years to come, bison will continue to graze in these oak savannnas, their impacts will continue to be assessed in experimental plots, and the public will continue to benefit from site access and programming. Our project has already attracted additional funding from the National Science Foundation's Long-Term Ecological Research Program, which will allow it to continue long after the initial support from the ENRTF. Our data are being disseminated through Cedar Creek's website and the National Science Foundation's Environmental Data Initiative.

PROJECT RESULTS USE AND DISSEMINATION
We have provided engagement opportunities for more than 19,000 visitors, including 2,172 K-12 students who attended field trips or online programs specifically about this research. The new bison gazebo has provided opportunities for a corps of 25 “bison naturalist” volunteers, spurred the creation of new educational resources including a savanna-themed feltboard and brochures, hosted open house events and tours, led to the design and construction of two new interpretive signs, and expanded the range of self-guided options for our community.

Project Completed: 6/30/2021
FINAL REPORT

Subd. 08d State Park Pollinator Habitat Restoration - $672,000 TF (FY2018)

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Appropriation Language
$672,000 the first year is from the trust fund to the commissioner of natural resources to restore at least 520 acres of monarch butterfly and other native pollinator habitats in at least seven state parks in the Minnesota Prairie Conservation Plan core areas and establish pollinator plantings and interpretive exhibits in at least ten state parks. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project restored approximately 520 acres of prairie/pollinator habitat in eight state parks where it will be permanently managed and protected. Additionally, educational pollinator plantings ranging in size from tenths of an acre to more than an acre were installed with engaging multi-sensory ADA-accessible interpretive exhibits at ten state parks.

OVERALL PROJECT OUTCOME AND RESULTS
Many species of pollinators are declining due primarily to habitat loss/degradation, diseases and parasites and pesticide exposure. This project focused on restoring 584 (520 originally planned) acres of prairie/pollinator habitat in eight state parks where it will be permanently managed and protected. Additionally, this project helped raise awareness about pollinators by establishing educational pollinator plantings from tenths of an acre to more than one acre in size with engaging multi-sensory ADA-accessible interpretive exhibits at 10 state parks.

Sites selected for habitat restorations were all within core areas identified in the Minnesota Prairie Conservation Plan. The sites themselves were former agricultural fields in state parks that contained non-native and invasive species. Site preparation included activities such as prescribed fire, control of invasive/problem species, woody stem removal, and disking. At Lake Bronson and Glacial Lakes State Parks, removal of encroached woody vegetation was the primary need to restore pollinator habitat through shearing/timber harvest. Following planting, sites were high mowed, spot treated for invasives and inter-seeded to ensure successful restorations. These sites will provide habitat for many species of pollinators such as bees, moths, and butterflies. For example, a recent study of prairie restorations at Glendalough State Park found more than 25 species of butterflies utilizing the restorations, including the Regal Fritillary, a Minnesota Special Concern Species. This project will also assist in meeting the goals of the Mid-America Monarch Conservation Strategy.

Educational pollinator plantings and exhibits were installed at 10 state parks within all but the Laurentian Mixed Forest Province. Interpretive exhibits were designed and constructed in cooperation with an exhibit contractor. Where needed educational plantings were established similar to the steps above albeit on a much smaller scale. Annual visitation at these 10 parks combined totals over three million visits annually.

PROJECT RESULTS USE AND DISSEMINATION
Educational pollinator plantings and exhibits provide an opportunity for millions of visitors annually to learn more about pollinators and the plant species which attract them. Attendance at these 10 parks combined is over three million visitors per year. The exhibits are regularly used by thousands of visitors per week based on park attendance and staff reports.

- The exhibit design was entered in the National Association of Interpretive Naturalists 2021 Media Awards competition and earned first place in the Outdoor Exhibits category. The award presentation was broadcast to over 800 interpretive professionals in December of 2021
- In summers of 2020 and 2021 this project was highlighted on the DNR Parks and Trails social media platforms as part of a monthly theme on butterflies. The 2021 campaign reached 33K Twitter followers and 151K Facebook followers.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 08e Enhancing Spawning Habitat Restoration in Minnesota Lakes – Research Project - $294,000 TF (FY2018)

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Appropriation Language
$294,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota, St. Anthony Falls Laboratory, in cooperation with the Department of Natural Resources to enhance efforts to increase natural reproduction of fish in Minnesota lakes by assessing wave energy impacts on near-shore spawning habitat. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The main goal of this project was to create easily accessible information on wave energy to enable successful habitat restoration projects and increase natural fish reproduction in Minnesota lakes. We created maps, in GIS format, of wave height and energy statistics for 457 lakes in Minnesota.

OVERALL PROJECT OUTCOME AND RESULTS
There are many ways in which healthy near-shore habitat and water quality in lakes is linked to wind and wave energy. Examples include walleye spawning habitat on nearshore gravel substrates, the distribution of submersed aquatic plants, sediment resuspension by wave action, and shoreline erosion. Successful lake habitat restoration requires good information on wind and wave energy, and this

information is commonly not available. The main goal of this project was to create easily accessible information on lake wave energy to enable successful habitat restoration projects and increase natural fish reproduction in Minnesota lakes. The project partnered the University of Minnesota with the MN DNR and included field measurements of wind and wave height on four lakes ranging in size from 350 to 5000 acres, wave modeling work to map typical wave energy on the shorelines of 457 Minnesota lakes, and experimental work in a wave flume to better understand how nearshore sediment responds to wave energy in lakes. A major part of the project was to develop models for wave height and energy that consider wind sheltering by trees, so that wave height predictions could be made for smaller lakes with fetches of a kilometer or less. The wave maps created by this study can be used by state agencies and lake associations to plan lake shoreline management, including habitat restoration projects, aquatic plant management, and shoreline erosion control.

PROJECT RESULTS USE AND DISSEMINATION
Electronic maps of wave height and energy created in this project will be uploaded to the Data Repository for University of Minnesota (DRUM), and details of the project will be published in a St. Anthony Falls Lab project report to document the methodologies used. The project PI gave a talk on the project at a conference on Sentinel lakes in March 2019 in Alexandria, MN, and is giving a poster presentation at the 2021 Minnesota Water Resources Conference.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08f Prescribed Fire Management for Roadside Prairies - $345,000 TF (FY2018)

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Appropriation Language
$345,000 the first year is from the trust fund to the commissioner of transportation to enhance the prescribed-fire program to manage roadsides to protect and increase biodiversity and pollinator habitat. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
MnDOT's fire program has grown exponentially since this funding was secured. All fire crews have gained extensive experience and have gained a lot of confidence on how and when fire should safely be used. The number of areas and districts in which fire occurs on MnDOT property has increased throughout this project. Within the next 5 years MnDOT will be conducting prescribed fire in 6 of its 8 districts around the state.

OVERALL PROJECT OUTCOME AND RESULTS
MnDOT fire program took major steps forward with this funding and has secured a self-sustaining fire

program. Prior to this funding DOT completed less than 5 burns a year, in the 3 years of this program DOT completed 78 burns that totaled 142 miles of ROW burned totaling 1,600 acres of Mn and US highway ROW burned statewide. Even with one years of no burning allowed due to COVID 19, we surpassed our goals of this project and doubled our acres completed. DOT's current burn program has changed how native planting will be installed in the future, by being able to help maintain them for long lasting success. More Roadside Rest Areas around the state will be planted with native vegetation, to help increase pollinator habitat and reduce maintenance cost associated with turf grass. Six MnDOT staff have received fire training on becoming burn bosses, with one person finishing all training and task books required. With additional staff able to complete burns, MnDOT's fire program will continue to grow and expand.

PROJECT RESULTS USE AND DISSEMINATION
A Master Partnership Agreement was drafted, completed, and currently in place which allows MnDOT to assist the MnDNR on all aspects of wildfire suppression and prescribed fire operations, this agreement includes funding for direct payment between the two state agencies. With MnDOT assisting the DNR in wildfire suppression, it is our hope that we will reduce the number of resources needed from other state agencies and contractors.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08g Minnesota Bee and Beneficial Species Habitat Restoration - $732,000 TF (FY2018)

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Appropriation Language
$732,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Pheasants Forever in cooperation with the University of Minnesota and the Minnesota Honey Producers Association to restore approximately 800 acres of permanently protected land to enhance bee, butterfly, beneficial insect, and grassland bird habitats. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project's goal was to enhance and study 800 acres of permanently protected habitat by converting low diversity grassland areas to high diversity native grasses and wildflowers. The result of our efforts was the successful enhancement of 1,949.69 acres of habitat to benefit pollinators and other wildlife.

OVERALL PROJECT OUTCOME AND RESULTS
Grassland habitat loss and fragmentation continue to be the major factor in the decline of monarchs, other pollinators and grassland wildlife. While we have restored hundreds of thousands of acres of

grasslands, our early restorations rarely considered the needs of pollinators, the value of milkweed species to the monarch, or the vegetative structural and species diversity required by many species.

This project sought to address the loss of habitat essential to pollinators by enhancing 800 acres of low diversity grasslands on permanently protected lands. These enhancements were monitored in collaboration with the University of Minnesota (UofM) to, inform practitioners of best practices and provide a path to future habitat enhancements for native pollinators.

Enhancement projects were solicited by Pheasants Forever (PF) and project partners through a sign-up period via an RFP sent to SWCD's and other private land partners in the agricultural region of Minnesota. Application were ranked and funded based on potential benefit to the program. Private contractors were hired by PF to complete enhancement work on 1949.69 acres. After enhancement work was completed researchers from the UofM monitored the sites to measure usage by pollinator species as well as measure native plant growth.

Pollinators are extremely important to the production of foods and other products that Minnesotans utilize, as well as other ecosystem services. Whether through funding or policy, the decline of pollinators suggests the need to put a greater emphasis on the protection, restoration, and management of their habitats. Once results are analyzed, the research conducted by the UofM will help improve our best management practices in pollinator habitat restoration and enhancement.

PROJECT RESULTS USE AND DISSEMINATION
The enhancement activities completed by this project did not result in the creation of any new tools or documents. Projects were occasionally highlighted in field tours, or via social media posts. The field research conducted by the UofM is now complete, but data analysis and results have yet to be finalized or published. Once complete, this data will be available to the public and should inform practitioners about improved methods for restoring and enhancing pollinator habitat.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08h Mississippi and Vermillion River Restoration of Prairie, Savanna, and Forest Habitat – Phase Ten - $213,000 TF (FY2018)

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Appropriation Language
$213,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Friends of the Mississippi River for continued implementation of the Metro Conservation Corridors partnership by improving at least 80 acres of habitat at approximately seven sites along the Mississippi

River and Vermillion River corridors. Expenditures are limited to the identified project corridor areas as defined in the work plan. A list of proposed restoration sites must be provided as part of the required work plan. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Friends of the Mississippi River increased and improved 133 acres of habitat at 6 sites along the Mississippi and Vermillion River corridors, linking existing nodes of high biodiversity. The project restored and enhanced prairie, savanna and forest habitat along the river corridors with a focus on increasing habitat for pollinators.

OVERALL PROJECT OUTCOME AND RESULTS

Through this project, Friends of the Mississippi River will increase and improve 82 acres of habitat at 7 sites along the Mississippi and Vermillion River corridors. Habitat fragmentation and degradation from non-native species, diseases and other causes threaten Minnesota's rich natural heritage. This situation will be exacerbated as the state's climate continues to change. A system of interconnected natural areas can help to lessen these impacts by providing both habitat and the ability for native species to move on the landscape in response to these changes. This is the goal of the Metro Conservation Corridors partnership and of this proposal. The projects on our list are all along the Mississippi and Vermillion Rivers, natural corridors that link the existing nodes of high biodiversity.

The overarching goal for this project is to restore and enhance prairie, savanna, and forest habitat along these river corridors. While these projects will improve habitat for a variety of species, FMR will specifically focus on increasing habitat for our diminishing pollinators. We will seed and install a diversity of host and nectar plants. The restoration activities, presented in existing natural resource management plans, include exotic invasive plant removal, soil preparation, spraying, seeding, mowing, plant installation and burning. To help reduce costs and to increase the educational outcomes, FMR will organize volunteer stewardship events to accomplish some of the restoration activities at some of these sites. These restoration activities will have multiple benefits. An important outcome will be to improve or increase habitat for native pollinators by increasing host and nectar plants. Seed mixes will exceed the Minnesota Board of Soil and Water guidelines, with many additional pollinator plant blooms in all seasons. Restoration activities at these sites will provide water quality benefits by installing deep-rooted prairie/savanna plants that help reduce erosion and sediment & chemicals from entering the rivers. Being within the Metro area, these sites provide examples of diverse native habitat for area residents to enjoy and learn about. A final goal of this project is to work with Metro Conservation Corridors partners to develop a more uniform restoration monitoring and evaluation protocol that also allows the data to be shared. Each of the specific sites in this project is in public ownership and have natural resource management plans in place to guide the habitat restoration and management activities and are on file at FMR. The Conservation Corps of Minnesota is on our contractor contact list and receive notice for all restoration Request for Proposals that we prepare and distribute.

FMR will conduct an evaluation for each of site upon completion of these grant-funded restoration activities and three years later. These evaluations will analyze how the activities achieved the goals for the project, present any unforeseen issues that impacted the achievement of those goals and lessons learned from the project.

PROJECT RESULTS USE AND DISSEMINATION
FMR promoted and disseminated information about this project through earned media, FMR's website (www.FMR.org), electronic & printed newsletters, and volunteer stewardship events. FMR has acknowledged ENRTF in all publications and events that refer to these projects. FMR will work with landowners to erect signage where ENRTF grant funds were spent.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08i Community Stewardship to Restore Urban Natural Resources - Phase Ten - $524,000 TF (FY2018)

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Appropriation Language
$524,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Great River Greening to work with volunteers for continued implementation of the Metro Conservation Corridors partnership to restore approximately 250 acres of forest, prairie, woodland, wetland, and shoreline throughout the greater Twin Cities metropolitan area. Expenditures are limited to the identified project corridor areas as defined in the work plan. A list of proposed restoration sites and evaluations must be provided as part of the required work plan. Plant and seed materials must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
To protect Minnesota's natural heritage, Greening restored and enhanced 310 ecologically significant acres in priority metro areas and engaged volunteers in a suite of activities to address the need for long-term management of projects. Greening disseminated results for the layperson through electronic channels and to professionals through a published paper.

OVERALL PROJECT OUTCOME AND RESULTS
We reached 123% of our acreage goals, restoring and enhancing 310 acres of significant ecological habitat, compared to the 252 acres anticipated. The 12 restoration and enhancement sites were selected based on ecological significance and potential for improvement. Restoration and enhancement improvements were made on prairie, forest, and wetland communities including habitat for rare species, within the mapped Metro Conservation Corridors.

We successfully engaged 468 volunteers in hands-on restoration, and 5 known observers via iNaturalist

app for a combined total of 473 contacts. Reaching this number was a challenge we met, as during the second half of this appropriation, we had to significantly and rapidly modify our community outreach and event models in response to the COVID-19 pandemic to safely engage our volunteers throughout 2020 and 2021. We were successful in our community engagement events with staggered start time, multi-shift days with smaller pods of volunteers, and strict safety guidelines in place. Furthermore, we also piloted independent volunteer outings utilizing the iNaturalist platform, allowing volunteers to explore project parcels and record their observations independently. These observations provided very useful data (e.g. benchmarking progress and identifying patches of exotic species) while engaging volunteers in a novel way.

To help address the need for innovative methods for long term maintenance, we also offered two additional levels of volunteer engagement beyond field volunteer and started using a digitized restoration evaluation for more standard, shareable data. The 'site monitor' level of engagement was successful, but the 'site steward' level of engagement was challenging due to a combination of the pandemic, and the effort needed to get landowners, GRG, and volunteers comfortable with making independent enhancement decisions.

PROJECT RESULTS USE AND DISSEMINATION
Greening highlighted projects over a suite of social media (twitter, Facebook), website, and external media. Examples from the final months of the appropriation include: May 2021 feature on our work at Inspiration easement; Oheyawahe/Pilot Knob Hill site highlighted during a March 2021 segment on KARE 11, then shared in Greening channels; the Blaine Wetland Sanctuary enhancement featured in our June 2021 Greening channels.

A peer-reviewed paper on the pollinator response to conservation haying and burning treatments at Six Mile Marsh authored by members of each stakeholder organization has recently been accepted for publication in 2021.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08j Economic Assessment of Precision Conservation and Agriculture - $400,000 TF (FY2018)

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Appropriation Language
$400,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with Pheasants Forever to demonstrate a new approach to promote conservation practices utilizing return-on-investment analysis and identifying revenue-negative acres on agricultural land to assist farmers in implementing conservation practices that will provide environmental and economic benefits.

This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project showcased opportunities available for farmers and landowners to implement profitable conservation practices on lands otherwise providing a negative return. Through this new approach to conservation delivery, we were able to put 1,216 acres of conservation on the landscape, providing multiple benefits to Minnesota's natural resources and economy.

OVERALL PROJECT OUTCOME AND RESULTS
With recent advancements of real-time yield monitoring, it has been demonstrated that, on many farms, 3-15% of cropped acres cost money to farm (revenue negative acres). By applying the current cutting-edge precision technology and focusing on return on investment (ROI) to deliver conservation, we worked with farmers to identify areas that make sense for them to apply conservation practices in a practical and profitable way. This new approach to conservation delivery, focused on revenue negative acres, provided insight to the consideration of profitable conservation practices, reasons for conservation adoption, and the delivery of conservation acres that otherwise would've continued to be in traditional crop production. In addition, this project demonstrated a high level of cooperation and coordination between agriculture and conservation.

By looking at the entire operation, at the enterprise level, current technology allows for acre-by-acre analysis to develop conservation solutions on acres that otherwise yield a negative return. This project worked directly with 72 farmers to analyze 45,214 acres and look for conservation solutions on 5,382 acres that are low yielding in comparison to the rest of the field or operation. Our findings show that of the analyzed acres, 12% of the acres fell below break-even yield, which is in the range of 3-15% revenue negative acres demonstrated by previous research (E Brand et al 2016). With the analysis and available program opportunities this project was able to meet farmer objectives while increasing profitability through conservation on 1,216 acres. These are acres that otherwise didn't receive consideration for conservation practices. While not all identified acres received immediate change, the overall conversation and influence of this project, opened the door for continued conservation consideration and future conservation adoption. The practices implemented provide direct benefit to Minnesotans through increased soil health, water quality, carbon sequestration, wildlife habitat, and other natural resources.

PROJECT RESULTS USE AND DISSEMINATION
This project resulted in the hiring of a precision ag & conservation specialist to work with farmers, landowners, trusted advisors and demonstrate the use of precision agriculture technology to deliver conservation on the landscape. This project helped launch the addition of multiple staff in additional states to both implement and influence conservation on the landscape. This project hosted or was a part of 66 different outreach event impacting 3,608 attendees. Outreach consisted of online webinars, attendance at tradeshows (such as the MN Ag Expo and FarmFest) along with varying presentations and meetings geared towards ag professionals, conservation professionals, and farmers/landowners.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 09 Land Acquisition, Habitat and Recreation

Subd. 09a Metropolitan Regional Parks System Land Acquisition - $1,500,000 TF (FY2018)

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Appropriation Language
$1,500,000 the first year is from the trust fund to the Metropolitan Council for grants to acquire approximately 197 acres of land within the approved park boundaries of the metropolitan regional park system. This appropriation may not be used to purchase habitable residential structures. A list of proposed fee title acquisitions must be provided as part of the required work plan. This appropriation must be matched by at least 40 percent of nonstate money that must be committed by December 31, 2017. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Metropolitan Council along with Washington County and Carver County acquired 12 parcels to increase recreational opportunities for the Regional Parks System. These critical acquisitions protected over three miles of Minnesota River and St. Croix River shoreline and 192 acres of high-quality natural resource land in Washington and Carver Counties.

OVERALL PROJECT OUTCOME AND RESULTS
The Metropolitan Council works with the Regional Park Implementing Agencies to protect critical lands and provide recreational opportunities for the Regional Parks System. This $1,436,000 ENRTF project was matched with $1.7 million in Council funds and Agency funds to purchase 14 parcels for the Regional Parks System.

Washington County acquired a 102-acre property for St. Croix Bluffs Regional Park with funding from this and a previous appropriation. The property contains critical habitats including hardwoods, mixed forest, open meadow, and 3,800 feet of St. Croix River shoreline. With the addition of this 102-acre parcel, the park now protects 5,000 contiguous feet of shoreline. Carver County acquired 13 parcels for the Minnesota River Bluffs Regional Trail, protecting 90 acres of natural resources and 3 miles of regional trail, much of it along the Minnesota River corridor.

Acquiring these properties permanently protects critical natural resources while providing additional recreational opportunities for the region. All properties funded are inholdings or parcels that are included in master plan-approved park boundaries. The Regional Park Implementing Agencies work only with willing landowners when acquiring lands with ENRTF, and they focus on acquiring lands with high natural resources and habitat value that are at risk of being developed.

PROJECT RESULTS USE AND DISSEMINATION
Articles were released both after the grant was awarded and after the Rowe parcel was purchased for

Washington County's St. Croix Bluffs Regional Park, including an article in the Pioneer Press on June 11, 2019. Carver County celebrated the opening of their rebuilt portion of the Minnesota River Bluffs Regional Trail on July 13, 2021 with a public celebration. Several news releases were published, including the SW News Media and on Carver County's website. The Council also issued news releases after each grant was awarded. The Agencies include the ENRTF sign when they install visitor signs. In addition, the Metropolitan Council and the Agencies acknowledge ENRTF for any media releases about the acquisitions.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09b Scientific and Natural Areas Acquisition, Restoration, Citizen Science and Engagement - $2,500,000 TF (FY2018)

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Appropriation Language
$2,500,000 the first year is from the trust fund to the commissioner of natural resources to acquire at least 250 acres of land with high-quality native plant communities and rare features to be established as scientific and natural areas as provided in Minnesota Statutes, section 86A.05, subdivision 5, restore and improve at least 1,000 acres of scientific and natural areas, and provide technical assistance and outreach, including site steward events. At least one-third of the appropriation must be spent on restoration activities. A list of proposed acquisitions and restorations must be provided as part of the required work plan. Land acquired with this appropriation must be sufficiently improved to meet at least minimum management standards, as determined by the commissioner of natural resources. When feasible, consideration must be given to accommodate trails on lands acquired. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Volunteers, staff, and contractors with Minnesota DNR completed enhancement and improvement activities on almost two-thousand acres of quality habitat on 75 of Minnesota's SNAs. A 10-acre wetland acquisition was added to Hastings SNA. Many thousands more people learned about, visited, or helped steward an SNA thanks to this funding.

OVERALL PROJECT OUTCOME AND RESULTS

Minnesota's Scientific and Natural Areas (SNAs) are public lands representing the state's best hope for protecting rare features and averting biodiversity loss. This appropriation strengthened the "science" in

SNA through monitoring-based habitat enhancement, citizen-science action and outreach, and strategic acquisition to protect additional high-quality natural lands. Over 1,930 acres across 75 SNAs were treated for terrestrial invasive species, received much-needed prescribed disturbance (e.g., prescribed fire, haying, etc.) or received other site improvement work, to maintain the overall quality of natural habitats for the rare and unique species that call these lands home. Such habitat work was guided by monitoring and site-assessment efforts taken on by staff as well as by volunteers: at least 190 SNA stewardship or interpretive events were held with an estimated attendance of nearly 6,000 participant volunteers donating thousands of hours to the educational, citizen-science, and stewardship aims of the SNA Program, led in part by the network of long-term volunteer Site Stewards serving at almost all SNAs by caring for the land and reporting observations. Online users observed upgrades to each SNA's webpage with improved interpretive narrative and consistent, unified themes; likewise, enhanced SNA social media presence and content have dramatically ramped up followers, subscribers, and forum membership numbers since this funding began, extending the reach and audience of the SNA Program on a variety of platforms to enhance public support for conservation. The project permanently protected a new tract consisting of 10 acres of high-quality wetland as an addition to Hastings SNA near the confluence of the Vermillion and Mississippi Rivers, important for water quality and for many special-concern and migratory bird species in the Mississippi flyway. Through this appropriation's support for programmatic acquisition work, around ten other SNA acquisition projects were recruited and developed, though several of these have proceeded instead on alternative funding.

PROJECT RESULTS USE AND DISSEMINATION

The SNA website is updated regularly, e.g., with improved species lists from monitoring efforts or for new or expanded SNAs, and with a frequently updated events calendar now also appearing in the "LCCMR Updates" e-newsletters. The 46th (Summer 2022) issue of the SNA Nature Notes e-newsletter was delivered to 10,790 subscribers (more than double since this appropriation began). The SNA Facebook channel now has ~9.1K followers, and the SNA Program contributes twice-monthly content to the DNR Instagram channel. The Minnesota SNAs Flickr group has 108 members currently sharing over 1,500 high-quality photos of the beauty and diversity of Minnesota's SNAs.

Project Completed: 06/30/2022
FINAL REPORT

Subd. 09d Minnesota State Trails Acquisition, Development and Enhancement - $1,038,000 TF (FY2017 - $999,000 / FY2018 - $39,000)

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Appropriation Language
$999,000 in fiscal year 2017 and $39,000 the first year are from the trust fund to the commissioner of natural resources for state trail acquisition, development, and enhancement in southern Minnesota. A proposed list of trail projects on authorized state trails must be provided as part of the required work plan. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project focused on expanding recreational opportunities and enhancing user safety on Minnesota's State Trails through the development of two new State Trail Segments, (1) the Casey Jones State Trail – Woodstock Segment, Pipestone County and (2) the Mill Towns State Trail – Cannon River Bridge and Trail Connection, Rice County.

OVERALL PROJECT OUTCOME AND RESULTS
As of June 30, 2020 the Minnesota Department of Natural Resources had completed the development of the two proposed new State Trail Segments, the Woodstock Segment of the Casey Jones State Trail near the community of Woodstock, Pipestone County and the new Mill Towns State Trail - Cannon River Trail Bridge and Trail in the City of Faribault, Rice County. Department of Natural Resources Engineering Staff completed all engineering and design required for the development of the two discrete trail segments and administered the associated construction contracts. All of the new State Trail infrastructure has been designed to meet the applicable requirements of the Americans with Disabilities Act (ADA) as well as trail design guidelines developed by Minnesota Department of Natural Resources and the Minnesota Department of Transportation. Although the Casey Jones State Trail Segment as originally proposed was to include the upgrading and bituminous surfacing of approximately 5 miles of the existing State Trail corridor, the project had to be revised when realized construction costs substantially exceeded the pre-design cost estimates. As revised, the Casey Jones State Trail Project consisted of the upgrading and improvement of the entire 5 miles of the existing State owned former railroad grade as originally proposed, however, the bituminous trail surfacing was limited to approximately 3 miles. The development of the new Mill Towns State Trail Cannon River Bridge and Trail has provided both the intended connection between the Mill Towns State Trail, the Sakatah-Singing Hills State Trail and the local trail system and a significant improvement in user safety realized through the elimination of the previously required "at-grade" crossing of TH21 at the Cannon River. Both of the new State Trail segments were substantially complete in 2019 and immediately opened to public use. Final project closeout was complete for both projects in late 2020.

PROJECT RESULTS USE AND DISSEMINATION
The Project's two Minnesota State Trail improvement and enhancement projects , the Casey Jones State Trail – Woodstock Segment and the Mill Towns State Trail – Faribault Canon River Bridge Crossing were completed through the collaborative and cooperative efforts of the Communities of Woodstock and Faribault, Pipestone County, the Friends of the Casey Jones Trail Association and the Mill Towns Trail Association. The Minnesota Department of Transportation's direct participation was also critical in the project's success. The project plans and specifications for each project were subject to review and approval by all project partners prior to implementation. Each of the project partners played a critical role in disseminating project information during both the design and construction phases of the projects. Following substantial completion of the Mill Towns State Trail – Cannon River Bridge and Trail Segment in Late 2019, the City of Faribault hosted a "Grand Opening and Ribbon Cutting". This event was held at the adjacent White Sands Trailhead, a municipally developed facility, and was well attended by members of the public and local dignitaries. Each of the communities and trail groups involved in

these projects remain active in advocating for further expansion and improvement of both the Casey Jones and Mill Towns State Trails. Each of the State Trail Maps published by the DNR have been updated to reflect the completed projects. The Environment and Natural Resources Trust Fund is acknowledged as a Project Partner on the Casey Jones Trailhead Sign in Pipestone and will be acknowledged with a sign that is to be affixed to the Mill Towns State Trail - Cannon River Bridge.

Project Completed: 06/30/2020
FINAL REPORT

Subd. 09e Native Prairie Stewardship and Prairie Bank Easement Acquisition - $2,675,000 TF (FY2018)

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Appropriation Language
$2,675,000 the first year is from the trust fund to the commissioner of natural resources to acquire native prairie bank easements in accordance with Minnesota Statutes, section 84.96, on approximately 335 acres, prepare baseline property assessments, restore and enhance at least 570 acres of native prairie sites, and provide technical assistance to landowners. Of this amount, up to $132,000 may be deposited in a conservation easement stewardship account. Deposits into the conservation easement stewardship account must be made upon closing on conservation easements or at a time otherwise approved in the work plan. A list of proposed easement acquisitions must be provided as part of the required work plan. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Permanently protected 287 acres of high-quality historically undisturbed native prairie, which house state threatened and special concerns species, Species in Greatest Conservation Need and a wide variety of pollinators. Prairie enhancement (1,227 acres), outreach, monitoring and research activities were implemented across the state to improve prairie habitat.

OVERALL PROJECT OUTCOME AND RESULTS
Through this appropriation, 287 acres of high-quality native prairie, which house state threatened and special concerns species, Species in Greatest Conservation Need and a wide variety of pollinators, were permanently protected through 5 Native Prairie Bank conservation easements (see attached parcel list). Protection efforts, through this appropriation and others, preserve some of the best remaining native prairie in the state for current and future Minnesota Citizens benefit. These remaining native prairies function at a significantly higher level and provide habitat to more species of insects, birds, reptiles, and mammals than restored prairie. Additionally, 21 Baseline Property Reports and 53 monitoring events

were completed and stewardship funds for the 5 closed Native Prairie Bank easements were enrolled into the Conservation Easement Stewardship Account.

A total of 705 acres of invasive species control and 522 acres of prescribed disturbance were completed to improve prairie quality throughout the prairie region of the state. Adaptive Management Monitoring was completed on 50 Native Prairie Banks. Knowledge gained through this monitoring and research will help landowners, DNR land managers and partner agencies improve the management of native prairie and wetlands.

DNR Prairie Specialists participated in 8 outreach events and engaged over 215 different priority prairie landowners on prairie protection, restoration, and enhancement. Prairie Stewardship Plans were completed for 14 landowners providing site specific management recommendations. The "Prairies of Minnesota Landowner Handbook" was published in June of 2021. To-date 3,500 copies of the book have been distributed to landowners and conservation professionals. A digital version of the book can be found on the DNR website.

Throughout this appropriation many challenges were encountered. A decrease in payment rates caused a higher decline rate, more time needed by landowners to decide on enrollment and the need for increased staffing to accomplish acquisition goals. This did allow for the acquisition of more acres for less and the return of a significant amount of money to the Commission for use on other great conservation projects. A pandemic froze or limited the ability to do many tasks, but staff got creative and looked for alternative approaches to get the work done.

PROJECT RESULTS USE AND DISSEMINATION
Fourteen Prairie Stewardship Plans were provided to native prairie landowners. These plans will guide the landowner's enhancement activities for well over a decade. The "Prairies of Minnesota Landowner Handbook" was published in June of 2021. To-date 3,500 copies of the book have been distributed to landowners and conservation professionals (who will continue to give the book to landowners managing prairies for years to come). A digital version of the book can be found here: https://files.dnr.state.mn.us/assistance/backyard/prairierestoration/prairie-handbook.pdf

All outreach materials produced through this appropriation followed ENRTF acknowledgement guidelines. Special thanks was given to ENRTF in the back cover of the book.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09f Leech Lake Acquisition - $1,500,000 TF (FY2018)

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Appropriation Language
$1,500,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Leech Lake Band of Ojibwe to acquire approximately 45 acres, including 0.67 miles of shoreline of high-quality aquatic and wildlife habitat at the historic meeting place between Henry Schoolcraft and the Anishinabe people. The land must be open to public use including hunting and fishing. The band must provide a commitment that land will not be put in a federal trust through the Bureau of Indian Affairs.

Project Completed: 08/30/2018
FINAL REPORT

Subd. 09g Mesabi Trail Development - $2,269,000 TF (FY2018)

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Appropriation Language
$2,269,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the St. Louis and Lake Counties Regional Railroad Authority for engineering and constructing segments of the Mesabi Trail. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

Project due to be completed: 12/31/2022
FINAL REPORT

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4. M.L. 2016 Projects Completed
January 15, 2021 – January 15, 2023

MN Laws 2016, Chapter 186, Section 2

M.L. 2016 Projects

MN Laws 2016, Chapter 186, Section 2 (beginning July 1, 2016)

Visit the LCCMR website for the most up-to-date project information and reports

Subd. 04 Water Resources

Subd. 04s Agricultural and Urban Runoff Water Quality Treatment Analysis - Phase II - $110,000 TF

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Appropriation Language
$110,000 the second year is from the trust fund to the Board of Water and Soil Resources for an agreement with the Blue Earth County Drainage Authority to continue monitoring a model demonstration for storage and treatment options in drainage systems designed to improve agricultural and urban water quality by reducing soil erosion, peak water flows, and nutrient loading. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The results will be used to implement the most cost effective BMPs and guide future maintenance to maximize the benefits and lifespan of the associated BMPs implemented on public drainage systems. The data can use used to inform larger watershed plans to meet local and state water quality goals.

OVERALL PROJECT OUTCOME AND RESULTS
Phase I Agricultural and Urban Water Quality Treatment Analysis data shows how combining agricultural best management practices (BMPs) on a public drainage system can significantly improve water quality in an agricultural landscape. Upon the completion of the Phase I report and analysis, the need for continued, and more detailed, monitoring was identified as well as a gap in available information on maintenance recommendations for the BMPs and associated costs.

Phase II analysis refined methodology and findings from targeted site location including Klein Pond, the two-stage ditch, and rate control weir. Monitoring samples were collected during 2016-2017 by graduate students at Minnesota State University – Mankato (MSU) and added to previously collected data in Phase I to develop long-term trends.

A formal report compiled the findings from Phase II. The report outlined the long-term effectiveness of BMPs, maintenance recommendations to ensure functionality and effectiveness of BMPs, and review of

BMPs lifetime costs to determine the most cost-effective water quality practices for drainage systems.

The report was published on the ISG website here. The findings were presented at multiple virtual conferences reaching of over 125 people. In addition, the report was sent in an email blast to 650+ individuals and was posted to social media to engage a larger audience and direct them to the website for more detailed information on findings.

The long-term study on CD 57 collected 10-years of monitoring data that provides decision makers and professionals with data to make informed decisions on having the greatest success with implementing and maintaining BMPs. Particularly in south-central Minnesota where drained agricultural lands dominate the landscape, a watershed approach to utilizing multi-purpose drainage management will play an integral role in meeting water quality goals. CD 57 can be used as a model for drainage systems and watersheds for implementing multiple BMPs with collaborative efforts from landowners, drainage authorities, county staff, and agencies. This project highlights the importance of long-term sustainable funding for water quality and resiliency programs targeting implementation of practices on agricultural lands.

PROJECT RESULTS USE AND DISSEMINATION
A formal report was developed supplementing the finding created in the Phase I report which summarized the monitoring data, long-term maintenance recommendation, and lifetime cost analysis. The report is posted to the ISG website here. The findings were presented in workshops, conferences, virtual water storage tours, email blasts, posts to ISG's website, and social media threads for drainage staff, county commissioners, watershed district managers, watershed management organizations, landowners, agency staff, non-profit organizations, academics, water resources engineers, and others from Minnesota and Iowa.
Project Completed: 06/30/2021
FINAL REPORT

Subd. 06 Aquatic and Terrestrial Invasive Species

Sub-Project 01: Fungi in Ash Trees: Towards Protecting Trees from Emerald Ash - $500,000 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Important new findings have been obtained about the fungi associated with the emerald ash borer (EAB). This knowledge helps better understand the biology and ecology of EAB invasion and provides new biological control agents that can be used to help manage this invasive pest.

OVERALL PROJECT OUTCOME AND RESULTS

The emerald ash borer (EAB) is an exotic beetle that has been introduced into the United States and is currently causing serious losses of ash trees in Minnesota. To effectively manage this pest, it is essential to understand the biology and ecology of the beetle and associated microorganisms. Our research has identified the diverse fungi that are associated with EAB. These include 1) canker causing fungi that work along with EAB to kill trees, 2) aggressive pioneer decay fungi that enter EAB wounds and cause hazardous conditions in ash trees attacked by the beetle and 3) fungi that can kill EAB with potential use as biological control agents. Laboratory and field studies have been done to test the pathogenicity of selected fungi on eggs, larvae and adult EAB. These studies have shown that fungi can kill EAB, and several species have been evaluated and are now available for field trials. This method of control for EAB provides an additional tool that natural resource managers will be able to use to control the pest. Methods of spraying and injecting trees have also been tested. Other fungi obtained from EAB galleries produce lesions and pathogenicity studies show that several of these canker causing fungi work in concert with EAB to kill trees. We also have a better understanding of the pioneer species of decay fungi that come into wounds made by EAB. These fungi cause extensive decay and strength losses early in the colonization process resulting in affected ash to become hazardous. These results, which are especially important in the urban landscape, indicate that timely tree removal is needed to avoid hazards produced by EAB associated wood decay fungi. Our research results provide important new findings for integrated pest management that will benefit Minnesotans long into the future.

PROJECT RESULTS USE AND DISSEMINATION

Results have been disseminated in scientific publications, presentations, and news releases. This includes journal articles on the diverse fungi associated with the emerald ash borer and fungi from EAB that produce cankers in ash trees, as well as presentations on the ovicidal effects of fungi on EAB and other aspects of biological control and management of EAB. Numerous news releases on fungi attacking EAB, protecting Minnesota's ash trees and others have taken place.

Subproject 01 Completed: 06/30/2022
FINAL ABSTRACT

Sub-Project 02: Understanding the Benefits and Limitations of using Goats for Invasive Plant Control - $445,533 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Targeted grazing by goats demonstrates some benefits for the control of invasive Rhamnus cathartica and the enhancement of native plant communities. While P. tenuis transmission to goats remains a

concern during invasive plant management, co-grazing goats with waterfowl may mitigate this seasonal disease risk.

OVERALL PROJECT OUTCOME AND RESULTS

The use of goats for invasive plant control is increasing, yet few data exist on the effects of goat browsing on invasive species populations or native plant community composition. The cost of this management strategy is also elevated in some regions due to mortality caused by a parasite of white-tailed deer, Parelaphostrongylus tenuis, that goats may be exposed to when browsing in areas where infected deer defecate. To address these issues, we used Rhamnus cathartica as a target species to quantify the short- and long-term effects of goat browsing for invasive plant control and non-target impacts on associated native plant communities. We found that goats provide temporary suppression of R. cathartica abundance but this invasive shrub rebounds following grazing cessation. Native vegetation was similarly temporarily suppressed, but in some cases native plant diversity reached higher levels following grazing treatments. A broader synthesis and meta-analysis of the targeted grazing literature revealed similar patterns for the effects of goats and other livestock used for targeted grazing of invasive or undesired plant populations. Importantly, consumption by goats kills the seed of R. cathartica, and other invasive plants with larger seeds, indicating that goats are unlikely to exacerbate invasions by spreading them to new areas. Finally, in evaluating the P. tenuis risk to goats, we conducted a retrospective study of P. tenuis-associated mortalities of small ruminants in Minnesota over a 19-year period, as well as examined whether co-grazing goats with waterfowl could reduce transmission risk through waterfowl consumption of the gastropod intermediate hosts that harbor this parasite. Overall, we determined that the P. tenuis-associated mortality rate of goats is low (<1%), though it is unclear how browsing for invasive plant control might affect this level. Through our co-grazing experiments, we found more gastropods in habitats after goats had browsed alone; however, we did not observe these increases when goats were co-grazed with waterfowl. In addition, waterfowl did not negatively affect overall gastropod abundance or diversity. Thus, waterfowl could reduce P. tenuis risk to goats without harming gastropod communities.

PROJECT RESULTS USE AND DISSEMINATION

Research highlights were regularly disseminated throughout the duration of our project. Over the course of our research, our project was featured in eight popular press articles within the midwest region, one Minnesota radio station and PBS's Prairie Lawn and Garden show. Our project team leveraged our research in 11 education events targeting primary, secondary, higher education-level students, and community members, and seven presentations to university, local, regional, and national scientific, natural resource management, and public audiences. We've also had four manuscripts published in peer-reviewed scientific journals, with a fifth nearing submission. Project highlights have also been shared on Twitter.

Subproject 02 Completed: 06/30/2022
FINAL ABSTRACT

Sub-Project 03: Genetic Control of Invasive Insect Species: Phase I - $296,655 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We have demonstrated (in lab cages) a powerful new approach to combat invasive insect pests. Genetically engineered male insects would be released to mate with wild females, who would not have offspring. This can crash a wild population, and it is applicable to any sexually reproducing insect.

OVERALL PROJECT OUTCOME AND RESULTS
With the overall goal of demonstrating our innovative genetic biocontrol approach in the pest insect Spotted Wing Drosophila, we had three specific objectives on this project: (i) demonstrate a proof-of-concept in the model laboratory insect and close cousin to SWD, Drosophila melanogaster, (ii) translate what we learned from D. melanogaster into the SWD species, and (iii) study the genome sequence of wild SWD so we can precisely design our engineered biocontrol agents to effectively suppress wild SWD populations in Minnesota.

Our outcomes and results for the first objective exceeded project expectations. We succeeded in making the proof-of-concept in D. melanogaster, and the engineered insects were 100% incompatible with wild-type flies. We made over a dozen versions. We also added additional genetic control elements to automatically sort the males from females, making the technology more economical to deploy for pest control.

We did not meet our objective two milestones (completing the engineering of SWD), however, we made good progress in that direction. Near the end of the award, we succeeded in making our first transgenic SWD flies, so we should be able to move quickly now in finishing the engineering process.

Our results from the third objective exceeded expectations. While we initially planned to sequence the genome of 20 wild-caught flies, we instead invented a new approach that allowed us to sequence the relevant genes from over 10,000 wild flies. We are using this data in our current engineering efforts with SWD.

This was a high-risk/high-reward project. We were able to overcome a tremendous amount of technical risk on the project so far, and the approach is looking very promising. We plan to continue to make progress towards Objective 2 in our second Phase of this project.

PROJECT RESULTS USE AND DISSEMINATION
We have disseminated our results through the normal channels available to academic labs (regional, national, and international conferences and workshops; peer-reviewed publications; patents; etc.). We are most proud of two high-impact publications from this work. The first was published in Nature Communications in 2020, and the second is currently undergoing peer review at a top-ranked journal. We will have at least two additional papers submitted in the next year that stem from this project.

Subproject 03 Completed: 02/28/2021
FINAL ABSTRACT

Sub-Project 04: Dwarf Mistletoe Detection and Management in Minnesota - $433,250 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We were able to identify key considerations for the early detection of the invasive American dwarf mistletoe on jack pine, including different detection methods and the need for field-level biology and identification education for foresters and loggers.

OVERALL PROJECT OUTCOME AND RESULTS
American dwarf mistletoe is an invasive species that infects and kills jack pine, a native tree species of Minnesota. American dwarf mistletoe is not currently present in Minnesota but has been detected in neighboring Canadian provinces. The goal of our project was to utilize Minnesota's native dwarf mistletoe, eastern spruce dwarf mistletoe (ESDM), to explore options for detection and management. Just like American dwarf mistletoe, ESDM results in mortality for its host tree, black spruce. We tested different types of detection methods. Google Earth was able to detect mortality, but we were unable to determine if mortality was caused by ESDM. Winter sampling resulted in higher potential false positives due to snow cover on tree. Summer sampling provided a clear view of the trees but movement within the stands were more difficult. Summer sampling was also used to explore impact of ESDM on forest ecosystems. ESDM is not a binary variable; lower levels of ESDM in black spruce stand resulted in higher tree species diversity and did not negatively impact regeneration.

With this new insight we explored different methods for predicting ESDM at the individual tree level and at the stand level using multiple different datasets. At the landscape level, we identified areas that have greater potential for impact from ESDM and linked those with stand and environmental variables which can provide foresters and natural resource management tools to prioritize management.

An additional part of our project was conducting focus groups and surveys with foresters and loggers within northern Minnesota. We found variable opinions regarding management and knowledge about ESDM and foresters and loggers identified the need for additional information about mistletoe and more data on results of management. We identified the need for training as a key component when considering early detection for the invasive American dwarf mistletoe.

PROJECT RESULTS USE AND DISSEMINATION
Results have been shared through talks at local, regional, and national meetings. We shared results through a special symposium: Lake States Lowland, Wet, and Floodplain Forests. Published papers include:
- Influence of eastern spruce dwarf mistletoe on stand structure and composition in northern

Minnesota,
- The Difficulty of Predicting Eastern Spruce Dwarf Mistletoe in Lowland Black Spruce,
- Results of a Qualitative Assessment of Northern Minnesota Loggers' and Foresters' Perspectives and Experiences with Dwarf Mistletoe in Black Spruce Stands, and
- Results of a Survey of Minnesota Foresters Regarding Knowledge of and Treatment Practices for Dwarf Mistletoe in Black Spruce Stands in Northern Minnesota.

Subproject 04 Completed: 11/30/2021
FINAL ABSTRACT

Sub-Project 05: Developing Spatially Explicit Bio-economic Dispersal Model to Aid with the Management of Brown Marmorated Stink Bug - $329,354 TF

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Subproject 05 Completed: 07/18/2021
Effects of Starvation, Age, and Mating Status on Flight Capacity of Laboratory-Reared Brown Marmorated Stink Bug (Hemiptera: Pentatomidae)

Sub-Project 07: Building Mechanistic and Process based Species Distribution Models for Common Tansy and Leafy Spurge: from Landscapes to Genomes - $351,188 TF

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Subproject 07 Completed: 07/18/2021
FINAL ABSTRACT

Sub-Project 09: Genetic control of invasive insects, Phase 2 - $60,000 TF

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Subproject 09 Completed: 12/31/2022
FINAL ABSTRACT

Subd. 06c Advancing Microbial Invasive Species Monitoring from Ballast Discharge - $368,000 TF

Research Project

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Appropriation Language
$368,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to identify bacteria in ship ballast water and St. Louis River estuary sediments, assess the risks posed by invasive bacteria, and evaluate treatment techniques for effectiveness at removing the bacteria from ballast water. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Bacterial communities and pathogen-containing bacterial genera were characterized in ship ballast water, throughout the St. Louis River estuary including commercial dock areas and muskellunge habitats to better understand the risk of discharging ballast water from commercial ships into this estuary.

OVERALL PROJECT OUTCOME AND RESULTS
While culture-based methods to detect indicator bacteria reduce the cost and complexity to monitor ballast and harbor waters, caution should be used when monitoring based on these indicators alone because their fates are not necessarily representative of bacterial cells in some pathogen-containing genera. Both UV-treatment and chlorination resulted in >99% removal of culturable indicator bacteria, however, each indicator responded differently with no regrowth of Enterococcus, moderate regrowth of E. coli for chlorine treated samples, and major regrowth of total bacteria after treatment. There were shifts in overall bacterial community composition after treatment including regrowth of cells from

genera that harbor pathogens (particularly Acinetobacter, Flavobacterium, and Pseudomonas). Initially, P. salmonis DNA appeared to be present in the surface water of the St. Louis River estuary, but this result proved to be incorrect. This finding was confirmed by sequencing bacterial DNA at various sites in 2017 and 2019, which did not detect the presence of Piscirickettsia DNA. Bacterial communities and the pathogen-containing bacterial genera (PCGs) subset in water and sediments at four commercial docks in the Duluth-Superior harbor were different from other sites in the St. Louis River estuary. Higher relative abundances of PCGs were found in commercial dock sediments compared to the rest of the estuary. While there were only minor differences in the relative abundance of PCGs in surface water throughout the estuary, DNA from the Flavobacterium genus was more abundant at docks than other areas. Discharge of ballast water may affect the prevalence of PCGs in the Duluth-Superior harbor. Treatment of ballast water prior to discharge may reduce any human and wildlife pathogen load. In addition, care should be taken when dredging dock areas because disturbing sediment may temporarily increase the chances of exposing recreational users to pathogenic bacterial strains.

PROJECT RESULTS USE AND DISSEMINATION
In total during this project, three graduate students were trained, two M.S. degrees will be completed, four poster and four oral presentations were made at regional and national scientific conferences and venues, and project results were disseminated to collaborators and colleagues at the U.S. EPA Mid-Continent Ecology Division and the Duluth Seaway Port Authority in Duluth, MN. One M.S. thesis will be appended to this project final report and the other will be forwarded when it is completed.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08 Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Subd. 08a Bee Pollinator Habitat Enhancement - Phase II - $387,000 TF

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Appropriation Language
$387,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to continue assessment of the potential to supplement traditional turf grass by providing critical floral plant resources to enhance bee pollinator habitat. Plant materials and seeds must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Florally enhanced fine fescue lawns provide forage for diverse bee pollinators, maintain recreational and

aesthetic value, and reduce the need for irrigation, pesticides, fertilizers, and mowing. In response to demand, many local retailers now sell bee lawn seed mixes, a trend that will likely grow in Minnesota and nationally.

OVERALL PROJECT OUTCOME AND RESULTS

Our research demonstrates how small changes to a landscape can have meaningful conservation impacts on pollinators. Within Minneapolis parks, florally enhanced lawns (containing Dutch white clover, self-heal, and creeping thyme) had more diverse and distinct bee communities than lawns containing just Dutch white clover. Fifty-five species of wild bees were found foraging on Dutch white clover, and the vast majority were native species; however, Apis mellifera, the European honey bee, was the most common species. Seven bee species were found only on self-heal and not observed on Dutch white clover. The addition of flowers allows lawns to maintain their recreational and aesthetic value while still providing high-quality forage for pollinators. Park visitors supported bee lawns (95%) for their aesthetics and bee conservation, and city land managers emphasized need for education on the multiple benefits of bee lawns. Flowering lawns are highly sustainable, utilizing low-input fine fescues that reduce the need for irrigation, fertilizer applications, and mowing. Bee lawns encourage residents to view lawn flowers as food for bees rather than as a nuisance, reducing the perceived need to apply herbicides to the landscape. In addition, Bee lawns have become increasingly popular throughout the state of Minnesota as a result of this work; many local home and garden retailers in Minnesota now sell bee lawn mixes, which include both flower seeds and fine fescues. The Lawns to Legumes (L2L) program strives to make pollinator friendly lawns a trend nationwide. A newly funded grant will support bee lawn research integrated with other urban ecosystems questions: National Science Foundation: The Changing Nature of Cities: Ecological and Social Dynamics in the Minneapolis-St. Paul Urban Ecosystem. We see this as an excellent extension and expansion of the LCCMR project that will build future collaborations with Minnesota State agencies, Twin Cities municipalities, non-government organizations and businesses.

PROJECT RESULTS USE AND DISSEMINATION

There has been an amazing amount of interest by the general public about bee lawns. We have published four peer-reviewed research articles, have given dozens of talks, workshops, podcasts, field days, classroom lectures, and scientific conference presentations on bee lawns. Bee lawn materials are accessible on three different UMN websites geared toward different audiences (the general public on the UMN Extension site which gets hundreds of thousands of visits every year, turfgrass audiences on the Turfgrass Science website and entomology audiences on the Bee Lab website). Our continued outreach on bee lawns will reach many thousands of Minnesotans.

Project due to be completed: 06/30/2021

FINAL REPORT

Flowering Lawns in Minneapolis Parks - 1 pg

Bee Lawns - Turf Grass with Flowering Plants - 2 pgs

Bee Lawns: Installing - 2 pgs

Testing the Establishment of Eight Forbs in Mowed Lawns of Hard Fescue (Festuca brevipila) for Use in Pollinator Conservation - 7 pgs

Turfgrass Species Affect the Establishment and Bloom of Kura Clover (Trifolium ambiguum) in Lawns - 6 pgs

FLOWERING BEE LAWNS - A TOOLKIT FOR LAND MANAGERS - 14 pgs

Exploring park visitor perceptions of 'flowering bee lawns' in neighborhood parks in Minneapolis, MN, US - 12 pgs

Applying 'action situation' concepts to public land managers' perceptions of flowering bee lawns in urban parks - 10 pgs

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Subd. 08b Measuring Pollen and Seed Dispersal for Prairie Fragment Connectivity – Research Project - $556,000 TF

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Appropriation Language
$556,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to determine habitat connectivity between prairie fragments by measuring plant movement by dispersal of pollen and seeds to improve prairie restoration implementation. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project determined habitat connectivity between prairie fragments by measuring plant movement of 6 species by dispersal of pollen and seeds to improve prairie restoration implementation. New modeling approaches indicated that spillover from established/remanent prairies is a more complicated process than previous thought and requires different land management.

OVERALL PROJECT OUTCOME AND RESULTS
When restored prairies are adjacent to remnant prairies, rare species will move into and establish in these remnant prairies. This is a process we call spillover. Species that move into remnants tend to be dispersed by wind or animals. Over 1200 hectares of restored prairies benefit from spillover from remnant prairies in Minnesota.

We created an interactive map for managers in Minnesota to use to determine how landscape connectivity would change when they either 1) removed a remnant prairie, or 2) added a prairie to a location via restoration.

We learned that in Minnesota grasslands, if we model connectivity of our existing habitat fragments by incorporating an actual dispersal kernel, we get very different estimates of connectivity than when we use traditional approaches. This work demonstrates the importance of using dispersal kernels for measuring connectivity.

PROJECT RESULTS USE AND DISSEMINATION
This project has been presented at the Ecological Society of America conference in 2018 to an invited session on the role of space for coexistence as well as in 2019. Additionally, our team presented findings at the Botany Society meetings in 2019, 2020, and 2021 and various intuitional research talks in 2019 and 2020. The list of published papers associated with this project can be found in our Overall Project Outcomes.

One of the main outreach foci of this project was to provide conservation agencies and the MPCP with tools that they can use to determine the degree of habitat connectivity and the necessary size of corridors, to promote the spread of desirable species. To that end, we created and an app to the Nature Conservancy, and the MN DNR in March 2019. This app can be found at MN Connectivity.

Project Completed: 06/30/2020
FINAL REPORT
Apps can help bridge restoration science and restoration practice
Species diversity and dispersal traits alter biodiversity spillover in reconstructed grasslands
Consequences of ignoring dispersal variation in network models for landscape connectivity

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Subd. 08d Evaluate Prescribed Burning Techniques to Improve Habitat Management for Brushland Species – Research Project - $267,000 TF

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Appropriation Language
$267,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to compare the effects on brushland habitat of conducting prescribed burning in spring, summer, and fall to provide improved management guidelines for wildlife habitat. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Lowland brush ecosystems provide critical habitat for a variety of wildlife. Lack of fire degrades habitat value. Our project suggests that prescribed burning in different seasons (e.g., spring, summer, fall) can be a tool to support a variety of outcomes, maintaining a diverse habitat that supports a diverse bird community.

OVERALL PROJECT OUTCOME AND RESULTS
Lowland brush ecosystems provide critical habitat for a variety of wildlife including over 80 Species of Greatest Conservation Need. These ecosystems depend on fire. Without fire, shrubs become dominant, reduce herbs, and reduce the quality of habitat for wildlife. Managers use prescribed burning as a tool in these ecosystems, conducting most burns in spring. We know that in other systems, summer and fall fires increase habitat value by creating patchiness in the vegetation. This patchiness supports greater plant and animal diversity. The objective of our project was to evaluate the effects of burn season on fire severity, woody and herbaceous plant communities, and breeding bird communities. Our goal was to understand whether burning in different seasons might improve brushland habitat to meet the needs of diverse wildlife and plants.

Four study sites were each broken into four 100-acre burn units including spring, summer, fall, and a control. At eight points per unit, we collected pre- and post-burn plant and breeding bird data. We

found similar levels of loss of aboveground shrub stems in all seasons in patches that burned. However, we found that spring burns burned more area than fall or summer. Overall, spring burns were the most successful at reducing woody stem density one year after burn. However, spring burns created a uniform layer of resprouting shrubs. This could reduce habitat quality. We found that when there was a greater variety of stem heights, we found more bird species. Thus, burning in just one season could homogenize brushlands reducing their value to wildlife. Overall, our project suggest that managers should view fire season as a tool to support a variety of outcomes and maintain a diverse habitat that supports a diverse bird community. Our data will be used to develop best management practices for brushland habitats.

PROJECT RESULTS USE AND DISSEMINATION
Our project results were presented at numerous regional meetings of natural resource managers, including several workshops focused specifically on the use of fire in management. In addition, two M.S. theses were completed (Lori Knosalla and Annie Hawkinson) with peer-reviewed publications in progress.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 08f - Forest Management for Mississippi River Drinking Water Protection - $300,000 TF

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Appropriation Language
$300,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the Crow Wing Soil and Water Conservation District to pilot a water protection approach for the watershed through development of forest stewardship plans and targeted riparian forest restoration projects. Any expenditures from this appropriation spent on forest management plans or restoration must be for lands with a long-term contract commitment for forest conservation, and the restoration must follow the Board of Water and Soil Resources' native vegetation establishment and enhancement guidelines. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Keeping forests alive and surrounding our communities is vital for water protection, provides safe drinking water to residents, and benefits wildlife populations into the future. Landowners within the Camp Ripley Sentinel Landscape completed 76 forest stewardship plans totaling 13,104 acres and 38 water quality practices in their woodlands.

OVERALL PROJECT OUTCOME AND RESULTS
Forests provide vital functions including water protection, providing critical habitat for wildlife, and contributing resources which communities rely on. The conversion of land within the Camp Ripley Sentinel landscape is happening at an alarming rate. Upland forest lands within LSP have declined by 28 percent (200,000 acres). These riparian forest areas are threatened by rapid urban and rural residential development within the City of Baxter, Crow Wing, Cass, Morrison, and Todd Counties (MN 2010 Census Data). This project aimed to work with private residents and certified forest plan writers to engage landowners into completing a forest stewardship plan and implement a best Management Practice on their woodlands. These plans provide important information about their forest resources and make it easier to enroll into forest protection programs like the Sustainable Forest Incentive Act or 2c. Parcels were targeted based on modeling, MPCA watershed Restoration and Protection Plan goals, and the county water plan. Landowners were reached through mailings or talking with their local foresters or certified plan writers in the region. In total, 76 forest stewardship plans (13,104 Acres) were written by SWCD technicians or certified forest plan writers. All landowners were then enrolled into some form of forest protection program like a conservation easement, SFIA, or 2c. In addition, 38 water quality projects were implemented on those properties to benefit drinking water as well as improve wildlife habitat and forest resiliency. Minnesotans will directly benefit from this work because 1.7 million people draw their drinking water from the Mississippi River. Forests are natural filters which traps pollutants and treat stormwater before it enters a water body.

PROJECT RESULTS USE AND DISSEMINATION
Mailers and in-person meetings were the two main modes of communication with landowners in the LCCMR boundary. The SWCD produced countless materials that were sent to prioritized landowners about forest plans and water quality BMP's. The best success with outreach came from in-person meetings with landowners and certified forest stewardship plan writers. The plan writers already had a great working relationship with the community and could disseminate materials quickly and have those 1 on 1 conversations. The Crow Wing SWCD is developing a story map to present the successes to landowners and constituents. It will be an interactive map with resources for landowners.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09 Land Acquisition, Habitat and Recreation

Subd. 09b Minnesota Point Pine Forest Scientific and Natural Area Acquisition - $500,000 TF

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Appropriation Language
$500,000 the second year is from the trust fund to the commissioner of natural resources in cooperation

with the Duluth Airport Authority to acquire approximately ten acres as an addition to the designated Minnesota Point Pine Forest Scientific and Natural Area located along the shores of Lake Superior in Duluth.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The effort to acquire 10 acres of high-quality old growth forest and beach dune habitat from the Duluth Airport Authority as a new addition to Minnesota Point Pine Forest SNA was unfortunately unsuccessful during this appropriation's time-frame. However, opportunities to bring these parcels under protection may yet exist.

OVERALL PROJECT OUTCOME AND RESULTS
This appropriation came about due to a Duluth Airport Authority (DAA) ENRTF proposal in 2015 for funds to transfer about 10 acres of outstanding biodiversity significance to the DNR to create a new addition to (and contiguous ownership and management of) the existing Minnesota Point Pine Forest Scientific and Natural Area (SNA). The appropriation was awarded in ML16 (FY17) to DNR's SNA Program instead, to purchase the parcels from DAA / the City of Duluth following a more typical acquisition project model. DNR worked with DAA to write their application for a public waters permit to build out into the St. Louis Estuary to realign the Sky Harbor airport's runway, and thereby release the flight-path airspace into which the old-growth pines have been vertically growing. DAA/FAA (Federal Aviation Administration) release of that designated airspace once the runway realignment was complete, and subsequent sale of those acres to the SNA Program, was included in DAA's application for the public waters permit, since several rare features and critical habitat would be thereby placed under permanent SNA protections. However, after at least two appraisals and several appropriation extensions, the City/DAA did not respond to the DNR's February 2021 offer at certified Fair Market Value, which has led to DNR's inability to complete this project with the appropriated funds on time. The City of Duluth was not successful in an attempt to amend the original appropriation language to allow for the remainder of these funds to be granted to the Duluth Airport for the runway re-alignment instead of as compensation for a sale of the land. Rather than returning unused funds at the end of the award to the ENRTF corpus, funds were reallocated by the Legislature to other projects on June 30, 2021.This effort involved years of collaboration and negotiation between the DNR and the City of Duluth / DAA, among other stakeholders involved including the Minnesota Legislature, the Duluth City Council, the FAA and LCCMR. While ultimately unsuccessful on this appropriation, opportunities for protecting these acres may yet exist.

PROJECT RESULTS USE AND DISSEMINATION
This project has had no results to disseminate to date. Because of this project's inability to progress into the latter stages of acquisition and designation, none of the work completed thus far (largely professional services for acquisition e.g. appraisals, and staff hours devoted to the project) was deemed appropriate for public dissemination.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09g Otter Tail River Recreational Trail Acquisition - $600,000 TF

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Appropriation Language
$600,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with the city of Fergus Falls to acquire approximately 16 acres along the Otter Tail River for a recreational trail and park. This appropriation is contingent on at least a $400,000 match of nonstate money. Prior to the acquisition, a phase 1 environmental assessment must be completed and the city must not accept any liability for previous contamination of lands acquired with this appropriation.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The City of Fergus Falls proposed, but was unable, to acquire 3,476 lineal feet of frontage on the Otter Tail River.

OVERALL PROJECT OUTCOME AND RESULTS
The City of Fergus Falls proposed to acquire 3,476 lineal feet of frontage on the Otter Tail River. The former Mid-American Dairy property, a 28.9 acre industrial site fronting on the Otter Tail River in downtown Fergus Falls, is currently owned by the Fergus Falls Port Authority. In preparation for the acquisition by the City of Fergus Falls and with the guidance of a work plan approved by the MPCA, the site has been carefully returned to a green field site from its former industrial use and subdivided into two parcels, with 11.57 acres identified as the location of a multi-use non-motorized trail.

By obtaining 11.57 acres from the Port Authority, the City would ensure in perpetuity the protection of 3,476 lineal feet of river frontage and foster recreational activities led by trail development. The acquisition would provide public access to river frontage that was previously inaccessible as well as create a trail link that would provide a major point of future connectivity between the Central Lakes Trail and north bound Pelican to Perham Trail, with eventual connection to the Heartland Trail. The Dairy trail segment factored into trail master plans initiated and approved by the City of Fergus Falls and Otter Tail County and recognized as regionally significant by the Greater Minnesota Parks and Trails Commission.

Unfortunately, the City of Fergus Falls was unable to secure the approval of the DNR's Appraisal Management Unit for acquisition of the property, rendering the aforementioned project outcomes incomplete. It is therefore not clear that Minnesotans will benefit from the protection of and recreational access to the Otter Tail River in this location. The failure of this project suggests a rigidity of policy by State agencies that counteracts the will of the Legislature.

DNR comment:
The DNR's Attachment E process, which requires the review that Fergus Falls mentions, is designed to ensure that the will of the legislature regarding acquisitions with ENRTF funds is followed. ENRTF session law requires that we pay no more than 100% of appraised value, and Office of Grants Management Policy 08-11 states that we have a duty to monitor pass-through grants to the same standards applied to other state grants.

Accordingly, we apply to ENRTF pass-through grants the same appraisal quality standards that we apply to our own land acquisitions and those of competitive grants the DNR awards. We are tasked with conducting valuations in a way that is independent and unbiased for the protection of the funding sources and taxpayers of the State of Minnesota. Technical reviews are designed to ensure that the appraiser complied with USPAP and DNR Supplemental Guidelines on completing appraisals.

Fergus Falls submitted two appraisal reports, reviewed under two different qualified reviewers. In both cases the reviewer determined the appraisal met neither USPAP standards nor DNR Supplemental Guidelines. To reimburse using an appraisal determined to be inadequate would not have been consistent with the expectations set in appropriation law or OGM policy for the administration of these grants.

PROJECT RESULTS USE AND DISSEMINATION
This project has been closely monitored by both the City of Fergus Falls' City Council and the Fergus Falls Port Authority by in-person updates from the project manager.

Project Completed: 06/30/2022
FINAL REPORT

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5. M.L. 2015 Projects Completed January 15, 2021 – January 15, 2023

MN Laws 2015, Chapter 76, Section 2

M.L. 2015 Projects

MN Laws 2015, Chapter 76, Section 2 (beginning July 1, 2015)

Visit the LCCMR website for the most up-to-date project information and reports

Subd. 03 Foundational Natural Resource Data and Information

Subd. 03g Minnesota Native Bee Atlas - $790,000 TF

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Appropriation Language
$790,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to supplement and enhance existing bee survey efforts by engaging citizens in helping to document the distribution and phenology of wild Minnesota bees and integrating data from all related bee survey efforts into a single publicly accessible, online tool and repository. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
The Minnesota Bee Atlas relied on volunteers to collect data on native bee distribution and diversity as well as previously unstudied nesting phenology. This data supplements existing information from the Minnesota DNR and UMN Insect Collection and can inform land management and policy decisions.

OVERALL PROJECT OUTCOME AND RESULTS
Although the plight of bees and other pollinators has been highlighted recently, the question of how bees are doing is complicated. There is still much to be known about which bees live where in Minnesota and their population status. From 2015 through 2019, volunteers documented over 25,000 bees in Minnesota as a part of the Minnesota Bee Atlas. They did this by submitting photos of bees to iNaturalist, adopting roadside survey routes to capture, identify and release bumble bees, and monitoring nesting blocks for stem-nesting bees.

Through this work, five species were documented that had previously not been recorded in Minnesota. While it's difficult to know if they are new arrivals or just newly documented, Minnesota is at the northern end of the range for 3 of those species and could be evidence of shifting ranges.

Non-lethal bumble bee sampling led to documentation of additional populations of the federally endangered rusty patched bumble bee (Bombus affinis). This data informs the US Fish and Wildlife Service species recovery plan.

The Bee Atlas documented nest structures and nest activity for stem-nesting bees that had not

previously been recorded. This information may inform management decisions that would impact the amount of forage or nesting habitat available for bees as changes could be made at times when bees are less active.

Finally, the Bee Atlas engaged members of the public beyond volunteer participants when volunteers became active in their own communities. Volunteers shared their knowledge of bees and pollinator conservation with youth scout groups, 4-H youth, Master Gardeners, Master Naturalists, and countless friends and neighbors.

PROJECT RESULTS USE AND DISSEMINATION
All records from the Bee Atlas can be found in publicly accessible databases, namely iNaturalist.org and the Minnesota Biodiversity Atlas. Additionally, species-specific information such as seasonality, floral associations, and identification for bumble bees and stem-nesting bees can be accessed through the University of Minnesota Extension. All volunteer training documents are also found on this page.

Publications relating to this work have been published in the Journal of Melittology and The Great Lakes Entomologist.

Project Completed: 06/30/2021
FINAL REPORT
Record of Anthophora (Clisodon) terminalis in a wooden trap-nesting block and comparison to available nesting information (Hymenoptera: Apidae) by Colleen Satyshur
Minnesota State Records for Osmia georgica, Megachile inimica, and Megachile frugalis (Hymenoptera, Megachilidae), Including a New Nest Description for Megachile frugalis Compared with Other Species in the Subgenus Sayapis by Colleen Satyshur

Subd. 06 Aquatic and Terrestrial Invasive Species

Sub-Project 01: Garlic Mustard Biocontrol: Ecological Host Range of Biocontrol Agents - $570,173 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
We were integral in the release of Ceutorhynchus scrobicollis in Canada, the first biological control agent for garlic mustard in North America. We moved closer to federal regulatory approval to release C. scrobicollis and C. constrictus in the United States. When achieved, these will offer the first viable control of garlic mustard in Minnesota woodlands.
OVERALL PROJECT OUTCOME AND RESULTS

Garlic mustard poses significant threats to our forest ecosystem. Research supported by this grant develops effective biological control of garlic mustard in Minnesota, the United States, and Canada, offering the first viable control option for this troublesome invasive plant. We gained a recommendation that Ceutorhynchus scrobicollis be considered for a release in the U.S. from the APHIS PPQ Technical Advisory Group. In follow-up consultation between USDA-APHIS-PPQ and USFWS, questions were generated that were intended to expedite writing the Biological Assessment for C. scrobicollis. Funding from this grant enabled us to address those questions with specific research on three federally listed species. COVID-19 altered our timeline, yet we will be submitting the third edition of the response in August 2021. This funding supported Entomology PhD candidate Mary Marek-Spartz analyze predictive tools used to determine the expected range of biological control insects introduced to a new region, define specific biological thresholds of C. scrobicollis, and develop a novel biennial stage-structured plant-herbivore population model. She improved the accuracy of this model through data generated in our monitoring efforts funded from this grant. Also supported on this grant, Project Scientist Dr. Katovich further defined the vernalization requirements for a garlic mustard which will greatly improve the accuracy of the projected range of garlic mustard in the US, a key factor in determining the risk of introducing specific biological control insects to North America. Additionally, she completed host specificity testing for C. scrobicollis and made significant progress towards completing the registration package for C. constrictus. We have a draft of the petition for the release of C. constrictus for biological control of garlic mustard. Due to technical difficulties in rearing threatened and endangered species out of their normal habitats, we will complete the few species needed at CABI, Delémont CH.

PROJECT RESULTS USE AND DISSEMINATION

Knowledge gains have been distributed widely through professional and land manager meetings. Additionally, we presented our findings to our colleagues at the triennial International Symposium on the Biological Control of Weeds, hosted in 2018 by our cooperators from CABI, CH. Generations.py is a software program publicly available with a novel biennial component enabling modelers to improve predictions of the dynamics and biology of biennial organisms. We played a key role in the first release of a biological control insect for garlic mustard in North America. Additionally, four to six papers will be published in professional journals. A petition for the release of C. constrictus will be submitted to USDA APHIS PPQ TAG this fall or early next spring.

Subproject 01 completed: 06/30/2021

FINAL ABSTRACT

Sub-Project 02: Mountain Pine Beetle, Phase II: Protecting Minnesota - $445,347 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Repeated surveys did not find mountain pine beetle in Minnesota. Scant few individuals were captured dispersing far from active infestations in western states. We found that local bark beetles and predators do not optimally recognize the insect's chemical signals, however, suggesting that such components of invasion resistance might be low.

OVERALL PROJECT OUTCOME AND RESULTS

Surveys over the course of this project did not detect any mountain pine beetle in Minnesota. Although absence data cannot rule out inappropriate lure choices, testing of a new lure within the Black Hills of South Dakota where mountain pine beetle is endemic found that the conventional lure worked well. No improvements were noted when testing a new formulation. Long distance dispersal transects revealed that mountain pine beetles can be captured up to 30 miles away from active tree-killing outbreaks, but these singletons represented a fraction of a fraction of the population. Dispersal pressure was much lower in the last year of the project when beetles returned to endemic levels, which is the norm in western forests for decades at a time. Thus, we expect that the risk of mountain pine beetle reaching Minnesota by blowing from infestations in the Black Hills of South Dakota, which is approximately 500 miles away from the nearest mature pine forests in Minnesota, is extremely low. If mountain pine beetle was to arrive in Minnesota, it would have to establish into an environment with new flora (species of pines) and fauna (other species of bark beetles as well as their predators) to which it had never been exposed. The only species of pine common to the Black Hills and Minnesota is Scots pine; exposures to the fungus that mountain pine beetle carries revealed strong localized responses of Scots pine to the inoculation sites with defensive chemicals known as monoterpenes. Surveys of Minnesota's community of bark beetles, competitors, and predators responding to lures of mountain pine beetle in comparison to similar in the Black Hills revealed nuanced, regional variations in responses, but overall strong fidelity to cures of predators associated with local prey. Thus, we expect that predators or competitors in Minnesota would not optimally recognize the aggregation pheromone of mountain pine beetle. In one case with direct comparative tests in the Black Hills, we noted that one of the most common bark beetles that would potentially compete with mountain pine beetle in Minnesota, Ips grandicollis, avoids the lure of mountain pine beetle. We did note a few mountain pine beetles in traps baited with the aggregation pheromone of Ips grandicollis when the traps were placed far from active infestations of mountain pine beetle. This finding suggests that mountain pine beetle could respond to such pheromones as a "last-ditch" effort to find habitat during endemic periods where there are insufficient numbers to mass-attack, colonize, and kill large trees. If true, mountain pine beetle could find an endemic niche in Minnesota's pine forests. Because we still lack knowledge about how mountain pine beetles persist in endemic states, and whether colonization densities might actually be lower in other species of Minnesota's pines if they have lower defensive responses, continued vigilance against mountain pine beetle as a threat to Minnesota's pine forests is warranted.

PROJECT RESULTS USE AND DISSEMINATION

We have published one scientific paper from this work, with four more moving toward publication with peer-reviewed journal targets. We gave numerous regional, national, and even presentations as venues such as the Entomological Society of America, the IUFRO Conference on Biological Invasions in Forests, the North American Forest Insect Work Conference, North Central Forest Pest Workshop, Western Forest Insect Work Conference, Upper Midwest Invasive Species Conference, the Sustainable Forest Education Cooperative, State Forest Health Cooperators, Northern Advanced Silviculture Program, Minnesota Forest Industries, and MN Department of Natural Resources Forestry Team.

Subproject 02 completed: 12/31/2021

FINAL ABSTRACT
Colonization and reproduction of potential competitors with mountain pine beetle

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Sub-Project 03: Biological control of the soybean aphid by Aphelinus certus - $479,859 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Results of this study indicate that the parasitoid Aphelinus certus provides sufficient mortality of soybean aphids to substantially decrease the need to apply insecticides against this pest.

OVERALL PROJECT OUTCOME AND RESULTS

Prior to the year 2000, the approximately seven million acres of soybeans in Minnesota suffered very little insect damage and were seldom subjected to insecticide applications. This changed with the arrival of the soybean aphid from Asia during that year. This aphid rapidly became the most important insect pest of soybeans due to its ability to substantially lower soybean yield when present at high densities on plants. This led to a 'new normal' that included widespread insecticide use in soybeans in Minnesota, with areas in excess of one million acres sprayed in bad aphid years. While predatory insects were capable of suppressing populations in some years, this level of control was not consistent. We noted the arrival of a new natural enemy of soybean aphid in Minnesota in 2011, however – the parasitoid Aphelinus certus – that appeared to have the potential to be a game changer. This insect lays its eggs into soybean aphids, and the developing larvae kill the aphids from within. Our main objective was to determine the extent to which this parasitoid could control populations of soybean aphids below the level that necessitates insecticide use. We also hoped to elucidate agronomic strategies that could lead to increased control by this parasitoid. Based upon a combination of laboratory, field and theoretical studies, we were able to show that A. certus is indeed capable for suppressing soybean aphid densities below the threshold levels that farmers use to initiate insecticide use. Our theoretical simulations suggested that such control occurs in approximately 10% of fields during a given year. These studies also pointed to overwintering success of the parasitoids as a critical factor determining the strength of aphid suppression. It therefore stands to reason that any agronomic factors that increase overwintering success improve the parasitoid's capability of suppressing soybean aphid.

PROJECT RESULTS USE AND DISSEMINATION

This research led to new analytical tools to analyze the ability of the parasitoid Aphelinus certus to control populations of the soybean aphid. It also provided novel information on the primary overwintering site of the parasitoid (within soybean fields) and aspects of its overwintering and diapausing strategy. This information can be used to predict when A. certus adults will emerge in a given field season. Lastly, the research quantified the extent of control provided by this parasitoid and generated novel hypotheses for how control can be improved.

We generated an analytical tool using a stage-based matrix modeling approach and published it in an open access Journal. This model can be modified based on environmental and life-history characteristics for this or similar host-parasitoid systems and the underlying R code is available upon request from the authors.

Subproject 03 completed: 09/30/2021

FINAL ABSTRACT

A matrix model describing host–parasitoid population dynamics: The case of Aphelinus certus and soybean aphid

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Sub-Project 04: Decreasing Environmental Impacts of Soybean Aphid Management - $570,000 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Management of soybean aphid relies on applications of broad-spectrum insecticides. This work aimed to decrease insecticide use and ameliorate associated environmental impacts through development of aphid-resistant soybean and advancement of remote scouting.

OVERALL PROJECT OUTCOME AND RESULTS

The invasion of US soybean by the soybean aphid resulted in dramatic increases in insecticide use, which has increased production costs for farmers and environmental and human-health risks. This proposal takes a two-pronged approach (preventative and therapeutic) to improve management of the soybean aphid through decreased insecticide input, which will result in increased environmental and economic sustainability of soybean production. Integration of preventative and therapeutic pest management tactics is fundamental to integrated pest management (IPM). For preventative management, we advanced the development and availability of aphid-resistant soybean. This included advancement of numerous resistant soybean lines already in the soybean breeding pipeline, including commercial release of one line. Furthermore, numerous crosses were made to incorporate different combinations of aphid-resistance genes into soybean lines, and to test and advance them through the pipeline. Novel research was also performed to examine the variability in susceptibility of aphid populations to these aphid resistant lines. For therapeutic management, we advanced the ability to use remote sensing for soybean aphid through a series of field experiments and technological advancements. Through caged experiments and open-field experiments, we documented that aphid-induced stress to soybean can be detected from drone-based sensors. In addition, through additional caged experiments we found that typical levels of defoliation (<5%) from another insect, the Japanese beetle, is unlikely to affect the ability to scout for soybean aphid; however, higher levels of defoliation (>33%) could impact scouting for

soybean aphid. In addition, we built hardware to host new algorithms for autopilots used to guide small drones for accurate and safe pest management missions. We have tested the algorithm in simulation and by post-processing data collected from flight tests. These advancements will help farmers prevent soybean aphid outbreaks through the use of aphid-resistant soybean and to more effectively respond to outbreaks through efficient drone-based scouting.

PROJECT RESULTS USE AND DISSEMINATION

An aphid-resistant variety stemming from the work has become commercially available. Results of this project have been actively disseminated to stakeholders and the scientific community. Project results were shared in extension presentations to farmers and agricultural professionals throughout the life of this project and a video was created for stakeholders. A publication for stakeholders listed available resistant soybean varieties. Updates on this work were also shared at several scientific conferences. This work has led to scientific publications on remote sensing applications and technology (2019, 2020, 2021), and aphid-resistant soybean, and led to detection of a new soybean pest.

Subproject 04 completed: 12/31/2021

FINAL ABSTRACT

Observability and Performance Analysis of a Model-Free Synthetic Air Data Estimator
Two-Stage Batch Algorithm for Nonlinear Static Parameter Estimation
Variation in Soybean Aphid (Hemiptera: Aphididae) Biotypes Within Fields
First Reports of Macrosaccus morrisella (Lepidoptera: Gracillariidae) Feeding on Soybean, Glycine max (Fabales: Fabaceae)
Detection of Stress Induced by Soybean Aphid (Hemiptera: Aphididae) Using Multispectral Imagery from Unmanned Aerial Vehicles
Air data fault detection and isolation for small UAS using integritymonitoring framework

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Sub-Project 05: Optimizing Tree Injections against Emerald Ash Borer - $320,000 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Emerald ash borer continues to spread and devastate Minnesota's urban forests, but deploying the right types of insecticides to ash trees in the right ways can offer tree conservation and protection with minimal risk to non-target organisms such as bees that visit flowers and worms that decompose leaves.

OVERALL PROJECT OUTCOME AND RESULTS

Emerald ash borer is an invasive insect that kills mature ash trees and has been spreading within Minnesota since its detection in 2009. Ash is a major component of many of Minnesota's urban forests. Injections of insecticides into ash trees can preserve trees indefinitely, but raises concerns for non-target

organisms in the environment such as bees and earthworms. For this study, we injected subsets of 1200 trees located in eight different cities in Minnesota with two different insecticides. We specifically tested products that were not neonicotinoids that have presented past risks to pollinators. Insecticides were injected into the trunks in summer of 2017, with periodic reapplications until 2020 while we measured crown health of each tree each summer until 2021. The original site selections were in cities with low pressure from emerald ash borer. We found over the four years of the study that injecting only half of the trees in a given site gave good protection to all trees. We were unable to determine, however, whether this associational protection (i.e., preservation of canopy in an untreated tree when proximate to a treated tree), winter mortality to EAB, or some combination of both was responsible for the site-wide excellent conditions that persisted five years after EAB was present in these communities. Measurements of tree phenology such as leaf out and leaf drop showed that insecticides did not alter the timing of such events. One of the insecticides, emamectin benzoate, showed excellent protection of ash seeds against seed weevils by the third year of the study, without affecting seed viability. We also canvassed the insect communities that visited the trees and harvested leaves for feeding trials with nontarget organisms, and measured chemical concentrations in the leaves. We found that insects communities were similar between treated versus untreated trees across seasons, that bees preferred visiting synchronously flowering plants such as flowering crab apples and rhododendrons versus ash trees, that trunk-injected chemicals were not reliably detected in all plant parts after injection, and that invertebrates such as worms showed no reduction in reproduction or feeding on treated leaves. As such, we concluded that detrimental effects of the insecticides tested on non-target organisms are not likely to be ubiquitous or widespread. In summary, when homeowners or communities are selecting a product to preserve urban ash trees, we recommend emamectin benzoate as a suitable and effective alternative to neonicotinoid-based products.

PROJECT RESULTS USE AND DISSEMINATION

This work has been submitted for publication at two peer-reviewed journals, with two more submissions planned. The work has been presented at regional, national, and international venues including workshops and conferences such as the Shade Tree Short Course, the Entomological Societies of Canada and America, the IUFRO Conference on Biological Invasions of Forests, the North American Forest Insect Work Conference, the Upper Midwest Invasive Species Conference, the USDA Interagency Annual Forum, and the North Central Forest Pest Workshop. A number of presentations were also given to local community forestry and resource manager groups throughout the project, and we enjoyed a high number of interactions with members of the public while working in their communities.

Subproject 05 completed: 12/31/2021

FINAL ABSTRACT

Effects of systemic insecticides against emerald ash borer on ash seed resources

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Sub-Project 06: Distribution and Traits of the Fungal Pathogen Fusarium Virguliforme that Influence Current and Future Risk to Soybean and Other Legumes in Minnesota - $383,581 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project has discovered factors that influence the ability of the fungus Fusarium virguliforme to become established as a destructive pathogen on crops in new areas of Minnesota. The results are foundational to understanding this pathogen and contribute to managing the diseases it causes on soybean and other crops.

OVERALL PROJECT OUTCOME AND RESULTS
The fungal pathogen Fusarium virguliforme, which causes sudden death syndrome (SDS) on soybean and root rot of other legumes, is an expanding problem for crop producers in Minnesota. Our research team has made discoveries regarding the pathogen's ability to spread and cause disease. First, a survey has confirmed the spread of the pathogen for the first time into seven counties in central and western MN. Second, studies of nutrient use suggest that F. virguliforme grows on a larger number of carbon and nitrogen sources than many other fungi in crop fields, likely giving it a competitive advantage. Analysis of competition between F. virguliforme and other fungi from crop fields revealed that while several fungi can inhibit its growth, multiple others are overcome by the pathogen, indicating it is a good competitor in soil and roots. Third, we determined it can survive to -40°C and thus its spread is not likely limited by cold temperatures. Fourth, in field and greenhouse experiments investigating host range, multiple crop species (black bean, pinto bean, kidney bean, and pea) showed symptoms of disease, and multiple other plant species were infected asymptomatically. Fifth, we completed a study and a publication on genetic and pathogenic variation among F. virguliforme populations in Minnesota and the Midwest. While genetic groups did not correspond to aggressiveness, three genetic clusters were identified, with two clusters likely contributing most to spread of this fungus. Sixth, we completed initial analysis of genomes from 35 isolates to investigate genes involved in pathogenicity and abilities to invade new environments. The projected trained one M.S. level and one postdoctoral level scientist, expanding expertise for addressing invasive plant pathogens. This project significantly advances fundamental and applied knowledge of F. virguliforme that can be harnessed for disease management and risk analysis by scientists, agricultural professionals, and crop producers.

PROJECT RESULTS USE AND DISSEMINATION
This project has discovered multiple factors that influence the ability of F. virguliforme to spread and become established as a destructive pathogen on crops in new areas. Results have been presented via University of Minnesota Extension programs to key agricultural professionals and crop producers across Minnesota that contribute to managing this pathogen and the crop diseases it causes. Results have also been presented at scientific conferences and are being published in scientific journals.

Subproject 06 completed: 06/30/2021
FINAL ABSTRACT

Sub-Project 07: Tools to Distinguish Native from Exotic Reed Canary Grass - $263,273 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS

This project used genetic techniques to find that most reed canarygrass in Minnesota is native to the state and not from Europe. Plant DNA was extracted from samples of reed canarygrass across the state. Due to this outcome, Tribal and State managers may choose to manage or preserve this species differently.

OVERALL PROJECT OUTCOME AND RESULTS

The goal of this project was to use molecular markers to determine native vs. exotic reed canary grass status in various locations across Minnesota growing along rivers (Des Moines, Minnesota, Mississippi, Red, Roseau, St. Croix), in fields, as commercially-grown cultivars (forage, ornamental), and preserved historic specimens in herbaria (<1940, presumed native) and a corollary set of samples from rivers in the Czech Republic as exotic comparisons (Activity 1); along Minnesota transportation corridors (highways) existing during the 1920s-1930s (Dust Bowl era) and Minnesota lakes (Bush, Cedar, Como, Phalen, Mille Lacs, Minnetonka, Square, White Bear) and Central Park (Activity 2). Due to Covid-19 travel restrictions, we were unable to get permission to collect along additional lakes. The number of plants analyzed totaled 3,430 (Activities 1,2). Plant DNA was extracted from each sample to determine genomic markers of short DNA sequences (2,889 highly differentiated single nucleotide polymorphisms, SNPs, out of 16,902 total markers) to distinguish native vs. exotic status. Genetic analysis of reed canarygrass showed that river populations are native Minnesota or North American types. Herbarium samples as well those from a native, unplowed field (Roseau, MN) were genetically similar to wild collections from five Minnesota rivers; forage cultivars in commercial fields (Roseau, MN) and along the Roseau River formed a separate group. The exotic central European populations were distinctly different from all native MN groups. Most variation is within (98.8%), rather than among (1.2%), populations, suggesting little divergence and a high level of shared genetic markers. Across the state, Minnesota rivers had 2-32 genetic variants present, some of which were shared among rivers. Thus, the majority of Minnesota reed canarygrass, while invasive, is native in origin and not exotic (European). Thus, based on this study, all of MN reed canarygrass is native; Tribal and State managers may choose to preserve this species.

PROJECT RESULTS USE AND DISSEMINATION

Dissemination of native vs. exotic status of all Phalaris results from Activity 1 has been reported on the Department of Horticultural Science website (http://horticulture.umn.edu), that of the PIs (http://horticulture.umn.edu/directory/faculty/neil-oanderson), as well as in all PIs/co-PIs Experts at umn.edu links (https://experts.umn.edu/). As many as 11 abstracts were published in national and international meetings, along with corollary public posters sessions or seminar talks to varied audiences of academics, land managers, students, and/or the public-at-large. We have kept State and Tribal Land Managers informed on the native status of MN reed canarygrass and have initiated discussions on approaches to managing this native species yet invasive. The investment by the state on control measures for this invasive grass warrant careful consideration of best management approaches to maintaining the native genetic diversity yet not encouraging the invasive spread of this grass into managed areas. Results were also communicated to the scientific community in peer-reviewed journal articles.

Subproject 07 completed: 06/30/2020
FINAL ABSTRACT

Sub-Project #8. Accurate detection and integrated treatment of oak wilt *(Bretziella fagacearum)* in Minnesota - $356,382 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project developed methods and approaches for better detection of oak wilt using spectroscopic technology and documented best practices to prevent spread of the disease.

OVERALL PROJECT OUTCOME AND RESULTS
Our team has made substantial progress on the development of methods and approaches for accurate detection of oak wilt in Minnesota forest using spectroscopic technology. We have also documented best practices for management efforts to prevent spread of the disease. Specifically, we have completed physiological experiments demonstrating the disease can be differentiated from other stress factors under controlled conditions (Activity 1). A manuscript on the greenhouse seedling experiment using leaf and whole plant spectroscopic data to differentiate oak wilt from bur oak blight and drought has been published in Tree Physiology. We have advanced analyses and ground-truthing of AVIRIS NG airborne imagery including model development and spectral index development for stress physiology in response to the oak wilt disease (Activity 2). In an outdoor field experiment using naturally growing oak saplings at the Cedar Creek Ecosystem Science Reserve, oak saplings were inoculated with oak wilt and compared to healthy saplings using leaf and canopy spectroscopy. Results indicate that physiological disease symptoms can be readily detected using spectral sensors at both leaf and canopy scales using statistical models and simple indices from spectral features linked to physiological stress. Lastly, treatments were completed at 20 oak wilt sites with a new “double plow line” to prevent spread of the disease through root grafts. Initial assessments indicate the approach is highly effective, but a final determination will be made 5 years after treatment, beyond the life of this project (funding secured from USDA Forest Service). Two postdoctoral scientists, a technical scientist, a first-year graduate student and two undergraduate research assistants received training and mentoring during the project.

PROJECT RESULTS USE AND DISSEMINATION
Our team has disseminated new knowledge from this project to local, regional, national and international audiences. A significant peer-reviewed publication has already come this project (Beth Fallon, Anna Yang, Cathleen Lapadat, Isabella Armour, Jennifer Juzwik, Rebecca A Montgomery, Jeannine Cavender-Bares. 2020. Spectral differentiation of oak wilt from foliar fungal disease and drought is correlated with physiological changes. Tree Physiology 40(3): 377–390, https://doi.org/10.1093/treephys/tpaa005). Others are in development. The team delivered 11 talks,

three posters, and one field tour to professional audiences. In addition, the project was featured in The Minnesota Daily and Market Science (scientific engagement at farmers' markets).

Subproject 08 completed: 06/30/2020
FINAL ABSTRACT

Sub-Project 10: Management Strategies for the Invasive Spotted Wing Drosophila - $478,876 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our project developed new cost-effective methods to help growers manage damage and reduce yield loss caused by the invasive Spotted-wing drosophila in small fruit while reducing pesticide use. Additionally, we have gained basic knowledge on the behavior and flight capabilities of this pest that will contribute to future management strategies.

OVERALL PROJECT OUTCOME AND RESULTS
Spotted wing drosophila (Drosophila suzukii, SWD) is an invasive fly that lays eggs in intact, ripening fruit such as blueberries, strawberries, and raspberries. This pest has caused considerable economic losses for small fruit growers. First detected in MN in 2012, SWD threatens 750 acres of raspberries, strawberries, grapes, and blueberries, in addition to its 5,000 high tunnel operations statewide. At the start of our project, current control tactics were limited to repeat applications of broad-spectrum insecticides that failed to adequately protect fruit from infestation, in addition to posing risks to the environment. Additionally, we faced gaps in understanding the basic biology ad behavior or SWD, such as migration and overwintering in Minnesota, which hindered our ability to recommend appropriate management strategies. To address this, we proposed three goals: 1) develop SWD forecasting tool using local migration and overwintering data; 2) investigate efficacy of alternative management techniques; and 3) research economic impact and develop decision making tools. As a result of our work, we have indirect evidence showing that SWD may be overwintering and little evidence that the SWD has the flight capabilities for long-distance movement. We learned that physical exclusion can effectively reduce SWD damage and is cost-effective for small farms and reduces the need for insecticide sprays. Our work on biopesticides and novel repellants shows promising results in the lab but is less consistent in the field, warranting new methods to increase field efficacy. Economically, we found that SWD is responsible for at least $2 million in losses annually to raspberry growers alone, establishing the need for management for the statewide fruit industry, and growers can benefit from adopting physical exclusion and biological based pesticides. Our science-based management recommendations for this best improves overall sustainability of small fruit production in Minnesota.

PROJECT RESULTS USE AND DISSEMINATION
Our project has resulted in six peer-reviewed publications in scientific journals, eight academic presentations, over thirty talks to grower audiences and dozens of online newsletters, articles, and blog submissions, and a grower decision making tool. Grower recommendations are available on the FruitEdge website and archives on the UMN Extension Fruit and Vegetable News. Through this work, we have leveraged an additional $750,000 in federal funds to further develop sustainable production and pest management techniques for small fruit in Minnesota.

Subproject 10 completed: 08/31/2021
FINAL ABSTRACT

Sub-Project 11: Will Future Weather Favor Minnesota's Woody Invaders? - $514,325 TF

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SOUND BITE OF PROJECT OUTCOMES AND RESULTS
Our findings tell the story of how exotic honeysuckle and buckthorn have invaded Minnesota forests, how and why new areas are likely to be invaded in the future, and how we may be able to mitigate invasion using native tree species.

OVERALL PROJECT OUTCOME AND RESULTS
Glossy buckthorn, common buckthorn, tatarian honeysuckle, and morrow's honeysuckle are woody species that have been introduced to Minnesota forests from other continents. All four species frequently dominate forests and exclude native plant species. Warming temperatures and continued dispersal of these species are likely to significantly increase their abundance throughout Minnesota, especially in northern Minnesota. However, most effort by researchers and managers alike has been given to reactive measures against invasion instead of increased understanding of invasion processes and/or preventative measures. This project evaluated the climate sensitivity of these four invasive species in a way that provides for more accurate threat assessment of each throughout the state and provides tools for Minnesotans to potentially slow invasion into new areas and protect Minnesota's forests. We analyzed growth rings of 274 trees to determine how quickly invasive species spread and characterize how native and invasive species have responded to past growing conditions. We found that growth rates of invasive buckthorn and honeysuckle are most similar to native cherries and ashes in southern Minnesota, but that the invasive species already are growing much faster than those native species in northern Minnesota. Within a forest, we found that buckthorn tended first to invade hilltops and subsequently spread to low-lying areas at a rate of 3-4m yr-1 (slower than honeysuckle, which spread at 6 m yr-1). We experimentally assessed 10 native species in addition to the four invaders to determine which are favored by changing temperature and rainfall patterns (i.e. their responses to future climate). We found invasive and more southern native species to be favored by warming

conditions in terms of their growth and survival, whereas more northern native species were often strongly disfavored. We established programs to detect current invasion at fine-scale spatial resolution and predict future invasion based on the findings above, and set up long-term experiments to test the ability of tree plantings to slow invasion into new areas.

PROJECT RESULTS USE AND DISSEMINATION
Results from this project were disseminated through multiple avenues, including conference presentations, journal articles, and popular media. Principally, dissemination efforts focused on academic journals. We have submitted one manuscript detailing results from Activity 2 for peer review. Three other manuscripts related to the project are in preparation and will be submitted during the spring of 2022. We are also collaborating with National Geographic for a feature on work supported by this grant, primarily results associated with Activity 2.

Subproject 11 completed: 12/31/2021
FINAL ABSTRACT

Subd. 08 Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Subd. 08b Propagating Native Plants and Restoring Diverse Habitats - $495,000 TF

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Appropriation Language
$495,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the Martin County Soil and Water Conservation District for a cooperative 13-county effort by Blue Earth, Brown, Cottonwood, Crow Wing, Faribault, Freeborn, Jackson, Lake, Le Sueur, Martin, Nicollet, Waseca, and Watonwan Counties to protect and expand native forest and prairie habitat for species in greatest conservation need in four regions of the state through collection and propagation of local ecotype native plants, habitat restoration efforts, and educational outreach. This appropriation is available until June 30, 2020, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This project enhanced the number and variety of native plant species on sites across the state of Minnesota. By working with a variety of partners, we were able to reach citizens from the border of Iowa up to Lake Superior, and teach many people about the importance of native habitats.

OVERALL PROJECT OUTCOME AND RESULTS
Minnesota is blessed to have a variety of habitats all across the state. The Thirteen Counties project focused on improving those diverse habitats by restoring uncommon native plant species. This had a secondary benefit of also providing habitat for other at-risk species. Local sourced species were chosen for planting that matched the growing conditions on the restoration site. Species selection was made depending on local

species availability and the characteristics of the sites.

Plant materials were collected locally from species that have little or no presence in restorations. Over 50,000 plants were propagated of 50 different species. Prior to establishing new native plant species on site, invasive species sometimes had to be removed. Restorations occurred on over 15 different sites across the state. Funds were directly used on sites in 4 different counties and technical assistance was provided to projects in 2 additional counties. While projects did not occur in 7 of the counties, project participants still heard updates about grant progress at regional meetings in southcentral Minnesota. The degree of invasive species removal varied from site to site. Some of the invasive species removed during this project were Common Tansy and Japanese Barberry. Resilient native species, such as Grass Leaved Goldenrod, were planted in place of the invasive species with the goal of being able to out-compete the invasive species long term. In Cottonwood County, for example, invasive buckthorn was removed and replaced with local dogwood shrubs.

Martin SWCD and project partners reached over 700 people (volunteers, students, etc.) through direct interaction at planting events and workshops. Thousands more were reached through social media, newsletters, radio, and local newspapers. Over 20 workshops and trainings were held as well. Some of the workshops were hands-on activities in the field, where others were more general topics in a classroom that focused on the difference between native and invasive species. Martin SWCD staff was able to share the knowledge they have gained about plant propagation from previous projects with other Southern Minnesota counties and with project partners at Crow Wing and Lake County SWCDs. The education transferred from experienced SWCD staff to new SWCD staff will be invaluable for years to come.

The most important achievement of this project is the number of people who learned more about habitats native to their region of the state. Individuals will take this knowledge and work on promoting and protecting native species in their own backyard, and pass it on for future generations to learn.

PROJECT RESULTS USE AND DISSEMINATION
Activities under this project were disseminated using a variety of different methods. Restoration sites were shown on Facebook as well as in videos on YouTube. Project information was also shared with numerous school classes, local elected Boards, volunteer organizations (Rotary Club, etc.), conservation clubs and at County Fairs. This project work was also covered in local newsletters and websites of the partner Soil and Water Conservation Districts. Over the years of the project, there were also a number of media outlets covering project work.

Project Completed: 06/30/2021
FINAL REPORT

Subd. 09 Land Acquisition for Habitat and Recreation

Subd. 09i Mesabi Trail Development Soudan to Ely - Phase II - $1,000,000 TF

Bob Manzoline
St. Louis and Lake Counties Regional Railroad Authority
111 Station Rd
Eveleth, MN 55734

Phone: (218) 744-2653
Email: bmanzoline@rrauth.com

Appropriation Language
$1,000,000 the first year is from the trust fund to the commissioner of natural resources for an agreement with the St. Louis and Lake Counties Regional Railroad Authority for the right-of-way acquisition, design, and construction of segments of the Mesabi Trail, totaling approximately seven miles between Soudan and Ely. This appropriation is available until June 30, 2018, by which time the project must be completed and final products delivered.

SOUND BITE OF PROJECT OUTCOMES AND RESULTS
This segment, approximately 3 miles, of the Mesabi Trail starting from Highway 169 underpass to County Road 88 has been completed. We were able to construct the trail on portions of the former railroad grade, however, we ran into many road blocks from landowners that wouldn't allow for the trail to be on their property. Several alternative routes were considered. Right-of-way, environmental permitting, trail design, engineering and construction were completed with the best available route for this paved segment of the Mesabi Trail. We also came across old culverts needing replacement and were able to complete the project within our budget.

OVERALL PROJECT OUTCOME AND RESULTS
Completing the Mesabi Trail segment from the Highway 169 underpass to County Road 88 required the following analysis criteria and steps: route alternatives analysis; historic/cultural resource; social, economic and environmental effects; agency coordination; reports, notices and hearings; wetland delineation and mitigation; and final outcome. Four alternative routes were considered and evaluated, with the best final route determined by the above analysis. There were many delays encountered after selecting the route, namely right-of-way acquisitions. Originally, we were looking to use the abandoned railroad grade for the majority of this trail segment. However, many landowners owned parcels along the grade not allowing for easements. We again needed to adjust our trail route and moved approximately 1.0 mile to be along the Highway 169 right-of-way. This in turn, needed further environmental wetland, impact evaluations and engineering. In the end, approximately 18 acres through 22 parcels were acquired with easements, fee title, lands that the Regional Railroad Authority purchased and Limited Use Permits required to be alongside the highway right-of-way. All were purchased with non-ENRTF funds. Other items not anticipated were two culverts needing replacement as they were deteriorating and required adequate water flow away from the trail and other landowner's properties. Construction of the trail, COVID and personnel were other setbacks on completing this segment. With these unanticipated events, we were able to complete this trail project under budget. This segment of the Mesabi Trail near Ely, MN will be enjoyed by outdoor recreationalists for many years to come and are another segment closer to completing the continuous path of the Mesabi Trail from Grand Rapids to Ely.

PROJECT RESULTS USE AND DISSEMINATION
This trail segment was discussed at a public meeting held for another segment of trail, known as "Camp Lake Road to Highway 1/169 Underpass," and received recognition in the Ely Echo News. This trail segment has also been presented at local gatherings such as Ely Rotary, Ely City Council, Morse Township Board of Commissioners, Ely Chamber of Commerce, Ely Economic Development Authority and Visit Ely Convention & Visitors Bureau. Mesabi Trail news and updates are provided through a variety of media, marketing and publications. Web site is: Mesabitrail.com.

Project Completed: 12/31/2022
FINAL REPORT

6. M.L. 2014 Projects Completed
January 15, 2021 – January 15, 2023

MN Laws 2014, Chapter 226, Section 2

M.L. 2014 Projects

MN Laws 2014, Chapter 226, Section 2 (beginning July 1, 2014)

MN Laws 2014, Chapter 312, Article 12, Section 8 (beginning July 1, 2014)

Visit the LCCMR website for the most up-to-date project information and reports

Sec. 08 Invasive Terrestrial Plants and Pests Center

Sec. 08 Invasive Terrestrial Plants and Pests Center - Research Project - $1,460,000 TF

Rob Vennette
U of M - Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC)
1992 Folwell Avenue
St Paul, Minnesota 55108

Phone: (612) 301-1405
Email: venet001@umn.edu
Web: http://www.mitppc.umn.edu/

Appropriation Language
$490,000 in 2015 is from the environment and natural resources trust fund for the Invasive Terrestrial Plants and Pests Center requested under this act, including a director, graduate students, and necessary supplies. This is a onetime appropriation and is available until June 30, 2022.

$970,000 from the environment and natural resources trust fund appropriated in Laws 2011, First Special Session chapter 2, article 3, section 2, subdivision 9, paragraph (d), Reinvest in Minnesota Wetlands Reserve Acquisition and Restoration Program Partnership, is transferred to the Board of Regents of the University of Minnesota for the Invasive Terrestrial Plants and Pests Center requested under this act, including a director, graduate students, and necessary supplies and is available until June 30, 2022.

Project Overview
Terrestrial invasive species are species that are not native to a location and that pose critical ecological and economic challenges once they become established in that location. They come in the form of plants, animals, insects, pathogens, and microbes that can cause harm to natural habitat, urban landscapes, and agricultural systems. The problems posed by terrestrial invasive species continue to grow as existing infestations expand and new exotic species arrive, many of which are poorly understood. New ideas and approaches are needed to develop solutions and to stay on top of emerging threats. The University of Minnesota is using this appropriation to help launch a new interdisciplinary Terrestrial Invasive Species Research Center charged with using scientific findings to support policy-making, application, and resource management practices that address the terrestrial invasive species affecting Minnesota. The center will coordinate initiatives focused on prevention of establishment, early detection and rapid response, development of new control methods and technology, integrated pest management, and minimizing non-target impacts of control. Proven tools and techniques developed at the center are intended to be implemented statewide as applicable.

Sub-Projects M.L. 2014, Sec. 08:

- *01: Novel Diagnostic Tools for Rapid and Early Detection of Oak Wilt* - $271,911
- *02: Early Detection, Forecasting and Management for Halyomorpha halys* - $616,081
- *03: Climate Change and Range Expansion of Invasive Plants* - $206,335
- *04: Cover It Up! Using Plant to Control Buckthorn* - $327,000
- *05: Terrestrial Invasive Species Prioritization* - $32,000

SOUND BITE OF PROJECT OUTCOMES AND RESULTS

Funding enabled the establishment of the Minnesota Invasive Terrestrial Plants & Pests Center (MITPPC). MITPPC now drives discoveries to prevent or reduce threats posed by priority invasive species to Minnesota lands. We bring University-of-Minnesota researchers together with partners from around the state, taking a programmatic approach to make thoughtful research investments and solve complex problems.

OVERALL PROJECT OUTCOME AND RESULTS

MITPPC, established by the Minnesota Legislature in 2014, has become a national leader in research to protect Minnesota's forests, prairies, wetlands, and agricultural lands from invasive species. Under this first appropriation, MITPPC set up its internal operations; established an advisory board, comprised of representative stakeholders from agriculture and natural resource sectors; developed a prioritization process and document upon which the RFP was based; made five research awards; and worked with LCCMR staff to appropriately document an ENRTF appropriation of this scope. Significant accomplishments include:

- Sub-project #1: Dr. Abdennour Abbas and his team developed novel detection and diagnostic tools for the oak wilt pathogen, generating patents and significant publications with spin-off applications for other invasive pathogens. These new technologies will reduce the time necessary to confirm the pathogen.
- Sub-project #2: Dr. William Hutchison and his team greatly improved our understanding of the biodynamics of the brown marmorated stinkbug, Halyomorpha halys. A stinkbug app ("The Midwest Stinkbug Assistant") and climate suitability models by Drs Twine and Snyder were important contributions for early detection and management of this pest.
- Sub-project #3: Drs. David Moeller and Ryan Runquist completed a deep dive into climate and range maps for 10 current and emerging invasive plants, including Palmer amaranth. Their maps can guide management decisions about surveillance and eradication efforts for these species.
- Sub-project #4: Dr. Peter Reich and colleagues have demonstrated the utility of planting native plants to help manage common buckthorn. Their findings suggest managers can simultaneously increase forest health, inhibit invasion, and reduce the need for investment in future buckthorn removals.
- Sub-project #5: Dr. Amy Morey provided critical on-going research into terrestrial invasive species (TIS) prioritization. A research publication summarizes MITPPC's unique approach to the process that has been applied to more than 200 TIS and drives its requests for research proposals.

PROJECT RESULTS USE AND DISSEMINATION

The MITPPC's impact can be measured by the dissemination of its applied results. In-person interviews and engagements (108 presentations around the state) and peer-reviewed publications (e.g., 12 papers in high profile journals as Restoration Ecology, the Journal of Economic Entomology, and the Journal of Biogeography) provide initial outlets to share progress of the Center. MITPPC amplifies these messages

and engages broader, diverse audiences through social media and on-line content, such as MITPPC's website, Twitter account, and YouTube channel and these messages are further amplified through other outlets (e.g., local press, newsletters, etc.).

Project Completed: 06/30/2022
FINAL REPORT - 64 pgs
Managing Invasive Buckthorn - 14 pgs
A participatory method for prioritizing invasive species: Ranking threats to Minnesota's terrestrial ecosystems - 10 pgs

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- **Spreadsheet of all research projects completed between January 1, 2021 and December 31, 2022.**

Environment and Natural Resources Trust Fund (ENRTF)

Research Projects completed between January 1, 2021 and December 31, 2022

Full abstracts are included in Section III. Completed Research Projects

Year	Subd.	Title	Organization	Project Manager	Funding Amount
2014	Sec 8	Minnesota Invasive Terrestrial Plants and Pests Center	U of MN - MITPPC	Robert Venette	$ 1,460,000
2015	06a-01	Sub-Project 01: Garlic Mustard Biocontrol: Ecological Host Range of Biocontrol Agents	U of MN - MITPPC	Roger Becker	$ 600,000
2015	06a-02	Subproject #2: Mountain pine beetle, Phase III: Protecting Minnesota	U of MN - MITPPC	Brian Aukema	$ 444,982
2015	06a-03	Subproject #3: Biological control of the soybean aphid by Aphelinus certus	U of MN - MITPPC	George Heimpel	$ 479,859
2015	06a-04	Subproject #4: Decreasing environmental impacts of soybean aphid management	U of MN - MITPPC	Robert Koch	$ 570,000
2015	06a-05	Subproject #5: Optimizing tree injections against emerald ash borer	U of MN - MITPPC	Brian Aukema	$ 318,927
2015	06a-06	Subproject #6: Distribution and Traits of the Fungal Pathogen Fusarium Virguliforme that Influence Current and Future Risk to Soybean and Other Legumes in Minnesota	U of MN - MITPPC	Dean Malvick	$ 383,651
2015	06a-07	Sub-Project 07: Tools to Distinguish Native from Exotic Reed Canary Grass	U of MN - MITPPC	Mary Rogers	$ 263,273
2015	06a-08	Sub-Project #8. Accurate detection and integrated treatment of oak wilt (Bretziella fagacearum) in Minnesota	U of MN - MITPPC	Jeannine Cavender-Bares	$ 356,382
2015	06a-10	Subproject #10: Overwintering, Migration and Development of Cost-Effective Practical	U of MN - MITPPC	Mary Rogers	$ 477,541
2015	06a-11	Subproject #11: Will Future Weather Favor Minnesota's Woody Invaders?	U of MN - MITPPC	Peter Reich	$ 526,000
2016	06a-01	MITPPC - Phase III - Fungi in Ash Trees: Towards Protecting Trees from Emerald Ash Borer and New Diseases	U of MN	Robert Blanchette	$ 500,000

Environment and Natural Resources Trust Fund (ENRTF)

Research Projects completed between January 1, 2021 and December 31, 2022

Full abstracts are included in Section III. Completed Research Projects

Year	Subd.	Title	Organization	Project Manager	Funding Amount
2016	06a-02	MITPPC - Phase III - Understanding the Benefits and Limitations of Using Goats for Invasive Plant Control	U of MN	Tiffany Wolf	$ 445,533
2016	06a-03	Sub-Project 03: Genetic Control of Invasive Insect Species: Phase I	U of MN	Michael Smanski	$ 296,655
2016	06a-04	Sub-Project 04: Dwarf Mistletoe Detection and Management in Minnesota	U of MN	Marcella Windmuller-Campione	$ 433,250
2016	06a-05	Sub-Project 05: Developing Spatially Explicit Bio-economic Dispersal Model to Aid with the Management of Brown Marmorated Stink Bug	U of MN	Senait Senay	$ 329,354
2016	06a-07	Sub-Project 07: Building Mechanistic and Process based Species Distribution Models for Common Tansy and Leafy Spurge: from Landscapes to Genomes	U of MN	David Moller and Ryan Briscoe Runquist	$ 351,188
2016	06a-09	Sub-Project 09: Genetic control of invasive insects, Phase 2	U of MN	Michael Smanski	$ 60,000
2016	06c	Advancing Microbial Invasive Species Monitoring from Ballast Discharge	U of MN - Duluth	Randall Hicks	$ 368,000
2016	08b	Measuring Pollen and Seed Dispersal for Prairie Fragment Connectivity	U of MN	Lauren Sullivan	$ 556,000
2016	08d	Evaluate Prescribed Burning Techniques to Improve Habitat Management for Brushland Species	U of MN	Rebecca Montgomery	$ 267,000
2017	03c	Preserving Minnesota Prairie Plant Diversity – Phase II	U of MN	Ruth Shaw	$ 900,000
2017	03f	Assessment of Microbes for Improving Wild Rice Restoration	U of MN - Duluth NRRI	Chan Lan Chun	$ 334,000
2017	03k	Cedar Creek Natural Area Wolf Recolonization Assessment	U of MN	Forest Isbell	$ 398,000
2017	03l	Effects of Wolf Predation on Beaver, Moose, and Deer	Voyageurs National Park	Steve Windels	$ 293,000

Environment and Natural Resources Trust Fund (ENRTF)

Research Projects completed between January 1, 2021 and December 31, 2022

Full abstracts are included in Section III. Completed Research Projects

Year	Subd.	Title	Organization	Project Manager	Funding Amount
2017	03m	Mapping Taxonomy and Environmental Toxicology of Minnesota Freshwater Sponges	U of MN	Anthony Schroeder	$ 258,000
2017	04b	Wastewater Nitrogen Removal Technology to Protect Water Quality	U of MN	Paige Novak	$ 450,000
2017	04e	Reassessing Toxicity of Petroleum Spills on Groundwater and Surface Water	St. Thomas University	Dalma Martinovic-Weigelt	$ 300,000
2017	06a	Aquatic Invasive Species Research Center - Phase II	U of MN - MAISRC	Nicholas Phelps	$ 2,700,000
2017	06a-04.3	Social Learning and Carp Removal	U of MN - MAISRC	Przemek Bajer	$ 189,475
2017	06a-08.2	Impacts of Invader Removal on Native Vegetation Recovery	U of MN - MAISRC	Daniel Larkin	$ 119,034
2017	06a-12.2	Historical Analyses of Spiny Water Flea Invasion Patterns	U of MN - MAISRC	Donn Branstrator	$ 53,795
2017	06a-15	Determining Highest Risk Vectors of Spiny Water Flea Spread	U of MN - MAISRC	Valerie Brady	$ 26,581
2017	06a-16.2	AIS Impacts on Walleye Populations and Mercury Concentrations	U of MN - MAISRC	Gretchen Hansen	$ 199,862
2017	06a-18.2	Genetics to Improve Hybrid and Eurasian Watermilfoil Management	U of MN - MAISRC	Raymond Newman	$ 236,423
2017	06a-20	A Novel Technology for eDNA Collection and Concentration	U of MN - MAISRC	Abdennour Abbas	$ 96,264
2017	06a-21.2	Field validation of mulitbeam sonar zebra mussel detection (Year 1)	U of MN - MAISRC	Jessica Kozarek	$ 14,247
2017	06a-22	Copper-Based Control – Zebra Mussel Settlement and Non-Target Impacts	U of MN - MAISRC	James Luoma	$ 152,090
2017	06a-23	AIS Management: An Eco-economic Analysis of Ecosystem Services	U of MN - MAISRC	Amit Pradhananga	$ 110,245
2017	06a-24	Genetic Method for Control of Invasive Fish Species	U of MN - MAISRC	Michael Smanski	$ 140,004
2017	06a-25	What's in Your Bucket? Quantifying AIS Introduction Risk	U of MN - MAISRC	Nicholas Phelps	$ 84,094

Environment and Natural Resources Trust Fund (ENRTF)

Research Projects completed between January 1, 2021 and December 31, 2022

Full abstracts are included in Section III. Completed Research Projects

Year	Subd.	Title	Organization	Project Manager	Funding Amount
2017	06a-28	Evaluating Innovative Coatings to Suppress Priority AIS	U of MN - MAISRC	Mikael Elias	$ 51,234
2017	06a-30	Managing Midwestern Aquatic Invasions in a Changing Climate	U of MN - MAISRC	Ranjan Muthukrishnan	$ 39,000
2017	07a	Extraction of Solar Thermal Energy in Minnesota	U of MN	Lian Shen	$ 250,000
2017	08c	Evaluating the Use of Bison to Restore and Preserve Savanna Habitat	U of MN	Forest Isbell	$ 388,000
2017	08e	Enhancing Spawning Habitat Restoration in Minnesota Lakes	U of MN - St. Anthony Falls Laboratory	William Herb	$ 294,000
2018	03e	Assessing Natural Resource Benefits Provided by Lichens and Mosses	U of MN	Daniel Stanton	$ 213,000
2018	03g	Conserving Minnesota's Forest Birds of Management Concern	U of MN - Duluth NRRI	Alexis Grinde	$ 500,000
2018	03h	Mapping Avian Movement in Minnesota	U of MN - Duluth NRRI	Alexis Grinde	$ 200,000
2018	03j	Develop Sonar Data Mapping on Three Rivers to Assess Suitability for Native Mussel Habitat	National Park Service	Nancy Duncan	$ 200,000
2018	03k	Conserving Minnesota's Nine Species of Freshwater Turtles	Minnesota Zoo	Seth Stapleton	$ 300,000
2018	04f	Evaluate Emerging Pathogens in Lakes, Rivers, and Tap Water to Keep Drinking Water Safe	U of MN	Timothy LaPara	$ 325,000
2018	04h	Mapping Antibiotic Resistance in Minnesota to Help Protect Environmental, Animal, and Human Health	U of MN	Randall Singer	$ 750,000
2018	06c	Evaluate Control Methods for Invasive Hybrid Cattails	Voyageurs National Park	Steve Windels	$ 131,000
2018	06f	Determining Risk of a Toxic Alga in Minnesota Lakes	Science Museum of Minnesota - St. Croix	Adam Heathcote	$ 200,000
2018	08f	Develop Strategies for Timber Harvest to Minimize Soil Impacts to Maintain Healthy and Diverse Forests	U of MN	Charles Blinn	$ 200,000

Environment and Natural Resources Trust Fund (ENRTF)

Research Projects completed between January 1, 2021 and December 31, 2022

Full abstracts are included in Section III. Completed Research Projects

Year	Subd.	Title	Organization	Project Manager	Funding Amount
2018	08g	Restoring Wetland Invertebrates to Revive Wildlife Habitat	MN DNR	Megan Fitzpatrick	$ 400,000
2018	10a	Subproject 01 - State-Wide Reconnaissance of SARS-CoV-2 in Drinking Water Supplies	U of MN	Timothy LaPara	$ 59,297
2019	03c	Quantifying Exposure of Minnesota's Raptors to Mercury and PFAS	Hawk Ridge Bird Observatory	Matthew Etterson	$ 250,000
2019	03g	Mapping Habitat Use and Disease of Urban Carnivores	U of MN	Nicholas McCann	$ 500,000
2019	03i	Den Boxes for Fishers and other Nesting Wildlife	U of MN - Duluth NRRI	Michael Joyce	$ 190,000
2019	03j	Red-headed Woodpeckers as Indicators of Oak Savanna Health	U of MN	David Andersen	$ 171,000
2019	03q	Forest and Bioeconomy Research	U of MN - Duluth NRRI	Rolf Weberg	$ 2,200,000
2019	03r	Minerals and Water Research	U of MN - Duluth NRRI	Rolf Weberg	$ 883,000
2019	04d	Quantifying Microplastics in Minnesota's Inland Lakes	U of MN - Duluth	Kathryn Schreiner	$ 200,000
2019	04i	Extracting Deicing Salt from Roadside Soils with Plants	U of MN	Bo Hu	$ 360,000
2019	04m	Setting Realistic Nitrate Reduction Goals in Southeast Minnesota	U of MN	John Nieber	$ 350,000
2019	04n	Mapping Unprofitable Cropland for Water and Wildlife	Science Museum of Minnesota - St. Croix	Jason Ulrich	$ 100,000
2019	04o	Evaluating Locally Sourced Materials for Road Salt Reduction	U of MN - Duluth NRRI	Chan Lan Chun	$ 162,000
2019	07a	Development of Clean Energy Storage Systems for Farms	U of MN - WCROC	William Northrop	$ 650,000