2018 State of Lake Superior Conference

Proceedings

Houghton, MI
Michigan Technological University
October 9-12

IAGLR

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International Association for Great Lakes Research
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The State of Lake Superior (SOLS) Conference was hosted by the International Association for Great Lakes Research (IAGLR), a scientific organization of researchers that encompasses all science disciplines with a common interest in the management of large lake ecosystems. The conference was held at Michigan Technological University in coordination with the Keweenaw Bay Indian Community's Natural Resources Department and Keweenaw Bay Ojibwa Community College. Over 275 participants attended the conference, representing 14 U.S. and Canadian federal government agencies, 7 state agencies, 8 tribal organizations, 18 universities, 11 non-profit groups, 4 local government units, 3 multi-national organizations, 3 media organizations, and 12 private industries.

October 9

Remote Sensing Technology Workshop

Hosts: Brian Huberty, US Fish and Wildlife Service; Colin Brooks, Michigan Technological Research Institute (MTRI)

The objective of this workshop was to continue to build a bridge between Lake Superior Lakewide Action and Management Plan (LAMP) managers and the GIS/Remote sensing experts in the region in order to answer the most pressing 'geospatial' questions about Lake Superior. Discussion included 'geospatial' opportunities related to LAMP implementations, prioritization, ecosystem functions protection, measurement of progress, and data needs analysis. Participants shared their 'geospatial' perspectives on how well scientists and researchers in the basin are answering the 'geospatial' questions of status and change for Lake Superior.

Public Session: Lake Superior Lakewide Action and Management Plan (LAMP)

This public session provided an overview of stressors and threats to Lake Superior, as well as actions being taken to protect and restore Lake Superior, as outlined in the LAMP. In addition to 30 government agencies who comprise the Lake Superior Partnership, 170 other groups have been involved in taking on-the-ground actions that contribute to achieving shared goals for restoring and protecting Lake Superior. A group of kayakers who call themselves "Four the Water" (www.fourthewater.com) shared stories from their 2018 journey around Lake Superior, including their citizen science monitoring of microplastics. The session identified opportunities to get involved in lakewide management efforts and to take action to protect the lake. Time was also allotted for networking with various Lake Superior managers from federal, state, and tribal government agencies who are assisting in LAMP implementation.

October 10

Focus on the Small Stuff: Life at the Bottom of the Lake Superior Food Web

Phytoplankton, microbes, and zooplankton represent essential and integral components of aquatic food webs, and recent information has demonstrated changing population dynamics and ecologies in the Lake Superior ecosystem. This session focused on these lower trophic levels in Lake Superior that constitute the foundation of the aquatic food web and their roles in carbon and nutrient cycling in this ecosystem.

Variations of Plankton Communities throughout Seasons and Space in Lake Superior

Authors: Kirill Shchapov, Large Lakes Observatory; Ted Ozersky, Large Lakes Observatory

Consequences of spatial variations and seasonality on zooplankton community and trophic structure in large temperate lakes are not well resolved, especially with little information about the winter period. This can be attributed to the logistical difficulties of sampling in winter and the spatial dissimilarities in environmental conditions in large lakes. To address this information gap, we studied the zooplankton of Lake Superior across a full year at five stations spanning an estuarine to pelagic gradient. Stable isotopes analysis of bulk zooplankton, along with the taxonomic and functional classification, were used to examine changes in the community and trophic structure. Zooplankton abundance across all stations was higher in summer than in winter, while community composition varied seasonally. Cladocerans were most abundant during mid-summer at nearshore stations. Calanoid copepods were proportionally most abundant in winter at offshore stations, while cyclopoids dominated nearshore stations in winter. Based on SIA analysis we found notes of carnivory in winter and late spring with switch to herbivory in summer. Our study shows that in Lake Superior, there is spatial variation in the seasonal development and trophic status of zooplankton and that food webs in different regions of large lakes may be affected differently by environmental change.

Light Climate and Algal Pigments along Lake Superior's South Shore

Authors: Andrew Bramburger, Natural Resources Research Institute, University of Minnesota-Duluth; Christopher Filstrup, University of Minnesota-Duluth

Algae contain a variety of auxiliary photosynthetic pigments aside from chlorophyll a. These pigments give the major divisions of algae their characteristic colorations and are reflected in their common names (i.e., green or blue-green algae). We examined relationships between the vertical distribution of algal pigments and wavelength-specific light intensity through the water column at several locations along the south shore of Lake Superior during stratified conditions. Stations represented a variety of tributary plumes, as well as offshore areas. We used particulate absorbance measurements from discrete depths to coarsely estimate relative abundance of algal pigments in the water column and compared these results to hyperspectral radiance profiles. We also collected algal samples in order to taxonomically characterize the algal community at different depths. Preliminary results show that the underwater light climate differs widely among tributary-influenced stations, and the vertical distribution of algae varies with light climate. This suggests that interactions between not only light intensity, but also light color and thermal stratification influence vertical structure of algal communities.

Small Stuff in Mud: Fossil Algae Support AOC Delisting in W. Lake Superior

Authors: Elizabeth Alexson, Natural Resources Research Institute, University of Minnesota-Duluth; Euan Reavie, University of Minnesota-Duluth; Richard Axler, Ctr. Water & the Environment, Natural Resources Res. Institute; Mark Edlund, St. Croix Watershed Research Station, Science Museum of Minnesota; Robert Pillsbury, University of Wisconsin-Oshkosh, Biology Dept.; Diane Desotelle, Desotelle Consulting

A paleolimnological investigation provided insight on long-term environmental impacts and remediation in order to support delisting of the St. Louis River Estuary (SLRE) Area of Concern. Various sedimentary indicators (fossil diatoms, diatom-inferred phosphorus, and algal pigments) were analyzed from six cores taken throughout the SLRE and another from western Lake Superior. Reductions in eutrophic diatom taxa such as *Cyclotella meneghiniana* after 1970 in certain cores suggested improvement in water quality over the last 40 years. However, in cores taken from estuarine bay environments, persistence of eutrophic taxa such as *Cyclostephanos dubius* and *Stephanodiscus binderanus* indicate ongoing nutrient problems. Increased diatom-inferred phosphorus and cyanobacterial pigments corroborate this trend. While it appears some of the legacy nutrient pool has been remediated, modern stressors like internal phosphorus loading and climate change may be contributing to ongoing water quality impairments. The trajectory of these recent changes serves as an early warning of future conditions.

Geomatics, Remote Sensing and Mapping the Lake Superior Watershed into the Future

This session addressed remote sensing in the Lake Superior watershed with respect to identifying existing data gaps and using current and emerging sensing tools to improve the understanding of biological, ecological and physical processes in the watershed. Presentations addressed remote sensing topics including optical, radar, LiDAR, sonar, and thermal technologies and platform applications, in addition to data analysis and interpretation.

Lake Superior Dynamic Wetland and Habitat Maps using Satellite Radar and Optical Imaging Systems

Authors: Brian Huberty, US Fish & Wildlife Service; Michael Battaglia, MTRI; Laura Bourgeau-Chavez, MTRI; Colin Brooks, MTRI; Brandon Krumwiede, The Baldwin Group at NOAA Office for Coastal Management; Brian Brisco, Natural Resources Canada; Jim Klassen, SharedGeo.org; Jennifer Corcoran, Minnesota Department of Natural Resources (DNR); Paul Morin, University of Minnesota; Trevor Host, University of Minnesota; Keith Pelletier, University of Minnesota; Lori White, Environment and Climate Change Canada (ECCC); Mary Miller, MTRI; Kevin Murnaghan, Natural Resources Canada

Lake Superior managers are asking, “Where have the waters, wetlands, and adjacent habitats changed across the basin?” Satellite and aerial views are essential and cost-effective scientific and management tools to track and observe wetland and associated habitat changes over time. These images come from a variety of optical cameras, RADAR or LiDAR sensors, which require petascale computing to ingest and process derived products. The presentation highlighted recent examples of a binational, multi-organizational collaboration to ingest and deliver dynamic wetland and habitat maps for Lake Superior as well as the rest of the Great Lakes basin.

Collaborators included Michigan Technological University, University of Minnesota, SharedGeo, US Fish & Wildlife Service, NOAA, Natural Resources Canada, and ECCC.

Remote, Near-Live Water Quality Monitoring with the Internet of Things

Author: John Coleman, Great Lakes Indian Fish & Wildlife Commission (GLIFWC)

The advent of small, inexpensive, low-power processors and water quality sensors allows for the development and deployment of equipment for near-live monitoring of the health of nibi (water). Stimulated by ideas from the Internet of Things (IoT), there has been a flurry of development of low-cost water quality monitoring platforms by "hackers." Those monitors most often report to the internet through either wi-fi or cell phone networks. With a total cost of around $100 and the ability to be solar powered, the deployment of remote, near-live, monitoring systems can be a tool for monitoring time-critical events. Primary obstacles to wider use are the logistics of deployment, the coverage of cell phone networks, and the need for expertise in processor programming. The speaker presented an overview of the state of "hacker" systems for monitoring nibi health that are suitable for remote deployment based on inexpensive parts and customized software. Examples of systems deployed and in development were discussed.

Hidden in Color: Manoomin Remote Sensing

Authors: Brandon Krumwiede, The Baldwin Group at NOAA Office for Coastal Management; Heather Stirratt, NOAA Office for Coastal Management; Jessica Koski, Bureau of Indian Affairs Midwest Regional Office

NOAA, together with the Bureau of Indian Affairs, has collaborated with several tribal communities and agencies to help provide technical assistance and support for the protection and restoration of wild rice, which is culturally significant to tribes in the Lake Superior basin. The project framework consists of four focus areas for wild rice: ecosystem services, education and outreach, remote sensing data collection and analysis, and restoration work.

The remote sensing data analysis and mapping will be useful to help with wild rice management, determine where to invest restoration efforts, and identify which areas are under threat from stressors. Funding for this project comes from the Great Lakes Restoration Initiative.

Creating a Multi-Temporal Digital Surface Elevation Model of the Great Lakes Basin

Authors: Jim Klassen, SharedGeo.org; Brian Huberty, US Fish & Wildlife Service; Keith Pelletier, University of Minnesota; Trevor Host, University of Minnesota; Jennifer Corcoran, Minnesota DNR

The elevation of surfaces across the Midwest changes every day. Snowpack, lake levels, new buildings, and plant growth highlight many features that are measured and mapped to some degree. However, change is not adequately mapped. This information is important to answer questions such as: Has a windstorm blown down a forest? How have the changing wetland water levels impacted waterfowl and wild rice production? Where are the new buildings?

This presentation discussed the creation of a multi-sensor, multi-temporal surface model as part of a Great Lakes Restoration Initiative project to map and understand the dynamic landscape that impacts the Great Lakes.

Using Yesterday's Imagery to Answer Today's Questions: The Importance of Historical Imagery in the Basin

Author: Andrew Strassman, US Geological Survey (USGS) – UMESC

Advanced technologies provide a vast array of new resources and tools in photogrammetry and imagery analysis, but the maintenance of historical imagery is critical to address today's challenges. The speaker described a proposal to map all the ash (*Fraxinus spp*.) within Grand Portage National Monument using imagery collected in October of 2006. This method will rely upon the original film imagery, now digital, being brought into a modern 3D platform. This project is being considered as preparation for an emerald ash borer (*Agrilus planipennis*) invasion, mitigation, and recovery. The speaker reviewed how this method can be applied across the basin's vast deciduous swamp forests.

Next Generation Hydrography and Riparian Area Mapping

Author: Jennifer Corcoran, Minnesota DNR

The current inventory of Minnesota's stream and river centerlines, derived from 1960's USGS Topo maps, does not accurately represent or encompass all water conveyance features across the landscape. By analyzing LiDAR-derived digital elevation models (DEMs), highly accurate water conveyance features and variable-width topographic riparian areas can be mapped to replicate flow and connection of surface waters across the landscape. Minnesota's Lake Superior Coastal Program and the Resource Assessment Office, both within the Minnesota DNR, have partnered to update hydrography within the Major 1 and Major 2 watersheds along the north shore of Lake Superior. This presentation described the methods used for updating watercourse hydrography for the DNR 24k Stream and River Centerline Inventory and for mapping variable-width riparian areas utilizing LiDAR-derived DEMs. Culvert inventories from multiple sources were verified and used to hydro-modify the LiDAR DEMs, which allowed for water movement and stream connectivity through digital dams features such as roads, bridges, and dams. The resulting stream lines are significantly more precise, and the variable-width topographic riparian areas can then be used to manage the restoration and construction of riparian buffer zones and improve the overall health of the watershed.

Landscape Change Across the Great Lakes: Petascale Computing of Satellite Stereo Imagery

Authors: Jennifer Corcoran, Minnesota DNR; Keith Pelletier, University of Minnesota; Jim Klassen, SharedGeo.org; Trevor Host, University of Minnesota; Brian Huberty, US Fish & Wildlife Service

Coastal wetlands are essential for recreational opportunities, wildlife habitat, flood mitigation, and filtering non-point source pollution in the Great Lakes basin. Existing wetland inventories are outdated, inaccurate, and frequently misrepresent the location and underestimate the extent of these ecologically significant landscape features. Object-based image analysis (OBIA) has been used extensively for mapping wetlands and other landscape features. Recent advances in the availability of high-resolution stereo satellite imagery and surface elevation mapping approaches using petascale supercomputing have created new opportunities for mapping and monitoring coastal landscape change within the basin. In this presentation, we expand on existing stereo image processing and OBIA-based mapping approaches by leveraging high-resolution remotely-sensed data and ancillary datasets to map and monitor changes in the landscape along the coasts of the Great Lakes. Attendees were briefed on the data, methods, and preliminary results from

efforts to map and monitor these complex landscapes in support of the Great Lakes Restoration Initiative.

Using Benthic Mapping to Support Research and Management in National Parks of Lake Superior

Authors: Jay Glase, National Park Service (NPS); Lara Bender, NPS; Brenda Lafrancois, NPS; Ted Gostomski, NPS; Jamie Hoover, NPS

The National Park Service (NPS) protects diverse underwater environments in Lakes Michigan and Superior. These habitats historically received less attention than terrestrial areas in the parks, and until recently, little was known about their bathymetry and character. With support from the Great Lakes Restoration Initiative, NPS has developed high-resolution bathymetric maps using LiDAR and multibeam sonar in three national parks of Lake Superior. The authors explored these emerging datasets, highlighted unique cultural and geological features discovered along the way, and discussed two specific applications for management and research. In the Apostle Islands, bathymetric and substrate data are analyzed to highlight promising habitats for native mussels and high-risk areas for invasive mussel colonization. On the north shore of Isle Royale at Hawk Island Reef, fisheries researchers from multiple agencies are attempting to track siscowet Lake Trout movement and habitat use. High resolution maps from that area are being used for placement of tracking devices and are providing detail about bottom habitat. Mapping data from Lake Superior parks and surrounding areas provide new opportunities for management agencies, academia, and the public to collaborate on diverse Lake Superior issues.

Mapping Hydrological Connections on Lake Superior to Identify Coastal Wetlands

Authors: Mary Miller, MTRI; Laura Bourgeau-Chavez, MTRI; Michael Battaglia, MTRI; Guy Meadows, Michigan Technological University; Colin Brooks, MTRI; Bradley Weiss, Michigan Technological University

Coastal wetlands provide wildlife with vital habitat. They protect neighboring uplands and shorelines from flooding and erosion due to storm surges or high lake levels. To support the wise management of coastal resources, the wetlands that are hydrologically connected to the Laurentian Great Lakes need to be identified. This was accomplished using hydrological modeling to predict connectivity using existing spatial data sets, image processing, and hydrological modeling. Multiple stream delineation tools were tested to identify the methodology that most accurately routed streams and channels under bridges and through road culverts. The authors automated an algorithm to identify coastal wetlands of the Lower Peninsula of Michigan. Connections at varying water levels were established using archival water level gage data and MTRI's binational Great Lakes coastal wetland map. The authors applied the algorithm to wetland sites on Lake Superior to complement ongoing research studies and to test portability. Validation efforts are underway using a combination of historical observations and comparisons with other methods of mapping connectivity.

Monitoring Surface Water and Wetland Inundation Extent Using Satellite Radarsat-2 Imagery

Authors: Michael Battaglia, MTRI; Laura Bourgeau-Chavez, MTRI; Sarah Banks, ECCC; Brian Brisco, Natural Resources Canada; Colin Brooks, MTRI

The timing, extent, and duration of flooding in wetlands and water bodies are important for wildlife habitat and have implications for coastal wetland zonation and invasive species

management. Radarsat-2 satellite radar imagery are being acquired every 24 days (May-Oct) over a select set of sites around the Great Lakes for the development of temporal maps of changes in surface water extent, water level, and flooded vegetation by a binational team of investigators. An automated thresholding and segmentation algorithm for surface water mapping has been published and applied to Radarsat-2 C-HV imagery collected at several sites along the Lake Superior coastline. While open surface water mapping is relatively straightforward to map, areas that are covered by vegetation are more complex, and therefore, developing an automated method is also more complex. Algorithms using polarimetric Radarsat-2 imagery are under development to map flooded vegetation extent. Progress has been made in utilizing polarimetric decompositions, backscatter (C-HH), and phase information. Once an automated algorithm for wetland inundation extent has been developed and tested, it will be applied to all incoming Radarsat-2 images over the Great Lakes, and both products will be made available to wetland managers in near real time.

The Lake-Land Connection: Watershed and Nearshore Process

The Lake Superior watershed encompasses a diverse set of landscapes that include the lake, forested uplands, coastal wetlands, inland lakes, and wetlands, as well as areas of urban development, agriculture, and mining. The lake faces threats from expansion of cities, mines, and agriculture in addition to altered hydrology resulting from climate change. Protection of the lake and the lake's ecosystems depend on research and resource management by universities, agencies, local groups, and communities. These activities focus on improving our understanding of the watershed, and how human activities in the watershed influence the lake and the physical, chemical, and biological processes that occur in the lake. Presentations explored a variety of research and management activities that enable us to understand watershed processes such as runoff and nearshore processes and conditions.

Protecting Buffalo Reef from Historic Mining Waste

Author: Steve Casey, Michigan Department of Environmental Quality

Buffalo Reef lies square in the path of 23 MMT (million metric tons) of migrating mine tailings discharged to Lake Superior 100 years ago. The copper mining tailings, locally called stamp sands, will chemically and physically disrupt the function of the reef and associated juvenile habitats. The Buffalo Reef Task Force is currently screening alternative management plans for protecting the reef. Those alternatives, as well as the scientific and engineering challenges facing the task force, were presented.

Temporal and Spatial Variability in Organic Carbon Concentration and Composition in Tributaries

Authors: Megan McConville, Northern Michigan University; Stephanie Berg, University of Wisconsin, Madison; Robert Mooney, University of Wisconsin, Madison; Peter McIntyre, University of Wisconsin-Madison; Christina Remucal, University of Wisconsin, Madison

Great Lakes tributaries represent a major source of dissolved organic matter (DOM) inputs. While DOM contributes to numerous environmental processes including carbon transport, redox cycling, and interactions with environmental contaminants, little is known about the temporal and spatial variability of organic carbon. The authors assessed seasonal DOM dynamics in >100 Lake Michigan tributaries over a period of one year. Dissolved organic carbon (DOC)

concentrations were used as a surrogate for DOM concentration, while UV-visible spectroscopy was used to assess DOM composition. DOC concentrations are higher in northern tributaries, where wetlands comprise a large portion of watershed area. DOM composition has less spatial variability and is related to watershed type by multiple linear regression. In heavily forested/wetland rich watersheds (i.e., northern Michigan watersheds), the spatial variability in optical properties was low, and this correlated with higher aromaticity and molecular weight. This indicates that DOM loading from forested/wetland rich watersheds to Lake Michigan is primarily terrestrial in origin, rather than microbial. Additionally, seasonal variability in DOM molecular weight suggests that the fraction of microbially-derived DOM increases during winter and spring. This work highlights the dynamic role of tributaries in connecting watershed and lake carbon budgets and has implications for Lake Superior tributaries.

Rain Event Implications for the Biogeochemistry of Lake Superior

Authors: Ellen Cooney, University of Minnesota-Duluth; Elizabeth Minor, University of Minnesota-Duluth, Large Lakes Observatory

The Great Lakes region of North America is expected to be greatly affected by climate change; it is anticipated that the intensity and frequency of extreme (top 1%) rain events will increase. This could lead to more runoff and increased riverine inputs to Lake Superior, thus affecting key biogeochemical parameters. Lake samples of plume and non-plume water were studied by coupling satellite data, water column sensor profiles, and discrete surface-water sampling for five rain events in Summer 2017 and analyzed for significant differences in biogeochemical parameters. Throughout a wetter than average summer season for the region (Duluth, top 30th percentile), it was determined that these plumes, relative to non-plume waters, had significantly increased concentrations of total organic carbon (TOC), dissolved organic carbon (DOC), and colored dissolved organic matter (CDOM), but not nutrient concentrations or particulate (>2 um) chlorophyll a.

EnviroDIY Open-Source Technologies for Cost-Effective Real-Time Lake Monitoring

Authors: Anthony Aufdenkampe, LimnoTech; Ed Verhamme, LimnoTech; Greg Cutrell, LimnoTech; Craig Taylor, LimnoTech; Beth Fisher, University of Minnesota; Bobby Schulz, University of Minnesota, Sara Damiano, Stroud Water Research Center

The last several years have seen a revolution in extremely low-cost and often open-source wireless sensing devices that share real-time data via the internet. The authors presented a number of projects to develop sophisticated, solar-powered wireless water and water quality monitoring stations by building on open-source electronics hardware and software at a fraction of the cost of commercial, black-box systems. The brain of our stations is the Arduino-compatible Mayfly data logger board, developed by the EnviroDIY community do-it-yourself (DIY) environmental science and monitoring.

The authors deployed high-frequency barometric pressure stations around Lake Michigan, sending data every minute to a prototype warning system for meteoric tsunamis. For a Watershed District, the authors developed stations that measured water depth, conductivity, turbidity, and temperature for $1500 per station. For Winona State University, the authors developed stations that measured water depth, conductivity, turbidity, dissolved oxygen, pH, and water temperature, in addition to rainfall, barometric pressure, humidity, and air temperature. In addition, these stations trigger an automated sampler based on turbidity values that exceed a threshold. All of

these stations are operational, and data are available at http://data.envirodiy.org. The authors are developing a small lake buoy that monitors chlorophyll, blue green algae (phycocyanin pigment), and other parameters.

Leveraging DNA to Identify Sources of Fecal Pollution in Lakes

Authors: James Herrin, Source Molecular Corporation; Mauricio Larenas, Source Molecular Corporation; Daron Stein, Source Molecular Corporation

Protecting public health from the serious risks posed by fecal pollution in the water is a concern by government officials, especially elected officers. Water managers face increasing pressure to keep lakes, rivers, and coastal waters clean from untreated discharges. But traditional methods used to monitor water quality are ineffective at distinguishing among sources.

Source identification is necessary to mitigate the problem. Too often, water managers equate fecal indicator bacteria (FIB) with disease-causing bacteria. Most of these FIBs are considered harmless and can sometimes even originate from non-fecal sources. Bacteria sources need to be identified in order to determine whether they are pathogenic.

Bacteria in urban stormwater usually have multiple sources such as humans, dogs, birds, and cattle from peri-urban lands. DNA is the gold standard in industries such as forensic science. Genetic technology is being applied to water quality monitoring to identify bacteria sources. Microbial Source Tracking (MST), a DNA-based test method, helps water managers determine where fecal pollution is coming from, pinpoint the host responsible for the fecal pollution, and evaluate best management practice (BMP) effectiveness. The presentation included a discussion on lessons learned and outcomes achieved in two MST projects in Massachusetts and California.

Evolution of a Long-Term Water Monitoring Program for Protection of Lake Superior Tributary Health

Authors: John Coleman, GLIFWC; Esteban Chiriboga, GLIFWC; Dawn White, GLIFWC; Ann McCammon Soltis, GLIFWC

In the 2011 Year of Intensive Monitoring, GLIFWC began a project to monitor aspects of the health of streams and rivers in the Chippewa Ceded Territories of the Lake Superior basin. Monitoring focused on nibi (water) that might be impacted by future hard rock mining development. That program identified three watersheds that had been unimpacted by recent mineral development but were the subject of interest in extraction. The project focused on providing baseline data to help protect the health of these tributaries to Lake Superior. Using a combination of water quality sampling, flow measurement, and near-continuous monitoring of water temperature and conductivity, GLIFWC has developed strong baseline datasets, which can help identify cases of increased pollution due to human activities. Since 2011, GLIFWC has located additional funds to continue and expand the collection of water quality and quantity data in those watersheds as well as to expand to additional watersheds. The 2011 Cooperative Science and Monitoring Initiative (CSMI) provided the resources and focus to start this program of long-term data collection that is contributing to understanding changes and potential changes in the health of nibi in at-risk tributaries.

Geochemistry of Southwestern Lake Superior Sediments with an Emphasis on Phosphorus Lability

Authors: Mauricio Tonello, UPF; Tayler Hebner, University of Minnesota-Duluth, Large Lakes Observatory; Robert Sterner, University of Minnesota-Duluth; Sandra Brovold, University of Minnesota-Duluth; Edson Bortoluzzi, UPF; Tales Tiecher, UFRGS; Gustavo Merten, University of Minnesota-Duluth, Department of Civil Engineering and Large Lakes Observatory

The purpose of this study is to provide information about Southwestern Lake Superior sediment P-lability and relate this information to the geochemical characterization of these sediments. Samples were collected from river input load, shoreline erosion, and lake sediment. Thirteen samples were submitted to P sequential extraction, and nine were submitted to geochemical analysis to evaluate the P lability. The sediments were composed of non-clay minerals of low P-reactivity (quartz, augite, calcite, dolomite, anorthite, microcline, and magnesite) and minerals with greater P-reactivity such as oxides (rutile and hematite) and clay minerals (kaolinite, smectite/vermiculite, chlorite, mica or illite, and interstratified clays). The total P concentration in the lake sediments, input load and shoreline erosion sediment groups (average of 1151, 945 and 837 mg kg–1, respectively) was very high. However, labile P-loosely sorbed and P-redox sensitive represented less than 10% of the total phosphorus. More than 80% of P in the sediments was associated with organic compounds and carbonates with low availability to biota. Findings indicate that input load, shoreline and lake sediments contain very low concentrations of P available to aquatic biota due to the presence of minerals with high chemical reactivity with potential to adsorb P.

Extreme Floods along Lake Superior's South Shore and Implications for Sediment Transport

Author: Faith Fitzpatrick, USGS

Several extreme floods have recently hit Lake Superior's southshore tributaries, including the 2012 flood in the Duluth area and the 2016 and 2018 floods across northern Wisconsin and the Upper Peninsula of Michigan. Flood peaks had annual exceedance probabilities of less than 0.002 (flood recurrence interval of greater than 500 years). USGS has conducted related studies of flood inundation, sediment transport, and geomorphic responses. Results from the studies assist in immediate repair of culverts and bridges as well as long-term planning and prioritizing for future floods and rehabilitation. Extreme erosion and sedimentation along main stems and floodplains are commonly seen following the floods. Sedimentation was especially noticeable upstream of constrictions such as culverts as well as in river mouths and deltas. In the Duluth area, habitat features associated with large wood and pools were less common following the 2012 flood. The amount of sediment delivered and temporarily stored in mainstems will likely take a decade or two to return to pre-flood states. Sediment delivered to overbank areas will take centuries to remobilize. High lake levels during floods allow for more sedimentation at river mouths and deltas.

Exploring the Relationship between Wetlands and Flood Risks

Author: Kyle Magyera, Wisconsin Wetlands Association

After the July 2016 storm in northwest Wisconsin, the Wisconsin Wetlands Association completed an exploration of the relationship between vulnerable infrastructure and upstream watershed hydrology in heavily damaged areas. The exploration revealed that gully formation and channel incision are disconnecting streams from historic floodplains and accelerating the

drainage of existing wetlands upstream of many repetitively-damaged culverts in Ashland County. These conditions can greatly reduce watershed storage and often contribute to downstream flood risks. This presentation shared examples of where erosion-induced wetland drainage is altering watershed hydrology and causing wetlands to underperform in providing flood protection benefits. Additionally, the speaker described potential stream-wetland restoration practices that can be implemented by natural resources and emergency managers to improve watershed health and the resilience of communities to extreme weather. The presentation concluded with a brief Q&A on research opportunities for better understanding the extent of erosion-induced wetland drainage in the Lake Superior basin and the role of stream-wetland restoration as a flood risk reduction strategy.

Decision Support for Slowing the Flow: A Multi-Metric Matrix Focuses Efforts to Reduce Peak Flows

Authors: Tom Hollenhorst, US EPA Mid-Continent Ecology Division; Michele Wheeler, Wisconsin DNR; Molly Wick, US EPA, Oak Ridge Institute for Science; Tom Bernthal, Wisconsin DNR; Andy Robertson, St. Mary's University - Geospatial Services; Christopher J. Smith, Wisconsin DNR

Northern Wisconsin has experienced three significant floods in the last six years that have caused millions of dollars in damage. Clearly, the region is receiving more frequent and intense rainfalls. Recently, local, state and federal partners have been trying to find ways to slow the flow of storm water running off the landscape as well as reduce the amount of sediment washing into Lake Superior. Conservation efforts have focused on slowing the flow with restoration projects designed to increase roughness and promote infiltration and watershed storage. Efforts have included wetland restoration, agricultural best management practices, and reforestation projects. To help prioritize these efforts, the authors developed a multi-metric decision support matrix to quantify and rank, across 1500+ sub watersheds, factors that might impact stream hydrology and water quality to maximize the positive impact of various slow the flow efforts. For each sub watershed, the authors calculated peak discharge and the amount of existing and potential watershed storage using newly available and updated Wisconsin Wetland Inventory, Wetland Functional Assessment and Potentially Restorable wetland data layers. The authors also evaluated the amount of open lands and forest. All of this was compiled in the matrix to score and rank sub watersheds for restoration priorities.

Working Together to Implement the LAMP

Working collaboratively, across jurisdictional boundaries and at a landscape level can be a daunting task for most individual organizations. Successful cross-boundary, landscape-level projects commonly consist of partners with strong relationships, promoting early and active conversations amongst themselves and other stakeholders. The purpose of this session is to highlight partners and/or projects that demonstrate strong partner engagement, collaborative planning, joint funding, and cooperative implementation. Presentations in this category highlighted successes, as well as obstacles, to working jointly on a wide variety of Lake Superior issues identified in the LAMP. Presentations showcased the process for establishing a network of practitioners and the benefits of working collaboratively on projects from across the Lake Superior basin.

Taking Action Together: A Multi-Agency Approach to Targeted Restoration on Public and Private Lands

Authors: Michele Wheeler, Wisconsin DNR; Valerie Damstra, University of Wisconsin Extension

Broad scale plans, like the Lake Superior LAMP, can provide great benefits in fostering an intentional and well-considered approach to natural resource management. However, they only provide true resource benefits when the ideas and actions therein translate into on-the-ground action. The US Forest Service and Natural Resource Conservation Service targeted the Wisconsin portion of the Lake Superior basin for a Joint Chiefs' project to restore critical habitat and improve water quality by working across political boundaries. To ensure that the initial nearly 1-million-dollar investment implemented the right projects in the right area, local natural resource experts established priorities across five focal areas: Brook Trout, water quality/slow the flow, Golden-winged warbler, Kirtland's warbler, and Sharp-tailed grouse. Each team created a GIS-based map of priority areas, identified top actions to improve conditions, and defined measures of success for restoration efforts.

The Brook Trout team used a three-pronged approach to establishing priorities. USGS stream modeling of future water temperatures helped define areas that are more likely to support Brook Trout in the future. US Fish and Wildlife Service status and distribution modeling identified areas that currently support Brook Trout. Management interests were also considered to focus efforts with regulations specifically working to protect Brook Trout, streams identified in broad scale management plans to protect Brook Trout, and the presence of non-governmental organizations (NGOs) that can help advance restoration work. Using these factors, the Team identified 20 top Hydrologic Unit Code (HUC) 12 watersheds as priorities for work. Top restoration practices recommended in these watersheds include: 1) barrier removal projects that do not expand habitat for Sea Lamprey or non-native trout, 2) establishing forested riparian areas, 3) instream structures in watersheds without heavy sediment loads, and 4) reducing sand bedload in streams with watershed restoration or bank stabilization. Success was defined as maintaining and increasing the number of catchments in targeted HUC 12s in which Brook Trout populations are self-sustaining based on the US Fish and Wildlife Service Brook Trout status and distribution project criteria.

The Slow the Flow/Water quality team used a similar approach. In the Wisconsin portion of the Lake Superior basin, land form and soils significantly influence stream networks and hydrology, with implications for both in-channel and nearshore sediment dynamics and habitat. The Red Clay Plain (elevation under 750 feet) is a band of relatively impermeable and erosive clay soils that parallel the Lake Superior shoreline. Above the Clay Plain, an area known as the transition zone (approximately 750-1,150 feet elevation) is characterized by wave planed topography from glacial Lake Duluth, leaving behind steep erosive channels with sand over clay prone to high erosion. Headwater areas of the basin (above 1,150 feet) are characterized by glacial till, rock outcrops, and a poorly developed stream network that is less erosive. Streams in the region are characterized as "flashy," meaning high flows are intense but of short duration (Robertson 1997). In addition to natural conditions that make streams erosion prone, changes in the basin's land cover have altered watershed hydrology. Research conducted by Verry (2001) showed that, when small watersheds exceed 60% open land, there is marked increase in runoff rates and volume of runoff in channel-forming bankfull flows. This causes streams to become unstable, overloads them with sediment, and reduces the quality of habitat for aquatic species. Based on these

watershed conditions and understanding of watershed processes, the Slow the Flow team ranked watersheds based on 1) amount of open land, 2) watershed position focusing on headwater areas, and 3) watersheds known to be heavy sediment producers: Fish Creek, Nemadji River, and Marengo River watersheds. In these priority catchments, top projects include increasing watershed storage capacity, reforestation, wetland restoration, road management, and agricultural best management practices

Other resource teams followed a similar process to establish a basinwide map of targeted areas and priority projects. Local partners from federal, tribal, state, and local governments and non-profits used the targeted resource team recommendations to implement cross-boundary resource conservation on both private and public lands. This regional approach ensured efforts are fully leveraged across jurisdictions and across the landscape.

From Awareness to Action: Traveling the Squiggly Pathway to Lead Private Landowners to Conservation

Authors: Valerie Damstra, University of Wisconsin Extension; Michele Wheeler, Wisconsin DNR

The author described efforts to engage local citizens in restoration of wildlife habitat and protection of water quality. Previous survey work has indicated that most forest landowners in Wisconsin report that beauty, wildlife, legacy, privacy, and nature are more important to them than investment, timber, and non-timber forest products. Although many landowners intend to implement some sort of wildlife habitat improvement on their land, lack of experience and uncertainty about opportunities working with government agencies are often barriers. In Wisconsin's portion of the Lake Superior basin, a public outreach campaign under the banner "My Lake Superior Northwoods" was implemented to recruit landowners in identified natural resource priority areas. Initial efforts focused on direct mail to addresses in priority areas, with offers of free site visits by a resource professional, printed materials and invitations to field tours. Over the course of 3 years, this work resulted in 88 site visits where partner resource professionals walked the land with citizens and completed a report of potential projects that meet landowner and resource objectives. Outreach led to 10 on-the-ground projects that included forest management plans, wetland or instream habitat restoration, and timber management. To improve the efficiency and effectiveness of outreach, the group tested a Facebook campaign as an alternative approach to reaching landowners. Called Woodscamp (https://wisconsin.woodscamp.com), this project engaged 27 landowners in site visits in six months.

Partners for Watershed Restoration (PWR) Group: Five years of Cross-Boundary Collaboration

Author: Jeff Koch, Superior Watershed Partnership

The Partners for Watershed Restoration (PWR) group, comprised of federal, tribal, state and local government agencies, academic institutions, non-profit organizations, citizen groups, and industry representatives, accelerates watershed restoration through sharing information and pursuing projects of mutual interest throughout the central and western Upper Peninsula. PWR was launched through creation of a steering committee in April 2013 and a subsequent workshop to discuss watershed threats affecting the western and central Upper Peninsula, as outlined in the Lake Superior Lakewide Action and Management Plan (LAMP). Shared priorities included threats to watersheds, restoration work underway, raising awareness of funding opportunities,

and generating ideas for future cooperation. Due to strong interest from the initial workshop participants, additional workshops were scheduled biannually to sustain dialogue, deliver trainings, and collaborate on projects.

Currently, PWR consists of over 200 members representing 60 organizations, an 11-member steering committee, and a paid coordinator. The steering committee makes decisions regarding the direction and focus of PWR while pursuing the following goals: implement the Lake Superior LAMP and Biodiversity Conservation Strategy priorities; increase communication across boundaries; identify opportunities to leverage and share resources; and increase awareness and engagement of public and private landowners. The coordinator ensures timely communication via email updates and bi-monthly newsletters that highlight upcoming events, useful tools and resources, funding opportunities, and partner project spotlights. The coordinator also schedules bi-annual member meetings where attendees can hear presentations about topics in watershed restoration, network with other PWR members, learn new skills, and visit project locations.

There have been many successful PWR projects over the last five years. Highlights include:

- The Keweenaw Bay Indian Community headed up the collection and analysis of road stream crossing data, which resulted in the creation of a regional, road-stream crossing geodatabase.
- A PWR sub-committee developed a tool to assist local organizations with prioritization of watersheds in the PWR area for Brook Trout habitat restoration.
- In the last two years alone, PWR has received approximately two million dollars in funding for watershed restoration projects, resulting in 93 miles of stream habitat restoration. In 2018, a four-person Great Lakes Conservation Corps (GLCC) crew, which is administered by the Superior Watershed Partnership, assisted eight different PWR partners with projects ranging from planting trees and native plants to removing invasive species, performing stream surveys, and improving boardwalks and trails.

Like other conservation partnerships, PWR has overcome initial challenges, including gaining clarity on group mission, membership requirements, and leadership model. Present-day challenges include more effective and efficient accomplishment reporting, especially for LAMP objectives. Much of PWR's success lies in its collective ability to share technical expertise and lessons learned, sustain a paid coordinator, engage the steering committee, and leverage resources to accelerate restoration.

The Power of Local; Stories of Protection, Restoration, Education and Results!

Author: Carl Lindquist, Superior Watershed Partnership

For two decades the Superior Watershed Partnership (SWP) has harnessed the power of local to achieve extraordinary results in protecting and restoring Lake Superior. This fast-paced presentation highlighted a wide range of stories from 3rd grader activists to globally unprecedented mine monitoring, from dam removals to permanently conserving wild shorelines, from engaging tribal teens to the Great Lakes Conservation Corps, from effective climate adaptation projects to free low-income solar units, from red buckets to green infrastructure, from wetland restoration to record-setting pollution prevention, from pollinators to plover, from involving faith communities to the arts community. It's all about harnessing the power of local (and that includes visitors to Lake Superior)!

Great Lakes Coastal Assembly – Colossal Collaboration Benefits Fish, Wildlife, and People

Authors: Christie Deloria, US Fish and Wildlife Service; Cherie Hagen, Wisconsin DNR - Office of Great Waters

In 2013, under the umbrella of the Upper Midwest and Great Lakes Landscape Conservation Cooperative (LCC), the "Great Lakes Coastal Conservation Working Group" formed. The collaboration's membership currently represents 6 federal (US and Canada), 8 state, 2 tribal, 1 academic, and 3 NGO partners focused on priority coastal conservation issues. When funding for the LCC network was eliminated and the structure dissolved in 2017, the Working Group re-named itself the Great Lakes Coastal Assembly (Assembly) and began expansion of its membership and scope to better represent basinwide perspectives and issues. Generally, the purpose of the Assembly is to: 1) promote collaborations aimed at management, restoration, and conservation of coastal areas; 2) assist organizations in assessing where investments should be made and aligning investments with regional, state, and local goals; and 3) identify needs for science and decision support and enable actions that help coastal managers make effective decisions.

To date, the Coastal Assembly has been focused on setting shared goals, strategies, and tracking collective progress on coastal wetlands especially through a pilot effort in the Saginaw Bay to Western Lake Erie geography. The approach taken reflects the adaptive management framework with five somewhat sequential steps of 1) identifying a priority (coastal wetlands), 2) setting shared goals/metrics around that priority, 3) identifying a strategy for meeting the goals, 4) implementing the strategy through coordinated on-the-ground actions, and 5) monitoring, research and tracking progress. The process is meant to be iterative. The Coastal Assembly has been working in all of the 5 steps of this framework over the last four years. Foundational to all 5 steps are the ideas of collaboration (building and maintaining), communication (internal to all the organizations and external to decision makers), and tracking process (rolling up efforts across organizations to show ecological and financial contributions through Blue Accounting).

Recently the Coastal Assembly finalized the goals and metrics from its Saginaw Bay to Western Lake Erie pilot. The goals include metrics related to plant and insect health, priority species populations, invasive species populations, natural shoreline and amount/diversity of coastal wetland. It is anticipated that the pilot and lessons learned from efforts to date could help influence and catalyze efforts to expand this approach into Lake Superior.

The authors presented an example of how this effort could be expanded by building upon the work of the Lake Superior Biodiversity Strategy. Both the LAMP and the Biodiversity Strategy identify coastal wetlands as an important habitat. For example, in the Biodiversity Strategy, the St. Louis River Estuary area was scored as a D, and a goal may be to improve that from a D to a C score. If the LAMP partnership is interested, other goals and metrics could be considered, in addition to the qualitative scores. These may include or be similar to the goals and metrics identified for Saginaw Bay to Western Lake Erie, or the metrics may need to be tweaked to better reflect the species/threats in this area. The Coastal Assembly is interested in exploring this more and gaining insights from local practitioners and researchers in Lake Superior.

Blue Accounting: Communicating Return on Investments in Great Lakes Restoration

Authors: Douglas R Pearsall, The Nature Conservancy; Scott Sowa, The Nature Conservancy; Tawny Mata, The Nature Conservancy

Hundreds of entities across the Great Lakes invest billions of dollars restoring and maintaining the Great Lakes, but there has not been a way to measure the effectiveness of these efforts to protect ecosystems, safeguard human health, and bolster the economy. In 2013, a call from the Great Lakes governors and premiers for a smarter and more comprehensive approach to monitoring water resources led to the creation of Blue Accounting (BA), a new initiative and online platform providing cutting-edge information services about the Great Lakes. This issue-based, goal-driven initiative focuses on integrating key datasets for metrics that help leaders manage the world's largest freshwater ecosystem more collaboratively, effectively, and holistically. BA addresses five pilot issues: Aquatic Invasive Species, Coastal Wetlands, Maritime Transportation, Phosphorus Control (Eriestat), and Source Water. For each issue, BA supports a collaborative group in the establishment of shared goals and metrics, tracking progress, and delivering compelling information to key audiences by providing services including facilitation, information management and delivery, situation analysis, and strategic engagement and communication. For Coastal Wetlands, BA is assisting the Great Lakes Coastal Assembly in achieving basinwide representation, finalizing ecological and socioeconomic metrics, compiling data, and building visualizations to enable tracking progress towards shared goals. The authors are currently focusing on providing information on coastal wetland investments (e.g., projects such as wetland protection, restoration, and enhancement that are funded by Great Lakes Restoration Initiative and state coastal management programs). The authors are also building out contextual information and visualizations to communicate the status of priority ecological metrics identified by the Assembly, including several indices of biological integrity (IBIs), a shoreline hardening index, and two measures of phragmites coverage. Blue Accounting helps to tell the story of coastal wetland conservation and management and provides useful information to funders, decision makers, and wetland managers. The authors intend to expand the set investment data and include additional ecological metrics such as priority wildlife and fish species and, in 2019, incorporate socioeconomic metrics related to the ecosystem services provided by coastal wetlands.

Currently, the Assembly and Blue Accounting are focusing on the coastal area from Saginaw Bay through Western Lake Erie but will support expansion to include Lake Superior and all the Great Lakes.

Welcome, Opening Ceremony & Plenary

Welcome from Keweenaw Bay Indian Community and Michigan Technological University

President Warren “Chris” Swartz, Keweenaw Bay Indian Community (KBIC), welcomed the audience to the SOLS Conference. KBIC is a fishing tribe that depends on Lake Superior for a living. Swartz explained that it is important to preserve Lake Superior for the next seven generations and to restore fish populations to historic levels. KBIC appreciates the collaboration of various agencies in efforts to restore and protect Lake Superior.

The *Woodland Singers*, members of the Ojibwa and Menominee Tribes, performed a traditional drum ceremony and sang tribal songs.

President Richard Koubek, Michigan Technological University, welcomed attendees to the conference and provided a brief background about himself and Michigan Tech. The university’s focus is on applying technology to solve problems, including those resulting from mining, which

has had an historical impact on Lake Superior. Due to its proximity to Lake Superior, Michigan Tech was originally founded as a mining school.

Plenary: Sustaining Lake Superior: Learning from Watershed History

Presenter: Nancy Langston, Author and Professor, Department of Social Sciences, Michigan Technological University

Langston is author of Sustaining Lake Superior, a book that describes how the climate is changing and how it is mobilizing pollutants. She discussed how communities can help sustain the health of Lake Superior in the face of climate change, invasive species, and emerging chemicals of concern. The challenges facing Lake Superior are many; yet local, regional, and international communities overcame enormous threats to the lake's ecosystems in the past century. Langston explored the lessons offered by the lake's environmental and social history as new interconnected challenges emerge. Langston is hopeful that through collaboration the value of Lake Superior can be preserved, despite the challenges and climate changes that are coming.

The Lake-Land Connection – Watershed and Nearshore Process, p.m.

Protection of Lake Superior through the Comprehensive Study and Protection of the Bad River Subbasin

Authors: Naomi Tillison, Bad River Natural Resource Department; Jessica Strand, Bad River Band of Lake Superior Tribe of Chippewa Indians

The Reservation for the Bad River Band of Lake Superior Tribe of Chippewa Indians is located along the southern shore of Lake Superior at the base of the Bad River sub-basin and with an additional portion of Reservation on Madeline Island. The Tribe's Natural Resources Department (NRD) focuses on studying, protecting, and addressing environmental concerns within Lake Superior watersheds. This presentation highlighted some of the work the NRD has done and continues to do that addresses threats and concerns that could impact Lake Superior, such as mining, non-point source pollution, stream barriers, and flooding. Information presented included efforts to protect the Bad River sub-basin from the headwaters to the wild rice waters (Kakagon/Bad River Sloughs). Information presented also included highlights of recent flooding and efforts to enhance resiliency, including improvements in culvert design and installation. Information was discussed in the context of how this work incorporates tribal values and concerns and protects Lake Superior for the next seven generations.

Inputs to Nearshore Lake Superior from the St. Louis River Estuary: The Role of Tributary Inflows

Authors: Richard Kiesling, USGS; Erik Smith, USGS; Paul Reneau, USGS Wisconsin

Discharge from the St. Louis River Estuary (SLRE) to Lake Superior is affected by inflows from multiple tributaries and water exchanges with Lake Superior through two connecting ship entries. Five index-velocity gages were installed in 2015 to continuously monitor water levels, flows, and velocity profiles in the SLRE. Water budget calculations for 2016 and 2017 indicate significant contributions from the St. Louis, Nemadji, and Pokegama Rivers as well as from smaller tributaries. Large inflow events produced brief synchronous discharge peaks out of the two connecting channels into Lake Superior, but synchronous outflows were frequently replaced

by a complex mixture of inflows through Duluth Entry and outflows through the Superior Entry. As a result, 70% of SLRE net discharge flows through Superior Entry. Total 2016 discharge and heat flux to Lake Superior were simulated using an Environmental Fluid Dynamics Code (EFDC) model. Simulations of total daily discharge from the SLRE had a Nash-Sutcliffe (N-S) coefficient of 0.80, with N-S coefficients for the Duluth and Superior entries of 0.41 and 0.57, respectively. Hourly simulations of Duluth Entry temperature for 2016 had a N-S of 0.71. The model will be validated against 2017 data and used to estimate constituent loads to Lake Superior.

Assessing Streamflow, Water-Quality and Streambed-Sediment-Chemistry Conditions in Areas of Known Mineralization in the Lake Superior Basin

Authors: Perry Jones, USGS Upper Midwest Water Science Center, Minnesota Office; Faith Fitzpatrick, USGS; Thomas Weaver, USGS; Laurel Woodruff, USGS Eastern Mineral and Environmental Resources Science Center

As part of the Cooperative Science and Monitoring Initiative (CSMI), streamflow, water-quality, and streambed-sediment-chemistry data were collected in 2014-16 in 14 watersheds in the western Lake Superior basin where minerals have and may be extracted. The 14 watersheds are located in the headwaters of the St. Louis River watershed in northeastern Minnesota, the Bad River watershed in northern Wisconsin, and 12 watersheds in the Upper Peninsula of Michigan. Water-quality samples were analyzed for total (unfiltered) concentrations of 22 trace elements, 8 major constituents, and 3 nutrients, and total and dissolved (filtered) organic carbon concentrations. Streambed-sediment samples were analyzed for 47 major and trace elements. The streamflow, water-quality, and streambed-sediment-chemistry data were interpreted and compared to historical streamflow and water-quality data to determine a range in levels of metals and other constituents within watersheds draining mineralized regions of western Lake Superior.

Geomatics, Remote Sensing & Mapping Lake Superior Watershed, p.m.

Using Autonomous Vehicles to Quantify Small Tributary Inputs to Lake Superior

Authors: Amy Marcarelli, Michigan Technological University; Colin Brooks, MTRI; Jamey Anderson, Michigan Technological University - Great Lakes Research Center; Karl Meingast, Michigan Technological University; Evan Kane, Michigan Technological University

Lake Superior receives inputs from thousands of tributaries that provide nutrients to the nearshore zone. Tributary plumes with elevated turbidity, lower nitrate concentrations, distinct water temperatures, and distinct dissolved organic matter character can be detected in the near-shore. These plumes are often easily visible using satellite imagery following large runoff events, yet quantifying the area, volume, and timing of these inputs across the full range of hydrologic conditions is challenging. The authors presented results from preliminary efforts using an underwater autonomous vehicle and an unmanned aerial system, coupled with boat-based water chemistry analyses to characterize tributary plumes in the region of the Keweenaw Peninsula. Sampling after a summer storm in July 2018 revealed that plume water can be detected using natural color imagery and continuous measurements of water temperature and conductivity. Autonomous technologies provide many advantages. They can be deployed during adverse weather conditions (e.g., high runoff, storm events), collect data when cloud cover may prevent the use of satellite remote sensing, and provide high-resolution data to accurately quantify the

area and depth of plume inputs. Such understanding is required to build detailed estimates of tributary inputs to Lake Superior and quantify their variation in time and space.

Monitoring Coastal Wetland Types and Invasive Plants with High-Resolution Satellite Imagery

Authors: Laura Bourgeau-Chavez, MTRI; Michael Battaglia, MTRI; Sarah Grelik, MTRI; Colin Brooks, MTRI; Amanda Grimm, MTRI

Coastal wetlands are vital to the health of the Great Lakes, yet they are vulnerable to changes in land use, climate, and invasive species. Adaptive management is essential to monitoring and mapping the distribution of native wetland types and invasive species. A binational team is working on developing methods for monitoring coastal wetlands using high-resolution Digital Globe optical and Radarsat-2 synthetic aperture radar (SAR) satellite imagery at sites around the Great Lakes including the St. Louis River Estuary (SLRE). These SAR and optical sensors are used alone and in combination for classification of wetland types, including discrimination of the invasive species, *Phragmites australis*. Novel work is underway using polarimetric SAR algorithms for detecting this invasive plant that would allow for timely data irrespective of cloud cover. The degree of invasion of non-native plants sometimes consists of very small patches, such as at the SLRE; however, these could expand quickly under the right conditions and must be monitored at high resolution for spread and control. The ultimate goal for automation of wetland type products across the Great Lakes requires development of approaches to improve mapping capability in lieu of site-specific field data and to adjust for between-scene variability.

Unmanned Aerial System Multispectral Imagery Mapping for Monitoring Eurasian Watermilfoil Treatments

Authors: Colin Brooks, MTRI; Amy Marcarelli, Michigan Technological University; Amanda Grimm, MTRI; Casey Huckins, Michigan Technological University; Richard Dobson, MTRI; Ryan Van Goethem, Michigan Technological University; Robert Smith, Les Cheneaux Watershed Council

The invasive submerged aquatic plant Eurasian watermilfoil (*Myriophyllum spicatum* or "EWM") can form thick stands and tangled mats of vegetation near the water surface, interfering with navigation, recreation, and native plants. Millions have been spent by environmental and natural resource agencies to reduce EWM, but it is challenging to quickly and accurately track the extent of EWM infestations and document the effectiveness of management methods. The authors have been collecting natural color, near infrared (NIR), and multispectral imagery from unmanned aerial system (UAS) platforms to map the extent of EWM establishment and responses to management in nearshore areas of Lake Superior and Lake Huron. Results show that with visible and NIR multispectral wavelengths, and suitable water and light conditions, UAS-enabled imaging is effective for monitoring EWM extent following management efforts. In the Pike Bay area near Chassel, MI, imagery collected before and after Diver Assisted Suction Harvesting (DASH) showed the reduction of biomass in the treatment area. UAS-enabled multispectral imaging provides another tool to study the management and ecology of submerged aquatic vegetation.

Remote Sensing of Stamp Sand Erosion and Deposition in Keweenaw Bay: Analysis and Results Sharing

Authors: Mike Sayers, MTRI; Colin Brooks, MTRI; Robert Shuchman, Michigan Technological University; W. Charles Kerfoot, Michigan Technological University, Great Lakes Research Center and Dept. of Biological Sciences; Michael Billmire, MTRI

A legacy of copper mining in the Keweenaw Peninsula includes 22.7 million metric tons (MT) of processed mining ore known as stamps sands that was deposited near the village of Gay, MI in the early 20th century. The authors' previous work using historical records, 2009 multispectral imagery, and 2008 LiDAR data showed that about 3 million MT remain in the original stamp sands pile, 12 million MT have been redeposited along 8 km of shoreline, 1 million MT have been used for road applications, and 10 million MT have moved into Grand Traverse Bay, covering the original lake bottom. These underwater stamps sands have begun encroaching onto Buffalo Reef, a productive spawning area for whitefish and Lake Trout. Analysis of 2009 depth-corrected aerial images showed that a nearby trough area is mostly filled with stamp sands and acts as a reservoir for material that threatens the reef. The authors updated this analysis with 2016 imagery from the US Army Corps, coupled with in situ sampling, to show how stamp sands migration and the degree of reef encroachment have changed. This information informs effective dredging strategies. The results have been shared through a user-friendly web mapping portal to help stakeholders.

Enabling Sharing of Lake Superior Remote Sensing Data through Multi-Portal Support

Authors: Michael Billmire, MTRI; Colin Brooks, MTRI; Mike Sayers, MTRI; Robert Shuchman, Michigan Technological University; Karl Bosse, MTRI; Reid Sawtell, MTRI

The types and temporal frequency of remote sensing products for Lake Superior and other Great Lakes have been increasing in recent years, providing more synoptic coverage of lentic water characteristics. The authors have been creating and sharing derived remote sensing products, including photic zone depth, Kd490, chlorophyll, suspended minerals, color dissolved organic matter, dissolved organic carbon, lake surface temperature, natural color imagery, and time-averaged products for Lake Superior. To enable greater access to these data for citizens, scientists, agency staff, and other stakeholders, the authors have been developing and improving the user-friendly Satellite Derived Great Lakes Remote Sensing web portal. MTRI has been working closely with the Great Lakes Observing System (GLOS) and NOAA Great Lakes Environmental Research Laboratory (GLERL) Coastwatch to increase access to derived remote sensing data through web mapping services for GLOS and algorithm integration for GLERL. These provide practical examples of enabling improved data sharing of Great Lakes scientific data to support diverse stakeholders.

Northern Exposure: Ongoing Investigations on Lake Superior's North Shore

The North Shore of Lake Superior has a broad diversity of habitats and unique ecosystems. Thunder Bay, Black Bay, and Nipigon Bay all provide significant habitat structure and unique hydrodynamic environments, but they also have historic and ongoing legacies of anthropogenic disturbance. Most of the water entering Lake Superior comes from the North Shore, the majority from the Nipigon River; additionally, a National Marine Conservation Area has recently been established on Lake Superior's North Shore, encompassing 10,000 km^2 of lakebed. This mix of issues and the vast scale of the region require a multifaceted approach to management, which

spans from the restoration and reestablishment of ecosystem integrity and fisheries in altered environments, to providing a greater understanding of some of the basic biology of fish and fisheries in this region. This session highlighted ongoing research on Lake Superior's North Shore, focusing on the distribution, movement ecology, and temporal patterns of fish communities and populations along the North Shore, highlighting species of particular conservation and management interests. Ongoing research into movement studies of various fish populations and the use of both traditional (index netting) and emerging technologies (stable isotopes, hydroacoustics, acoustic telemetry) to better understand fish populations along the North Shore were presented.

Life History Shifts in Steelhead (Oncorhynchus mykiss) along the North Shore of Lake Superior

Authors: Kyle Stratton, Lakehead University; Michael Rennie, Lakehead University

Size selective mortality can drive evolutionary changes in fish populations. Portage Creek has been subjected to various environmental changes and selective pressures over the past few decades which have impacted the life history strategies and characteristics of its Steelhead. The objective of this research is to use life history theory to predict how Portage Creek Steelhead life history traits are expected to respond to the different selective pressures present in their environment. The authors showed that high rates of exploitation of adults, density-dependence of in-stream juveniles, and mortality on small juveniles have all affected the life history strategies expressed by Portage Creek Steelhead. The authors found that during high rates of exploitation of adults, Steelhead were predominantly smolting at age 1 and reaching maturation at a relatively young age of 3 or 4 years. Once harvest was no longer a factor in Portage Creek, the Steelhead were still smolting and reaching maturation at an early age. Contemporary data show that the Steelhead are now smolting at age 2 and reaching maturation at a later age. The authors' results add further evidence that populations of Steelhead along the North Shore should be continuously monitored and strictly managed.

Movement Diversity Links to Life History in Black Bay Walleye (Sander vitreus)

Authors: Graydon McKee, Lakehead University; Eric Berglund, Ontario Ministry of Natural Resources and Forestry (OMNRF); Anthony Chiodo, OMNRF; Fischer Friedrich, OMNRF; Erin Dunlop, OMNRF, Trent University; Thomas Pratt, Fisheries and Oceans Canada; Michael Rennie, Lakehead University

The vast area covered by the Laurentian Great Lakes encompasses a number of aquatic ecosystems and crosses multiple geopolitical boundaries. This makes the understanding of fish movement ecology important, particularly for populations that are the focus of ongoing recovery efforts such as Black Bay Walleye. Given the potential for long-range migration in this species, variation in life history strategy could lead to partial migration, with differences in resource use and survival. By making use of an acoustic telemetry study initiated in 2016, the authors tracked Walleye movement and survival within and immediately outside of Black Bay. The authors further compared movement strategies to growth as a proxy of life history. Walleye movement showed no time-dependent patterns, and survival was consistently high across space and time. Walleye displayed two distinct movement strategies; migrators left Black Bay entirely for brief periods during the summer, while residents remained within the bay for the entire year. Migratory Walleye grow larger than their resident counterparts, which may be an indicator of sexual dimorphism in movement strategies.

Comparing Ship-Based to Sled-Based Acoustic Estimates of Cisco (Coregonus artedi) in Lake Superior

Authors: Ryan Grow, University of Minnesota-Duluth; Thomas Hrabik, University of Minnesota-Duluth; Daniel Yule, USGS Great Lakes Science Center; Bryan Matthias, University of Minnesota-Duluth; Jared Myers, US Fish and Wildlife Service; Chad Abel, Red Cliff Band of Lake Superior Chippewa

Down-looking acoustic surveys are commonly used to determine fishery status for resource managers, particularly in the Great Lakes and marine systems. However, there are some limitations and biases built in to traditional down-looking acoustic surveys. In this study the authors examined the use of a multi-directional acoustic sled to overcome these limitations while examining Lake Superior Cisco (*Coregonus artedi*), which is a species of interest to fishery managers. The authors concurrently deployed the acoustic sled during traditional down-looking surveys to directly compare fish densities obtained from each type of gear, which the authors then followed with a mid-water trawl to inform the acoustic data with species composition. The authors findings from western Lake Superior indicate that there is a significant difference between fish densities detected by the sled survey and the ship-based down-looking survey (Shipμ=148fish/hectare, Sledμ=678fish/hectare, $p<0.001$, df=23), which suggests that a portion of pelagic fish biomass was missed by the down-looking survey. The authors' also provided analyses of species detection differences between the two approaches. This study also seeks to provide a baseline for future studies looking to discover which species in a given system are most effected by traditional survey biases, and future work into using alternate forms of acoustic sampling to inform fisheries management and research.

Lake Sturgeon Movements in Black Bay

Authors: Thomas Pratt, Fisheries and Oceans Canada; Lisa O'Connor, Fisheries and Oceans Canada; William Gardner, Fisheries and Oceans Canada; Fischer Friedrich, OMNRF

The application of acoustic telemetry tools to fully recovered Lake Sturgeon populations in the Great Lakes has revealed multiple migratory behaviours within the same population. It is uncertain whether the same range of behaviours can be expected in a small, recovering population with more limited habitat options. In spring 2016, the authors tagged 20 Lake Sturgeon (mean TL = 1184 mm, mean age at tagging 13.6 yrs) with 10-year acoustic tags in Black Bay, Ontario, to take advantage of an existing acoustic telemetry array designed for a Walleye movement study. The authors' study objectives were to examine migratory behaviour, identify potential spawning rivers and spawning periodicity, and identify critical habitat and spatial extent (home range, area of occupancy). The authors' limited data to date indicate that these fish exhibit an exclusively resident migratory behaviour, with no excursions observed outside of Black Bay. Fish have only been observed migrating up one of two potential spawning rivers (Black Sturgeon River) during the spawning season. A change in acoustic receiver placement to affect a grid pattern in the north part of the bay will allow a better assessment of habitat use and home range starting in 2017 and as the study moves forward.

Evaluating Spatial Variation in Lake Superior Food Web Connectivity

Authors: Marissa Wegher, Lakehead University; Aaron Fisk, University of Windsor; Timothy Johnson, OMNRF, Glenora Fisheries Station; Michael Rennie, Lakehead University

As one of the largest freshwater lakes in the world, Lake Superior's size can be limiting to research studies. Many studies are only able to analyze a specific region and make general inferences to the lake as a whole, despite the fact that community structure is spatially variable. The amount of spatial variation that occurs lakewide is unknown. Stable isotopes of common fish species and their prey were analyzed to understand the variability of resource use and energy flow through the lake. Samples were collected from four geographically and limnologically distinct regions along a depth gradient. Results indicated the community structure of the Western Arm was at a lower trophic level than the other three regions, and baseline planktonic carbon signatures were more variable in the two deeper regions than in the shallow regions. Pelagic species (i.e., Lake Trout, Bloater, Herring, Smelt) had an increased dependency on benthic derived food sources as depth increased; this pattern is most defined in the deeper regions. These data suggest that resource use varies both regionally and at different depth strata in Lake Superior. Knowing the amount of inherent spatial variability in Lake Superior may help us identify common properties of other healthy large lake systems.

Coaster Brook Trout Rehabilitation in Canadian Waters of Lake Superior—Challenges and Success

Author: Eric Berglund, OMNRF

Coaster Brook Trout (*Salvelinus fontinalis*) rehabilitation has been recognized as a high priority among fisheries management agencies in the Lake Superior basin since 1990 and particularly since the development of a lakewide rehabilitation plan in 2003. Remnant stocks of Coaster Brook Trout persist in only a few areas in Lake Superior, one of which is Nipigon Bay, Ontario, Canada. This area was renowned for its large Brook Trout and supported a legendary sport fishery dating back to the 1850's. Although Brook Trout populations persist in the region, they are a fraction of their historical abundance. This presentation highlighted the progress and ongoing efforts that OMNRF has made in advancing the understanding of Coaster Brook Trout populations and the progress towards rehabilitation goals, through standardized assessment surveys and successful partnerships with stakeholders.

Protection of the Lake Superior Ecosystem

Lake Superior is regularly defined as the most pristine of the Great Lakes, with areas of high-quality habitat. However, as communities around the basin continue to address legacy contamination, the lake is also highly susceptible to future threats. This susceptibility, a renewed focus on restoration, and finite resources require increased attention be brought to active protection management if the lake's high-quality habitat will be able to survive those threats. Definitions and perceptions of what constitutes protection differ around the lake, among and within agencies, which results in inherent difficulty in tracking successful implementation. This session explored how protection should be included in high-level adaptive management and connected to forecasting activities, how projects already underway in Lake Superior can help forward protection management, and examples of what "protection" means to management agencies throughout the basin.

Stakeholder Feedback on the Protection of Lake Superior Protection (1 of 2)

Author: Rob Hyde, ECCC

Lake Superior is regularly defined as the most pristine of the Great Lakes, with areas of high-quality habitat. However, it is not immune to existing or future threats. This susceptibility requires increased attention be brought to active protection management to help support the sustainability and adaptability of the Lake's habitat in the face of those threats. Natural resource protection generally refers to efforts that prevent the future damage or degradation of the environment. But different definitions and perceptions of the desired outcome of protection efforts make describing "successful" protection management difficult.

This presentation first introduced existing protection efforts that are identified in the Lake Superior Lakewide Action and Management Plan (LAMP). Because successful implementation of any targeted protection effort requires a defined desired result, this presentation also showcased stakeholder input regarding the desired outcomes of protection management (i.e., What should protection activities in Lake Superior work towards?).

Stakeholder Feedback on the Protection of Lake Superior Protection (2 of 2)

Author: Jennifer Vanator, GLIFWC

The Lake Superior basin is generally regarded as the cleanest of the Great Lakes. Keeping it that way requires active management to maintain high-quality conditions. Adequate support for natural resource protection requires a general agreement and understanding about what activities constitute protection. However, definitions and perceptions of what constitutes protection differ around the Lake, among and within agencies. A better understanding of the myriad of protection management concepts as they relate to Lake Superior and its associated habitats can help lead to an agreement about what activities constitute protection and therefore a better understanding of how implementation of protection activities can be accounted for, tracked, and assessed. Together, these can lead to better integration of protection into the overall management of Lake Superior.

A stakeholder survey was released to the public in advance of the SOLS Conference to obtain a picture of how protection is viewed and pursued throughout the Lake Superior basin; 184 responses were received from US and Canadian federal agencies, state and provincial agencies, tribal agencies, local governments, NGOs, academia, and private citizens. The responses demonstrated that many conversations about protection are occurring around the basin, but they also highlighted some of the disconnects that must be addressed.

A. <u>Outcomes</u>

When given three choices, the overwhelming percentage (85.3%) of respondents chose "ability of ecosystems to retain functions when faced with known threats or other changes" as the desired outcomes of protection activities. "Achievement of a defined state of natural resources," was a desired outcome in 39.1% of responses, while "preservation of existing baseline conditions" was a desired outcome in 37.5% of responses.

B. <u>Activities – Assigned Categories</u>

When provided with 8 categories of activities and asked to rank them from "not a protection activity" through "very important protection activity," each activity was considered to be at least

a somewhat important protection activity by a majority of respondents. The categories and percentage of respondents who found them to be important are listed in order below:

- Enforcement of existing laws, 94%
- Planning/Zoning, 91%
- AIS prevention, 90%
- Outreach/Education, 88%
- Monitoring baseline/trends, 87%
- Land acquisition/easements, 81%
- Ensure adequate representation, 79%
- Forecasting future conditions, 72%

C. Additional Activities

Over 70 respondents provided additional activities that they considered to be important protection activities. Many seemed to be specific examples of activities that would have fit into the broader protection categories listed above. This shows that people think about these activities in very different ways, and illustrates an important disconnect: *how do we bundle discreet actions into broader actions, particularly in ways that are useful for long-term management plans*.

In addition, these responses provided three additional categories of activities that were not listed above: restoration, strengthen legal/regulatory regime, and adaptation.

D. Outcomes that the protection activities are supporting

The activities were grouped according to the outcomes that they support. While 85% of people said that the retention of ecosystem functions was the desired outcome of protection activities, more of the protection activities that were identified as important supported the preservation of existing baseline conditions than the other two outcomes. *The actions that respondents claimed were important are not supporting the outcomes that respondents identified as important.* Respondents seem to recognize a need to focus on processes, but most of the work to date seems to have a narrower focus, on identifying the state of resources and existing conditions, with less emphasis on focusing actions based on the processes we want to preserve.

E. Current Protection Activities

Some respondents provided examples of protection activities that their agencies are currently performing. Listed in order of highest number of respondents pursuing that activity, these activities are: species/habitat protection; monitoring; acquisition; developing plans; public engagement; AIS identification, treatment, and prevention; developing a protected status for areas of land or water; supporting or restoring stream or land connectivity; planting land; pollution or hazard mitigation; pursuing regulatory actions; long-term maintenance of an area; species inventory; and political action.

By comparing those activities that were identified as important for protection with those activities that respondents were currently pursuing, it is clear that they do not match up. More respondents identified strengthening the regulatory regime, undertaking planning or zoning activities, restoration, and public engagement activities as important than are currently pursuing those activities. On the other hand, many more people are pursuing AIS, monitoring, and acquisition or easement activities than identified them as being important.

These results demonstrate a disconnect between activities people think are important to pursue, and those they are pursuing.

F. Reasons Protection Activities Are Not Supported

Respondents were asked if they had protection projects or initiatives that they wanted to pursue but were not supported, why those activities were not supported. In order, the reasons given were: lack of political support, complexity of the problem or solution, competing interests, and unknown relevancy to protection. The majority of respondents did not know why their projects or initiatives were not supported.

G. Metrics

The survey asked people whose agencies were undertaking current protection activities to provide the metrics used by those agencies. Relatively few metrics were provided. Those that were provided were: acres/miles of land/stream, population numbers, water quality, number of structures, amount of people participating in public events, percentage of land in protected status, number of plans developed, and indicators. These metrics are all numerically based and, especially when taken independently, have limited insight into complicated relationships involved in ecosystem functions. These metrics are intensely project specific. *The limited metrics currently available might limit the types of activities that agencies can pursue*.

H. Takeaways

Some of the takeaways of the public survey are:

- The majority of respondents think that the retention of ecosystem functions is the desired outcome of protection activities.
- The activities most often identified as important for protection support the preservation of baseline conditions more so than retention of ecosystem functions.
- The activities respondents currently pursue do not match up with the activities they identified as important.
- Respondents recognized that it is important to focus on process, but activities undertaken to date seem to have a narrower focus, on identifying the state of resources and existing conditions, with less emphasis on focusing actions based on the processes we want to preserve.
- There needs to be a common understanding of how to bundle discrete protection activities into broader actions, especially in ways that are useful for long-term management plans.
- Limited types of metrics are currently available to track protection activities, and that risks limiting the types of activities we can pursue. Current metrics do not seem to track ecosystem functions.

Smart Lake Concept: Innovation and Collaboration Lake by Lake

Authors: Ed Verhamme, LimnoTech; Bryan Stubbs, Cleveland Water Alliance; John Bratton, Limnotech

Innovation and collaboration are two key concepts needed to improve how we approach solving difficult Great Lakes problems. This presentation focused on how technology, including sensors and data management systems, is changing the way scientists and managers innovate and collaborate. Technology is transforming virtually every sector of our economy, and

environmental monitoring, management, and research are no exceptions. Recent advances include low-cost sensors, data loggers, telemetry, analytics, and more powerful data storage and visualization hardware and software. The Smart Lake Concept, as originally proposed by the Cleveland Water Alliance to support harmful algal blooms (HABs) and hypoxia work on Lake Erie, builds off of the Smart City initiative and has broad implications across the Great Lakes including Lake Superior. Recent work on Lake Erie demonstrates how the Smart Lake vision embeds innovation, collaboration, sustainability, and decision support in its application to pressing lakewide issues.

Ecological Forecasting: Informing Management and Protection of the Lake Superior Ecosystem

Author: Madeline Magee, Wisconsin DNR

Lake Superior, with its variety of coastal and in-lake habitats, supports extraordinary in-lake, nearshore, and on-shore biodiversity. However, these important habitats are susceptible to existing, projected, and as-yet unknown threats. Actively protecting Lake Superior habitat will be a critical component of ensuring the long-term ecosystem function of the Lake. One path towards efficient and effective long-term ecosystem protection is the use of forecasting to identify locations and actions that will achieve the greatest impact. The author provided an overview of ecological forecasting and what kind of information can be obtained through these forecasting initiatives. Ecological forecasting can tell us where and when high-value habitats may be at risk to loss of ecosystem services and identify those that are likely to be resilient to changes in stressors. For less-resilient habitats, forecasting can help to understand how changes in drivers may alter habitat in the future and guide management efforts to develop resistance to those changes. The author provided an example of how forecasting can be used in strategic protection. The Minnesota DNR used forecasting to identify 176 deep, clear lakes in Minnesota that will provide habitat under predicted climate change scenarios, as long as their watersheds remain forested rather than converted to agriculture or to urban/suburban land uses. They assessed the threat of conversion from forested to other land use type for each of the "refuge" watersheds, and created maps scoring watersheds based on the price of land. Using the maps of threat and investment efficiency, the Minnesota DNR identified priority watersheds where there was high threat to being converted from forested watershed and where land prices were low (see Jacobson et al. 2013. Protecting cisco oxythermal habitat from climate change: building resilience in deep lakes using a landscape approach. *Advances in Limnology*, 64:323-332). Now, the Minnesota DNR is working with partners to buy land in priority watersheds that can be maintained as forest land permanently.

Tracking, Assessing and Reporting on Protection through Habitat Metrics

Authors: Britney MacLeod, ECCC; Jocelyn Sherwood, ECCC

Effective protection strategies require defining desired future ecosystem conditions that, if achieved, are likely to result in the persistence of biodiversity. However, answering questions such as *How much should be protected?* and subsequently tracking, assessing, and reporting on progress can be challenging. Science-based habitat guidelines that incorporate metrics can be used to identify clear, measurable, and achievable targets which then enable project teams to more effectively track and report on progress. ECCC has developed various habitat guidance and planning tools that are intended to facilitate effective conservation planning. *How Much Habitat is Enough?* (3rd edition, 2013) provides habitat guidelines for southern Ontario that have been widely adopted, while *How Much Disturbance is Too Much?* (draft) provides preliminary

guidance for more intact landscapes where opportunities exist to conserve regional and local habitat mosaics. Across the largely intact – but increasingly threatened – Lake Superior ecosystem, these tools may act as a guide for selecting relevant metrics that consider the various scales, jurisdictions, and protection goals across the basin. Using ECCC habitat guidance as a reference, this presentation discussed the utility of a metric-driven approach for identifying effective protection strategies.

Group Discussion: Tracking Methods, Forecasting Techniques, and Goal Development for the Protection of Lake Superior

Author: Michele Wheeler, Wisconsin DNR

The session included a 40-minute facilitated discussion that sought to gather feedback from participants on protection strategies for the Lake Superior basin. A draft definition of protection was presented as: Effective protection of the Lake Superior basin includes maintenance and improvement of ecosystem functions that allow for resiliency and adaptation to future threats. Feedback from participants included:

- Look to the International Union for Conservation of Nature (ICUN) for perspectives on resource protection.
- The Open Standards for Conservation approach (utilized by the Canadian Wildlife Service of ECCC) was recommended as a resource for defining desired outcomes of protection.
- Consider language, with protection often interpreted as excluding human involvement, while participants emphasized the need to include people as part of the ecosystem, and ensure human communities are also resilient. Many suggest using the term "conservation" instead of "protection."
- Protection, in this way of thinking, is one tool to achieve conservation, which includes both protection and restoration.
- A question was raised about whether there is a need to consider ecosystem composition (e.g., biodiversity, native species, etc.) as well as ecosystem function.
- Suggestion to move past the notion of "protecting Lake Superior" and try to define more specifically the components and functions that should be protected.

Next, an approach to protection strategy and metric development was presented for feedback. The approach focused on a way to connect desired protection outcomes with metrics and actions. General objectives from the Great Lakes Water Quality Agreement (GLWQA) were used as a broad representation of services of value and an organizing framework. Session participants were asked to identify an ecosystem function that works to protect one selected general objective, followed by actions that would protect that function, and a metric that could be used to track progress of those actions (Figure 1). A summary of contributions to this activity is available upon request.

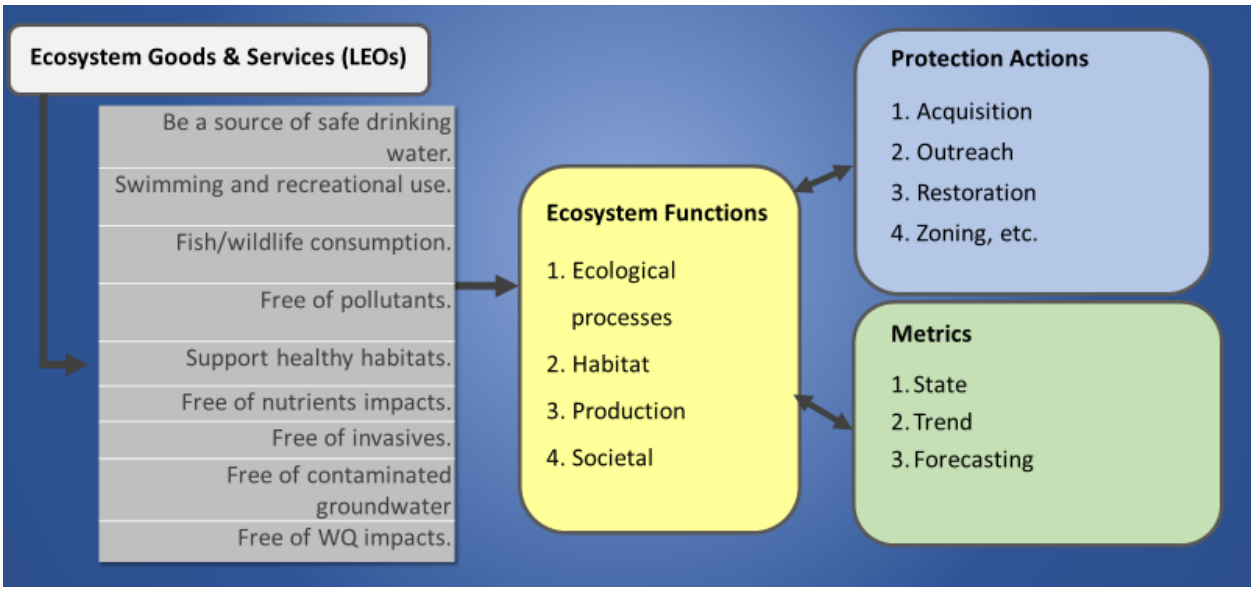

Figure 1. Schematic of approach to developing protection activities and metrics towards ecosystem functions associated with lakewide ecosystems objectives (LEOs).

Feedback from session participants included:

- Overall, the approach was deemed favorable, but more consideration is needed.
- Coordinate with existing efforts such as the Great Lakes Source Water group.
- There are groups that have stepped the LEOs down even further; work with the information available.
- Utilizing this approach for all LEOs would be a big undertaking. To make this achievable, consider prioritizing which LEOs to focus on.
- Hard to complete the exercise without more time.

Aquatic Invasive Species

The Lake Superior ecosystem has remained a relatively cold spot for nonindigenous species introductions, but additional stressors may increase the frequency and susceptibility of this ecosystem to invasive species establishment. This session provided the opportunity to present new research on non-native species that have become established in Lake Superior and monitoring and citizen science based initiatives for their detection and prevention of their spread.

EDRR Efforts of Flowering Rush (Butomus umbellatus) in the AuTrain River

Author: Elise Desjarlais, Lake to Lake Cooperative Invasive Species Management Area (L2L CISMA)

In 2016, an infestation of flowering rush (*Butomus umbellatus*) was reported and confirmed in the AuTrain River in Alger County, Michigan. This was the first—and remains the only known—infestation in the Upper Peninsula and the entirety of the Lake Superior watershed. Efforts by the L2L CISMA and its partners were put forth to map the infestation and follow through with the establishment of monitoring plots to observe various treatment efficacy rates.

While flowering rush has been removed from the Michigan Invasive Species Watch List, this infestation poses a unique situation that calls for the same protocol that a watch-list species might. Early detection and rapid response (EDRR) can mitigate the damage done by an invasive infestation to native ecosystems, and given the unique circumstances of this population (both in location and the population abundance), urgent efforts have been given to its presence.

Non-native Species Introductions into the St. Louis River Estuary versus Lake Superior, 1883-2018

Author: Doug Jensen, University of Minnesota Sea Grant Program

Non-native species introduction data for the St. Louis River Estuary (SLRE) and Lake Superior were obtained from the Great Lakes Environmental Research Laboratory's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) and augmented with records from Minnesota Sea Grant. Data included location of introduction, year of first sighting, type of organism, pathway for introduction, and current status.

From 1883 to 2018, 11 more non-native species were introduced into Lake Superior (n=81) compared to SLRE (n=70). For SLRE, introductions included: 24 aquatic invertebrates (34%), 17 fish (24%), 15 riparian terrestrial plants (22%), 7 aquatic/wetland plants (10%), 7 fish diseases/parasites (10%), but no algae/bacteria were reported. Similarly, Lake Superior introductions included: 22 invertebrates (27%), 19 fish (24%), 14 riparian terrestrial plants (17%), 7 aquatic/wetland plants (9%), 9 fish diseases/parasites (11%), and 10 algae/bacteria (12%). For both systems, GLANSIS used 13 categories to characterize non-native status, two of which, established and collected, explained >96% of those reported.

Since 2006, six additional non-natives have been found. During this period, aquatic discoveries averaged 0.5 species/year, down half from a decade ago. Pathways for introduction were discussed. Understanding what is invasive, and interrupting the pathways for spread are critical to improve the management of aquatic invasive species in Lake Superior.

The Invasive Diatom Didymosphenia geminata, a Lake Superior Native

Author: Michael Gretz, Michigan Technological University

Didymosphenia geminata is a huge pennate diatom that was much sought after in the early 20th century as a "trophy" checklist species and was rarely seen. In recent years, blooms producing mats which can exceed 20 cm thick and 100 percent coverage have redefined "Didymo" as a harmful invasive in many areas of the world. Lake Superior joined the Didymo "club" in 2008 with the discovery of extensive mats between the Lester River and Grand Portage and later in the St. Marys river. Characteristic Didymo mats are composed of extracellular stalks extruded and woven together by cell division, migration, etc. The chemical nature of the stalks and patterns/control of secretion define Didymo blooms. (A bloom of stalk-less cells would appear as a very thin brown film on the substratum!) Didymo stalks are a unique mineralized polysaccharide composite composed of calcite nanofibers with amorphous silica embedded in a sulfated polysaccharide/protein complex. Stalk carbonic anhydrase and phosphomonoesterase: phosphodiesterase activities may be related to *D. geminata* viability. From a biotechnology perspective, Didymo stalks have utility as an adsorbent for hazardous metal removal.

Early-Detection Monitoring Survey Addressing Dreissenid Incursions to Apostle Islands National Lakeshore

Authors: Jonathan Barge, ORAU (contractor to US EPA); Anne Cotter, US EPA; Chelsea Hatzenbuhler, US EPA Oak Ridge Institute for Science and Education (ORISE); Joel Hoffman, US EPA Office of Research and Development; Christy Meredith, National Research Council/US EPA; Greg Peterson, US EPA; Sara Okum, ORISE; Erik Pilgrim, US EPA; Anett Trebitz, US EPA; Molly Wick, US EPA, Oak Ridge Institute for Science

The notion that Lake Superior is inhospitable to *dreissenid* survival has been repudiated by recent finds on shipwrecks, commercial fishing gear, and substrates in the Apostle Islands (APIS) region. Motivated by National Park Service concerns surrounding these finds, the US EPA in 2017 conducted an intensive sampling campaign of APIS coastal waters, aimed at understanding *dreissenid* prevalence and distribution and providing baseline data for potential impacts on zooplankton and benthic invertebrates. The 100-site effort combined randomly selected and targeted sites (e.g., dock and mooring areas), and collected zooplankton, benthos, video footage, e-DNA water, and water chemistry data. *Dreissenid* veligers were found in almost half of the zooplankton samples, but at very low numbers compared to the other Great Lakes. The authors did not find settled *dreissenids* in any benthos samples or videos. Veliger densities were highest in western APIS waters, especially around Sand Island. The authors lack information to determine whether these veligers are locally produced or transported there from established Duluth-Superior Harbor populations by longshore currents.

Geomatics and Remote Sensing Workshop

Session Chairs: Brian Huberty, US Fish and Wildlife Service; John Jereczek, Minnesota DNR

Attendees participated in a discussion of how LAMP goals could be supported by the geomatics community within and exterior to the Lake Superior Partnership Working Group. Members of the geomatics community expressed support for increasing collaboration, shared use of data, and desire to provide analytical support/geomatics products.

Public Session: Scientific Challenges of Developing a Plan to Protect Buffalo Reef

Free and open to the public, this session provided an overview of the scientific challenges associated with protecting Buffalo Reef. A century ago, 23 million tons of mine tailings were dumped into Lake Superior. Wind, waves, and currents have pushed these tailings toward Buffalo Reef, a valuable area for fish spawning. This copper-laden waste, also called stamp sands, has covered over a third of the reef and a similar amount of nearby juvenile whitefish habitat. The US EPA initiated the Buffalo Reef Task Force two years ago to develop a management plan to preserve and protect Lake Trout and whitefish populations. This session described alternatives being considered to protect the reef in the future, provided an open discussion on the challenges, and discussed options to overcome them.

October 11

Citizen Science: Leveraging Our Sense of Place to Learn About and Protect Lake Superior

Lake Superior is massive and complex. Government/tribal agencies conduct some regular monitoring of Lake Superior waters to discern her complicated patterns but have limited time and resources to address the many complicated natural resource challenges facing Lake Superior. The use and reliance on citizen science data collection programs to help address those challenges has expanded nationally and regionally to provide datasets that may not otherwise be possible to collect. This session highlighted the diversity of citizen science projects in the Lake Superior basin, challenges to addressing quality assurance of citizen science data, and the value of citizen science data to addressing management issues. The session enlightened stakeholders about how citizen science can be employed to assess and monitor Lake Superior ecosystems as well as increase science communication with the public.

Lake Superior's Lingering POPs Contamination

Author: Melvin Visser, Independent

POPs, persistent organic pollutants such as PCBs, chlordane, and toxaphene were banned a third of a century ago but remain above target levels. PCBs have an identifiable presence in soils, landfills, and sediments, but toxaphene and chlordane are not found near our shores. Why do these chemicals linger in our fish?

As a member of the citizen advisory committee of the US EPA's Lake Michigan LAMP, the author learned that extensive US EPA research (1994/5) revealed how PCB deposition from the air controlled the lake's PCB levels. The Arctic Monitoring and Assessment Programme (1998) disclosed the hemispheric travel of POPs and the need for global banning. Other than a partial ban of DDT, global governance has proven to be ineffective in banning chemicals useful to Earth's rapidly developing manufacturing countries. The recalcitrance of Great Lakes POPs toxicity was documented in the author's book *Cold, Clear, and Deadly: Unraveling a Toxic Legacy* (MSU Press 2007.)

Examination of ongoing efforts to eradicate PCBs through local efforts indicates that efforts are having little to no effect on Lake Superior's fish. The POPs ecosystem is the hemisphere, and to reduce their presence in Lake Superior, it will be necessary to eliminate primary hemispheric sources.

Using Citizen Scientists to Collect Spatially Distributed Hydrologic Data through Crowdsourcing

Author: Tiffany Sprague, Natural Resources Research Institute

Citizen science opportunities have grown steadily in recent years, supporting academic and agency research and monitoring, and providing a valuable form of community and formal education and environmental awareness to citizens. Crowdsourced data collection by citizens has relied heavily on affordable, smart technology to collect, share, and store large quantities of informational data. CrowdHydrology is a crowd-sourced citizen science project where the general public submits water depth data, read from a staff gage placed in a stream or lake. Citizens text in the depth value to a national database maintained at the University of Buffalo;

the data can then be viewed or downloaded from an online platform. Duluth was the first city in Minnesota to participate in this program, with 15 gages currently installed, and more to be installed in 2019/2020 in nearby cities and townships. Not only do gages provide cost-effective indicators of stream response to weather conditions, they serve to provide the general public, students, and life-long learners and observers a sense of place, stewardship, and environmental literacy.

Crowdsourcing the Search for Ghost Nets on Lake Superior

Authors: Titus Seilheimer, Wisconsin Sea Grant; Heather Bliss, GLIFWC; Alfred House, Apostle Island Sport Fishermen's Association

Plastic pollution in the Great Lakes can come in many forms, but ghost nets are likely the most dangerous to boaters and anglers. These lost and unmarked nets can become hazards, especially to anglers using trolling gear. Wisconsin Sea Grant, the Apostle Islands Sport Fishermen's Association, GLIFWC, and the NOAA Marine Debris Program partnered in a campaign to raise awareness about ghost nets in Lake Superior and to more efficiently remove them. The project informs anglers and boaters of the risks associated with marked commercial nets and ghost nets. Best management practices help commercial, tribal, and subsistence fishers to avoid conditions where nets could be lost. Anyone encountering a ghost net is encouraged to report the net, so it can be quickly removed. This project led to the removal of more than 5 km of ghost nets, which helps make Lake Superior a safer place for recreation and enjoyment. Local knowledge from informed anglers and tribal law enforcement help to remove ghost nets more efficiently.

It's Time to Embrace the Abundance of Citizen Science: Assessing Superior Biodiversity with CitSci.

Author: Tom Hollenhorst, US EPA Mid-Continent Ecology Division

Citizen science activities and applications have increased by leaps in bounds in recent years, propelled by many different local, state, and federal initiatives. Electronic platforms for citizen science combined with social media have provided for explosive growth of sites like E-Bird, I-naturalist, Citsci.org, SciStarter, and many other applications that support citizen science. About this time the Association of Citizen Science was formed along with establishment of the first peer-reviewed journal for citizen science in 2016. In 2001 the Global Biodiversity Information Facility (GPIF.org) was established to provide an open-source platform for sharing information about where and when species have been recorded. Data sources range from museum specimens collected long ago to geotagged smartphone photos and observations shared by citizen scientists. To date, GPIF curates more than 1 trillion species occurrence observations from around the world. This project assessed more than 30 million GPIF occurrence records that exist for WI, MN, MI, and Ontario, and summarized those that were observed within the Lake Superior watershed. The author discussed the abundance of citizen science data, most common sources, and how these data can be used to identify hotspots of biodiversity and citizen science participation across the Lake Superior basin.

Physical Processes and Physical-Biological Connections in Lake Superior

Physical processes (waves, currents, turbulence, ice, temperature, sediment, etc.) play an important role in affecting chemical, biological, and ecological response in Lake Superior. Hydrodynamic models continue to develop improved capability to represent physical processes.

Presentations in this session included physical processes of importance to ecological phenomena in Lake Superior from both modeling and observational perspectives.

Sensitivity of a Lake Superior Biophysical Model to Atmospheric Forcing Conditions

Authors: Mark Rowe, Cooperative Institute for Great Lakes Research; Eric Anderson, NOAA/GLERL

In lakes and oceans, surface mixed-layer depth has an important influence on phytoplankton growth and productivity. The mixed-layer depth relative to euphotic zone depth controls light exposure to the phytoplankton. Deepening of the mixed layer in the fall can entrain nutrients into the mixed layer from below. The authors investigated the influence of atmospheric forcing on mixed-layer depth and the spatiotemporal distribution of phytoplankton biomass and productivity in a biophysical model of Lake Superior. The authors used the Finite Volume Community Ocean Model (FVCOM), with unstructured grid as implemented in NOAA's new experimental Lake Superior Operational Forecast System Model: element size of 2 km max., 84 m min., 500 m mean, and 20 sigma layers. The biological model was implemented using the FVCOM General Ecological Module, with the nutrient-phytoplankton-zooplankton-detritus (NPZD) model of Rowe et al. (2017, Limnol. Oceanogr. 62:2629-2649). With a relatively simple biological model, having uniform initial NPZD and no nutrient additions, the authors illustrated the spatiotemporal patterns of phytoplankton abundance that result from the interaction between atmospheric forcing, mixed-layer depth, circulation, and bathymetry in a relatively high-resolution model of Lake Superior.

Radiatively Driven Convection in a Deep Lake

Author: Jay Austin, Large Lakes Observatory, University of Minnesota-Duluth

Radiatively driven convection occurs in freshwater lakes when they warm in the springtime while the water temperature is below the temperature of maximum density. Shortwave radiation heats near-surface water, increasing its density, and driving instability which acts to redistribute heat and other constituents throughout the water column. This process can dominate the circulation of large, mid-latitude lakes like Lake Superior for several months of the year. Observations of this process from an autonomous glider and from a set of moorings are used to characterize the spatial and temporal scales of the phenomenon. The moored observations show that instability builds at the surface on scales of hours, bottom warming begins roughly 6 hours after sunup, and the water column homogenizes at night. Glider observations suggest the formation of distinct convective chimneys with horizontal scales on the order of tens of meters. Results are compared to a simple numerical model of eddy-driven mixing, which suggests that the redistribution of properties from this process is orders of magnitude stronger than traditional eddy-driven mixing. Fieldwork planned for 2019 and 2020 will address the issue of fine lateral scales of variability with innovative observational techniques.

Assessing the Effect of Waves and Climate Change on Siscowet Foraging Habitats in Lake Superior

Authors: Quinnlan Smith, University of Minnesota-Duluth; Thomas Hrabik, University of Minnesota-Duluth; Trevor Keyler, University of Minnesota-Duluth; Bryan Matthias, University of Minnesota-Duluth

Siscowet (*Salvenius namayacush siscowet*) are the most abundant of four morphological variations of Lake Trout in Lake Superior. In order for siscowet to capture prey, a certain amount of light is needed in the environment, which can be scattered and focused by surface waves. The objectives of this project were to predict the effect of surface waves on light attenuation, and assess how changing surface wave sizes influence light attenuation patterns with regard to siscowet visual foraging habitats. A previous project, where Keyler et al. (in review) used model predictions of visual foraging habitats for siscowet, was the basis for this research. Estimates of direct surface illumination and light-specific siscowet foraging success were used to predict foraging habitats. Sine waves were used to simulate surface waves, so wave characteristics could be manipulated. With increasing wave heights at a given solar angle, a wave focusing and scattering event can be seen in regard to siscowet foraging habitat. Larger solar angles lead to a larger and more gradual wave-focusing event. Future projections indicate a larger wave size and changing foraging habitats. The model can be applied to different organisms that perform diel migrations in relation to light intensity to predict visual foraging habitat.

Satellite Geodetic Sensor Monitoring of Physical Processes in Lake Superior

Authors: C K Shum, School of Earth Sciences, Ohio State University; Yuanyuan Jia, Ohio State University, Division of Geodetic Science, School of Earth Sciences; Philip Chu, NOAA/GLERL; Ting-Yi Yang, School of Earth Sciences, Ohio State University; Ehsan Forooton, School of Earth and Ocean Science, Cardiff University; Kuo Chungyen, Department of Geomatics, National Cheng Kung University, Taiwan; Pengfei Xue, Michigan Technological University

Lake Superior, the largest lake of the Great Lakes and the largest lake in the world by surface area, has a complex regime of physical and biological processes. Some of these processes adversely affect the well-beings of citizens in the Great Lakes region due to abrupt weather episodes and environmental and ecological degradations. Under an increasingly warmer climate with shifting of snowlines to the north, increased precipitations and storms, it is plausible that the extent and severity of these adverse effects have exuberated the vulnerability of Great Lakes citizens. Lake Superior, though the only controlled lake in the Great Lakes system, has recorded its highest water level since 1986. This presentation described the proposed use of contemporary satellite geodetic and all-weather sensors (altimetry, GNSS, SAR, GRACE), some potentially providing near-real time observations to improve our understanding these physical processes. These observations, some of which have not yet been part of the Great Lakes CoastWatch nor the Great Lakes Observing System, include lakewide geocentric water level, wave height, wind speed, lake ice extents and (possibly) thickness, lake storage, water vapor, vertical land motion, water color, and potentially meteotsunami signals. Finally, the authors described the use of a complex independent component analysis (CICA) technique to model these 4D observations as a possible tool for Lake Superior assimilative modeling studies.

Spatiotemporal Interpolation of Satellite Images for Chlorophyll Measurement Using a Particle Model

Authors: Pengfei Xue, Michigan Technological University; David Schwab, MTRI, Michigan Technological University; Reid Sawtell, MTRI; Mike Sayers, MTRI; Robert Shuchman, Michigan Technological University; Gary Fahnenstiel, Great Lakes Research Center/MTRI, Michigan Technological University

Ocean color satellite-derived estimates of water properties are generally discontinuous in spatial and temporal coverage due to cloud cover. The authors described a novel method for providing

an objective estimate of the spatially and temporally continuous distribution of a satellite-derived water property with an application to the estimates of chlorophyll concentration in Lake Superior. The method uses calculated wind-driven lake circulation from a hydrodynamic model to estimate the evolution of the chlorophyll concentration field between available imagery. This new technique considers hydrodynamic effects by integrating a property-carrying particle model (PCPM) and an Eulerian concentration remapping approach. One of the important characteristics revealed from the analysis is the seasonally-dependent and region-specific chlorophyll concentration, which is significantly controlled by seasonal hydrodynamic conditions. Analysis suggests that, without adding extra sampling cost, moving a few sampling locations from offshore water to sample the embayments and southern coasts can provide more accurate characterization of the spatial pattern of chlorophyll concentration in Lake Superior. Furthermore, the authors found that Lake Superior chlorophyll concentrations do not appear to have changed significantly over the past 12 years and likely only slightly or not at all over the last 50 years, which differs from that in the other upper Great Lakes.

Development and Application of a Real-Time Water Environment Cyberinfrastructure for Kayaker Safety

Authors: Chin Wu, University of Wisconsin-Madison; Joshua Anderson, University of Wisconsin-Madison

Assessing pertinent environmental variables to categorize a skill level to safely navigate the water environment can be difficult for inexperienced kayakers, especially at the Mainland Sea Caves of the Apostle Islands National Lakeshore, Lake Superior. The authors presented a new cyberinfrastructure that provides kayakers with real-time data access and a Safety Index (SI) with consideration of multiple environmental factors to characterize the degree of navigational difficulty for classifying kayaker skill levels. Specifically, radar reflectivity was added to improve forecasts of dangerous conditions caused by convective storms using state-of-the-art weather and wave modeling. Spectral characteristics of surface waves were employed to correlate the occurrences of extreme and freak waves. In addition, unexpectedly dangerous conditions like coastal upwelling and freak wave occurrence due to changing wind directions were considered. A contingency plan was implemented to handle the issue of possibly missing required environmental data. Display of the SI and visualization of other real-time environmental data are communicated by a power-efficient kiosk. Web analytics demonstrated a public interest in real-time water conditions and need for the onsite kiosk to provide the latest information to kayakers before entering the water.

Phosphorus Sediment Cycling and Budgets in Lake Superior

Authors: Sergei Katsev, University of Minnesota-Duluth; Jiying Li, University of Minnesota-Duluth

The authors characterized the efficiency of P recycling in Lake Superior based on a detailed study of sediments at 13 locations (26-318 m water depth) across the lake. Analyses included porewater measurements, chemical extractions for P and Fe fractions in solid phases, and characterization of sediment-water exchange fluxes of P. Despite the low efficiency of P remobilization in deep sediments (only 12% of deposited P is recycled), effluxes of dissolved phosphorus (2.5-7.0 μmol m-2 d-1) still contributed up to 40% to total P inputs into the water column. In the deeply oxygenated Fe-rich sediments of Lake Superior, phosphate effluxes are regulated by organic sedimentation rather than sediment redox conditions. A mass-balance

model that takes this sediment P cycling into account successfully reproduces the historical data for total phosphorus levels in the water column. The model predicts that the time scale over which the total phosphorus (TP) content of Lake Superior responds to changes in external loadings is on the order of two decades.

Lake Superior Species at Risk

Lake Superior remains the only Great Lake with self-sustaining and relatively abundant populations of native species such as Diporeia, Lake Trout, Brook Trout, Deepwater Sculpin, and coregonids such as the Kiyi. However, existing stressors such as habitat destruction, mining activities, nutrient pollution, and non-native species introductions threaten these and other native Lake Superior species. This session highlighted studies on the biology and ecology of Lake Superior fish, wildlife, and native plants that are at risk or threatened within the watershed.

1970s Red Clay Dam Site Restoration

Authors: Brad Matlack, Carlton Soil and Water Conservation District; Jonathan Sellnow, US Department of Agriculture-Natural Resource Conservation Service (NRCS)

In the 1970's the Carlton Soil and Water Conservation District (SWCD) was a local sponsor for a multi-state, multiple watershed project known as the Red Clay Project. In Carlton County, 18 sediment control structures were constructed in two sub-watersheds of the Nemadji River to settle out sediment in reservoirs before it reached Lake Superior. Now, 40-plus years later, many of these structures have failed or are in danger of failing soon.

The Elim Dam, one of the largest of the "Red Clay Dams," has a 7-acre pond area and a concrete, principal spillway behind a 46-foot-high embankment. Pool surveys have verified that very little storage capacity of the original design remains due to accumulated sediment.

The dam is a fish barrier on Elim Creek for native Brook Trout moving up Skunk Creek and into the cool spring-fed water of upper Elim Creek. Because of the dam's size, dam removal and stream restoration options will be costly. Based on RFP information for a stream restoration on Skunk Creek, 1 mile downstream of the Elim Dam, it is estimated that $200,000 will be needed for this engineering study along with $20,000 for SWCD contract management and administration.

Rediscovering a Coaster Brook Trout Population

Authors: Christopher Adams, Michigan Technological University; Casey Huckins, Michigan Technological University; Amy Marcarelli, Michigan Technological University; Henry Quinlan, US Fish and Wildlife Service; Troy Zorn, Michigan DNR Fisheries Division, Marquette Fisheries Research Station

Migratory Brook Trout, known as Coasters, were once common in Lake Superior and its tributaries. Efforts to restore Coasters are limited by a lack of information on remnant populations. The authors monitored Brook Trout in the Pilgrim River, a Lake Superior tributary in Houghton County, Michigan, to determine if the Coaster life history was present and to better understand spatial and temporal characteristics of movements. Since 2014, approximately 600 Brook Trout have been implanted with Passive Integrated Transponder (PIT) tags, and four in-stream antenna stations were deployed at key locations in the watershed to record movements of tagged fish. The authors have documented movement out of the river in the late fall and early

winter, and movement back into the river in the spring, suggesting that the Coaster life history persists in this system. The authors have also documented upstream and downstream movements of up to 14 kilometers within the Pilgrim River. Habitat parameters such as stream flow and temperature will be used to build models for predicting movement. Seasonal survival will be estimated using mark-recapture modeling. This information is critical to justify current harvest restrictions and inform other population enhancement efforts in the Pilgrim River and other Lake Superior tributaries.

Native Unionid and Dreissena polymorpha Distributions in Apostle Islands National Lakeshore, 2017

Authors: Toben Lafrancois, Northland College; Mark Hove, University of Minnesota; Michael McCartney; Minnesota Aquatic Invasive Species Research Center

Native mussels (Bivalvia: *Unionidae*) are benthic filter feeders and ideal sentinel species. As pelagic integrators, they are cornerstones of food web, contaminant bioaccumulation, and related studies. A 1991 SCUBA survey of the Apostle Islands National Lakeshore found several beds of mussels and no zebra or quagga mussels (Bivalvia: *Dreissenidae*). Since that time, *dreissenids* have been detected in the Apostle Islands. The authors' 2017 survey repeated the 1991 work to assess changes in both native and invasive mussel densities. Native mussels were found at all sites previously reported and also in Quarry and Presque Isle Bays of Stockton Island. The mussel bed near Long Island increased in density between 1991 and 2017 with observed signs of recruitment. Mussel populations in Red Cliff and Raspberry Bays declined in density with no obvious signs of recruitment. Three species previously reported were not found in 2017 and are potentially extirpated. Principal components analysis showed three community groups that explained 48% of the variation in community composition. Zebra mussels (*Dreissena polymorpha*) were collected near Sand Island, Stockton Island, and Red Cliff Bay at low densities. No quagga mussels were found but have been reported from areas too deep for divers.

Impacts of Stocked Splake on Lake Trout and Brook Trout Fisheries

Authors: Liz Tristano, Wisconsin Sea Grant and Wisconsin DNR; Brad Ray, Wisconsin DNR; William Fetzer, Wisconsin DNR

Fish stocking is a common means by which management agencies may enhance or create fisheries. However, stocking in the Great Lakes has been dynamic, with practices changing as new information becomes available. In Lake Superior, a variety of species have been stocked, with variable success. One such species is the Lake Trout x Brook Trout hybrid, splake (*Salvelinus namaycush* x *S. fontinalis*). Splake stocking began in response to declining Lake Trout populations in the 20th century, but evidence of introgression with its parent species suggests that splake may threaten recovering Lake Trout, as well as Brook Trout populations. This study reviewed the history of splake stocking and examined the risks and benefits of stocking splake in Lake Superior, including probability of introgression, competitive interactions between splake and Brook or Lake Trout, splake harvest and economic returns, and long-term impacts to Lake Superior fisheries. Preliminary findings suggest that splake have the capacity to reproduce with both parental species and with other splake, potentially to the detriment of Brook and Lake Trout reproduction. Moving forward, it is important to fully understand splake impacts on Brook and Lake Trout and to weigh the risks of stocking splake in Lake Superior waters.

Results from the 2016 Cooperative Science Monitoring Initiative (CSMI) Intensive Year on Lake Superior

Overview of Lake Superior CSMI Activities in 2016

Authors: Paris Collingsworth, Purdue University; Eric Osantowski, US EPA, GLNPO; Todd Nettesheim, US EPA, GLNPO

The binational Cooperative Science and Monitoring Initiative (CSMI) under Annex 10 (Science Annex) of the Great Lakes Water Quality Agreement coordinates agency science and monitoring in support of management of the Great Lakes ecosystem. The process includes enhanced monitoring and science-based field activities which are conducted in one Great Lake per year, tied to the information needs identified by the Lake Partnerships. The 2016 Lake Superior CSMI investigations by federal agencies and partners addressed key knowledge gaps among the broad themes of chemicals and nutrients, aquatic communities, and habitat and wildlife. This presentation provided an overview of the CSMI five-year cycle that involves the development of science priorities, field year planning, intensive field year science and monitoring, analysis and reporting to decision-makers. Highlights from reporting and outreach efforts on other lakes was also discussed.

A Lake Superior Carbon Isoscape

Authors: Joel Hoffman, US EPA Office of Research and Development; Matthew Pawlowski, ORISE; Anne Cotter, US EPA; Peder Yurista, US EPA

The stable isotope composition of fish tissue is an intrinsic marker that can be used to track animal movements or identify distinct zones of feeding. Subtle but persistent isotopic differences in open waters through either depth or space may allow us to detect otherwise unobservable movements and feeding behaviors. In two years (2011, 2016) we used the CSMI field program to measure the carbon stable "isoscape" across Lake Superior. In both years, we found surprising variability: carbon stable isotope ratios ranged from -23 to -29‰. By depth, the carbon stable isotope ratio of particulates in the deep chlorophyll layer was 13C-depleted compared to the epilimnion, and the epilimnion was more isotopically variable than the deep chlorophyll layer. Spatially, the most distinct feature was an eastern gyre represented by 13C-depleted values towards the center of the gyre. Principal component analysis revealed that the isotopic variability was related to both algal taxonomy and particle C:N. We conclude that there is sufficient isotopic variability to provide the foundation for feeding and movement studies to examine depth- and spatial-based differences in the Lake Superior food web.

Great Lakes DNA Barcode Reference Library: Mollusca, Annelida, and Minor Phyla

Authors: Susan Daniel, Buffalo State College, Great Lakes Center; Lyubov Burlakova, Great Lakes Center at SUNY Buffalo State; Alexander Karatayev, Great Lakes Center at SUNY Buffalo State; Knut Mehler, Great Lakes Center at SUNY Buffalo State

In recent years, the research and development of DNA-based tools has improved both their sensitivity and costs. This technology has the potential to be useful in the early detection of aquatic invasive species, and can increase the scope of surveillance compared with traditional sampling approaches. The development of more complete species-specific libraries of DNA signatures is an essential step to enable more taxonomically rich and spatially extensive species

surveillance and monitoring programs in the Laurentian Great Lakes. The Great Lakes Center at SUNY Buffalo State aims to expand the taxonomic coverage of The Barcode of Life Database (BOLD) DNA barcoding reference library and has assembled a large collaborative team including leading barcoding and taxonomic experts for a wide diversity of targeted taxa. By preliminary estimations, 70% of Annelida, 34% of Bivalvia, 56% of Gastropoda, and 70% of other taxa (Bryozoa, Cnidaria, Kamptozoa, Nematomorpha, Nemertea, Platyhelminthes, and Porifera) known from the Great Lakes lack catalogued barcodes. In 2017-2019 we are planning to collect and identify 190 species and extract genetic material for barcoding. We already collected over 100 samples in the Great Lakes and their watershed and identified over 50 species needed for barcoding.

Trends in Lake Superior Benthos with Particular Emphasis on the Amphipod Diporeia spp.

Authors: Knut Mehler, Great Lakes Center at SUNY Buffalo State; Lyubov Burlakova, Great Lakes Center at SUNY Buffalo State; Alexander Karatayev, Great Lakes Center at SUNY Buffalo State; Jill Scharold, US EPA Mid-continent Ecology Division

A lake-wide nearshore benthic survey was conducted in Lake Superior in 2016 as part of CSMI to assess the current status of the macroinvertebrate community with particular focus on the amphipod *Diporeia*. Benthic samples were collected at 59 nearshore stations, 25 of which were previously sampled in 1994, 2000, and 2003. The most common benthic taxon by density in 2016 was *Diporeia* (48%), followed by *Oligochaeta* (32%), *Sphaeriidae* (16%), and *Chironomidae* (2%). However, at 22 of the 25 previously sampled stations we found a significant decline of *Diporeia* densities in 2016 compared to 1994 (paired t-test, $P < 0.001$), and at three of these 25 stations *Diporeia* completely disappeared. *Oligochaeta*, *Sphaeriidae* and *Chironomidae* declined at some of the stations in 2016 compared to 1994, but the changes were not significant. In contrast to other Great Lakes, *Dreissena* spp. have not established in Lake Superior and therefore cannot be a reason for *Diporeia* decline, suggesting that benthivorous fish predation or other environmental factors might have caused the changes. This decline in nearshore *Diporeia* density should be checked against inter-annual variation. The decline stresses the importance of annual monitoring of permanent stations to detect significant temporal trends.

Stability in Lake Superior's Zooplankton Community: Results from CSMI Surveys 2006-2016

Authors: Matthew Pawlowski, ORISE; Michael Sierszen, US EPA; Elizabeth Hinchey Malloy, US EPA Great Lakes National Program Office (GLNPO); Peder Yurista, US EPA; Jack Kelly, US EPA Mid-Continent Ecology Division; Jill Scharold, US EPA Mid-Continent Ecology Division; James Watkins, Cornell University

Probabilistic, whole-lake zooplankton surveys of Lake Superior were completed in 2006, 2011, and 2016 under the CSMI. Zooplankton community structure and biomass in Lake Superior differ by depth, so sampling locations in these surveys were depth-stratified (<30 m, 30-100 m, >100 m), and both whole-column and epilimnetic zooplankton tows were collected at each station. Results showed that zooplankton biomass has been stable within each depth strata since 2006. These results are similar to those from GLNPO's annual summer survey. However, zooplankton are not sampled in areas shallower than 90 m during annual GLNPO surveys, and the literature lacks recent information about zooplankton in these shallow areas of Lake Superior. The authors' results showed that zooplankton density and biomass were highly variable within and between years at stations shallower than 30 m. Because the CSMI surveys sampled relatively few stations in this stratum, the ability of CSMI surveys to detect changes in zooplankton

communities in these shallow areas may be reduced. Therefore, the authors recommend that future Lake Superior CSMI surveys add or reallocate sites to the underrepresented nearshore areas of the lake. This might improve the ability of CSMI surveys to detect potential zooplankton community changes throughout the lake.

Lake Superior Fish Community CSMI Project Update

Authors: Mark Vinson, USGS Lake Superior Biological Station; Daniel Yule, USGS Great Lakes Science Center

The Great Lakes CSMI has supported three rounds of biological community sampling on Lake Superior since 2005. Lakewide collections of nutrients, zooplankton, *Mysis*, benthic invertebrates, and fish were completed in 2005-6, 2011, and 2016. This work has provided data on the status and trends of the major ecosystem components and has been the primary building block for the development of an ecosystem model. The fish community is dominated by native species, with the only common occurring invasive fish being rainbow smelt (*Osmerus mordax*) in nearshore waters. Over this sampling period, major changes in the fish community were decreases in some whitefish species (*Coregonus artedi, C. hoyi, C. kiyi*) and deepwater sculpin (*Myoxocephalus thompsonii*) populations. Lake Trout (*Salvelinus namaycush*), particularly offshore siscowet Lake Trout, populations remained high over the sampling period. Nearshore lean Lake Trout consumed primarily Rainbow Smelt and offshore siscowet Lake Trout consumed mostly deepwater sculpin and *Coregonus* species. Declines in some *Coregonus* species populations is thought to be due to low recruitment over the past 20 years.

Lake Sturgeon Index Survey for Lake Superior

Authors: Joshua Schloesser, US Fish and Wildlife Service; Henry Quinlan, US Fish and Wildlife Service; Thomas Pratt, Fisheries and Oceans Canada

The Lake Superior Lake Sturgeon Index Survey was designed to address assessment, research, and management needs that facilitate Lake Sturgeon rehabilitation. Surveys were part of the CSMI on Lake Superior in 2011 and 2016, and will continue to occur every five years in conjunction with CSMI. Over 20 governmental and tribal agencies and universities cooperatively sampled Lake Superior waters immediately adjacent to historic and current spawning tributaries (19 tributaries, 17 sampling locations), targeting juvenile and sub-adult Lake Sturgeon. Survey objectives were to: 1) describe the current status, 2) index relative abundance and detect trends over time, and 3) describe the biological characteristics of Lake Sturgeon in Lake Superior. A total of 365 and 310 Lake Sturgeon were captured during 2011 and 2016, respectively. The presentation summarized changes in CPUE, size structure, condition, growth, and genetic assignments among survey locations and between sample years. The Lake Sturgeon Index Survey has demonstrated the ability to collect valuable biological information on an understudied life stage of Lake Sturgeon in Lake Superior.

Early Detection and Monitoring for Aquatic Invasive Species in Lake Superior

Authors: Jared Myers, US Fish and Wildlife Service; Michael Seider, US Fish and Wildlife Service; Mark Brouder, US Fish and Wildlife Service; Anett Trebitz, US EPA; Joel Hoffman, US EPA Office of Research and Development

Complete prevention of new species introductions, along with containment and reduction of non-native nuisance species that are already present, is a challenging but appropriate goal for Lake

Superior. To evaluate the effectiveness of the current regulatory framework for aquatic nuisance species, federal, state, provincial, and tribal natural resource agencies worked together to implement early detection and monitoring programs at eight locations across Lake Superior. Early detection surveys have typically relied on deployment of traditional sampling gears and taxonomic identification using physical characteristics. However, DNA-based identification approaches have been the subject of experimentation in the Port of Duluth-Superior (DNA metabarcoding of ichthyoplankton samples; eDNA metabarcoding for fish detection) and Apostle Islands (DNA metabarcoding of zooplankton samples) and could lead to improved survey accuracy moving forward. Continuing to adhere to an adaptive approach for early detection will ensure the delivery of a program that is responsive, transparent, efficient, and effective.

Broadening Social Perspectives of Lake Superior Resources

This session focused on social aspects of Lake Superior resources, including recreational fishing and associated issues in human and environmental health. Topics included Lake Superior angler demographics, stakeholder perspectives (including women recreational anglers), and related topics in environmental health.

Anishinaabe Perspectives on Great Lakes Water Resources

Author: Andrew Kozich, Keweenaw Bay Ojibwa Community College

Proactive water policies require a thorough understanding of human-water relationships as conservation becomes an increasingly important management objective in the Great Lakes basin. Surprisingly few researchers have examined residents' perspectives on water resources, including underlying values, beliefs, and attitudes related to conservation. Native American (Anishinaabe) perspectives on water have received even less attention in the scientific literature. The author used semi-structured interviews to examine Anishinaabe perspectives on water resources across the Keweenaw Bay Indian Community of northern Michigan. This presentation offered insight on the cultural significance of water as well as views on household water conservation. Findings provide a rich foundation for follow-up quantitative research using an established theoretical model to explain household conservation intentions.

Angler Demographics: Examining Lake Superior's Salmon/Trout Anglers in Relation to Salmon Stocking

Authors: Richelle Winkler, Michigan Technological University; Erin Burkett, Michigan Technological University

In recent years, the number of anglers across the Midwest has been declining, but not much is known about the composition of those who fish Lake Superior specifically. Angler declines can impact agency funding, habitat programs, and fisheries policy and management. For example, managers stock about 1.8 million non-indigenous salmonine fry in Lake Superior waters for recreational fishing. Stocking raises controversy with concerns over how hatchery fish impact native ecosystems and about whether expenses are justified. Understanding changes in the angler population and relationships between fishing participation and stocking programs informs future stocking and other fisheries management decisions. This study examines the changing demographics of anglers who fish Lake Superior for salmon/trout and projects future fishing participation. The authors pay particular attention to the impacts of birth cohort (generational

differences) on fishing participation, and explore correlations between fish stocking programs and angler participation by birth cohort. The presentation addresses: (1) How many US-based anglers fish Lake Superior for salmon/trout and in which states do they reside? (2) What is the age and generational composition of these anglers? (3) What changes can we expect by 2030? (4) To what extent do generational differences in fishing participation correlate with fish stocking practices?

Exploring Resilience in Rural Lake Superior Communities

Author: Teresa Bertossi, PhD Candidate, Prescott College, Sustainability Education and Instructor at Northern Michigan University, Earth, Environmental, and Geographical Sciences Department

The author's research explores capacities for resilience as a pathway towards sustainability in rural Lake Superior communities. Communities in this region, like many rural settlements in a changing world, lack economic diversity, resulting in environmental degradation, poverty, outmigration, aging population, lack of affordable housing, and loss of jobs. Further, decision making to determine what trade-offs are acceptable when managing ecosystem services in rural, coastal communities has exacerbated power inequalities and limited sustainable resilience and adaptation. This research explores opportunities and constraints for rural livelihoods and innovation in an effort to envision opportunities for place-based economic transformation and opportunities for basinwide cooperation. Research questions include: 1) In what ways might rural places build social-ecological resilience by better linking rural livelihoods to conservation and protection of the bio-cultural landscape of rural Lake Superior communities? 2) What might be learned from rural residents who have already self-organized to enact new spaces to diversify economies and improve qualities of life in their communities? and 3) What social-ecological spatial relationships might exist within the Lake Superior basin when social and ecological imperatives are mapped? Mixed-methods include ethnography, landscape reading techniques via circumnavigation of Lake Superior, digital storytelling, narrative analysis, and social-ecological coupling.

Using Participatory Photovoice to Highlight Women's Fishing Experiences

Authors: Erin Burkett, Michigan Technological University; Amber Voght, Itiviti AB; Angie Carter, Michigan Technological University

Recreational fishing is an important cultural and economic activity for Michigan residents, but despite the popularity of fishing, only 20% of Michigan's recreational anglers are women. Providing fishing opportunities to all stakeholders, including women, requires understanding how individuals begin fishing, the reasons they do or don't continue to fish, and their experiences fishing more broadly. This research uses a participatory action research method called Photovoice to explore the following research questions: 1) How do Michigan women become recreational anglers? 2) What is it like to be a woman who fishes? 3) How do these experiences influence whether or not women continue to participate in recreational fishing? Photovoice invokes explanations of social processes that are inaccessible to more quantitative techniques like traditional social surveys by using a combination of individual photography, facilitated group discussions, and reflection. Research participants (all women who live and fish in Michigan) document their fishing experiences, share and discuss their perspectives and knowledge with each other and the researcher, and develop personal narratives associated with

their photographs. Project findings will be shared with the public and Michigan DNR staff as a tool for understanding women anglers.

PCB Contamination, an Industrial Legacy in Michigan

Authors: Emily Shaw, Michigan Technological University; Noel Urban, Dept. Civil & Environment Eng., Michigan Technological University

Michigan's industrial history has left a legacy of contamination that continues to cause harm. Polychlorinated biphenyls (PCBs) are a globally ubiquitous pollutant and are the most frequent contaminant at US and binational Areas of Concern (AOC). Two US AOC sites are associated with Lake Superior, and PCB contamination occurs at both. Consumption of contaminated fish represents a direct connection between humans and PCBs.

Using multi-variate statistics (e.g., analysis of variance (ANOVA) and multiple linear regression (MLR)), this research examined Michigan Department of Environmental Quality fish contaminant data to determine how scientific findings can inform policy decisions. Specifically, are our remediation efforts successful, and how does PCB contamination at AOC and non-AOC sites differ? Linear regressions, with PCB concentrations vs. time, show significantly decreasing trends but may be misleading due to methodological differences, making remediation work difficult to evaluate. Furthermore, trends varied greatly between and within AOC and non-AOC sites. ANOVA and MLR tests showed that there are significant differences between fish PCB concentrations at AOC and non-AOC sites, and these differences are important in predicting PCB concentrations. Despite similar total concentrations, congener profiles for different species vary and are significantly different between AOC and non-AOC sites ($p<0.002$).

Lake Trout Collapse in Lake Superior: Integrating Multiple Stressors across Complex Boundaries

Author: Nancy Langston, Michigan Technological University

In the late 19th and early 20th centuries, several key fisheries in the Great Lakes were depleted by a combination of commercial fishing, pollution, and habitat loss. While indigenous, Canadian, and US governments attempted to address the declines, the political complexity of different jurisdictions led to regulatory paralysis that thwarted effective action to protect and restore key fisheries. Lake Trout (*Salvelinus namaycush*) were an exception. Even after other fish populations crashed, Lake Trout appeared to be surprisingly resilient. But in the mid-20th century, their populations steeply declined after Sea Lamprey populations increased. Yet Sea Lamprey invasions alone were not the sole cause of Lake Trout declines, and focusing on them alone ignores the larger context of ecological change and restoration in the Great Lakes. Management of Lake Superior fisheries requires an understanding of historical context, indigenous management, and policy constraints, as well as fisheries research.

Legacy and Emerging Chemicals in Lake Superior

This session addressed topics including human biomonitoring and environmental trends of legacy pollutants in Lake Superior fish and wildlife, and recent studies of emerging pollutants such as next-generation pesticides, micro-plastics, new potential persistent bioaccumulative and toxic contaminants, perflouro alkyl substances, brominated flame retardants, pharmaceuticals, and personal care products. Presentations included fate and transport modeling of pollutants, results from recent advancements in analytical chemistry such as non-targeted analysis, mercury isotope analysis, and technologies to destroy or remove contaminants from the Lake Superior basin.

Reducing Mercury Exposures through Biomonitoring and Patient Education

Authors: Patricia McCann, Minnesota Department of Health; Mary Turyk, University of Illinois at Chicago

Fish consumption is associated with elevated blood levels of methylmercury. The developing nervous system is especially vulnerable to exposure to methylmercury. A recent study found that 10% of newborns tested in the Lake Superior basin region of Minnesota had blood mercury levels indicating maternal exposures above the US EPA reference dose (RfD). These results led to collaborations with the Sawtooth Mountain Clinic, Grand Portage Health Service, Cook County North Shore Hospital, Trust Lands Grand Portage Band of Chippewa, Lake County Public Health, and the Minnesota Department of Health to reduce mercury exposure in women of childbearing age and pilot an in-clinic screening for high mercury exposure. Nearly 500 women from Grand Portage and the Cook County, Minnesota area participated in the *Fish are Important for Superior Health* (FISH) Project and over 100 participated in the Mercury Screening Project in Lake County. Three percent of FISH participants had blood mercury levels above the RfD. Participants received education to encourage choices that minimize exposures to mercury while maintaining the health benefits of eating fish.

Characterizing Microplastics from Lake Superior: Insights and Challenges

Authors: Elizabeth Minor, University of Minnesota-Duluth, Large Lakes Observatory; Roselynd Lin, Large Lakes Observatory, University of Minnesota-Duluth

By design, plastics are durable and long-lasting, and they have entered the environment in large quantities. An increasing area of concern for aquatic scientists is microplastic (<5 mm, >300 um) and nanoplastic (<300 um) particles. Aquatic invertebrates and fish have been shown to ingest these small particles. In addition to the direct challenges posed by microplastic/nanoplastic ingestion, such as false satiation leading to nutritional deficits, microplastics may also absorb toxins that can affect organism health.

This presentation described current techniques and challenges in microplastics measurement and recent findings from Lake Superior waters and beach sands. Microplastics in western Lake Superior's surface waters were predominantly fibers, with fragments as the second most abundant morphology. Polyvinyl chloride, polypropylene, polyethylene, and polyethylene terephthalate were the prevalent polymers. Lake Superior's surface waters also contained many non-plastic fibers, which were cellulosic and very similar to cotton. The plastic content of western Lake Superior's surface waters appears to be affected by season, with more particles per square kilometer found in May than August/September. Beach sand from the Apostle Islands

National Lakeshore contains mainly fibers, though preliminary results show that many of these are not plastic as determined via melt testing.

Using Mercury Stable Isotopes to Determine Sources of Mercury in the Food Web of the St. Louis River

Authors: Sarah Janssen, USGS; Joel Hoffman, US EPA Office of Research and Development; Ryan Lepak, University of Wisconsin-Madison; Bruce Monson, Minnesota Pollution Control Agency; David Krabbenhoft, USGS

Mercury (Hg) contamination in the Great Lakes region is a prevalent concern due to elevated Hg concentrations in fish in relation to human health and wildlife guidelines. The lower St. Louis River, the largest tributary to Lake Superior, exhibits fish Hg concentrations double that of the open lake. Despite these highly elevated concentrations, it is difficult to infer the sources of Hg to these fish due to multiple potential Hg inputs (e.g., precipitation, legacy, or upstream runoff). The aim of this study was to utilize Hg stable isotopes to elucidate Hg sources to the St Louis River food web including benthic invertebrates, prey and game fish. Invertebrates and prey fish (perch and shiners) from the St. Louis River exhibited Hg isotopic fingerprints similar to Hg-contaminated sediments (δ202Hg = -0.6 to -0.4), indicating bioaccumulation of legacy Hg. Game fish (walleye and pike) displayed greater variability in isotope values, with some individuals exhibiting highly enriched signatures (δ202Hg = 0.8 to 1.2) compared to prey species, likely due to precipitation. This indicates that legacy Hg is the prevalent source to smaller fish species in the St. Louis River, but larger species can be exposed to different Hg sources based on foraging habits.

Long-Term Trends in Legacy and Emerging Contaminants in Bald Eagle Nestlings

Authors: Bill Route, US National Park Service, Great Lakes Network; Cheryl Dykstra, Raptor Environmental; Kelly Williams, Ohio University; Rebecca Key, US National Park Service

The US National Park Service monitored concentrations of legacy chemicals (PCBs, DDT, DDE, and DDD), heavy metals (mercury and lead), and emerging chemicals of concern (PFCs, PBDEs, and others) in bald eagle nestlings from 2006 through 2015. Monitoring was conducted at six study areas in and adjacent to three national parks in the upper Midwest, including Apostle Islands National Lakeshore on Lake Superior (n = 374 nestlings at 162 territories). The authors presented trends in PCBs, DDE, mercury, PFCs, and PBDEs dating back to 1989, including historical data provided by the Wisconsin DNR. The authors showed patterns of contamination along Lake Superior's south shore and compared these patterns with riverine systems in Wisconsin and Minnesota. Trends in legacy and some emerging chemicals monitored in this study declined following US and Canadian air and water quality actions. Trends in some isomers of PFCs and congeners of PBDEs continue to be of concern.

"When can we eat the fish?": Research, Policy, and Variability for Lake Superior in 2050

Authors: Valoree Gagnon, Michigan Technological University; Judith Perlinger, Michigan Technological University, Civil & Environmental Engineering Dept.; Noel Urban, Dept. Civil & Environment Eng., Michigan Technological University; Hugh Gorman, Michigan Technological University; Noelle Selin, Massachusetts Institute of Technology; Ashley Hendricks, Michigan Technological University; Giang Amanda, University of British Columbia; Huanxin Zhang,

University of Iowa; Aditya Kumar, Michigan Technological University; Emily Sokol, Michigan Technological University; Emma Norman, Northwest Indian College

"When can we eat the fish?" is a question motivating transdisciplinary research at Michigan Technological University. In a National Science Foundation (NSF)-sponsored project titled, "Managing Impacts of Global Transport of Atmosphere-Surface Exchangeable Pollutants (ASEPs) in the Context of Global Change" (2013-2018), researchers and community partners investigated the fate and transport of ASEPs globally and within the Lake Superior basin. This presentation outlined how a safe fish future was investigated and shared forecasted results for 2050. Specifically, it highlighted spatial and temporal variability of: 1) atmospheric deposition rates, 2) mercury and PCB levels, and 3) regional, national, and international policy impacts on particular regions. In addition, it discussed important considerations such as tribal fish consumption rates and practices, meanings of "health" at different scales, and implications associated with primary versus secondary emissions. The conclusion emphasized transdisciplinary expertise as crucial for facilitating the kind of research necessary to address problems as complex as those associated with legacy contamination. The research serves as a reminder that strengthening collaborative relationships (across various expertise, jurisdictions, and communities) is an important pathway toward integrating productive research and policy in the Lake Superior basin and abroad.

Econse Water Purification Systems Pilot Study Results for the Treatment of PCBs and POPs

Authors: Nicole Gibson, Econse Water Purification Systems; Derek Davy, Econse; Neil Sosebee, Econse; Andrew H Amiri, Econse Water Purification Systems Inc.

Despite successful large-scale clean-up efforts, PCB concentrations in Great Lake fish tissues continue to remain too high for unrestricted safe consumption. Although manufacture and mainstream use has been discontinued, organisms are still bioaccumulating PCBs. Several reasons have been identified: depositions from atmospheric sources outside local jurisdiction, the persistence of the chemical itself, in-lake recycling, and aqueous inputs from tributaries.

Econse Water Purification Systems Inc. piloted a technology to destroy PCBs and other POPs on site without the need for incineration or transportation of toxic waste. This presentation described Econse's cost-effective approach for treating aqueous inputs of PCBs to meet local guideline limits. It also presented results of a pilot project demonstrating the technologies' effectiveness and discussed the applicability of the technology to treat other parameters and chemicals of mutual concern.

Non-Targeted Approaches to Emerging Chemical Discovery in the Great Lakes Fish Monitoring and Surveillance Program

Authors: Bernard Crimmins, Clarkson University; Sujan Fernando, Clarkson University; Sadjad Fakouri Baygi, Clarkson University; Aikebaier Renaguli, Clarkson University; Michael Milligan, SUNY Fredonia, Dept. of Chemistry; James Pagano, SUNY @ Oswego, Environmental Research Center; Philip Hopke, Clarkson University; Thomas Holsen, Dept. Civil & Environ. Eng., Clarkson University

For decades monitoring programs have sought to understand the effect of persistent, bioaccumulative and toxic chemicals (PBTs) in environmental systems. The Great Lakes Fish Monitoring and Surveillance Program (GLFMSP) has used Lake Trout (*Salvelinus namaycush*) as a bioindicator to understand the temporal and spatial trends of legacy and contemporary

contaminants such as brominated flame retardants, polychlorinated biphenyls, organochlorine pesticides, and mercury throughout the region. Typically, programs like GLFMSP have focused on PBTs previously detected in the Great Lakes and/or other regions. Recently, GLFMSP has expanded to include non-targeted or "shotgun" screening experiments for new potential PBTs. The goal of this element is to provide a comprehensive picture of anthropogenic chemicals impacting the system. The current approach requires an array of advanced instrumentation, including high resolution mass spectrometry and multidimensional gas chromatography. This, in turn, results in a tremendous amount of information requiring sophisticated data reduction strategies to parse out the relevant chemical features. Insights into the chemical space gleaned from the new analytical methods were presented. The discussion also provided insights into the development of hybrid approaches that enable programs to capture known and unknown chemical signatures in a multi-decadal monitoring program framework.

Status of the ZDDP and Future LAMP Actions on Persistent, Bioaccumulative, and Toxic Substances

Author: Jesse Martus, Minnesota Pollution Control Agency

The author provided a summary of the Zero Discharge Demonstration Program (ZDDP) of the Lake Superior Lakewide Action and Management Plan. The Lake Superior Chemical Committee, a binational committee consisting of partner agencies around the lake, has been working since 1991 to reduce and eliminate the discharge of nine persistent bioaccumulative toxic chemicals. The Committee researches discharge sources and existing inventories, reports on emissions data, and tracks chemical concentrations in air, water, and biota over time. It sets strategies to achieve further discharge reductions and ranks strategies to set priorities for funding.

In addition to ZDDP chemicals, the Lake Superior Chemical Committee works to implement strategies to reduce Contaminants of Mutual Concern (CMC) put forth by the Annex 3 Core Team under the Great Lakes Water Quality Agreement. Along with mercury and PCBs, PFAS is a CMC that the committee has set as a top priority for reducing known discharges to Lake Superior today. This presentation discussed PFAS sources in the Lake Superior basin, gaps in information, and current and future actions.

Chemicals of Emerging Concern in Waters, Sediments, and Fish Used by Grand Portage Chippewa

Authors: Seth Moore, Grand Portage Band of Lake Superior Chippewa; Tiffany Wolf, UMN; Mark Ferrey, Minnesota Pollution Control Agency, Environmental Outcomes; Mark Jankowski, US EPA Office of Environmental Review and Assessment, Region 10; Jessica Deere, University of Minnesota, College of Veterinary Medicine; Yvette Chenaux-Ibrahim, Grand Portage Band of Lake Superior Chippewa; Matteo Convertino, Graduate School of Information Science and Technology, Hokkaido University; Nick Phelps, University of Minnesota, Minnesota Aquatic Invasive Species Research Center; Alex Primus, University of Minnesota, College of Veterinary Medicine; Dominic Travis, University of Minnesota, College of Veterinary Medicine

The Grand Portage Indian Reservation and partners are assessing threats by chemical pollutants to the sustainable use of tribal natural resources within lacustrine habitats and fish species used by the Minnesota Chippewa, threatening the culture of the Minnesota tribes. Many pharmaceutical chemicals are toxic or endocrine active, adversely affecting fish and wildlife at part per trillion concentrations. The authors surveyed for presence of heavy metals, endocrine

active chemicals, pharmaceuticals, and synthetic hormones within subsistence fish species, waters, and sediment.

The authors sampled 28 sites for water, sediment, and fish tissue and screened for 141 CECs and 17 hormones. At least one chemical was detected in all water, sediment, and fish samples from all locations, with a range of 1-10 chemicals found in fish tissue samples per site, 1-59 chemicals found in sediment samples per site, and 1-84 chemicals found in water samples per site. In water samples, 109 CECs and hormones were found. In sediments, 71 CECs and hormones were found. In fish, 37 CECs were found. Some chemicals were detected across a large percentage of sites and sample types. The results will guide land and chemical management practices and promote a sustainable food and ecosystem within the Grand Portage Indian Reservation.

Wastewater Treatment on the Shore of Lake Superior

Author: Lindsay Menard, City of Thunder Bay

On the north shore of Lake Superior, the City of Thunder Bay operates one of Canada's few Biological Aeration Filtration (BAF) Wastewater Treatment Plants. The Atlantic Avenue Wastewater Treatment Plant serves approximately 100,000 people, with a rated capacity of 84.5 million litres per day (22.3 MGD). The BAF, including a nitrification stage, was commissioned in 2005 and has undergone various improvements. One BAF process improvement and one study of a contaminant of emerging concern were explored in this presentation.

Aeration is an essential component of the BAF process operation and one of the significant contributors to operational costs. A BAF process upgrade was completed in 2015 where 16 smaller size air blowers were replaced by three turbo blowers. This improvement was beneficial in many ways, including: 35% energy savings for aeration, noise reduction from 120 dB to less than 80 dB, and a reduction in waste generation by eliminating the requirement for blower lubricants.

Aware of contaminants of concern in Lake Superior, in 2017 an investigation of the microfiber concentration in the plant influent and the removal efficiency throughout the plant processes occurred. In its current operation, the plant is removing roughly 90% of incoming microfibers.

Elucidating the Role of Legacy and Recent Mercury in Great Lakes Coastal Wetlands

Authors: Nathan Johnson, University of Minnesota-Duluth; Amber White, University of Minnesota-Duluth; Jeff Jeremiason, Gustavus Adolphus College

Production and export of methylmercury (MeHg) to surface waters is a critical first step in mercury bioaccumulation. The purpose of this study was to identify MeHg export hotspots in a Great Lakes Estuary with a history of industrial influence. Sediment, porewater, and surface water were collected from sites encompassing high-carbon sheltered embayments, intermediate-carbon clay-influenced bays, and low-carbon industrially influenced bays in the St. Louis River Estuary near Duluth, Minnesota. Total and methylmercury in sediment varied over 3 orders of magnitude in the ecologically diverse system. Despite having lower sediment total mercury than industrial bays, wetland-like sheltered bays contained the highest MeHg. Porewater MeHg was not consistent with solid-phase MeHg and appeared to depend on both porewater sulfide and solid phase carbon. In surface water, under low-flow conditions, locations isolated from the river channel contained MeHg concentrations 3-4x higher than the river, suggesting that these areas could be net sources of MeHg. MeHg in hexegenia and fish with high spatial fidelity contained

more MeHg in the upper reaches of the estuary. The results provide a basis for understanding the origins of MeHg loading to surface waters within a complex freshwater aquatic environment that could form the basis for effective resource management decisions.

The Adaptive Governance of Toxic Compounds in the Lake Superior Basin

Authors: Hugh Gorman, Michigan Technological University; Valoree Gagnon, Michigan Technological University

In a transdisciplinary project to examine the effect of toxic substances that travel by atmosphere-surface exchange, bioaccumulate, and give rise to the need for fish consumption advisories in Lake Superior, project investigators invited community members to identify questions and concerns of interest to them. One of the questions that emerged was "When will it be safe to eat fish without worrying about toxic contamination?" Another was "Are we learning anything in our efforts to reduce toxics or just pushing paper around?" The first question was addressed by modeling the transport of mercury compounds and PCBs to Lake Superior to 2050 under three different policy scenarios and translating the associated levels of depositions to fish tissue concentrations. The second question was addressed by examining the system of governance in place to address the problem of fish tissue contamination and examining what has been learned over time. This presentation addressed both questions in the form of six policy points identified as necessary to eliminate the need for fish consumption advisories in the Lake Superior basin and elsewhere.

Welcome, Update & Plenary

Ed Verhamme, IAGLR Board Member, welcomed participants to Thursday's plenary session and encouraged everyone to complete a conference survey, which was emailed following the conference. Guy Meadows of Michigan Technological University thanked the conference organizers for planning and hosting a successful conference for approximately 270 participants.

Update: State of Lake Superior Ecosystem

Presenter: Elizabeth Laplante, US EPA, US Co-chair of Lake Superior Partnership Work Group

Overall, Lake Superior is in good condition, especially compared to other Great Lakes such as Lake Erie. More protection than restoration actions are needed to maintain the ecosystem status. Major habitats are in generally good condition lakewide, although habitat conditions vary from region to region around the lake. Concentrations of legacy contaminants like mercury and PCBs are decreasing or stable, but some contaminants continue to drive the need for fish consumption advisories. Fisheries are in good condition, supported by a robust lower food web. Native species diversity remains intact, and native species dominate over invasives. Major threats to Lake Superior include chemicals of emerging concern, impacts from mining and climate change, invasive species, impaired habitat connectivity, and excess nutrients. As part of lakewide management, the Lake Superior Partnership continues to work toward addressing threats.

Participants were asked to complete a brief survey to provide their input on science and monitoring priorities for the next CSMI year of intensive monitoring on Lake Superior.

Great Lakes Water Tension in the 21st Century

Presenter: Peter Annin, Director of Mary Griggs Burke Center for Freshwater Innovation, Northland College, Ashland, Wisconsin

From Waukesha to Foxconn, and the massive water diversion in Chicago, Great Lakes water tensions continue to make news across the region. Throughout history, Lake Superior has often been on the frontline in the Great Lakes water diversion debate, including the highly controversial Nova proposal of 1998, which planned to use ocean-going tankers to ship 158 million gallons of Lake Superior water to Asia every year. Annin is publishing a major revision of his award-winning book, The Great Lakes Water Wars, which was released on October 3, the 10th anniversary of the Great Lakes Compact. Annin's presentation helped cut through the confusion surrounding the Great Lakes water diversion debate and put Great Lakes water tensions in a regional, continental, and global context.

Status and Trends in the Lake Superior Fish and Aquatic Community

This session informed the audience of the current condition and trends of the Lake Superior fishery and aquatic community. Leads of the session included members of the Lake Superior Partnership Aquatic Community Committee and Great Lakes Fishery Commission Lake Superior Technical Committee. The organizers identified a list of a dozen topics and potential speakers for the conference. Sessions included topics such as lower trophic level composition and trends, status of the Lake Superior prey fish community, management and trends of commercially and recreationally targeted fishes, status of species in need of rehabilitation, status of Lake Superior wetlands, and the anticipated impact of climate changes on the Lake Superior fish community.

Status and Trends of Cisco in Lake Superior

Author: Daniel Yule, USGS Great Lakes Science Center

Cisco (*Coregonus artedi*) are an important native prey fish in Lake Superior that support a commercial fishery with lakewide yields approaching 1000 metric tons annually. The sustainability of these fisheries is currently a fishery management concern because Cisco recruitment, measured by the catch of age-1 Cisco in spring with an annual lakewide bottom trawl survey, has been sporadic and generally in decline since the early 1990s. Adult Cisco exhibit a pelagic existence, so ship-based down-looking acoustic methods are combined with mid-water trawl sampling to estimate abundance. Results of lakewide CSMI surveys conducted during 2003-06, 2011, and 2016 were coupled with agency surveys of spawning aggregations and age distributions to provide an update of Cisco status and trends. The results of adult surveys generally support the recruitment index findings and suggest that lakewide abundance of Cisco is trending down. Because down-looking acoustic surveys are used to set harvest quotas, a new multi-directional acoustic sled having the capability of sampling the entire water column was developed to test the efficacy of down-looking surveys. This new technology is being used to study the degree that ship-based down-looking surveys may underestimate abundance of adult Cisco. The presentation closed with preliminary results of this ongoing project.

Impacts of Emerging Ecological and Fishery Stressors on the Lake Superior Ecosystem

Authors: Bryan Matthias, University of Minnesota-Duluth; Thomas Hrabik, University of Minnesota-Duluth; Joel Hoffman, US EPA Office of Research and Development; Daniel Yule,

USGS Great Lakes Science Center; Michael Seider, Wisconsin DNR; Owen Gorman, USGS; Mark Vinson, USGS Lake Superior Biological Station

Lake Superior is unique among the Laurentian Great Lakes in that it has ecological communities dominated by native species in both nearshore and offshore areas. However, the Lake Superior ecosystem is undergoing significant changes to both nearshore and offshore food webs, including prey fish population declines. These changes are likely affecting ecosystem functions, trophic dynamics, and fishery yields. The objective of this study was to use EcoPath with EcoSim to explore how the declines in the prey fish populations influence Lake Superior ecosystem dynamics. The secondary objective was to explore how recent sporadic recruitment trends of Cisco *Coregonus artedi* influence the Lake Superior ecosystem compared to recruitment trends from the 1980s and 1990s. The authors focused on the population-level responses and harvest trends of the native piscivores, Lean and Siscowet Lake Trout *Salvelinus namaycush namaycush* and *S. n. siscowet*, along with the major prey fish *Coregonus* spp., *Osmerus mordax*, *Cottus* spp., *Myoxocephalus thompsonii*.

Ongoing Walleye (Sander vitreus) Acoustic Telemetry in Black Bay and the Black Sturgeon River

Authors: Michael Rennie, Lakehead University; Fischer Friedrich, OMNRF; Lindsey Boyd, OMNRF; Rachael Hornsby, OMNRF; Anthony Chiodo, OMNRF; Eric Berglund, OMNRF; Erin Dunlop, OMNRF, Trent University; Thomas Pratt, Fisheries and Oceans Canada

Once home to the largest Walleye fishery on Lake Superior, the Black Bay Walleye population crashed in the early 1960s. The population decline is currently attributed to overfishing and spawning habitat loss caused by construction of the Camp 43 dam on the Black Sturgeon River. In efforts to facilitate rehabilitation of the Walleye population, a moratorium was placed on commercial Walleye fishing in 1969 and yellow perch in 2002 in Black Bay. Fall Walleye Index Netting surveys have indicated limited recovery thus far. To improve our understanding of Black Bay Walleye ecology, and factors that may limit their recovery, an acoustic telemetry project was initiated in 2016. To date, 182 Walleye have been implanted with acoustic transmitters with high annual survival. In the 2018 season, 58 acoustic receivers were distributed in key locations in Black Bay and the Black Sturgeon River to identify spatial and temporal patterns such as migratory behaviours and spawning localities.

Home Range and Spatial Distribution of Juvenile Lake Sturgeon in Eastern Lake Superior

Authors: Lisa O'Connor, Fisheries and Oceans Canada; Thomas Pratt, Fisheries and Oceans Canada; William Gardner, Fisheries and Oceans Canada; Stephen Chong, OMNRF; Joshua Schloesser, US Fish and Wildlife Service

Lake Sturgeon (*Acipenser fulvescens* Rafinesque, 1917) populations are greatly depressed compared to historic abundance throughout the Great Lakes. Population surveys targeting juveniles at historical spawning tributaries in Lake Superior began in 2010. In Eastern Lake Superior, Goulais and Batchawana Bays were found to have catch rates higher than any other locations in Lake Superior. Beginning in 2014, the authors began tagging fish in both bays with acoustic telemetry tags: 88 Lake Sturgeon were tagged with 10-year Vemco V16 tags, and 19 were tagged with smaller 2-year Vemco V9 tags. A hydroacoustic array was placed in both Goulais and Batchawana Bays and extended around Whitefish Bay, providing binational coverage of approximately 99,000 ha of eastern Lake Superior. Lake Sturgeon exhibited spatial

habitat use patterns based on seasonality, diurnal light, and fish size. Overwinter, sturgeon were generally found at depths of 15-25 m and gradually moved shallower during the summer months to depths of 5-8 m. Many of the larger fish utilized the entire area of Whitefish Bay, while others limited their home range to individual bays. Diurnal movements showed sturgeon moved to deeper waters during daylight hours; however, smaller sturgeon were consistently found in deeper waters compared to larger sturgeon.

Trends in Yield of Commercially Important Fish Species in Lake Superior

Author: Samuel Michaels, GLIFWC

From the times of Lake Superior Chippewa trading with early European settlers, to meeting the food consumption needs of the modern age, Lake Superior has long-supported a valuable commercial fishery. Since the 1800's, Lake Whitefish, Lake Trout, and Cisco have continued to be the most commercially sought-after fish species. However, factors such as overfishing, lack of regulation, market demand, and the arrival of the Sea Lamprey adversely affected the abundance of these species. Commercial yield of Lake Trout and whitefish declined to low levels during the late 1950's and early 1960's while landings of Cisco were dramatically reduced in some areas of the lake during that same time. Fortunately, a combination of fisheries regulations and lamprey control have facilitated recovery of fish populations, thus commercial yield has generally increased on a lakewide scale since the mid 1900's; however, the magnitude and trends of commercial yield of whitefish, Lake Trout, and Cisco continue to vary by species and geographic location within Lake Superior.

Diet and Habitat Overlap among Lake Superior Ciscoes and Rainbow Smelt

Authors: Caroline Rosinski, USGS Lake Superior Biological Station; Mark Vinson, USGS Lake Superior Biological Station; Daniel Yule, USGS Great Lakes Science Center

As native *Coregonus* restoration moves forward across the Laurentian Great Lakes, understanding the spatial and trophic niche these species and other non-native planktivorous species occupy may help define restoration goals and fish stocking plans. The authors used stomach content analyses to report on trophic overlap and occurrence data to report on spatial habitat overlap among three *Coregonus* species (Cisco *C. artedi*, Bloater *C. hoyi*, and Kiyi *C. kiyi*) and Rainbow Smelt (*Osmerus mordax*). Fish were collected from 111 locations throughout Lake Superior from May to September 2016. Bloater, Kiyi, and Rainbow Smelt consumed primarily Cladocerans and Calanoid copepods as juveniles and *Mysis* as adults. In contrast, Cisco consumed mostly Cladocerans and Calanoid copepods throughout their life. *Bythotrephes* made up 27% of Cisco summer diets by mass. Diet overlap was high among Bloater, Kiyi, and Rainbow Smelt and low between Cisco and any of the other species. In contrast to diets, spatial overlap among species was low. Rainbow Smelt occupied shallower nearshore, Bloater occupied deeper nearshore, and Kiyi occupied offshore waters. Bloater, Rainbow Smelt, and Kiyi were principally benthic oriented. Cisco occurred throughout the lake but occupied limnetic waters. Overall, there were few individual locations and times where all species were collected simultaneously.

Lake Superior Cisco Harvest and Management

Authors: Brad Ray, Wisconsin DNR; Cory Goldsworthy, Minnesota DNR

Harvest management policies for Cisco in Lake Superior range from bycatch allowances to 15% of the hydroacoustic-derived spawning stock biomass estimates within jurisdictions. From 2012 to 2016, average Cisco harvest in Minnesota and Ontario declined 18% and 19%, respectively, compared to the previous five-year average. Average harvest in Wisconsin waters increased 42% compared to the previous five-year average. In all jurisdictions annual harvest declined from 2012 to 2016 due in part to Cisco caviar supply exceeding market demand; however, currently low market demand should not be viewed as an effective tool to ensure sustainability of Cisco stocks given the continued lack of strong recruitment events. In Minnesota and Wisconsin, where similar mesh sizes are used (70 – 76 mm stretch mesh), the 2009 year-class comprised approximately half of the total harvest in 2014. Based on the USGS year-class strength index, density of the 2005 and 2009 year-classes were similar; however, contribution of the 2005 year-class to the 2014 roe fishery was only 3% in Minnesota and 1% in Wisconsin, indicating that longevity of year-classes of similar magnitude may be relatively short, given current levels of exploitation.

How Are Lake Superior's Wetlands? Eight Years, 100 Wetlands Sampled

Authors: Valerie Brady, University of Minnesota-Duluth; Donald Uzarski, Central Michigan University, IGLR, CMUBS, and Department of Biology; Matthew Cooper, Northland College, Mary Griggs Burke Center for Freshwater Innovation; Dennis Albert, Oregon State University; Nicholas Danz, University of Wisconsin-Superior; Josh Dumke, Natural Resources Research Institute, University of Minnesota-Duluth; Thomas Gehring, Department of Biology and Institute for Great Lakes Research; Erin Giese, University of Wisconsin-Green Bay's Cofrin Center for Biodiversity; Alexis Grinde, Natural Resources Research Institute, University of Minnesota-Duluth; Robert Howe, University of Wisconsin-Green Bay; Ashley Moerke, Lake Superior State University; Gerald Niemi, University of Minnesota-Duluth; Holly Wellard Kelly, Natural Resources Research Institute, University of Minnesota-Duluth

The Great Lakes Coastal Wetland Monitoring Program has been charged by US EPA's Great Lakes National Program Office with sampling the large Great Lakes coastal wetlands every five years to assess their biotic condition (www.greatlakeswetlands.org). This effort, funded by the Great Lakes Restoration Initiative, began in 2011, and the third year of the second five-year sampling round was recently completed. In that time, the authors sampled approximately 100 unique Lake Superior wetlands, most in multiple years, for birds, anurans, fish, aquatic macroinvertebrates, aquatic and wetland plants, and water quality. These data show that Lake Superior coastal wetlands support, on average, 27 bird species, 4 anuran species, 14 fish species, 43 aquatic macroinvertebrate taxa, and 41 wetland plant taxa. Invasive species were not detected in some wetlands while others contain a relatively high number of invasive taxa. Those most invaded are typically in invasion hot-spots such as near working ports. IBI scores and condition metrics generally show Lake Superior wetlands to be in better biotic condition than wetlands in the lower lakes, but with exceptions in areas with legacy contamination and near more development. In particular, wetland vegetation is often scored high quality, while bird, fish, and macroinvertebrate scores are more variable.

State of Lake Superior Non-Native Salmonids (2012-2016)

Authors: Brad Ray, Wisconsin DNR; Kyle Rogers, OMNRF; Cory Goldsworthy, Minnesota DNR

Since their introductions into Lake Superior, non-indigenous salmonines have provided recreational anglers with additional nearshore and tributary angling opportunities. Each jurisdiction monitors angler harvest of native and non-native salmonids from the recreational fishery. Although native Lake Trout appear to be the most sought-after species in the fishery, non-native salmonids continue to play an important role. Non-native salmonids accounted for an estimated 32% of the total harvest in the sport fishery between 2012 and 2016. Native species, specifically Lake Trout, accounted for the other 68%. The fish community objective for non-indigenous salmonids in Lake Superior is being met. Populations of Chinook Salmon, Coho Salmon, and Rainbow Trout (steelhead) appear to be healthy and are being sustained by wild reproduction. This has allowed management agencies to reduce stocking of non-native species while meeting rehabilitation goals of native species such as Lake Trout. The only stocking of non-native salmonids that remains caters to boutique fisheries: Brown Trout in Wisconsin waters; Kamloops Rainbow Trout in Minnesota, which will also be phased out in the near future; and Chinook Salmon in the Kaminstiqua River, a tributary to Thunder Bay.

Changes in the Lake Superior Fish Community, 1953-2017: Collapse, Recovery, and an Uncertain Future

Author: Owen Gorman, USGS

The Lake Superior fish community has undergone dramatic changes over the past 65 years, beginning with conditions before Sea Lamprey and overfishing collapsed the native community (1953), the nadir (1960s), early stages of recovery (1970s), explosive recovery (1980-1990s), and decline (2000s). The author described the state of the fish community at each of these stages, and factors leading to the collapse, promoting recovery, and causing the decline were described with the aim of providing greater understanding of the regulation of populations and informing management to promote effective strategies for conserving native fish stocks in the face of an uncertain future. The author described the present state of the fish community in light of anticipated climate changes and increasing demands of a growing human population in the 21st century.

Mining Contamination, Remediation and Legacy in Lake Superior

This session focused on mining legacy effects and remediation, principally embayments and rivers around Lake Superior. Active programs include research and remediation of copper mining effects in the Keweenaw Peninsula of Michigan and legacy iron mining sites in Michigan, Wisconsin, and Minnesota.

Copper-rich "Halo" Around the Keweenaw Peninsula of Lake Superior: Mass Mill and the Ojibwe

Authors: W. Charles Kerfoot, Michigan Technological University, Great Lakes Research Center and Dept. of Biological Sciences; Noel Urban, Dept. Civil & Environment Eng., Michigan Technological University; Carol MacLennan, Michigan Technological University; Jaebong Jeong, Great Lakes Research Center and Department of Civil and Environmental Engineering,

Michigan Technological University; Sophia Ford, Department of Social Sciences, Michigan Technological University

A century ago, shoreline copper stamp mills on the Keweenaw Peninsula sluiced over 64 million metric tonnes of tailings into Lake Superior. The amount of copper released was massive relative to background loading (ca. 3-10X the anthropogenic copper inventory of deep-water Lake Superior sediments). The release created a major copper "halo" around the Keweenaw Peninsula that extends out tens of kilometers, marked by a buried copper maximum in coastal sediments. The authors examined how discharges from one of the smaller mills (Mass Mill, 1902-1919, 2.7 million tonnes) left tailings along the coastline that moved across Native American jurisdictional boundaries. The fine fraction ("slime clays") dispersed broadly across Keweenaw Bay, whereas the coarse fraction (stamp sands) crept eight kilometers southward along the shoreline, intercepting beaches and riparian habitats, and reached the mouth of L'Anse Bay at Sand Point. Sediment core profiles and a detailed ICP-MS analysis showed how metal-rich fine clay fractions funneled early into L'Anse Bay. Flux calculations emphasized that the copper "halo" continues to be maintained, despite declining surface copper concentrations. Tribal remediation is addressing contamination on Sand Point, yet the century-long scenario argues strongly against mining companies discharging tailings into coastal waters.

Buffalo Reef & Grand (Big) Traverse Bay Stamp Sand Migration and Remediation

Authors: Robert Regis, Northern Michigan University; W. Charles Kerfoot, Michigan Technological University, Great Lakes Research Center and Dept. of Biological Sciences

Stamp sand (the basaltic waste by-product of copper milling operations) has dramatically impacted the littoral and beach geomorphology and aquatic habitats along the eastern side of the Keweenaw Peninsula. About 22.7 MMT of material was dumped into Lake Superior from two stamp mills operating at Gay, Michigan (from 1901-1932). A fraction remains there; almost half migrated along the beach, and almost half winnowed into Lake Superior. Erosion of the waste pile continues at present. Beach and longshore drift of tailings affected the entire coastal area 8 km southward to the Traverse River breakwall. Stamp sand along this area has negatively impacted critical fish breeding grounds (Buffalo Reef) and benthic invertebrate communities, damaged recreational properties, dammed river mouths, and filled wetlands. At the breakwall, stamp sand accumulated to approximately 1-2 m height above the structure, overtopping it during storms and inflowing to the Traverse River Harbor of Refuge. Initial dredging (2016) by the Michigan Department of Environmental Quality to remove the stamp sand in the harbor was reversed by a single recent storm (October 2017). Because of changes in beach morphology, storm waves were able to breach the beach crest and flood 100 m+ across the width of the beach, damaging recreational properties. Near-record high lake levels contribute to the problems.

Where Does It Come from? Mine Contamination and the History of Lake Superior's Copper Mills

Author: Carol MacLennan, Michigan Technological University

Around 1890, Lake Superior's Copper District in the Keweenaw Peninsula began erecting stamp mills on the shores of the lake, moving from interior locations. A majority of these eight mills operated for about 30 years into the 1930s and one of them into the 1950s. At Freda-Redridge, five mills deposited 39.2 metric tons into Lake Superior; two Gay mills deposited about 22.5, and one mill at Assinins/Keweenaw Bay about 2.7 – totaling over 64 metric tons of stamp sands

along the shores of Lake Superior. Their accumulated mass along shorelines and their copper content affect residences and sensitive fisheries and wetlands. The author described the history of copper milling along Keweenaw's Lake Superior shores, the character of stamp sand deposits at each site, what is known about their movement into the lake and further along the shore, the environmental concerns that have arisen, and the efforts to contain or remediate these copper-bearing sands. This short overview provided perspective on the multiple dimensions of a regional problem.

Diporeia and Copper Mining Waste along the Keweenaw Peninsula of Lake Superior

Authors: Varsha Kausika Raman, Michigan Technological University; W. Charles Kerfoot, Michigan Technological University, Great Lakes Research Center and Dept. of Biological Sciences; Martin Auer, Dept. of Civil Engineering, Michigan Technological University

The amphipod *Diporeia* is considered to be an indicator of ecosystem health in Lake Superior. It is widely distributed across shelf, slope and profundal habitats, reaching maximum abundances in a band of shelf habitat termed the Ring of Fire. Monitoring along the north shore of the Keweenaw Peninsula at Freda-Redridge in the 1970s showed significant correlations between *Diporeia* and copper content proximate to a stamp mill. More recently, concern has been expressed about the copper-*Diporeia* dynamic along the south shore of the Peninsula where copper-rich stamp sands from the Gay stamp mill are migrating toward Buffalo Reef, an important Lake Trout spawning ground. The authors sampled 150 stations along the north and south shores of the Peninsula, to evaluate the response of conditions along the north shore to five decades of natural recovery and the relationship of copper-rich sediment to *Diporeia* abundance along the south shore. No significant recovery of *Diporeia* was observed at the north shore sites in the 1970s; however, copper enrichment was noted at deeper locations in the nearshore. Elevated copper content and low densities of *Diporeia* were observed at the south shore site.

Archaeological Considerations on Industrial Heritage and the State of Lake Superior

Author: Timothy Scarlett, Michigan Technological University

Humans have mined resources in the Lake Superior watershed for thousands of years. Industrial Archaeology is an evolving field of inquiry that provides useful standpoints to consider the interplay of humans, geoheritage, and the lake's ecological systems. Michigan Technological University faculty and students have studied mines, mining, and mining communities from an archaeological perspective for more than half a century. Archaeology's longue durée can improve our understanding of the history of mining on Lake Superior, its environmental consequences, and its role in human communities. Moreover, among the tensions between natural and cultural heritage, preservation and restoration, economic renewal and cultural revitalization, archaeology and critical heritage studies both provide frameworks to imagine new collaborations and alliances in solving post-mining and post-industrial problems.

Modelling the Hydrologic Effects of Iron Mining and Ditching in the St. Louis River Basin

Authors: Tim Cowdery, USGS; Anna Baker, USGS

Effective stewardship of the St. Louis River Basin (SLRB) requires understanding of how past land uses may have altered groundwater flux to rivers, lakes, and wetlands. In cooperation with a consortium of Chippewa bands in Minnesota, USGS is developing hydrologic models for the SLRB which can help to estimate how landscape alteration may have affected the hydrology of

this region. Two groundwater models are being developed: a broad, basin-scale 2-dimensional analytic-element model and a detailed 3-dimensional finite-difference inset model focused on the Mesabi Iron Range. The basin-scale model is being used to quantify regional flow patterns and to examine the effect of ditching in the central wetlands of the SLRB. Results indicate that ditching may reduce the extent of permanent wetlands in the basin by 8% percent. The basin-scale model provides boundary flows to the inset Iron Range model. The Iron Range model, which is currently under construction, involves comparing scenarios that simulate flow conditions before and after iron mining in the Mesabi Iron Range. Results of this study will provide a foundation for water resources decision-making in the SLRB and will increase our understanding of the hydrologic effects of historic mining in the basin.

Reconstruction of Ancient Mining Pollution on Isle Royale using Analyses of Lake Sediment

Authors: Kathryn Vall, University of Minnesota-Duluth; Byron Steinman, Large Lakes Observatory and Department of Earth and Environmental Sciences, University of Minnesota-Duluth; David Pompeani, Department of Geography, Kansas State University; Kathryn Schreiner, Large Lakes Observatory and Dept of Chemistry & Biochemistry, University of Minnesota-Duluth; Seth Depasqual, Cultural Resources, Isle Royale National Park

Isle Royale and the Keweenaw Peninsula of Michigan are home to some of the oldest examples of native North American metalworking and land use. The authors' research aims to produce a reconstruction of the timing, spatial patterns, and environmental impacts of mining activities on Isle Royale through sedimentological and biogeochemical analysis of lacustrine sediments. The authors also seek to produce a parallel record of paleoenvironmental conditions to assess the potential impacts of environmental change on ancient mining cultures.

Lily Lake, on Isle Royale, Michigan, has been exposed to very little human land use change relative to other lakes on the island (e.g., there are no ancient mine pits in the immediate catchment) and thus is well suited for reconstructing past environmental changes. Preliminary results from the metals analysis of bulk sediment from Lily Lake provide evidence of Middle Archaic mining activity that is temporally consistent with radiocarbon-dated artifacts from lakes located adjacent to ancient mine pits on Isle Royale and the Keweenaw Peninsula of Michigan. Additional work is required to assess the relative influence of natural versus anthropogenic processes that may have influenced metal concentrations in Lily Lake sediment and to improve our understanding of pollution transport mechanisms and flux.

October 12

Workshop: EnviroDIY – Low-cost Sensors for Environmental Monitoring

Hosts: Ed Verhamme and Anthony Aufdenkampe, LimnoTech

This free workshop demonstrated the EnviroDIY technology platform, which enables new low-cost sensors to be built and deployed with off-the-shelf electronics. The founder of the movement, Anthony Aufdenkampe, provided an overview of the history of the project and how scientists and ordinary citizens can deploy cost-effective and robust monitoring networks at a fraction of the cost of traditional technology. Participants with an interest in monitoring received hands-on experience through assembling a station, programming, and data management.

Hydrologic and Hydraulic Analysis and Operational Forecasting for Lake Superior Regulation

Lake Superior stands out not only as the world's largest body of freshwater by surface area, but also for its relatively high ratio of surface area to contributing drainage area (approximately 0.6). As a result, its overall water budget, known as the net basin supply, is highly sensitive to variability in lake evaporation and over-lake precipitation. Ice cover on the lake can also vary significantly from year to year, as can the occurrence of weather patterns that carry lake-effect snow out of the basin. Further complicating long-range forecasting of net basin supply, the geographic location of Lake Superior makes its seasonal climate potentially subject to oceanic-atmospheric teleconnections with the Atlantic, Arctic, and Pacific Oceans. The outlet of Lake Superior via the St. Marys River is the only point of regulation on the Upper Great Lakes, and the flow in the St. Marys River depends, in part, on the balance between Lakes Superior and Michigan-Huron and requirements for habitat, navigation, coastal interests, and hydropower generation. Increased accuracy and lead-time in hydrologic forecasts, along with advancements in tools to understand and predict the lake-to-lake routing and hydraulic conditions of the St. Marys River, can improve the ability to balance water levels and mitigate the social and ecological impacts of excessively high or low levels. This session focused on recent and ongoing efforts to increase the accuracy of water budget and hydraulic analyses and operational hydroclimatic forecasts for the purpose of water level regulation.

Lake Superior Regulation 101

Author: Melissa Kropfreiter, US Army Corps of Engineers

The St. Marys River is the only connection between Lake Superior and the lower Great Lakes. The river falls approximately 20 feet in a short three-quarter mile stretch, creating swift moving water known as the St. Marys Rapids. Since 1797, when the first lock was built to allow boats to bypass these rapids, various navigation and power structures have been erected along the river. Today, a collection of structures such as hydropower plants, navigation locks, and a gated dam (known as the Compensating Works) exists at the head of the rapids. Over the past 100 years, several plans have been utilized to regulate Lake Superior's outflow. The current 2012 regulation plan was designed to deliver robust performance under a wide range of possible hydrological conditions. It considers the water level of both Lake Superior and Lake Michigan-Huron and acknowledges the needs of various interest groups including navigation, hydropower, and riparian owners. The plan tries to maintain much of the natural variability in lake levels while being consistent with the capacities of current discharge structures. This presentation provided an overview of Lake Superior regulation, water levels, and the connection between the two.

Operational Modelling of the Water Cycle in the Great Lakes Region at Environment and Climate Change

Authors: Dorothy Durnford, ECCC; Vincent Fortin, ECCC; Gregory Smith, ECCC; Frederic Dupont, ECCC

The Water Cycle Prediction System (WCPS) for the Great Lakes and St. Lawrence River is a regional scale Earth system model. This system runs on an operational basis at ECCC with 7-day support. It provides twice-daily forecasts of 3.5 days. WCPS consists of a network of linked models. It simulates the complete water cycle, following water as it moves from the atmosphere to the surface, through the river network and into lakes, and back to the atmosphere. Information

concerning the water cycle is passed between the models. Products from WCPS include lake water levels and temperatures, lake ice cover, and water supplies to the Great Lakes. This necessitates the forecasting flows for all tributaries of the Great Lakes watershed. This presentation described the system, its skill, and its products.

Update of Coordinated Great Lakes Regulation and Routing Model for Improved Modeling Flexibility

Authors: Zoe Miller, US Army Corps of Engineers - Detroit District; Lauren Fry, US Army Corps of Engineers - Detroit District; Tim Hunter, NOAA GLERL

Over the past decade and a half, the Coordinated Great Lakes Regulation and Routing Model (CGLRRM) has functioned as a tool that both the US and Canada have used to determine regulated Lake Superior outflow and produce forecasts of water levels and outflows of the Great Lakes and their connecting channels. When developed, the goal of the CGLRRM was to serve as a modeling framework that had capabilities of interfacing previously developed standalone hydrologic and hydraulic models that were built by various government agencies for regulation, research and operations. In recent years, a need to integrate new regulation plans, new net basin supply models, and other features has surfaced. In addition, a need to adapt the FORTRAN source code for maintenance sustainability, in response to fewer FORTRAN programmers, has triggered a major update and conversion of the CGLRRM into Python (3.6). The new modeling framework incorporates a new data handler, developed by NOAA's Great Lakes Environmental Research Lab (GLERL), which enhances flexibility, facilitating experimentation and development of future regulation plans and numerical methods. This presentation demonstrated the application of the data handler in collaboration with the traditional routing program that produces water levels for the middle lakes.

Interactions between Lake Superior and the Regional Weather and Climate

As the largest lake in the world by surface area, Lake Superior's interaction with the overlying atmosphere is in many ways comparable to that of the oceans. Large-scale weather systems passing over broad stretches of water often lead to high winds and large waves in autumn, significant amounts of evaporation and lake-effect snow in winter, extensive ice cover by early spring, and summer phenomena such as advection fog and lake breeze boundaries. At the same time, climate change is causing Lake Superior to undergo significant decreases in winter ice cover, earlier spring stratification, and rapid warming of summer water temperatures. The impacts of these changes on the hydrology and ecology of the world's largest lake are only beginning to be understood. This session explored lake-atmosphere interactions within the Lake Superior ecosystem, including modeling to anticipate future climate changes and their impacts.

BIG HEAT and BIG CHILL: Impact on the Timing and Magnitude of Primary Production in Lake Superior

Authors: Marcel Dijkstra, University of Wisconsin-Oshkosh; Martin Auer, Department of Civil Engineering, Michigan Technological University; Nancy Auer, Biology Department, Michigan Technological University; Rasika Gawde, Department of Civil and Environmental Engineering, Michigan Technological University

The thermal regime, particularly the duration, depth and strength of stratification, plays a governing role in dictating the time course of primary production in phosphorus-poor systems

like Lake Superior. Further, climate change may impart a high degree of inter-annual variation to the lake's thermal regime.

The authors sampled a transect extending offshore from Michigan's Keweenaw Peninsula in Lake Superior bi-weekly from May through October for an average year (2011), a record-breaking warm year (2012; "BIG HEAT"), and an extremely cold year (2014; "BIG CHILL").

Markedly differing thermal regimes and nutrient-plankton dynamics were observed among years: specifically, the time course of stored phosphorus content and biomass accrual in the phytoplankton and manifestation of an upper mixed layer, and the degree to which summer-long primary production was maintained, i.e. the presence of a summer desert with respect to production. The potential impact of the climate-driven summer desert on the lower food web was discussed, and future plans for model simulation of the phenomenon and coupling with regional climate models were considered.

Fall Storms and Large Waves: Lake Superior's Notorious "Gales of November"

Authors: John Lenters, University of Wisconsin-Madison; Norma Froelich, Northern Michigan University; Holly Roth, Northern Michigan University

Lake Superior is the world's largest freshwater lake by surface area, and given its midlatitude location and large fetch, the "Big Lake" is notorious for strong autumn storms and large wave events. Perhaps the most well-known storm occurred in November of 1975, which resulted in the sinking of the Edmund Fitzgerald, solidifying the "Gales of November" in Great Lakes shipwreck lore. Significant wave heights during the peak of the 1975 storm have been estimated at 30 feet or more, with much higher maximum wave heights for individual, rogue waves. With the advent of data buoys on Lake Superior in 1979, a 40-year record of offshore wave activity is available during the ice-free seasons of May-November. Additional nearshore buoys have been deployed over the past decade, and a "bomb cyclone" on October 24, 2017, led to a 29-foot wave event along the southeastern shores of Lake Superior. This was a record-setting event on the Great Lakes for the modern buoy era and—combined with unusually high lake levels—resulted in significant coastal erosion, property damage, and loss of life. This presentation provided an historical overview of Lake Superior's large wave events, observational records from buoys, and coastal storm impacts.

Decadal Variability of Lake Superior Ice Cover and Water Temperature: An Ecosystem in Transition?

Authors: Peter Blanken, University of Colorado; John Lenters, University of Wisconsin-Madison; Christopher Spence, ECCC; Yafang Zhong, University of Wisconsin-Madison; Steve Vavrus, University of Wisconsin-Madison; Michael Notaro, University of Wisconsin-Madison

Lake Superior is one of the most rapidly warming lakes in the world. Warmer winters, declining ice cover, increased solar radiation, and earlier stratification have all combined to create a "perfect storm" of factors leading to rapid warming of Lake Superior's surface waters. This impact is particularly true for deeper, offshore regions of the lake, where changes in the onset of stratification are much more sensitive to antecedent spring conditions than in shallow, nearshore regions. Somewhat perplexingly, much of this decadal-scale variability in Lake Superior ice cover and summer water temperature has been characterized as a step change, or "regime shift," which occurred following the warm, El Niño winter of 1997-98 and lasted through at least 2010. The authors reexamined the 1998 regime shift in the context of more recent data, which show

that the transition has persisted through 2017 across a variety of metrics, including annual maximum ice cover, stratification onset, and summer water temperature. Interannual variability in these metrics has increased, however, and recent model results suggest that our ability to predict Lake Superior's transitioning state is extremely limited. This result argues for renewed investment in Great Lakes research to improve our understanding of large-lake ecosystems and our ability to anticipate future change.

NOAA Great Lakes CoastWatch New Data, Products and Services

Authors: Philip Chu, NOAA/GLERL; Songzhi Liu, CIGLR/University of Michigan

CoastWatch is a NOAA/NESDIS-wide program designed to provide near real-time satellite derived data and applications to support federal, state, and local stakeholders and the research community. The Great Lakes CoastWatch node focuses on Great Lakes region specific data, products, and services.

Satellite-derived data offer high spatial coverage and temporal frequency and have been used to complement in-situ observations and validate numerical model outputs in the past few decades. The long-term lake surface temperature, lake levels, ice covers, winds, and other variables derived from various satellite sensors provide invaluable tools for regional climate studies.

The authors supplied an overview of the NOAA CoastWatch program and introduced CoastWatch datasets such as the new GOES-16 SST, synthetic aperture radar (SAR) winds /ice maps, and VIIRS/MODIS ocean color (chlorophyll). In addition, methods to access CoastWatch data, tools, and servers were discussed.

The 2016 Flood Event: Factors Affecting Stream Crossing Culvert Survival

Author: Kevin Brewster, Superior Rivers Watershed Association

On July 11, 2016, severe thunderstorms across northwest Wisconsin dropped 8–10 inches of rain in an 8-hour period. Stream gages recorded a flow increase from 300 to 40,000 cubic feet per second in 15 hours. Region-wide flood costs exceeded $30 million, with over 150 road/steam crossings destroyed. In 2017, the Superior Rivers Watershed Association undertook a culvert flood survivability study focusing on the Marengo River watershed. Fifty-four culvert stream crossing catchments were evaluated using LiDAR elevational data, Ashland County Highway Department culvert installation records, Wisconsin DNR Wiscland2 land cover data, and other information. Using the NRCS Toolbox application for ArcMap, culvert catchments (range: 28-6,355 acres) were delineated and tabulated for mean slope, stream power index (SPI), vegetational cover type extent, and channel to road surface height. Mean potentially restorable wetland (PRW) scores were calculated for catchments based on post-flood Wisconsin DNR/St. Mary's College (MN) wetland assessment studies. Significant differences in mean values ($p<0.05$) between washed-out and surviving catchments were observed in channel to road surface height (10.5 feet washed-out, 6.7 feet survived) and mean PRW score (2,334.9 washed-out, 6,535.4 survived). No significant differences were observed between mean catchment slope, SPI, or vegetational cover type extent.

Profiling Radar and Snow Microphysical Properties from Extended Ground Observations on Lake Superior

Authors: David Beachler, NOAA National Weather Service; Mark Kulie, Michigan Technological University

The authors presented results from a ground-based profiling radar and in-situ snow microphysics observational suite located at the Marquette, Michigan, National Weather Service Weather Forecast Office in the Upper Great Lakes near the southern shore of Lake Superior. Combined Micro Rain Radar (MRR) and Precipitation Imaging Package observations were presented for numerous case studies both to illustrate the capabilities of these instruments and to document unique radar and concomitant microphysical properties associated with different snowfall modes frequently observed in this region.

The value of these ground-based observations for cloud microphysics parameterization improvements and spaceborne remote sensing applications was discussed, including the radar reflectivity to snowfall rate relationship dependence on snowfall mode and seasonal MRR analyses that emphasize the predominance of shallow snowfall events in the Upper Great Lakes.

Meteorology-Related Challenges on Western Lake Superior

Author: Dan Miller, NOAA National Weather Service, Duluth Forecast Office

Western Lake Superior and the resulting land-water temperature differences, combined with the surrounding topography, produce many challenges for operational weather forecasters throughout the entire year. These challenges include: 1) meso-scale effects on wind speed and direction, and their subsequent effect on wave growth and propagation, 2) drainage flow from higher terrain onto the nearshore waters, 3) rip current forecasting, 4) forecasting lake-effect and lake-enhanced snow, 5) severe thunderstorm initiation and propagation (including wake-low events and seiches/meteo-tsunamis), 6) a nearly stationary heavy snow band produced by a standing gravity wave, and 7) freezing spray. The author provided examples of each of these phenomena, their related impacts, and challenges not only in forecasting them, but also in communicating weather messages to the diverse group of users of weather information on Lake Superior. Finally, the author briefly summarized some of the various ongoing research projects that attempt to address these challenges.

Status and Trends in the Lake Superior Fish and Aquatic Community, a.m.

Emissions Regulations and Food Web Shifts Alter Mercury Signatures of Top Predator Fish

Authors: Ryan Lepak, University of Wisconsin-Madison; Joel Hoffman, US EPA Office of Research and Development; Sarah Janssen, USGS; David Krabbenhoft, USGS; Jacob Ogorek, USGS; Daniel Engstrom, Water Resources Science Program University of Minnesota; Elizabeth Murphy, US EPA, Great Lakes National Program Office; James Hurley, University of Wisconsin-Madison

Environmental geochemists frequently use archives of sediment, peat, and glacial ice to reconstruct historical trends in atmospheric mercury (Hg) deposition to ecosystems. The authors used a long-term fish archive, measuring Great Lakes whole fish Hg stable isotope ratios, to

relate temporal changes in Great Lakes Hg concentrations to varying Hg sources. In addition, food web tracers (carbon [C] and nitrogen [N] stable isotope ratios) identified food web influences on total Hg concentration variability (180 to 810 ng g-1). By utilizing Hg, C, and N stable isotopes, the authors showed a significant shift in Hg sources to fish (1988-1992) and periods when diet transitions led to the assimilation of contrasting Hg pools (2000 to present). The 1988-1992 δ202Hg shift, confirmed by two sediment cores, was likely caused by reductions in regional Hg emissions. In contrast, the post-2000 isotope transitions were likely the result of altered food web pathways, which revealed a benthic diet shift following dreissenid mussel invasion. The continued recent shifts in δ202Hg suggest fish are continuing to respond to changes in US mitigation strategies, and highlight the importance of regional source reduction in affecting Hg concentration and isotopic distribution in Great Lakes fisheries.

Brook Trout Population Distribution and Rehabilitation Status in Lake Superior

Authors: Henry Quinlan, US Fish and Wildlife Service; Evan C. Boone, US Fish and Wildlife Service; Edmund J. Isaac, Grand Portage Band of Lake Superior Chippewa

Coordinated agency efforts to assess and restore Brook Trout populations throughout the Lake Superior basin have been underway for over 20 years. The Brook Trout rehabilitation plan for Lake Superior serves as a guide with the common objective to maintain widely distributed, self-sustaining populations throughout their original habitats. Recommended actions include harvest management, tributary habitat restoration, and stocking of Lake Superior basin genetic strains. On the water Brook Trout related projects are largely targeted at population assessment and monitoring. A standardized shoreline electrofishing survey initiated in 2015 provides a mechanism to describe and compare Brook Trout population status within and among locations. Shoreline areas of Nipigon Bay, Grand Portage, and Isle Royale show the highest Coaster Brook Trout catch per kilometer, ranging from 2.1-6.6 fish per kilometer. Abundance and distribution of Coaster Brook Trout have increased in areas with conservative harvest regulations. In Lake Superior tributaries, PIT tag monitoring efforts have resulted in discovery of several coaster populations, and periodic gamete collection efforts continue to provide genetically suitable fish for stocking efforts.

Sea Lamprey Control in Lake Superior

Author: Todd Steeves, Fisheries and Oceans Canada, Sea Lamprey Control Centre

Sea Lamprey (*Petromyzon marinus*) control began on Lake Superior in 1950 with installation of mechanical weirs on tributaries to block spawning migrations of adult Sea Lamprey. Use of lampricides as a control tool began in 1958 and, by 1961, 72 streams were treated with 3-trifluoromethyl-4-nitrophenol (TFM). The effects were immediately obvious when 86% fewer Sea Lamprey were captured during spawning runs, the marking rate declined on host species, fewer larvae were collected from streams, fewer streams were used for spawning, and abundance of fish increased in the lake. Since 2005, increased control effort reduced Sea Lamprey abundance, and during 2008–2009, spawning-phase Sea Lamprey abundance was within the target level for the first time since 1998. Despite increased effort, the general trend in Sea Lamprey marking rates continues to increase, and Sea Lamprey-induced mortality on Lake Trout (*Salvelinus namaycush*) continues to exceed fishing mortality.

Education, Outreach and Connecting Lake Superior Science to Teachers and Educators

This session targeted formal and informal educators, from classroom teachers who are engaging their students in innovative research and/or stewardship projects to unique programs being conducted by universities, units of government, and state/provincial/national government agencies. This session shared effective modes for disseminating scientific knowledge and motivating Great Lakes stewards.

Enhancing Learning in the Science Classroom: Integrating Concepts into a Theme

Author: Sarah Geborkoff, Houghton Portage Township Schools

Research has shown that, if concepts are integrated into a common theme, student learning will take place at a deeper and more meaningful level. At Houghton Middle School (HMS), the 7th grade general science course incorporates grade-level Next Generation Science Standards in the areas of earth, life, and physical science under the theme of 'The importance of water: Its properties, availability as a resource, and human impacts on its quality.' During the school year, students complete volunteer work at both Huron Creek (a local urban stream) and the HMS forest and gardens as well as learn about different science, technology, engineering, and math (STEM) careers. The year-long project is supported by the Lake Superior Stewardship Initiative and by funds awarded with the 2016 Dan Wolz Clean Water Education grant. Additionally, the project fueled three winning student teams in the national Lexus Eco Challenge competition.

eCYBERMISSION: 6th through 9th grade National Science Competition with a Community Impact

Authors: Gretchen Hein, Michigan Technological University; Siona Beaudoin, Lake Linden-Hubbell High School; Beau Hakala, Lake Linden-Hubbell High School; Gabriel Poirier, Lake Linden-Hubbell High School

For the past three years, students at Lake Linden-Hubbell High School have participated in eCYBERMISSION (a virtual nationwide science/engineering competition) where their focus has been on what can be done with stamp sand. Stamp sand is a waste product from historical copper mining practices and has been deposited along the shorelines of lakes in the Keweenaw Peninsula. The projects were:

7th Grade: Electroplating the Copper from Stamp Sand

8th Grade: What Types of Plants Can Be Grown Directly on Stamp Sand?

9th Grade: Stamp Sand as a Fine Aggregate in Concrete

The students' outreach activities have included engaging with fifth and third grade students at two local elementary schools, presenting their research at the 2017 Lake Superior Youth Symposium and the Calumet Public Library, and discussing their projects with the USEPA in Washington, DC and Chicago, IL. This presentation focused on an introduction to eCYBERMISSION, the teams' projects, accomplishments, and outreach activities.

Connecting Schools and Communities in the Stewardship of Lake Superior and its Watershed

Authors: Joan Chadde, Center for Science & Environmental Outreach, Michigan Technological University; Lloyd Wescoat, Center for Science and Environmental Outreach; Emily Gochis, MiSTEM Network Region 16; Shawn Oppliger, Western Upper Peninsula Center for Science, Math, and Environmental Education/Copper Country Intermediate School District

Since 2008, the Lake Superior Stewardship Initiative (LSSI) has brought together schools and community partners in the western Upper Peninsula of Michigan to prepare K-12 students to become knowledgeable citizens concerned about the Lake Superior watershed and actively engaged in stewardship projects in their communities.

The LSSI is part of a statewide Great Lakes Stewardship Initiative funded by the Great Lakes Fishery Trust and Wege Foundation. LSSI incorporates place-based education curricula, teacher professional development, and student-designed stewardship projects to develop a lifelong commitment to Great Lakes health. Approximately 15 schools, 75 teachers, 3000 students, and 50 partner organizations participate annually. Stewardship projects include the creation of rain gardens, vegetable gardens, new interpretive trails, a disc golf course, monitoring of streams, and more. The authors described the organizational structure, funding, and impact on students.

Rivers2Lake: Connecting Lake Superior Science to Teachers and Students in the Watershed

Author: Deanna Erickson, Lake Superior National Estuarine Research Reserve/Superior Rivers Watershed Association

Using a unique mentoring model, the Rivers2Lake education program connects scientists with students and teachers, bringing real world learning into the classroom. The project, a partnership between the Lake Superior National Estuarine Research Reserve and the Superior Rivers Watershed Association with funding from NOAA, increases student engagement, sense of place, and teacher commitment to place-based learning. In this interactive session, the author explained what teachers and schools need from the research and outreach community and described how to make important personal connections that can help support research and learning.

2019 Lake Superior Youth Symposium: Engaging High School Students with the Future of the Greatest Lake

Authors: Amy Kireta, University of Minnesota-Duluth; Joan Chadde, Center for Science & Environmental Outreach, Michigan Technological University; Valerie Coit, University of Minnesota-Duluth; Frank Maragi, University of Minnesota-Duluth

The Lake Superior Youth Symposium (LSYS) is a biannual, three-day, interdisciplinary and international experience for 8th-12th grade students and teachers. The 2019 LSYS will bring together ~350 middle and high school participants from communities around the Lake Superior watershed to the University of Minnesota-Duluth on May 16th-19th. The Symposium's mission is to broaden and deepen student understanding of the science, history, art, and culture, as well as the challenges of protecting one of the greatest bodies of water on the planet. The Symposium's theme, "We are Lake Superior," will explore the personal and community meanings of the big lake, while educating, inspiring, and motivating. Students will learn about Lake Superior through interactive workshops, field trips, and hands-on activities. The authors want participants to become the leaders and voices that will maintain and promote a healthy Lake Superior in their hometowns. LSYS is a unique opportunity for educators and experts to connect with future Great

Lakes leaders and decision makers by sharing expertise, experiences, and learning new perspectives. The authors highlighted the biennial Symposium's history (held since 1995 at locations around the lake), the planning process, impacts on participants, and the 2019 LSYS overview, while looking to attract a host for 2021.

What It Means to GLOAT

Author: Lake Superior, The Great Lakes

To preserve the Great Lakes, we must not be silent in our mission. We must speak up for the water, and we must speak loudly. Twitter has given us a platform to do this, from scientists, to environmentalists, to journalists, and simply anyone who loves fishing, kayaking, or swimming in the Great Lakes. As the GLOAT (Greatest Lake of All Time), I have taken to Twitter to make sure the world knows of my existence and the importance of my preservation. Together, we must excite the masses about my body of water, my siblings' lesser bodies of water, and more. Some well-placed puns, facing off with volcanoes and a little gloating, can make this possible.

Workshop: Citizen Engagement Strategy

Hosts: Nancy Langston and Carol MacLennan, Michigan Technological University

This workshop initiated a dialogue on how citizens, state agencies, industry representatives, and tribes can best engage the mine waste and permitting policies. Invited panelists presented an overview of their experiences and strategies for engaging communities, with a focus on the lessons learned. Small group discussions addressed questions such as: what are the major concerns today in communities dealing with legacy waste? How can experiences with past mines help citizens address new mine proposals and construction? How accessible is the policy and decision process for local citizen engagement? How can agencies best involve and incorporate diverse public perspectives, without allowing the process to be hijacked? What lessons have existing organizations learned from their involvement? Workshop participants developed a list of best practices for productive citizen engagement in community mining issues.

NOAA's Next-generation Lake Superior Operational Forecast System (LSOFS)

NOAA is in the process of upgrading the Great Lakes Operational Forecast System (GLOFS). As a part of this, the next-generation Lake Superior Operational Forecast System (LSOFS) will include an expanded forecast horizon, fine-scale coastal resolution and an expanded domain, improved lake-level tracking, and ice forecast guidance. Partners from the Great Lakes Environmental Research Laboratory (GLERL) and the National Ocean Service (NOS) presented the new LSOFS and the implementation plan for the upgraded Great Lakes models.

In addition, the International Great Lakes Datum (IGLD), which is the system by which lake elevations are referenced in the Great Lakes, is in the process of being updated to IGLD 2020, and the US and Canada plan to publish the new datum in 2025. The IGLD, established and maintained under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, was defined in 1955 by precise geodetic leveling and water level transfers, and then the datum was updated in 1985. Due to glacial isostatic adjustment and other local effects, the datum should be revised every 25-30 years.

This workshop provided information on the next-generation LSOFS, the update to the IGLD, and effects on local stakeholders. It was also an opportunity for users and stakeholders to provide feedback on NOAA products and services.

NOAA's Operational 3-D Lake Circulation Forecast Modeling Systems for the Great Lakes

Authors: John Kelley, NOAA/NOS/OCS; Eric Anderson, NOAA/GLERL; Aijun Zhang, NOAA/NOS/CO-OPS; Gregory Lang, Great Lakes Environmental Research Laboratory; Yi Chen, NOAA/NOS/OCS; Machuan Peng, NOAA/NOS/CO-OPS; Ayumi Manone, SNRE-CILER, University of Michigan; Ed Myers, NOAA/NOS/OCS

NOAA's Great Lakes Operational Forecast System (GLOFS) provides nowcasts and forecast guidance of two-dimensional water levels and three-dimensional currents and water temperatures. GLOFS is run four times per day on NOAA's Weather and Climate Operational Supercomputer System. GLOFS uses a 3-D hydrodynamic forecast model along with the forecasts from the National Weather Service (NWS) National Digital Forecast Database to generate predictions out to 60 or 120 hours depending on the lake. GLOFS predictions are displayed on NOS web sites: tidesandcurrents.noaa.gov and nowcoast.noaa.gov. Digital output is available at opendap.co-ops.nos.noaa.gov/thredds/catalog.html. GLOFS predictions have been available operationally since 2006 and are used by commercial and recreational mariners, fishermen, NWS weather forecasters, Harmful Algae Bloom forecasters, US Coast Guard, and researchers. GLOFS is being upgraded by the National Ocean Service and GLERL to use the Finite Volume Community Ocean Model (FVCOM) to provide users with higher resolution and more accurate lake predictions and possibly ice coverage and thickness predictions. An FVCOM-based Lake Erie forecast system (LEOFS) was implemented in 2016, and an FVCOM-based Lake Michigan and Huron forecast system (LMHOFS) will be implemented in 2019.

NOAA's NOS develops, tests, and operates 3-D oceanographic forecast modeling systems to provide short-term forecast guidance of 2-D water levels, 3-D water levels, 3-D water temperatures, and 3-D salinity for coastal waters, estuaries, and the Great Lakes out to 48 or 120 hours. The development cycle starts with user requirement analysis for specific harbors, ports and water bodies, system design, model system development, model evaluation with user feedback, and finally the transition to operational status.

The modeling system depends on weather forecast models and river observations. Forecast models are run 4 times/day and monitored 24 x 7 by the National Weather Service and NOS. Forecast guidance is displayed on web pages, and they are available in digital formats. Maps of forecast guidance are also available. Forecast guidance supports safe and efficient navigation and emergency responses such as oil spills and search and rescue missions. Guidance is also used for environmentally sound management of the coastal zone.

The GLOFS originated from a collaborative research project between NOAA/GLERL and The Ohio State University in the 1990's to develop a 3-D oceanographic forecast modeling system for the Great Lakes to provide semi-operational forecast guidance of water levels, water temperature, and currents. The next phase in the evolution of GLOFS is to migrate from Princeton Ocean Model to FVCOM as the core 3-D oceanographic (hydrodynamic) forecast model to provide higher spatial resolution, improved depiction of the vertical temperature structure, and to incorporate ice forecasts.

Development of NOAA's Next-Generation Lake Superior Operational Forecast System (LSOFS)

Authors: Eric Anderson, NOAA/GLERL; Gregory Lang, Great Lakes Environmental Research Laboratory; John Kelley, NOAA/NOS/OCS; Aijun Zhang, NOAA/NOS/CO-OPS; Yi Chen, NOAA/NOS/OCS; Machuan Peng, NOAA/NOS/CO-OPS; Ayumi Fujisaki-Manome, University of Michigan; Philip Chu, NOAA/OAR/GLERL; Ed Myers, NOAA/NOS/OCS

NOAA is in the process of upgrading the operational hydrodynamic forecast modeling systems for the Great Lakes, collectively known as the Great Lakes Operational Forecast System (GLOFS). The next-generation Lake Superior Operational Forecast System (LSOFS), which will transition to operations in 2020, will provide a dramatic increase in spatial resolution (from 2.5 km offshore to 200 meter nearshore), expand the model domain to include key areas of need, include lake-level tracking (e.g., hydrologic), extend the forecast horizon to 120 hours, and include ice forecast guidance. The new LSOFS is being developed with the Finite Volume Community Ocean Model (FVCOM), an unstructured grid that solves the governing equations in three-dimensions. FVCOM has been successfully implemented to upgrade the Lake Erie Operational Forecast System, is in transition for the Lake Michigan-Huron forecast system, and has been employed for numerous studies of the Great Lakes. Overall, the next-generation system will provide improved forecast guidance of lake conditions including currents, water temperatures, water levels, and ice. In this presentation, the NOAA team debuted the next-generation Lake Superior model, discussed future plans, and solicited user feedback.

NOAA's original LSOFS became operational in 2004 and used the Princeton Ocean Model to develop 3-D currents and temperatures as well as water level fluctuations at a resolution of 5 to 10 km. The upgraded LSOFS will use FVCOM and have resolutions of 200 m for the coastlines and 30 m for tributaries, and it will include lake levels and ice forecasts. FVCOM uses an unstructured mesh adapted for fresh water. It is finite volume, 3-D, and free-surface. It incorporates the Los Alamos Sea Ice model, which is also adapted to fresh water. The lateral boundary conditions have river inflows at 10 locations across the US and Canada, an outlet at the St. Marys River, and take into account overlake precipitation.

The grid has approximately 90,000 nodes and 174,000 elements along with 21 Sigma layers. Observations are collected from NOS and CHS water level gauges, three National Data Buoy Center buoys, four Great Lakes Observing System buoys, and one thermistor chain.

Updating the International Great Lakes Datum

Author: Laura Rear McLaughlin from NOAA Center for Operational Oceanographic Products and Services on behalf of the Vertical Control – Water Level Subcommittee on the Great Lakes Basic Hydraulic and Hydrologic Data (http://GreatLakesCC.org/)

The use and management of the Great Lakes-St. Lawrence River system require knowledge and measurement of water levels, depths, volumes, and flows throughout the region. A fundamental requirement for coordinated management is a common height reference system or vertical datum by which water levels can be measured and meaningfully related to each other. The International Great Lakes Datum (IGLD) is the system by which lake elevations are referenced in the Great Lakes. The joint United States and Canadian datum, established and maintained under the auspices of the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, was first defined as IGLD (1955), by precise geodetic leveling and water level transfers. Due to glacial isostatic adjustment and other local effects, the datum should be revised every 25-30 years. IGLD (1955) was updated to IGLD (1985) and now, through the Coordinating Committee,

IGLD (1985) is in the process of being updated to IGLD (2020), with a planned publish date of 2025. An overview of what the IGLD datum is and how it will be revised, and what that means for local stakeholders, was presented.

The International Great Lakes Datum (IGLD) is a common height reference system for Great Lakes water levels and all related products, first defined in 1955. This is internationally coordinated between the US and Canada and it is critical for activities like power generation, marine transportation, and commerce. The datum needs to be updated periodically due to the vertical motion of the land. Changes in elevations from 1955 to 1985 were 1 foot in Lake Superior, 0.7 feet in Lake Michigan, and 0.5 feet in Ontario. The previous updates were conducted in 1955 and 1985, and the expected release of the next update is scheduled for 2025. The new datum will use improved science and technologies to more accurately measure velocities and lake topography.

Two major activities of the new IGLD include a campaign to record accurate water levels through permanent and temporary gauges in Canada and the US as well as to accurately determine the absolute height of the gauge reference and water level. This is a multi-year effort, and it helps determine the crustal motion at the water level station for the velocity model.

Impacts of the new IGLD on several operations, products, and services in the Great Lakes region include water level regulation and forecasting, coastal habitat restoration, coastal zone management, and planning for flood and erosion predictions and structure design and construction. A final component is the economic viability and safety of commercial and recreational navigation, including charts, ports/harbors, and dredging of navigation channels.

NOAA Workshop (Friday at 10:40-12:30)

This workshop continued the discussion that began in the session held immediately prior to the workshop on development of the Lake Superior Operational Forecast System (LSOFS). Participants exchanged ideas and provided input on the model to NOAA modelers.

Watershed and Nearshore Processes in the Chequamegon Bay/Apostle Islands Region

The Chequamegon Bay/Apostle Islands region of Lake Superior is rich in diverse landscapes and human influence ranging from pristine coastal wetland systems in the Apostle Islands and Bad River/Kakagon Sloughs to one of the greatest concentrations of agricultural land use within the Lake Superior basin. Chequamegon Bay is one of the warmest, shallowest, most isolated, and southerly bays in Lake Superior. The Bay and surrounding Apostle Islands are heavily influenced by dynamic interactions between tributary runoff and open lake processes, which were highlighted during a record flood event in July 2016. Recent proposals for a large-scale iron mine and concentrated animal feeding operations have coalesced research efforts from a wide range of institutions, agencies, local groups, and communities to understand watershed and nearshore quality and processes in this region of Lake Superior. Presentations in this session explored a variety of topics specific to the Chequamegon Bay/Apostle Islands region, ranging from invasive species to the emergence of cyanobacterial blooms in western Lake Superior.

Eradication of Non-Native Phragmites in the Chequamegon Bay Region

Author: Gabrielle VanBergen, Red Cliff Band

The author presented a collaborative project led by the Red Cliff Band of Lake Superior Chippewa and conducted in the Chequamegon Bay region to eradicate one of the only known sources of non-native phragmites (*Phragmites australis subsp. australis*) in the Lake Superior basin. Project funding was provided by US EPA and Bureau of Indian Affairs through the Great Lakes Restoration Initiative. Red Cliff's primary partners included the cities of Bayfield and Washburn, WI. A 2016 genetic study determined that recently-established area populations of non-native phragmites were related to those used in three local wastewater treatment plant reed beds. If non-native phragmites were to continue spreading, this invasive plant would pose a significant threat to 14,000 acres of Lake Superior coastal wetlands in Wisconsin. After conducting an alternatives analysis study into other wastewater treatment technologies, project partners undertook the extensive task of completely retrofitting all three facilities with native phragmites throughout the summer of 2018. The author described all aspects of the project and lessons learned, including the initial study, monitoring and treatment, and the rigorous inspections and safe transport of an invasive species from the Chequamegon Bay region to a landfill in Superior, WI.

Identifying Potential Sources of Cyanobacteria Blooms to Lake Superior

Authors: Kaitlin Reinl, Large Lakes Observatory, University of Minnesota-Duluth; Brenda Moraska Lafrancois, National Park Service; Robert Sterner, University of Minnesota-Duluth

Lake Superior is viewed as highly pristine; however, it is warming the fastest of the Great Lakes, and more recently, local cyanobacteria blooms have been observed near the Apostle Islands. Experiments were conducted during the summers of 2017 and 2018 to investigate sources of cyanobacteria blooms to the Apostle Islands. The 2017 experiments used a factorial design with three regional locations (Harbor, Rivers, and Apostle Islands), two nutrient conditions (high and low N:P), and three temperatures (15, 20, and 25 °C). Cyanobacteria were most abundant from the River and Harbor regions at low N:P and 25 °C. The results of the 2017 experiments suggest that cyanobacteria blooms are being delivered from inland locations to the Apostle Islands. As part of the 2018 experiments the authors are evaluating 26 inland locations as potential sources of cyanobacteria to Lake Superior, and identifying similarities among sites that produce cyanobacteria in large numbers. If water temperatures and nutrient delivery to the nearshore in Lake Superior continue to increase, conditions which sustain blooms for longer periods may occur. Furthermore, as cyanobacteria blooms become more common in inland water bodies, there may be more sources of blooms to Lake Superior, increasing the occurrence of blooms both spatially and temporally.

Emergence of Cyanobacterial Blooms in Western Lake Superior

Authors: Brenda Moraska Lafrancois, National Park Service; Kaitlin Reinl, Large Lakes Observatory, University of Minnesota-Duluth; Robert Sterner, University of Minnesota-Duluth; Sandra Brovold, University of Minnesota-Duluth; Todd Miller, University Wisconsin-Milwaukee

Cyanobacterial blooms have become common in parts of the Great Lakes but have rarely been reported in Lake Superior. The authors described the emergence of cyanobacterial blooms in western Lake Superior following extreme rainfall events. In each case, surface blooms emerged

several weeks after such rainfall events, as sediment-laden tributary plumes began to dissipate. The authors described the extent, duration, and composition of previous bloom events and characterized conditions surrounding blooms. The authors offered detailed insights into the August 2018 bloom, using data from a nearshore monitoring station at Meyers Beach, Apostle Islands National Lakeshore, as well as data from a targeted bloom response effort. Previous bloom events have been dominated by *Dolichospermum spp*. and concentrated along the south shore of western Lake Superior, stretching from Superior, Wisconsin, to east of Cornucopia, Wisconsin. Extreme precipitation events followed by warm, calm surface water conditions preceded each surface bloom. Although preliminary data suggest that levels of algal toxins in 2018 did not present a risk to public health, bloom events generate significant public and management concern. Given the predicted increase in the frequency of intense precipitation events in this region, future cyanobacterial blooms may be expected.

Episodic Shifts in Nearshore Lake-Atmosphere CO2 Exchange Following a Major Storm

Authors: Joshua Delvaux, University of Wisconsin-Milwaukee; Harvey Bootsma, University of Wisconsin-Milwaukee

Episodic, major storm events can significantly alter the metabolic balance of lakes. Notably, increases in surface pCO_2 have been observed following storm events; however, the impact of such events on large lakes has been largely understudied, more specifically, the nearshore areas of large lakes. To assess the influence of storm events on the metabolic balance of these dynamic transition areas, the authors quantified nearshore Lake Superior lake-atmosphere CO_2 and O_2 exchange over the 2016 summer, thereby encapsulating a major storm event (July 11th). The region was characterized by a net CO_2 sink and O_2 source (0.4 ± 0.2 mol m-2 and 2.7 ± 1.1 mol m-2; respectively), indicating a net autotrophic system; however, a sudden inverse shift in this trend was observed, coinciding with the storm event. The synchronicity between trends in CO_2 and O_2 exchange indicated a similar driver (i.e., photosynthesis/respiration). The abrupt, short-lived shift towards net heterotrophy immediately following the storm event appears to be more so due to decreased water clarity and associated suppressed phytoplankton primary production rather than increased biological breakdown of dissolved organic carbon. The authors' results suggest that the dominant regulator of community metabolism in nearshore areas of large lakes following storm events is internal carbon processing.

Tributary Influences on Nearshore Water Quality in Lake Superior's Chequamegon Bay

Authors: Matthew Hudson, Northland College, Mary Griggs Burke Center for Freshwater Innovation; Matthew Cooper, Northland College, Mary Griggs Burke Center for Freshwater Innovation; Randy Lehr, Northland College, Mary Griggs Burke Center for Freshwater Innovation; Christopher McNerney, Northland College

Chequamegon Bay (CB) is one of the warmest, shallowest, most isolated, and southerly bays in Lake Superior; it is an ideal location to study effects of climate change and eutrophication on nearshore water quality. Since 2014, the authors have conducted an integrated sampling program to collect baseline data in CB, with the goal of understanding how nearshore water quality relates to physical processes and tributary loading to affect ecosystem processes. The authors' approach includes: 1) maintaining a series of continuous stream discharge monitoring stations and developing estimates of suspended sediment and phosphorus loading to CB; 2) collecting semi-monthly water chemistry profiles, phosphorus, chlorophyll, suspended sediment, and plankton samples from 12 stations in CB; and 3) completing a ROMS hydrodynamic model for CB and

the adjacent Lake Superior nearshore. Results indicate that large storm events lead to episodic pulses of sediment and phosphorus to CB. The authors presented expanded analyses of watershed loading and in-lake water chemistry datasets, with a particular focus on identifying linkages between tributary loading and CB water quality and identifying signals in the datasets that differentiate baseline and episodic, event-driven conditions that could assist with understanding how future climate and/or land use changes will affect ecosystem conditions.

Closing Ceremony

The *Woodland Singers*, comprised of members of the Ojibwa and Menominee Tribes, performed a closing ceremony to officially end the conference.