The Centre for Ecosystem Management (CEM) Symposium

June 21st - 22nd 2023

University of Guelph

2023 Summary Report

Event at a Glance

Attendees

Over 20 in person; mostly researchers, managers and scientists

Event Sponsors

Great Lakes Fishery Commission and the University of Guelph

Key Topics

Identify emerging themes in global environmental change as well as ecosystem science and ecosystem management; **seek** input on key needs and methods for the successful implementation of ecosystem management within the Great Lakes basin; **facilitate** learning amongst researchers, resource managers, and students with respect to issues facing the management of the Great Lakes fisheries.

Guest Speakers:

- Tricia Mitchell, Regional Director (Department of Fisheries and Oceans)
- Trisha Westman, Acting Director (Ontario Ministry of Natural Resources and Forestry)
- Dr. Andrew Muir, Director (Great Lakes Fishery Commission)
- Robert Lambe, Executive Secretary (Great Lakes Fishery Commission)
- Dr. James Bence, Emeritus Faculty (Quantitative Fisheries Center at Michigan State University)
- Dr. Joey Bernhardt, Assistant Professor (University of Guelph)
- Dr. Anna Gardmark, Professor (Swedish University of Agricultural Sciences)
- Dr. Sarah Gaichas, Research Fishery Biologist (Northeast Fisheries Science Center)
- Dr. Eli Fenichel, Associate Professor (Yale School of the Environment)
- Henry Lickers, Canadian Commissioner (International Joint Commission)
- Dr. Stuart Ludsin, Professor (Ohio State University)
- Randall Claramunt, Fisheries Chief (Michigan Department of Natural Resources)
- Andy Todd, Manager (Ontario Ministry of Natural Resources, Lake Ontario Unit)
- Bruce Mighton, Manager (Ontario Ministry of Natural Resources, Upper Great Lakes Unit)
- Mitch Baldwin, Manager (Ontario Ministry of Natural Resources, Lake Erie Unit)
- Vic Santucci, Program Manager (Illinois Department of Natural Resources for Lake Michigan)
- Ryan Lauzon, Fisheries Assessment Biologist (Chippewas of Nawash)
- Dr. Seth Moore, Director (Grand Portage Band of Lake Superior Chippewa)
- Dr. Susan Doka, Researcher (Department of Fisheries and Oceans)
- Dr. Marten Koops, Research Scientist (Department of Fisheries and Oceans)
- Dr. Len Hunt, Research Scientist (Ontario Ministry of Natural Resources and Forestry)
- Dr. Erin Dunlop, Research Scientist (Ontario Ministry of Natural Resources and Forestry)
- Dr. Andrew Honsey, Fisheries Biologist (USGS Great Lakes Science Center)

Emerging Themes

The need for: **collaboration** to include Indigenous rights holders, managers and stakeholders to create a strong tie to stewardship interests; the **collection of existing data sets** relating to the Great Lakes; the **collection of new data sets** through future research projects that will aid in understanding the key processes behind ecosystem function and the subsequent development of effective systems for ecosystem monitoring.

Suggested Actions

Build working relationships with Indigenous rights holders, managers and stakeholders; **develop** a strategic advisory board with representation from various agencies and communities to acquire access to existing data; **initiate** a series of research projects focusing on aquaculture, food web modelling, watershed restoration, fish habitat and management, and ecosystem valuation.

Contents

Part 1: The CEM Symposium

Event Context & Purpose

The University of Guelph's Centre for Ecosystem Management (CEM) organized a workshop to seek the input of individuals, organizations and government agencies regarding what would be necessary for the Centre to succeed in the Great Lakes. The two days of meetings were promising, with great participant engagement that combined scientific perspectives on ecosystem science/management with viewpoints from various people and organizations interested in the successful implementation of such an initiative.

Ecosystems involve both the physical environment and the set of all biotic interactions that occur within. As such, the scale of ecosystem studies is large; involving cross-habitat and cross-ecosystem interactions that play critical roles in the maintenance of diversity and ecosystem function (e.g., secondary production, water quality). Given that global changes in the environment are known to be altering a wide variety of both physical and biotic processes, it is critical to embed a larger ecosystem-scale perspective into the management of fisheries. Fisheries research has developed formidable quantitative tools, but these are often focused only on the population level and rarely consider the "big picture".

Further, large scale spatial processes link macrohabitats and whole ecosystems thereby challenging traditional management boundaries. The Quantitative Fisheries Center (QFC) at Michigan State University has done a remarkable job on the Great Lakes with respect to traditional fisheries management but has a mandate that typically focused on the management of single species (although they have clearly taken important multispecies approaches as well). The QFC's success is what has led to the CEM's desire to complement their work by placing greater emphasis on studying and managing ecosystems at large. Given global change is fundamentally rewiring food webs both within and across ecosystems, the CEM sees this aspect of ecosystem management as being critical to the sustainability of fisheries, nutrient management, and the maintenance of biodiversity overall.

The mandate of this new Centre for Ecosystem Management is to facilitate the science and subsequent application of a broadly-based ecosystem perspective to better conserve and manage fisheries as well as other natural resources across the Great Lakes region.

This symposium explored modern concepts in ecosystem science, their application to effective management, and future directions needed to fully integrate an ecosystem management perspective in the Great Lakes region. The primary objectives of the symposium were to:

(1) **Launch** the University of Guelph's CEM.

(2) **Identify** emerging themes in global environmental change, ecosystem science and ecosystem management.

(3) **Create** an open forum for researchers, resource managers, and students to facilitate learning, collaboration, and growth in the management of the Great Lakes fisheries.

In line with these objectives, we note that the goal of this document is to: i) have in writing the thoughts on the successful implementation of the CEM at its origin to look back on ii) use this document as a resource for present and future directions; iii) chart the path of the CEM in relation to this document, and iv) promote collaboration and trust between interested partners.

Symposium: Talks and Discussion

The symposium was structured purposefully to deliver a day of general research and management from the larger ecosystem science and management community followed by a day of drilling more specifically into issues relating to ecosystem management in the Great Lakes. Symposia presentations on Day 1 included world-leading researchers and managers in aquatic ecosystem concepts, their application in management and their perspective in future development. Day 2 involved a more focused Great Lakes perspective with breakout groups integrating scientists and managers on the Great Lakes.

For simplicity, and in order to focus on the key recommendations and outcomes of these seminars as well as discussions and outbreak groups, we have put the detailed summary of the talks and the details of the breakout group discussion in the Appendix A: Working Group Report. Below, we outline the two-day schedule, speakers, and titles.

Day 1: Ecosystem Science and Managements

- Tricia Mitchell, Regional Director (Department of Fisheries and Oceans)
- Trisha Westman, Acting Director (Ontario Ministry of Natural Resources and Forestry)
- Dr. Andrew Muir, Director (Great Lakes Fishery Commission)
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- Dr. Sarah Gaichas, Research Fishery Biologist (Northeast Fisheries Science Center)
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- Henry Lickers, Canadian Commissioner (International Joint Commission)
- Dr. Stuart Ludsin, Professor (Ohio State University)
- Randall Claramunt, Fisheries Chief (Michigan Department of Natural Resources)
- Andy Todd, Manager (Ontario Ministry of Natural Resources, Lake Ontario Unit)

Day 2: Ecosystem Management Issues in the Great Lakes

- Bruce Mighton, Manager (Ontario Ministry of Natural Resources, Upper Great Lakes Unit)
- Mitch Baldwin, Manager (Ontario Ministry of Natural Resources, Lake Erie Unit)
- Andy Todd, Manager (Ontario Ministry of Natural Resources, Lake Ontario Unit)
- Vic Santucci, Program Manager (Illinois Department of Natural Resources for Lake Michigan)
- Ryan Lauzon, Fisheries Assessment Biologist (Chippewas of Nawash)
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- Dr. Erin Dunlop, Research Scientist (Ontario Ministry of Natural Resources and Forestry)
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Emerging Recommendations

The CEM symposium brought together many viewpoints spanning multiple countries and disciplines (managers, economists, ecologists, conservation biologists, Indigenous, etc.). Despite this breadth there was a remarkable convergence on several issues and talking points which included the following:

1. **Defining the CEM (what scale, ecosystem management versus ecosystem-based fisheries management) and partners:** Who was missing from the table/discussions?
    a. Indigenous, Agriculture and Agri-food Canada (AAFC), and Environment and Climate Change Canda (ECCC) were suggested on numerous occasions.

2. **The "Bungee Cord Interaction"**: The Manager – Scientist interaction is fundamental.

3. **Declining productivity** (and numerous species interactions under climate and nutrient changes, e.g., invasive mussels) a major issue in the Great Lakes with many specific important issues (e.g., lake whitefish decline) that revolve around this larger issue.

4. **Ecosystem effects on fish recruitment** (likely connected to point number 3 above).

5. The **role of habitat and fisheries productivity** (here, at least at the macrohabitat scale, this is linked to points 3 and 4 above).

6. The **role of human dynamics and behavior** (including socio-economic) and the feedbacks in ecosystem management and sustainability.

7. **Science transfer** (general and science-manager) & CEM – e.g., simple ideas explained graphically and put out in the mainstream to promote education and understanding.

8. **Indigenous role absent and their perspective on "management"** – two-eyed seeing and western science as a coupled holistic knowledge base as we note that the word "management" might be problematic for the holistic Indigenous perspective.

9. **Multi-stressors and climate** a major issue in the Great Lakes with many specific important issues that revolve around including connectivity and land-water interactions (e.g., nutrients and land management). This was mentioned several times in the symposium including the holistic perspective of management.

10. Need for **synthesis of a data-rich set of ecosystems.**

11. Aid in the development of **monitoring** systems.

12. **Leveraging relatively unused research areas** like evolution and genomics by developing data-rich monitoring tools (see point 11 above as well).

13. **Collaboration** is critical.

14. **QFC-CEM interactions** would benefit the science-management divide.

Part 2: CEM Response and Direction

2.1 Background and General Objectives/Approach

We end by presenting the initial directions and approaches of the CEM in its first few years with its long-term goal of successful CEM operation in the Great Lakes Basin. The purpose of this meeting was to bring everyone to the table to seek input on key needs and methods for the successful implementation of ecosystem management. Arguably, the question asked most frequently was whether CEM was interested in ecosystem management (EM) or ecosystem- based fishery management (EBFM). We see the CEM posed quite broadly since the goal is to aid in the development of management on key issues and a broad mandate will be required for an effective long-term Centre for Ecosystem Management.

We realize that although our current researcher breadth is minimal, we can collaborate with researchers (both of national and international origin) who are broadly trained and have already published reports on fisheries, nutrient dynamics, land modification, socio-ecological dynamics and even economic valuation.

Consistent with the need for a broad mandate, society has noted the critical role of understanding the complex human connections between the socio-political and the environment. As expressed by Ralph Rogoff in a summary for *Dear Earth* (a contemporary artist expedition):

> *"The urgency of our situation today – and the frightening scale of the potential calamity ahead of us if we fail to drastically reduce our destructive impact on the environment – makes it tempting to point fingers at a long list of enablers and agents of ecological devastation. Yet, as the artists in Dear Earth remind us, the most impactful art goes beyond outraged protest or a cry for immediate action, and instead deepens our engagement with the subject in ways that ultimately nurture both our understanding and our capacity to act. Many of the works in the exhibition address complex webs of interconnected issues, illuminating how the growing ecological crisis is inextricably entangled with cultural, social, and political arenas. In the process, they reaffirm art's irreplaceable role in prompting us to perceive and think about the world around us in ways that challenge our past assumptions."*

The artist's contributions highlight not only the socio-ecological connections but the requirement for a deeper understanding; a more holistic and interconnected viewpoint for aiding our capacity to respond to environmental change. This is similar to the holistic stewardship that we heard about from several participants during the symposium, emphasized in particular by Ryan Lauzon (Fisheries Biologist for the Chippewas of Nawash). **We feel compelled to position the CEM under a broad mandate both spatially (at the Great Lakes basin scale connecting ecosystems through land and water) and conceptually (with an emphasis on increased understanding at all scales including the socio-ecological).**

Nonetheless, we intend to accomplish this broad mandate by collaboration (interacting and engaging different disciplines and managers) as well as picking focused topics across this spectrum initially. **In essence, we intend to grow into our broad mandate**. We will thereby scientifically support the application of ecosystem management (e.g., land modification and nutrients at the local, regional, and global scale) but also use ecosystem-based fisheries approaches as a focused

approach to aid the sustainability of fisheries. This approach is entirely consistent with the definition of ecosystem based management as stated by Jack Thomas (1994):

> *Definition (EM): Ecosystem management is a holistic approach to natural resource management, …. in order to integrate human, biological, and physical dimensions of natural resource management. Its purpose is to achieve sustainability.*

This discussion leads us to our first and most general objective and its accompanying approach:

General Objectives: *to foster the development of both the science for ecosystem management (broadly defined, see above) and its application to management and sustainability.*

General Long-Term Approach: *the approach will largely be a broad ecosystem management (EM) vision (e.g., consider human-ecosystem coupling, land to water implications for nutrient management) but as a lot of our work will be directed at fisheries our approach will also frequently employ ecosystem-based fisheries management (EBFM; e.g., whole food web models, or ecosystem indicators) as mean to predict and decrease uncertainty around the implications of management actions/responses.*

We note that while we are named the Centre for Ecosystem Management, the role of science behind ecosystem management is significant and implied. Unlike the more quantitative and significantly developed population ecology that frames traditional fisheries management (often referred to as single species management), much fundamental science and discovery at the ecosystem level remains, arguably due to the complex system dynamics it seeks to understand. While complex, ecology and ecosystem science has increasingly begun to focus on the dynamics of these more complex entities (e.g., recent industry of meta-ecosystem work and modelling) and the path for successful management seems increasingly promising and necessary in the face of anthropogenic change that is cascading through ecosystems (e.g., Baltic Sea, North Atlantic fisheries).

2.2 CEM Pillars

Consistent with the International Joint Commission or IJC (SAB-Great-Lakes-Science-Strategy-summary-report_2022.pdf (ijc.org)), our approach is to develop our general understanding of the key **processes** behind ecosystem function/services and then use this understanding to apply those ecosystem management practices that are entrenched in modern scientific developments. In a simplified sense, this process-based study is the structure-function relationship alluded to in the definition of Ecosystem Management offered by Christensen (1996) below:

> *"Ecosystem management is management driven by explicit goals, executed by policies* ***… and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function****."*

Our goal is to develop work with a focus on the Great Lakes basin. We intend our research and management approaches to also play a leading role in the growing ability to manage ecosystems globally. We emphasize that we will draw largely from our focus on the Great Lakes as an iconic set of ecosystems to accomplish this.

We see **four general pillars defining our approach** in developing ecosystem science and management that are relevant to society. The pillars are as follows:

i. A **management pillar** that links science to needed management problems.

ii. A **research and development pillar (R&D)** that will focus on data and conceptual synthesis.

iii. A **two-eyed seeing pillar** that seeks to bridge i) and ii) above with Indigenous knowledge in ways that further aid ecosystem stewardship and help maintain the resilience and health of all the ecosystems in the Great Lakes Basin.

iv. An **educational outreach pillar** that includes training of highly qualified personnel, societal education, and outreach with a focus on explaining complex scientific outcomes in an easily digestible manner.

We envision the CEM as being comprised of individual researchers that both are involved in applications (i.e., intersection of science and management) as well as scientific research and development. Being a Centre that is funded through a university, however, means researchers need to also comply with tenure conditions (i.e., publish). As such, we see our pillars forming a "win-win" arrangement with both academic interests (i.e., University of Guelph, College of Biological Sciences) and partner agencies (i.e., Great Lakes Fishery Commission, Department of Fisheries and Oceans, Ontario Ministry of Natural Resources and Forestry, etc.). We also intend to engage in collaborations with Indigenous communities interested in Great Lakes stewardship to facilitate pillar (iii) towards engaging traditional knowledge from the inception of the CEM.

With the general objectives and approach outlined we now veer towards outlining our initial target research as well as management objectives and approaches.

2.3 CEM Targeted Starting Approaches

Collaborations: Science, Indigenous Knowledge, and Management

Our work in research, synthesis and management application is highly collaborative and thereby accomplishes several things. Firstly, collaboration creates a strong tie to stewardship interests amongst Indigenous rights holders, managers and stakeholders; a tie that is clearly necessary for meaningful applied science transfer to management. Secondly, collaboration allows us to grow our expertise from the core team of three researchers to many more. We feel we have the researchers required to do this very effectively.

Synthesis

Related to collaboration, one major area for ecosystem management and structure-function research requires the synthesis of existing data within the Great Lakes (across ecological hierarchy), across ecosystems in the Great lakes basin (patterns within and across lakes), and across sociological and human systems. The idea of data synthesis was repeated frequently.

We see the CEM taking advantage of the data rich position of the Great Lakes to advance both science and management. The CEM will be active in the synthesis of existing data locally and globally. We note that we will need to collaborate to acquire access to data and hope that agencies and scientists will aid us in this aspect as unfortunately to our knowledge data is not easily compiled in one area (we note that Dr. Stu Ludsin and collaborators have started compiling a relevant database and promised us access when it is finished).

We further note that the existence of untapped data allows for the rapid development of critical research infrastructure in ecosystem management which is an area of research novel to the Great Lakes. Towards this critical aspect of research and management we are running highly collaborative research projects that utilize the data-rich Great Lakes. This work includes the development of ecosystem-level indicators that can be used on their own for management or in tandem with stock assessments. From CEM meetings with Department of Fisheries and Oceans (DFO) scientists we have determined that there are numerous groups working on areas like this (e.g., Currie, Ward).

2.4 Some Initial Research Projects

Below we discuss several starting research projects that are being conducted by CEM core researchers, peripheral CEM members (University of Guelph) and agency researchers.

Fisheries and Food Webs

1. **Declining Pelagic Productivity in a Changing World** (invasives, nutrients, climate). With numerous researchers from the DFO, Great Lakes Fishery Commission (GLFC), Ontario Ministry of Natural Resources and Forestry (OMNRF) and other universities (e.g., Aaron Fisk, University of Windsor) we are seeking to run a series of projects that collectively contribute to the development of a series of food web models for management in the Great Lakes. This work will both develop ecosystem indicators and food web models that will allow projections of different management levers aiding management (management strategy evaluation).

Landscape: Nutrients to Fish Management and Restoration

2. **Watershed Restoration and Sustainable Food Production in the Great Lakes Basin.** In collaboration with Dr. Andrew MacDougall and Alternative Land Use Services (ALUS), a community of farmers and ranchers that "seek nature-based solutions to sustainable food production" (see https://alus.ca/), we plan to apply for funding from the Great Lakes Protection Initiative (GLPI) to install wetlands and riparian zones in the Lake Erie watershed. Monitoring and natural experiments will occur around the restoration effort from the fields to the Great Lakes.

3. **Landscape biomonitoring infrastructure (Freshwater Ecosystem Assessment and Monitoring; FEAM).** Grant is 1 of 4 being put forward for 2024-2025 Canadian Foundation of Innovation by the University of Guelph in collaboration with Trent University, University of Windsor, and other research institutions. This infrastructure will include high-level equipment to biomonitor density across the food web in space and time as well as physical and abiotic variables. The

infrastructure seeks to complement and intersect with the "within Great Lake" Real-time Aquatic Ecosystem Observation Network (RAEON) program.

Fish Habitat and Management

4. **Biological cues, timing windows, habitat use and management** (towards building regulations). In collaboration with the DFO (e.g., Dr. Tyler Tunney), we are running workshops that will create novel science and produce white papers about managing building around ecologically critical timing windows in biological habitat.

Aquaculture in the Great Lakes

5. **Towards Sustainable Cage Culture on the Great Lakes: Looking for Win-Win** in terms of eDNA benthic approaches to "assimilative capacity" of cage cultures and the role of "pelagic" cage cultures as nutrient subsidies to pelagic food chains (OMAFRA grant rewarded, which is being used to get 2:1 matching from NSERC Alliance growing the "pelagic nutrient subsidy side"); and cage cultures as a lever for pelagic production under human impact and strongly coupled to First Nations Aquaculture & Ontario Aquaculture Association and Industry. This work will require collaboration with peripheral University of Guelph researchers Dr. Neil Rooney (ecosystem scientist), Dr. Ryan Prosser (eco-toxicologist), Dr. Robert Hanner (eDNA) and CEM core member Dr. Kevin McCann.

Ecosystem Valuation of the Great Lakes

6. We are bringing in external researchers who are experts in ecosystem valuation work. Dr. John Livernois has agreed to run a collaborative network regarding the evaluation of the Great Lakes.

2.5 Education and Outreach

Our educational and outreach starting point is perhaps the least developed. We have received funding (via a MITACS grant) for a young researcher working on field sampling with the Toronto Region Conservation Authority (TRCA), however, an outlined educational approach remains. We note that we have hired, on a part-time basis, modelling experts (Drs. Joey Bernhardt and Kevin Cazelles) and have discussed with them running summer multi-week workshops on food web models and approaches among other things. Any agency feedback with respect to education and outreach would be welcome as we develop this area of the CEM.

2.6 Governance Structure

We recently attended a Strategic Advisory Board (SAB) meeting of the Quantitative Fisheries Center (QFC) so as to consider implementing a similarly styled governance structure. We intend to have a strategic advisory board (SAB) with representation from the Memorandum of Understanding (MOU) agencies (i.e., GLFC, DFO, OMRF) as well as the Indigenous, University of Guelph (administration and researcher), and external science communities. The symposium did note that we are missing water quality agency perspectives if we seek a larger mandate. This will be a consideration as we build the SAB. The exact number and personnel remain to be determined

as we chart our path forward, but we intend to have the SAB and the terms of reference in place by March 2024.

2.7 CEM Future

In 10 years' time, we aim to have a Centre that is not only leading ecosystem management on the Great Lakes but also playing an international role in the global scientific infrastructure and application for ecosystem management. As ecosystems go from land to water joining together multiple ecosystems that intersect in terms of management, we see our Centre expanding to have researchers that cover this terrestrial-aquatic continuum and consider the interactivity of these interacting systems as fundamental to the feedbacks that govern biodiversity and its ecosystem services. We see the Centre hosting and playing a major role in the development of synthetic data contributions to the Great Lakes. Finally, we see the Centre being formed - and defined - by tight collaborations between science and management.

Citations

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Appendix A: Working Group Report

Symposia presentations on Day 1 included world leading researchers/managers in aquatic ecosystem concepts, their application in management and their perspective in future development. Day 2 involved a more focused Great Lakes perspective with breakout groups integrating scientists and managers on the Great Lakes.

In what follows we document the talks, discussions and breakout groups (in temporal order) towards creating documentation of this multi-perspective event. The goal of this document is to: i) record the thoughts on the successful implementation of the Centre for Ecosystem Management (CEM) at the origin; ii) use this document as a resource for present and future directions; iii) chart the path of the CEM in relation to this document, and iv) promote collaboration and trust between interested partners. We end by presenting the initial directions and approaches of the CEM in its first few years with its long-term goal of successful CEM operation in the Great Lakes Basin.

Day 1 – Ecosystem Science and Managements

1.2 Overview from Partners on Vision/Needs from the CEM

Tricia Mitchell, Regional Director (Department of Fisheries and Oceans)

Tricia Mitchell began by saying that the gathering offers the opportunity to reflect on the importance of sustainable practices in protecting these freshwater ecosystems, and the vital role that ecosystem management plays in achieving that goal. In thinking about the vision that the Department of Fisheries and Oceans Canada (DFO) has for the CEM, she delivered six priorities for the Centre.

The first, overarching priority ought to be collaboration. This is perhaps the most important function that the DFO sees for the Centre. The challenges facing the Great Lakes and their fisheries are complex and require collaboration across various stakeholders. The DFO vision for CEM is centered around fostering partnerships and engaging with Indigenous communities, government agencies, environmental organizations, academic institutions, and local communities. By bringing science and management experts together across organizations, we can leverage collective knowledge, resources, and expertise to develop comprehensive and sustainable management strategies for the Great Lakes.

The second priority is research. Research is the cornerstone of effective ecosystem management. The DFO's vision for the CEM emphasizes the importance of research in understanding the unique dynamics of the Great Lakes ecosystem. The DFO is investing in studies that explore the health of aquatic species, water quality, invasive species management, and the impacts of climate change on these freshwater systems, and this Centre offers the opportunities to do this collaboratively with partners. Advancements in our scientific understanding will allow for more informed, evidence-based management decisions, and ultimately drive more sustainable management practices.

The third pillar in this vision for the CEM is conservation. The Great Lakes are home to diverse and fragile ecosystems that require coordinated and concentrated conservation efforts. The hope is that the CEM will serve as a hub for conservation initiatives in the region. We envision a collaborative platform where researchers, policymakers, and stakeholders can come together to develop strategies for habitat protection, restoration, and biodiversity conservation. By

safeguarding these ecosystems, we can ensure the long-term sustainability of the Great Lakes' fisheries and preserve their ecological integrity.

The fourth priority is innovation. Embracing innovation is crucial for addressing the unique challenges facing the Great Lakes. The DFO's vision for the CEM includes supporting and promoting innovative technologies and practices that can enhance the conservation and management of these freshwater systems. This may involve the adoption of advanced monitoring techniques, data analytics, and integrated modeling approaches. By harnessing innovation, we can improve our ability to detect and respond to environmental threats, optimize resource allocation, and mitigate the impacts of human activities on the Great Lakes.

Next is education. Education and public awareness are vital for fostering a sense of stewardship and engagement with the Great Lakes. The DFO's vision for the CEM is to prioritize educational initiatives aimed at local communities, schools, and the broader public. By increasing the understanding of the importance of the Great Lakes and the need for sustainable practices, we can empower individuals to become active participants in their conservation. We also would like the CEM to position itself as a training hub for professionals in our field, aiding in the dissemination and training of DFO-developed tools as well as tools developed by all Great Lakes partners. Education will play a critical role in building a lasting connection between people and these freshwater ecosystems.

And the final pillar or priority she highlighted for the CEM is adaptive management, recognizing the dynamic nature of the Great Lakes and the need for adaptive management strategies. We hope that the CEM will serve as a platform for monitoring and assessing the impacts of various stressors, such as pollution, habitat degradation, and climate change. By integrating scientific research with real-time data and stakeholder input, we can adapt our management approaches to ensure the resilience and sustainability of the Great Lakes' ecosystems for future generations.

Mitchell ended by saying that the Department of Fisheries and Oceans Canada is committed to supporting the CEM as an important initiative for the sustainable management of the Great Lakes. She emphasized that the DFO was a partner in helping to establish the CEM and will continue to support it moving forward. The DFO brought several of their best research scientists for this launch, and they actively participated in this symposium to help set the agenda moving forward. Mitchell hoped that the CEM could be a vehicle through which we could work together to ensure that the Great Lakes, and the aquatic species that they are home to, remain healthy, vibrant, and productive.

Trisha Westman, Acting Director (Ontario Ministry of Natural Resources and Forestry)

Trisha Westman started by describing the Ministry of Natural Resources and Forestry (MNRF) as being responsible for sustainably managing Ontario's resources. Towards this, management and policy decisions are supported by a balance between extensive monitoring, assessment, and applied research. Further, she argued that Indigenous communities are an essential component in Ontario's approach to fisheries management. In addition to being rights holders, fish are of central importance to Indigenous communities, and the First Nations possess a wealth of multi-generational knowledge and understanding. Using science and engaging with Indigenous communities in the decision-making process has improved relations: staff are working together with Indigenous communities across the province to take a collaborative and active involvement approach (e.g., two-eyed seeing).

The MNRF are significant participants in Great Lakes governance with substantial experience managing complex fisheries. Because of this, the MNRF has a wealth of archived biological

samples and historical data that can be leveraged in addition to staffing expertise that can also be leveraged including Great Lakes managers, management & assessment biologists, and research scientists.

The CEM should help inform Great Lakes decision-making working towards ecosystem informed fisheries management. To do this, the CEM should address emerging science gaps associated with broader ecosystem stressors and fish population/food web dynamics. This work ought to be complimentary to the Quantitative Fisheries Center (QFC) and other Great Lakes-focused collaboratives. Using models, the CEM could play a significant role in helping to forecast future threats and ecosystem states considering climate change adaptation in combination with other stressors (e.g., invasives). The CEM may want to consider taking advantage of the broader mandate to include watershed, terrestrial/wetland/landscape linkages to Great Lakes ecosystems. Other key areas could be human dimension considerations such as the benefits that people derive from the Great Lakes and the behaviours of these individuals.

Finally, Westman ended by advising that the CEM - in line with MNRF science principles: Applied, Collaborative, Credible and Anticipatory - recommend a governance structure that includes the key Memorandum of Understand (MOU) partners to help guide the CEM.

Dr. Andrew Muir, Director and Robert Lambe, Executive Secretary (Great Lakes Fishery Commission)

The Great Lakes Fishery Commission (GLFC) started by pointing out that the theme of the opening session is “Partnerships”, so it is fitting to note that without the strong partnership we’ve had among those five organizations, we would not be celebrating the launch of the CEM today. They then noted that it is interesting to think of the words “ecosystem” and “partnership” and the things they have in common. Ecosystems are “living things working together to form a bubble of life”. A partnership is where “two or more things – people, organizations, etc. – work together on a common objective or objectives.

Further, they reflected on the concept of ecosystem management and that this concept has been with science and management for five decades or so, but people still generally agree that we’re still struggling to embrace the management of our valuable natural resources on an ecosystem basis. They noted that humans embrace the concept of “division of labour” to enhance focus to achieve specific objectives, although people unfortunately aren’t always as clever at integrating their knowledge and efforts to develop “shared objectives” in the public interest.

Perhaps there is no better example of that than with Great Lakes water quality and Great Lakes fisheries. In terms of water quality, we know we must manage nutrient loading to manage water quality, and more specifically, to reduce the impacts of algal blooms. In terms of fisheries management, we know we need nutrients to sustain the aquatic food web without which we cannot have healthy fish and sustainable fisheries. Why is it that we struggle to manage nutrient loading in our lakes and why is it that we are experiencing harmful algae blooms in the near shore of Lake Erie, while suffering through declining offshore productivity in the same lake? When we recently brought water quality managers and fishery managers together to discuss this dilemma, both sides concluded and agreed on the fact that is a “wicked problem”, however, we have failed to make much progress on how to address it.

They then continued saying that wicked problems, as we know them, will never be resolved or addressed without a deep understanding of all the causal factors contributing to the problems and that we must understand the full context – the ecosystem – within which the problems exist to

solve them to allow the ecosystem to work as it is supposed to so that the public good can be served. Without the science to understand ecosystem function, without that intelligence to inform resource management decision making at an ecosystem level, we'll continue to toil within our divisions of labor and continue to be frustrated that, despite our hard work and achievements within our own silos, the public report card continues to yield less than satisfying grades. They then suggested that the CEM will be an extremely important resource at turning that around in the coming years and decades.

Furthermore, and noted from a GLFC perspective, they argued that we need to look no further than the treaty that formed the GLFC itself to see the need for a more mature approach to managing our resources. Article IV (4) of the Great Lakes Fisheries Convention Act charges the GLFC with taking measures to maximize sustained productivity of any stock of fish within the Convention Area; well, one cannot have healthy fish and fish stocks without healthy habitat – without a healthy aquatic ecosystem. Again, the GLFC looks to the CEM to help it and its partners maintain healthy fish communities for the benefit of the ecosystem and sustainable fisheries.

Finally, they concluded by saying that there is more to ecosystem management than understanding the biological dimensions of the ecosystem. In a world where economics and outputs, measured by such factors as gross domestic product, are playing greater roles in what is important to the public, we must do better at determining and expressing the value of ecosystem services in ways that capture the attention of the public and legislators. With the ever-increasing competition for public and philanthropic dollars, it is incumbent upon us to be able to express the value of ecosystems services in economic terms so that ecosystems are not only protected, but investments in rehabilitation and restoration are seen as sound economic investments by governments and organizations at all levels – and not just "feel good" expenditures because they seem like the right thing to do.

The GLFC has been engaged with a broad network for about five years to try and advance this difficult work of determining how to value ecosystem services. The main outcome of that work was the need for a "community of practice" to harness expertise from around the globe to focus this seemingly unexplored aspect of ecosystems. We hope that this is an area that the CEM can become more engaged in as well as it evolves.

Dr. James Bence, Emeritus Faculty (Quantitative Fisheries Center at Michigan State University)

The Quantitative Fisheries Center (QFC) at Michigan State University (MSU) has a broad mission to provide education, outreach, and service to benefit the management of Great Lakes fishery resources. The focus of much of the work of QFC is in two areas: (1) fishery stock assessment and other fishery estimation models, and (2) structured decision making (and related tools such as Decision Analysis and Management Strategy Evaluation). Note that (1) and (2) are not totally disjoint as stock assessment procedures are part of management and assessment modeling is sometimes built into simulations used in SDM. While not all the assessment and SDM work is single species, in general QFC has not worked at what most would view as the ecosystem level.

In some ways the QFC is a bit of a fish out of water among the panel of partners giving presentations because the QFC is not a management agency. Despite this, Michigan State University is one of the signatories of the agreement establishing CEM, and the QFC being the action arm for MSU with respect to the responsibilities of the agreement. MSU responsibilities under that agreement include: (1) cooperating with the University of Guelph (UG) in research and/education/training, (2) participating in synthesis science activities organized by CEM, (3)

jointly (with CEM) hold an annual symposium alternating every other year between UG and MSU and (4) facilitate academic exchanges (people!) between MSU and UG. Thus, CEM will give QFC a chance to provide its expertise toward ecosystem-level questions without needing to become ecosystem science and management experts. The QFC brings the following areas of expertise that we believe will be synergistic in the partnership: (1) expertise in decision science (we expect two faculty members in this area), (2) experience in distance education and workshop training for working professionals (what works, what does not), and (3) experience meeting agency and academic objectives (i.e., we have had continual and enthusiastic University and agency financial support).

This is what CEM success looks like to Bence with a QFC/MSU centric lens: (1) QFC and CEM communicate about ongoing research and in-service training and collaborate when appropriate, (2) the annual symposium is vibrant and leads to impactful applied research, (3) QFC and CEM engage in regular academic exchange, and (4) CEM and QFC excel in both meeting agency needs and academic metrics (publications, grants, students) in part because of our collaborations.

Dr. Joey Bernhardt, Assistant Professor (University of Guelph)

As a representative of the CEM, Dr. Joey Bernhardt gave a 10,000-ft view of its vision and values. Bernhardt began by motivating the audience by proposing that we can all agree that nature is vital for human existence and a good quality of life. However, we are now living in a biodiversity crisis. The biosphere, on which humanity depends, is being altered to an unparalleled degree across all scales. While the world is becoming increasingly interconnected, it is also becoming increasingly unequal.

Human activities have dramatically reconfigured the fabric of life of the planet, in many ways, and it's beginning to fray and unravel. While it hasn't totally unraveled yet, it's showing signs of stress. In this context, there have been calls for transformative change at all levels of governance and scales. With this setting, Bernhardt suggested that the first component of transformative change is recognizing that challenges related to climate change, nature, and achieving a good quality for everyone are interconnected. Nutrient cycling, land-use, and water pollution are some examples of interconnected issues. The key to transformative change is not thinking in terms of silos, but thinking in terms of systems, and this runs from local to global scales.

Bernhardt then suggested that a solution to interconnected environmental challenges is to develop an integrated ecosystem approach to resource management. This is the approach that we are fostering and advancing at the CEM. There are several components to this approach: First, it recognizes humans as part of ecosystem. Second, it focuses on connections: connections between sectors, connections between multiple objectives, connections between food web components, connections between land and water. Third, it's inclusive. It includes diverse values and knowledge systems that operate in parallel, and thus promotes equity. Finally, it's adaptive: it includes learning, monitoring and feedback loops, so it helps coping with inevitable uncertainties that are inherent in a changing world.

Bernhardt ended the talk by suggesting that we will do our work at the CEM guided by a set of the following core values:

Generosity: Engaging and generous collaboration (intellectual generation and generosity).

Inclusive: Fostering an inclusive climate where everyone feels welcome and supported to thrive.

Cross-boundary: Disciplinary boundaries, national boundaries, cultural boundaries, etc.

Collaborative: Focused on building collaborations across disciplines and with diverse partner organizations.

In the end, Bernhardt argued that we at the CEM hope these combined activities will lead to several impacts into the future, including strong partnerships, the science to support healthy aquatic ecosystems, and ultimately, better outcomes for people and for nature.

Audience Comments (C)

C1. Who is missing as a partner?

Replies: The CEM should seek Indigenous input and collaboration from the beginning. People also suggested that important larger landscape level management issues (land management, nutrients, climate change) suggest greater intersection with Environment and Climate Change Canada (ECCC) and Agriculture and Agri-Food Canada (AAFC). This latter aspect depends on focus of the CEM (see CEM response which suggests their mandate is a broadly posed holistic ecosystem management that includes human dimensions, and nutrients).

C2: What about global great lakes like the African lakes? Does CEM seek to play a role there in the future?

Replies: Both the panel and members from the CEM thought this was a possibility, helping move ecosystem management (EM) related issues and sustainability globally and in places where scientific infrastructure is required. There was some suggestion that the International Association for Great Lakes Research (IAGLR) may also wish to play a collaborative role.

1.3. Keynote Speakers and their Messages

1.3.1 Of Food Webs and Fisheries

The first section of talks drew from researchers involved in already successful ecosystem management scenarios and both researchers involved in the food web/ecosystem modelling side of management. Anna Gardmark is a researcher who has done much work in the Baltic Sea while Sarah Gaichas is involved with NOAA and the Northeast Fisheries Center.

Dr. Anna Gardmark, Professor (Swedish University of Agricultural Sciences):

Dr. Anna Gardmark began by emphasizing that climate warming is speeding up in oceans and lakes and that this warming is expected to alter wild fish production globally. These increased average temperatures are also projected to increased asymmetrically in the north with bodies of water like the Great Lakes seeing significant changes in water temperature.

She then discussed an artificial heating since 1980 in the Baltic Sea from Forsmark Nuclear plant water discharge and that this heated area was contained allowing for the potential for a “natural” warming experiment. Indeed, and remarkably, the bay had been monitored both inside and outside the artificially warmed area since 1977 and that they had been conducting series of warming experiments in this area (and mesocosms) since 2014. These experiments allowed them to look at

population abundances, body growth, maturation rates, fish biomass production, mortality, metabolism and evolutionary adaptations.

An immediate result of these experiments was the agreement with a more general literature on the impacts of climate warming that they have observed fast body size growth since 1977 in fish (Huss et al., 2019). Gardmark also noted that effects of whole-ecosystem warming were species specific and tended to depend on average body size of the species with faster growth changes in small individuals. As an example, only among small-bodied perch experienced a growth increase with temperature and the strength of this response gradually increased over the 20+ year warming period.

The research group found that whole-organism maximum consumption increased more slowly with body mass than metabolism (Lindmark et al. 2022); a result, they argued, that leads to the prediction that optimum growth temperatures decline with body size. Using an independent dataset, they confirmed this negative relationship between optimum growth temperature and body size. Under these conditions, and alarmingly, small individuals of a given population exhibit increased growth with initial warming, whereas larger conspecifics could be the first to experience negative impacts of warming on growth. These results suggest a metabolic cost under warming mechanism for size truncation and increased growth rates.

Gardmark then provided evidence that mortality rates significantly increased for species in the artificially heated bay relative to the reference point (Lindmark et al. 2023) and that this mortality was driving shifts in the size-distribution of fish towards cohorts dominated by more smaller individuals and fewer larger adults (Lindmark et al. 2023). The culmination of all these changes appeared to lead to lower overall fish biomass production a result of the loss of larger individuals (van Dorst et al. 2019).

Having looked at trait responses to warming, Gardmark then considered the impact of warming on rewiring food web interactions. She argued that interaction changes drive population-level bottlenecks thereby affecting possible predatory fish collapse and/or the inability for larger species of fish to recover from major perturbations. Overall, these sets of food web changes led to declines in fisheries yield (Lindmark et al. 2019; Thunell et al. 2021). She noted that there were clear patterns in interaction strengths with some modules showing strong increases with the potential for altered overall resilience of the food web.

Dr. Sarah Gaichas, Research Fishery Biologist (NOAA Northeast Fisheries Science Center)

Dr. Sarah Gaichas started with the National Oceanic and Atmospheric Administration's (NOAA) definition of ecosystem-based fisheries management as:

> *A systematic approach to fisheries management in a geographically specified area that contributes to the resilience and sustainability of the ecosystem; recognizes the physical, biological, economic, and social interactions among the affected fishery-related components of the ecosystem, including humans; and seeks to optimize benefits among a diverse set of societal goals.*

She emphasized that the definition recognizes the holistic and dynamic nature of human interactions with ecosystems. Notably she referred to the fact that NOAA fisheries strongly support implementation of ecosystem-based fisheries management (EBFM) to better inform decisions regarding trade-offs among and between fisheries (commercial, recreational, and subsistence), aquaculture, protected species, biodiversity, and habitats. Further, and consistent with this, the NOAA document she cited argues "recognizing the interconnectedness of these ecosystem

components will help maintain resilient and productive ecosystems (including the human communities on which they depend), even as they respond to climate, habitat, ecological, and other environmental change."

Gaichas' expertise revolves around the implementation of an ecosystem perspective into fisheries management. She started by arguing that traditional systematic approaches often employ stock assessment, single species catch limits and only occasionally intersect with ecosystem approaches (e.g., including some species interactions and ecosystem level trade-offs) but more work needs to be done. She argued that ecosystem information can support these approaches by adding key tools like ecosystem indicators and management strategy evaluation (e.g., with multi-species/ecosystem models).

After these opening remarks Gaichas showed examples to highlight how these approaches can mesh. She argued that the connection of ecosystem approaches to stock assessment (she emphasized that these are a continuum of approaches that can interact) aids the involvement of ecosystem management in decision making. Her work revealed the ability to include easy-to-read "ecosystem indicators" (e.g., tables with physical, lower and upper trophic level indicators combined in the Alaskan ecosystem example) which allow us to absorb suites of ecosystem-level changes that provide context for the stock assessment. Further, her work showed examples of structured decision-making processes including "management strategy evaluation" (MSE) – whereby models produce simulations to aid understanding/predicting outcomes to different management levers. Gaichas provided convincing applied examples using ecosystem indicators within stock assessments, risk assessments, and management strategy evaluations from the US East Coast. Overall, a focus on developing *decision processes* that can use ecosystem information is a key approach going forward. The success of the examples presented and continued use of ecosystem information in management hinges on scientist-management collaboration with stakeholder engagement throughout. This work looked like a promising example of where the Great Lakes would like to be in 10 years regarding ecosystem management. Further, her emphasis on combining ecosystem information to traditional stock assessment and single species approaches may act as a natural collaboration for CEM and the QFC.

1.3.2: Ecosystem Management and Coupled Systems

This section sought to emphasize the truly dynamic nature of ecosystem management. Specifically, that the large-scale perspective of ecosystem science and management includes critical dynamic coupling that is often ignored. In this section we invited guest speakers who explored two different aspects of these connections. One, the coupling of human dimensions to fisheries and ecosystems and two, the coupling of ecosystems through the fundamental role water plays as a great connector (e.g., water moves nutrients and toxins potentially from great distances through streams and rivers to the Great Lakes). As such, landscape changes are intimately tied to fisheries outcomes.

Dr. Eli Fenichel, Associate Professor (Yale School of the Environment)

Dr. Eli Fenichel reviewed his collaborative research on the intersection of ecology and economics, arguing that economics and human behaviour are dynamically embedded in ecological systems and these interactions are critical to the sustainable management of complex natural systems. More specifically, his talk covered: i) the interaction of people and ecosystems; ii) economically valuing changes in ecosystems using natural capital; iii) what economics brings to measuring ecological change, and iv) a short commentary on working with economists.

In the first section of his talk, Fenichel used Hunt et al. (2021) to discuss work on forecasting the behaviour of recreational fisherman under global changes (climate, invasive bighead and grass carp, broader socio-demographic change) to understand the looming changes in Great Lakes fisher behaviours that will influence their sustainability. This work used social survey fisher data that produced a statistical model to predict fishing trips based on site attributes. They employed this model to predict recreational fishing in the future under different global change scenarios showing an example of how socio-ecological work can help forecast a changing fisher behavior landscape.

Notably, as ecosystems store large amounts of wealth that society relies on, our inability to measure ecosystem wealth properly causes large problems in environmental sustainability. Towards this fundamental problem, Fenichel drew extensively from Yun et al. (2017) to show that the holistic approach of ecosystem-based management may be linked directly with recent advances in the economics of inclusive wealth. Here, they drew from Natural Capital theory to estimate shadow prices (market prices adjusted for their actual function, e.g., prey is worth more than their market value as they also fuel predator fish whereas predators on the other hand eat things, we harvest them so they may be worth less in terms of their shadow prices). This adjusted value led to the situation where an ecosystem-based management scenario (considering multispecies simultaneously) produces greater societal wealth than a single species management perspective – the feedbacks between species and their harvesting producing outputs where there was a balance between predators (higher market price, reduced shadow price) with prey (lower market price, higher shadow price). This case study elucidates the dangers of misvaluing interacting harvested species and shows that a holistic perspective (i.e., ecosystem-based management) may also produce greater wealth to society.

Finally, Fenichel began to wrap things up by talking about interacting with economists for environmental sustainability. He pointed out that the successful management of complex socio-ecological systems will require research that couples both human and ecological dynamics. Such research requires collaboration between the natural and social sciences. Despite this, such collaborations are not mainstream yet and require work. He pointed out that the academic system unwittingly has created scenarios where there are not necessarily strong incentives to initiate needed research collaborations. Fenichel then discussed the results of a survey of researchers in economics and natural sciences that found evidence of researcher perceptions and incentives consistent with disciplinary-based differences that yield incompatibilities between economists and natural scientists. He ended by suggesting ways to facilitate such important collaborations (see Jaeger et al. 2023).

Henry Lickers (International Joint Commission)

Unfortunately, Commissioner Lickers was ill and unable to attend, however, Lickers' thoughts regarding the intersection of science and traditional Indigenous knowledge can be found at https://www.ijc.org/en/letter-henry-lickers.

1.3.3: Implementing Ecosystem Management in the Great Lakes

Our final section of talks turned directly to the major issue at hand, that is the implementation and needs for ecosystem management on the Great Lakes. Here, we drew in experts from the science side of ecosystem management (Dr. Stuart Ludsin, OSU) and the management side (Andy Todd, OMNRF and Randall Claramunt, MDNR).

Dr. Stuart Ludsin, Professor (Ohio State University)

Dr. Stuart Ludsin defined "true ecosystem management" and commented on the implementation of ecosystem management in the Great Lakes. Along the way, he pulled from examples including a look at the response of fish to productivity in Lake Erie, here showing empirically the potential for differential responses of species to nutrient additions. These community-level differential responses highlight the intersection of both abiotic and biotic responses at the multi-species level.

Ludsin framed his discussion by first showing that humans are clearly impacting ecosystems globally through a variety of means including habitat modification/destruction; eutrophication; overfishing; climate change; and invasive species. Having set the stage for a highly impacted Great Lakes ecosystem in need of an ecosystem perspective, Ludsin then defined management along a continuum of approaches going from single species to true ecosystem-based management, with a gradient of approaches in between.

Towards understanding the requirement of true ecosystem-based management, he outlined the general goal of this approach and its core principles from Dolan et al. (2010). Notably, it seeks to maintain a healthy, productive and resilient ecosystem that can sustain the services needed and wanted by society. Further, true ecosystem-based management is guided by the following common core set of principles:

i) Involve stakeholders in the entire process.
ii) Make decisions based on sound science.
iii) Manage natural resources adaptively.
iv) Consider the whole ecosystem.
v) Seek to sustain and maintain biodiversity generally.

He then argued that the Great Lakes Water Quality Agreement (GLWQA) is the closest to an ecosystem-based management approach with cooperation across agency interactions (including USA and Canada). Nonetheless, while the GLWQA is a great example of two countries working cooperatively for the same goal, true ecosystem-based management is not yet occurring in the Great Lakes as different ecosystem services are still managed independently (e.g., water quality vs. fisheries vs. tourism vs. shipping).

Very recently, in collaboration with Mohiuddin Munawar and Ken Minns, they convened a workshop on "*Ecosystem Approach in the 21st Century: Guiding science and management*". Here, they organized 14 expert participants from different disciplines to ask w*hat is preventing true ecosystem-based management in the Great Lakes?*

The group identified several priorities to ensure successful ecosystem management. Specifically, they argued the following:

i) Clear and common vision of goals.
ii) Stakeholder "buy in" at all levels.
iii) Understanding of existing governance.
iv) Sustained program support.
v) Integrated interdisciplinary science.
vi) Clear and transparent communication.

Ludsin then turned to some parting thoughts using Lake Erie as an example, noting that managing multiple ecosystem services in a changing ecosystem can create a wicked management landscape.

As such we critically need science that assesses trade-offs with management plans that account for ecosystem change.

To exemplify this trade-off, Ludsin then discussed how fisheries harvest has varied with changes in productivity in Lake Erie. Here, the yellow perch has tended to increase with increasing productivity. Given this, meeting water quality targets (reducing phosphorous and nitrogen) is likely to reduce yellow perch yields. Other fisheries harvest has varied with productivity, with lake whitefish decreasing with increased aquatic productivity. Here, then, meeting water quality targets is likely to increase lake whitefish yields.

Finally, Ludsin ended by arguing we are making progress in achieving true ecosystem-based management in the Great Lakes basin (GLWQA), but important challenges exist with respect to how we set goals, engage stakeholders, communicate, conduct science and make decisions. Nonetheless, despite these challenges, true ecosystem-based management offers the best chance to rehabilitate the Great Lakes ecosystem and identify ways to protect the diverse resources/services it provides.

Randall (Randy) Claramunt, Fisheries Chief (Michigan Department of Natural Resources)

Randy Claramunt voiced several cautionary points to consider in the implementation of ecosystem management. He noted that the history of salmon introductions set the stage for ecosystem management and that the declining offshore productivity from the mussel invasion has elevated that need greatly. From his extensive salmon experience, his first word of caution is that just because we can alter ecosystem structure and function, we need to be very careful to avoid sending any message that implies we can control the Great Lakes ecosystem and food webs. This caution later resonated with words from Ryan Lauzon and the Chippewas of Nawash who emphasized that humans cannot control ecosystems.

Claramunt went on to discus Michigan's successful relationship with the Quantitative Fisheries Center at Michigan State University, which began with the building of one of the first stock assessment models for Chinook salmon in Lake Michigan. He highlighted this as being a great example of how researchers and managers can work together. Even so, he emphasized that the utility of stock assessment models to assess predator-prey balance in the Great Lakes could benefit greatly from a broader ecosystem framework. Claramunt felt it would be important keep the management needs/focus/application in lock step when setting a vision for CEM. This idea was also echoed in the talk of Andy Todd (see below).

The third word of caution focused on uncertainty, and this led to a discussion on this topic (see comments below from audience). Claramunt posed the question: How does the research and management community, especially when talking about modeling food web dynamics, appropriately recognize uncertainties?

Next, Claramunt talked about the difficulty in communicating ecosystem approaches and messages. An issue raised a few times related to arguments over whether the CEM may help in terms of science transfer with respect to communicating these approaches. He argued that managing nutrients and nutrient pathways is going to be one of the next challenges for the Great Lakes community. He suggested a fourth word of caution, and that was to have an appropriate balance between basic and applied research. In Claramunt's words, "We need CEM to allow for adaptive management strategies whereby we attempt to address a broken linkage and then measure the effectiveness of our actions. Specifically, I'd like to know if the cisco reintroduction in Lake Huron will help increase nutrient pathways between near and offshore, or will it have no effect?"

His last word of caution was to ask that fish community goals and objectives be linked with CEM and their work. He talked about a stocking strategy for Lake Huron that is comprised of lake trout, chinook salmon, coho salmon, steelhead, and Atlantic salmon where management strategies have made small adjustments to the composition based on diets, indices of survival, and returns to the fishery. However, he emphasized that they are also trying to achieve a balanced and resilient predator-prey dynamic. What composition of predators would a food web model suggest has a higher probability of promoting a balanced predator-prey dynamic? This aspect of bringing resilience ideas to the aquatic management ought to be included within the CEM mandate.

Andy Todd, Manager (Ontario Ministry of Natural Resources, Lake Ontario Unit)

Andy Todd started off by considering what's in a name? He reiterated that the CEM stands for Centre for Ecosystem Management. With this, he raised the notion that management implies more than science, and implicitly includes human values and social and economic elements within a political/inter-jurisdictional context. He then said that he will make the case that it will take more than science to achieve success in ecosystem management.

For context, Todd noted that in Ontario there are three key areas that provide policy and guidance related to fisheries management. First, Ontario provides direction through a range of provincial and federal legislation and policy such as the Fish and Wildlife Conservation Act, Ontario Fisheries Regulations, Invasive Species Act, Endangered Species Act, the Provincial Fish Strategy, local management plans and more. Second, the binational Great Lakes Water Quality Agreement also provides direction related to water quality, nutrients, areas of concern, habitat and species and other elements through several annexes, lake-wide management plans and agreements between Canada and the United States and between Ontario and Canada called the Canada/Ontario Agreement (COA). Lastly, Ontario manages the Great Lakes fisheries in collaboration with our US partners and Indigenous communities under the auspices of the Joint Strategic Plan for Great Lakes Fisheries with the support of the Great Lakes Fishery Commission.

Furthermore, Lake Ontario's broad fish community direction is provided in the Lake Ontario Fish Community Objectives, which were developed in partnership with the New York State Department of Environmental Conservation. The development process included advice from stakeholders and formal public consultation through Ontario's Environmental Registry. New York followed a similar consultation process as required, and in 2013 the Fish Community Objectives were formally approved and became the guiding fisheries management policy for Ontario and New York.

Todd then discussed how the assessment programs are designed to inform on progress towards lake-wide and local fish community objectives and support management decisions such as stocking, harvest allocation and regulations. A key point – everything we do is done in the context of the broader fish community and the ecosystem we are working in. The action, for example, of stocking walleye in Hamilton Harbour is designed to influence the local fish community which is degraded. The OMNRF is intentionally trying to create more top predators to improve the species mix and overall health of the local ecosystem – the bonus being, we are seeing a local walleye fishery develop.

From the discussion today, he said it will take more than good science to advance ecosystem management. Collaboration is key since no single agency or jurisdiction has the management authority or expertise to address the inherent complexity that broader ecosystem-based approaches present. Communication is critical.

By default, ecosystem-based management requires us to think at broader spatial and temporal scales often moving away from local immediate interests towards landscape scales over decades. It can be a challenge scientifically to work at this scale, but it is also difficult from a pragmatic point of view when dealing with local interests (trying to sustain budgets over time, etc.).
Lastly, Todd pushed the idea that we need to cultivate a new generation of managers, so they have the skills and tools to practice ecosystem-based approaches.

Todd then referred to a NOAA report: In 2010, ecosystem-based management was established as a national priority under a US White House executive order. This set expectations and drove a few initiatives. Specifically, in 2021 NOAA published the results of a study that evaluated how things were going. The NOAA study included results of interviews with scientist, managers and policy makers. Interestingly, only 1/3 of the respondents thought ecosystem-based management was being successfully implemented.

There is a lot in the report about science, but it also presents several non-science barriers to implementation. Todd explained that when he read the report, it confirmed what he was experiencing and thinking about in preparation for this symposium. From a manager's perspective, having the right science is not sufficient. There are several challenges that will make or break success. He then talked about the management challenges and the future role of CEM, pondering how it could help overcome the non-science barriers to ecosystem-based management. He wondered if these non-science issues were something in scope for CEM? And further, if addressing these non-science barriers is not in scope for CEM then who can managers turn to for help?

Ecosystem management, Todd said, is multi-jurisdictional and multi-disciplinary. Even more so within the Great Lakes context (he illustrated this with a graphic here of the complexity that often exists between governance, policy development and operational delivery and subject area expertise). It is a challenge just to understand who does what and to recommended trying to map these relationships out so that there is sufficient situational awareness to develop a strategic and coordinated approach.

As an example, the Great Lakes Fishery Commission has established a successful governance framework, but it takes an ongoing commitment of all parties to keep it effective. Expanding the context to include broader ecosystem management will require new or strengthened connections and linkages to the Great Lakes Water Quality Agreement and other areas. Success in ecosystem management will require public support now and into the future. To the extent that managers will be able to develop long term strategies and action plans required to see success in ecosystem-based management will depend in part on public support today and over the long haul.

There clearly was strong public concern for the health of the Great Lakes that lead to support for the actions under the Great Lakes Water Quality Agreement. That support has lasted for over 50 years and enabled long term actions that have resulted in much improved ecosystem health. While there is still more to do, public concern and support appear to remain strong. Lasting public support requires a deeper understanding and appreciation of ecosystems and how they function, and it requires patience because it will take time to see results. Is there a role for CEM in helping build public awareness and support for ecosystem-based management?

He then turned to discuss Jack Vallentyne, who was a scientist involved in the early days of the Great Lakes Water Quality Agreement. Jack was someone who advocated for an ecosystem-based approach in the 1980s. Jack also understood how important it was to build broad public awareness given that we are all part of the biosphere and we need to think and act in that context. Jack wore

a globe on his back to illustrate the point and was an effective communicator. He recognized that we needed to instill the ecosystem concept and context into the younger generation. Jack, also known as "Johnny Biosphere", was arguably ahead of his time. While Todd was not suggesting CEM scientists start wearing globes on their back, he did feel that scientists can play an important role in communication to help build public understanding that in turn can lead to support for ecosystem-based approaches. He ended by noting that Jack was able to cut through the complexity of ecosystem management and reach a young audience.

(*You can learn more about Dr. Jack Vallentyne: https://limnology.org/notable- limnologists/john-reuben-way-vallentyne/)

Todd then turned to a brief perspective on uncertainty and the challenge of constant change. Ecosystem-based management is fraught with uncertainty. While we can calculate the uncertainty related to data or a prediction which helps modelers frame their predictions, there is an element of uncertainty in ecosystems that we just need to accept. He related this to Heisenberg's uncertainty principle, which basically says you can't accurately know both the position of a particle and its velocity at the same time. In this case, the more accurately you measure the one the less accurately you can measure the other. It goes on to suggest that the very act of measuring a particle's velocity changes the velocity thereby limiting our ability to measure it accurately.

While Heisenberg was referring to quantum mechanics (Todd says, "To be clear, I am not a physicist!"), there are some interesting parallels to ecosystems which are in some current state while also moving and evolving through time. It is impossible to completely measure the state of an ecosystem at any point in time because it would take too long, and it would change before you completed the assessment. We must accept some uncertainty.

Another related idea comes from Anthony Giddens on Structuration Theory, which basically says that things act on each other and change each other which creates a dynamic situation. We need to accept uncertainty and dynamic change which has implications for defining science needs, setting long-term goals and then developing and implementing action plans (all while the ground is often moving under our feet); this is the world managers live in.

Todd then asked several questions that are fundamental to ecosystem management. How do we define ecosystem management science needs to address management challenges not yet apparent? How do we decide what science to invest in? Here he used the opportunity to show the basic relationship between science and management and the idea of positive tension. The arrows in the diagram he presented are connections that can be stretched like bungee cords or elastic bands. Sometimes science pulls along management with the bungee cord while other times managers pull science. The important point is that the bungee cord exists between the two.

Typically, monitoring science is closely connected to applied management because it serves to inform status and trend and progress towards specific management objectives. Applied research is similarly closely connected to management and policy. Investment decision for monitoring and applied research are straight forward. Investing in leading research is more challenging. Leading research may be out in front of management, exploring new approaches, uncovering new knowledge, seeking out the unknowns and it may serve to pull management along. Sometimes management is out in front and pulling research along. The key point here is that science and management need to stay connected. Sometimes the connection is stretched but it should not break. Todd calls this positive tension in that science and management share the same overall goal. The tension is a sign of sincerity and collaboration where both parties act in each others best interest.

From Todd's experience, no amount of quantitative scoring process can entirely resolve the dilemma on where to invest in research, rather it requires a certain amount of faith. Managers can't be expected to know exactly what is needed to solve future problems, we can and should have faith in our scientists to explore new ideas and bring new thinking to the management table. Managers need to trust science and scientists need to guard that trust. It will be difficult to know exactly what research to focus on but if the CEM can help maintain the connections between science and management we will likely be in good shape.

Todd concluded by connecting some of the discussion today that identified several challenges related to ecosystem management, many of which are not science-based. As we consider the role of CEM, where it should start and how it will evolve, success will require attention of many of the management challenges related to science and non-science issues.

Audience Comments: As both managers touched on the idea of "uncertainty", this sparked some discussion. Someone, for example, expressed a fear of not recognizing uncertainty as it is a fact when managing a complex ecosystem.

Day 2 – Ecosystem Management Issues in the Great Lakes

1.4. Manager Perspectives on Needs and Implementation of Ecosystem Management

Bruce Mighton, Manager (Ontario Ministry of Natural Resources, Upper Great Lakes Unit)

Bruce Mighton began by highlighting the significant recreational and commercial fisheries in Lakes Huron and Superior, noting that Lake Huron is also home to some of the most significant freshwater aquaculture in Canada including approximately 95% of Ontario's aquaculture production. We note that the CEM, in collaboration with OMNRF scientists, are already involved in looking at the impacts of aquaculture on food webs in Lake Huron and have found that they can subsidize offshore pelagic production to lake trout when cage culture is placed in deep cold-water zones that are easily accessible to cold-water fish communities (attract prey (e.g., cisco) and lake trout; e.g., Gutgesell et al. 2022).

Mighton then went on to discuss the key issues that plague he and his team in the Upper Great Lakes, the key issue being the role of invasive species ("invasives") on ecosystem dynamics. He suggested that invasives, notably dresseinid mussels, have significantly impacted these food webs creating "remarkable shifts" in the dynamics of the fish communities. He noted further that these impacts cascade to affect people and their livelihoods. Mighton argued that a key role for CEM might be to help reduce the uncertainty in this vexing problem and further help in the communication of these ideas in terms of science transfer to the public. Finally, he commented that the CEM should bring Indigenous participation into their program.

Mitch Baldwin, Manager (Ontario Ministry of Natural Resources, Lake Erie Unit)

Mitch Baldwin started by arguing that he will bring three things to bear that his team see as critical issues to Lake Erie. The first issue revolves around developing further understanding of the key factors influencing fish productivity and recruitment in the Great Lakes basin with special emphasis on the central basin of Lake Erie. Part of this issue is the poor recruitment/success of the important fish yellow perch that has seen several years of poor recruitment. Similarly, and

worrisome, white bass have started to show signs of poor recruitment. These issues may be compounded by climate change.

Second, Baldwin argued that his team is interested in predator-prey dynamics in Lake Erie as things like prey switching (food web rewiring) have been noted and key prey species, like shiners, have almost disappeared. These issues make it urgent to begin to piece together energy transfer rates across the food web with a critical need in understanding the flux of energy into top predators and quota species and how this may impact these fisheries and the food web in general. Baldwin noted that the CEM can play a role in understanding these issues and in creating easily interpretable scientific output. Again, towards a critical role of science transfer in relaying the dynamics and understanding of complex food webs that we manage.

Third, Baldwin noted that his team is interested in further understanding the role of habitat change on fish community and its production in the Lake Erie basin. Here, habitat change is broad and includes such things as dam removal, wetland creation/removal, physical habitat loss, invasives, sedimentation and channelization.

Finally, Baldwin suggested that a consideration for the human dimension (e.g., socio-economic considerations per Eli Fenichel on Day 1) would be beneficial including forecasting what the future of fisheries might look like and how they might alter key markets. While most management is in 4-year periods this long-term perspective would be helpful. He added that this needs to be a collaborative space in general and agreed with the general consensus that Indigenous participation was necessary.

Andy Todd, Manager (Ontario Ministry of Natural Resources, Lake Ontario Unit)

Andy Todd began by agreeing that he sees the same challenges as his colleagues before him and pointed out the job of the manager is to manage and set realistic expectations for constituents. He noted CEM may be able to help this through increased understanding.

Todd then suggested that perhaps the biggest issue is the one of declining offshore productivity that is impacting things like the world class trout/salmon fisheries and their prey base. He noted that even if there is nothing, we can do about it, it is helpful to understand what is causing this to manage expectations. He then pointed out that climate change is another area we need to develop science and understanding with things like ice cover severely reduced or gone. Similarly, we need to understand what is happening in our watersheds as they are instrumental in the success of our migratory species and key ecosystem services. This connectivity plays a major role in ecosystem functions that people rely on.

Todd then pointed out that while scientific understanding itself can be helpful, monitoring is the "bread and butter" of managing and wondered if that is an area the CEM could also play a role in. Specifically, can ecosystem science suggest ways to monitor that can be useful in informing emerging management issues?

Finally, Todd felt there needed to be discussion about what we mean by ecosystem management and that the definition needed to be inclusive and connected to existing approaches like traditional single species approaches. This connection is a means to help management in all ways.

Vic Santucci, Program Manager (Illinois Department of Natural Resources for Lake Michigan)

Vic Santucci polled people he works with on the key problems in Lake Michigan (similarly Huron). The top issue was the role of dreissenid mussels as a massive perturbation to the ecosystem that is again impacting dynamics and people's livelihoods. Another key issue was the valuation of habitats relative to fish production (e.g., offshore versus nearshore). Consistent with this, the issue of offshore declines in production relative to historical production levels is a major concern with energy transfer between macrohabitats (offshore to nearshore and vice versa) and up the food chain.

Santucci suggested that recruitment bottlenecks were areas of concern for several species but especially lake whitefish. This is a big unknown with some researchers suggesting that this could be influenced by thiaminase in a manner like lake trout. Lake Michigan is also interested in whether the ecological conditions for coregonid restoration are met and if so, what species is most appropriate for restoration?

Santucci then reiterated that understanding ecosystems also helps justify management actions with people and suggested that information may aid management actions like lake-wide dreissenid control. Such background understanding helps management decisions and again suggests that a scientific centre may be able to play a significant role in science transfer. He gave an interesting example of a summit that played a big role in informing people and helped them understand the decline in yellow perch relative to Green Bay.

He also pointed out that a topic that receives less attention, but is still critical, is the near disappearance of diporeia. There is speculation as to why, but Santucci believes the "deep science" is still missing. Finally, he suggested that a cost-benefit analysis of habitat restoration, both ecologically and economically, would be beneficial. Further understanding of these nearshore restoration projects acting as a means for adaptive management is needed.

Ryan Lauzon, Fisheries Assessment Biologist (Chippewas of Nawash)

Ryan Lauzon is the Management Biologist at the Chippewas of Nawash Unceded First Nation for the commercial fishing waters of the Saugeen Ojibway Nation (SON). This area includes Point Clarke in Lake Huron, extending to the international boundary around the Saugeen (Bruce) Peninsula to Craigleith in Georgian Bay. His role as Management Biologist looks very different in many respects from traditional Western approaches due to differing perspectives on what has been described as management. In his talk he described how elders such as Vernon Roote have explained that the Anishnaabe language does not include an equivalent word for management. Furthermore, elder Roote has shared how what the Western world would describe as management is approached through a series of teachings about the relationship between humans and "the water beings".

Indeed, Lauzon has heard from the fishers at Nawash that some of them characterize their relationship with fish as one that is like that of family members. To provide further context, he describes how at the Chiefs of Lake Huron Conference, the concept of management was discussed and it was suggested that fish could not or should not be managed by humans, and instead we are seeking to manage human relationships to the waters and "the water beings". Considering these perspectives, it is not the role of the management biologist to attempt to manage fish, but instead to provide all the information from both Western science and the Saugeen Ojibway Nation so that the SON can make informed decisions on how to manage the human side of the fishery equation.

These differences in perspective between the Saugeen Ojibway Nation and the Western approach to management ultimately leads to a primary goal of the Chippewas of Nawash Unceded First Nation fisheries assessment program, which is recognition and acceptance of the Saugeen Ojibway Nation jurisdiction in decision making within their territory. Lauzon proposes three reasons why this is an important goal for not only the Saugeen Ojibway Nation, but for the wider Great Lakes community as well:

1. Ethics: recognition that this is the right thing to do and is fully within the spirit of reconciliation.

2. Legal: to meet obligations under the United Nations Declaration on the Rights of Indigenous Peoples which has been signed into law, and furthermore to improve consultation under Section 35 of the Canadian constitution.

3. Better decision-making: inclusion of diverse perspectives and knowledge systems will lead to better informed decisions and foster innovation.

Given the generally poor state of the environment and fish populations in Lake Huron, with the dramatic declines of the culturally and commercially important lake whitefish, the need for better-informed decisions and innovation has never been greater.

Dr. Seth Moore, Director (Grand Portage Band of Lake Superior Chippewa)

Dr. Seth Moore started by arguing that there is an expanding role in lake protection stewardship and co-management, with modern governments recognizing the vital role of Indigenous perspectives. His work is one that merges Ojibwe culture and world view with ecosystem management.

This world view has lessons to teach for co-stewardship such as the "7th generation planning" idea which suggests that everyone is connected to seven generations such that any decision made today will impact not just the individual but someone far into the future. Further, the concept of oneness, a holistic perspective, emphasizes the role of all things (animals, plants, lakes, streams, rivers etc.) is ecosystem health and resilience. Moore pointed out that one tribal leader felt that tribes speak for those that cannot speak – a particularly simple and powerful way to point out the oneness idea. The right to hunt, fish and gather comes with the right to non-toxic food and water.

Moore then defined ecosystem health in a manner that was consistent with the tribal world view:

> *Ecosystem health recognizes the inherent interdependence of the health of humans, animals and ecosystems and explores the perspectives, theories and methodologies emerging at the interface between ecological and health services (Wilcox 2004).*

Seth then outlined three major areas for ecosystem science and stewardship:

1. Climate Science and the Great Lakes: Here, thermodynamic impacts promise to have significant effects on communities and especially obligate cold-water species across all trophic levels (influencing areas like trophic transfer). Further understanding of science that is pointing out match-mismatch issues in ecology (e.g., zooplankton-phytoplankton phenological mismatches that can decouple energy flow). Finally, recruitment changes that

can be driven by climate change/variation which may greatly affect ecosystem health and resilience.

2. Harvesting and Nutrient Recycling: Moore noted that the extraction of massive amounts of fish over many years is likely to greatly disrupt nutrient balance in food webs as this means the extraction of enormous amounts of nitrogen, carbon, and phosphorous. These are oligotrophic systems and the removal of lots of nutrients can have significant impacts in this case.

3. Pharmaceuticals, Biota and Human Health: Moore argued that large quantities of pharmaceuticals and toxins entering the water need to be understood as they influence the health and functioning of biota (even if they are sub-lethal) and human health. These impacts can change behaviour, drive trophic cascades and significantly alter the structure and functioning of Great Lakes ecosystems.

Finally, Moore ended by suggesting six key areas for government and academia to aid interactions with First Nations and the tribes of the USA. They were:

1. Recognize inherent sovereignty.
2. Recognize that biodiversity, subsistence lifestyles, cultural and human health are being threatened by climate change.
3. Develop funding and technical assistance that can aid capacity for limited nations.
4. Promote indigenization of conservation and tribal perspectives at the highest funding and policy levels.
5. Develop and fund co-stewardship.
6. Promote and develop the recruitment of Indigenous peoples in a Science, Technology, Engineering and Math (STEM) capacity.

Questions (Q1): Is there a provincial or federal level policy for ecosystem-based management (or ecosystem-based fisheries management?): The USA has done this well by developing a roadmap or implementation plan and such a roadmap or implementation of ecosystem management is needed here too.

Answer 1a: No direct policy but ecosystem management is implicitly considered. Not aware of anything specific.

Answer 1b): Nothing specific but considered and things like the Joint Strategy Plan are pushing this along.

Question (Q2): Is the CEM planning to be reactive (almost all issues raised were ones driven by reaction to current issues) or also proactive to things like rising polyfluoroalkyl substances (PFAs), etc.? Is this because we are missing people, other agencies at the table?

Answer 2a: There are lots of things going on and things like PFAS are being covered, we were bringing things of the utmost urgency to the table here. It is not that this is not important but that we have groups working on these issues as they emerge.

Answer 2b: It was agreed that the collaborative space for issues like this need other ministries at the table that could contribute significantly to these broad issues.

1.5 Breakout Group Responses (Management Opportunities)

In response to the breakout groups, the following notes were summarized from all groups. Here, these were summarized in two groups, what was missed and then what are identified as the major challenges for ecosystem management on the Great Lakes. Below we include the compiled list of issues in point form that came out in the "bear pit" (i.e., summarized responses to group discussions) organized by participants under two categories:

i. What was missed in the management expert panel discussion?

- Did not hear DFO talking about what they are interested in managing. Assume it is not just about fisheries but includes habitat management.
- Habitat valuation also not discussed (although some managers did talk about this as a need - see Vic Santucci).
- Idea of interactions between dreissenids and climate change. Multiple stressors as a group were not specified. Should not consider just dreissenids.
- Increasing threats of pathogens and disease with things like introductions from aquaculture.
- Ecosystem management. Not fisheries, not stock but are we expanding the scope? If it is true ecosystem-based management. Do you need to consider it in your research or is this the focus of the research.
- Overall – is CEM about all ecosystem management or is it about fisheries management in an ecosystem context?
- What is the priority for CEM?
- Gap in focus – change in nutrient pathways (e.g., the dreissenid issue is really about energy and nutrient pathways).
- If we are going to expect to manage the ecosystem, we first need to understand the ecosystem. To use Lake Erie as an example, we don't really understand all the functional groups and how they interact with each other. This is pre-requisite to managing it.
- Scope and breadth of work that the CEM is expecting to undertake. Is it broader than fisheries?
- Scope again: Some missing pieces – in particular water quality people like Lakewide Action and Management Plans (LAMPs).
- Many things not really included (e.g., right down to often-missed things like vessel traffic).
- Could talk more about restoration of native species.
- Did not hear about aquatic invasive species, and aquaculture was not emphasized.
- Things will become much more complicated if there is a switch to ecosystem management as a framework (e.g., stock assessments).
- What is the medium for ecosystem management?
- Gap identified – is there anywhere where environment or other ecosystem components are a variable included in stock assessments or management decisions?
- When considering the management of major species of interest, we rely on information from many distant sources such as nutrients or lower trophic levels. Would need to include these experts in these fields to be included.
- In addition to less knowledge of the inputs, there are many fish species that are poorly understood.
- Some communities within the larger ecosystems are poorly understood relative to some others (e.g., wetlands) and how these fit into and have an impact on the systems of higher interest.
- There has been a history of too much focus on species and others have been ignored.

- Scale of management actions (spatial and temporal) to learn as we go and modify actions. Need to be tracking the effectiveness or management actions and this is one way to do that (adaptive management approach).
- Did not hear a lot about human dimensions.
- Did not hear a lot about physical attributes of the lakes (don't have a good inventory of the habitats within the lakes).

ii. Identify the Challenges

- Need to understand the ecosystem first or else you cannot make management decisions to have a desired effect.
- There can be skepticism about buying into ecosystem management. A possible approach would be to build a model to allow managers and users to explore relationships and improve understanding. There is a danger for models – they are not good at predicting outcomes (maybe use the term "forecasting").
- Human dimensions – what do people want, this is vague as it stands.
- Not a good inventory of the habitat (chemical, physical, biological) across the lakes.

1.6 Science Perspectives on Opportunities of Ecosystem Management

Dr. Susan Doka, Researcher (Department of Fisheries and Oceans)

Dr. Susan Doka discussed several integrated science-management approaches that importantly linked complex sets of data to models in a manner that provided management support. These models combined natural variability, climate variability and human impacts together with fish and fish habitat to look at a variety of issues the DFO is interested in. Specifically, she mentioned fish, aquaculture, species at risk, fish habitat and invasive species. Altogether the approaches drive science to support integrated decision making, an issue clearly relevant to the application of ecosystem science, in its various forms, to management.

Doka then pointed out that both uncertainty in process and ecosystem controllability dictate the type of management that can be applied. Specifically, high control systems are required for successful adaptive management whereas low control and low uncertainty are more aligned with a principal of precaution. She then discussed IJC-integrated response models with an example dealing with water quality and quantity and their integrated role on conservation. She noted this approach uses a shared vision model that brings a lot of different agencies and stakeholders to the table and employs valuation (ecological and otherwise). Similarly, the Cycles of Monitoring, Evaluation and Assessment is another related integration approach that employs detailed spatial and habitat data to produce population, community and ecosystem level predictions and outcomes.

She also referenced two recent papers that used novel techniques to create an ecological accounting system (Doka et al. 2022) and a national or regional integrated planning approach for complex cumulative effects scenarios (Cormier et al.2022).

Ryan Lauzon, Fisheries Assessment Biologist (Chippewas of Nawash)

Ryan Lauzon began by showing a picture of an enormous lake whitefish to emphasize that a lot of the research they are interested in currently relates directly, or indirectly, to the serious declines in lake whitefish in Lake Huron. The approach is a holistic view of the decline and so takes into consideration the life history from egg to larval fish, juvenile to adult lake whitefish (whole life history) and what may be driving this decline.

He then spoke of the role of "two-eyed seeing" defined as:

> "*Learning to see from one eye with the strength of Indigenous Knowledge, and ways of knowing, and from the other eye with the strengths of Western Knowledge and the ways of learning and use both eyes together for the benefit of all." Mi'ikmaw elder, Dr. Albert Marshall*

This sounds easy and makes a lot of sense, but in practice it is still being worked out. He then noted that his science works by collaborating with the membership of SON to develop research questions. Some of the key issues that they are interested in and concerned about are the role of stocking in declining fish species (lake whitefish) which is already in decline in pelagic productivity, which may add to the pressure on species. Lauzon alluded to the fact that role of stocking on ecosystem health and resilience is not well understood and should be investigated more. This is an area where they are looking into using two-eyed seeing approaches. They are looking at the non-native salmonines, but they are also looking at the interactions between lake trout and lake whitefish including the diet and isotopes. On the SON side, they are doing interviews as part of understanding the implications of stocking.

Lauzon ended by emphasizing that Indigenous membership and leadership are "with his science the whole way", from development to analysis which he felt was critical to fostering trust. He cited Reid et al. (2021) as a paper perhaps all could learn from.

Dr. Marten Koops, Research Scientist (Department of Fisheries and Oceans)

Dr. Marten Koops noted that his career has moved him across the ecological hierarchy from behavioural ecology, life history to population, community and ecosystem ecology. His work is highly quantitative, and he uses models to solve science-management problems usually on key issues affecting the DFO, including those relating to fish habitat, food webs and fisheries.

He argued important challenges and opportunities in ecosystem science and management occur in three broad categories which he called: i) conflicting management objectives; ii) knowledge gaps; and iii) ecological surprises.

i. Conflicting management objectives: Conflicting management objectives occur because ecosystem management is the shared responsibility of numerous agencies and stakeholders. As such, different agencies with different objectives may see the world differently. Dr. Koops noted viability theory and safe operation space as two approaches that may allow ecosystem management to deal with conflicting objectives. Safe operating spaces, for example, are used at the global level currently and include the definition of sets of states that are deemed acceptable, the goal is not necessarily to reach an optimal one but rather one that falls in an acceptable region. CEM notes that these safe operating spaces are highly related to new ecological ideas of "early warning signals" or "structural early warning signals" which in a sense are trying to define the boundaries of safe operating space.

ii. Knowledge Gaps: Koops argued that at least two critical knowledge gaps exist in the Great Lake's ecosystems. Firstly, the important area of monitoring for management has inconsistent coordination of monitoring at the across-agency scale (e.g., water quality versus fisheries). Secondly, the Great Lakes are a data rich system, and this means that there are ample amounts of unanalyzed data and synthesis to be done that would help piece together our understanding of the whole ecosystem. Koops then suggested that a powerful

approach here may be INLA (Integrated Nested Laplace Approximation) which accounts for spatial and temporal autocorrelations or dependencies (van der Lee et al. 2022; Enders et al. 2021).

iii. Managing Ecological Surprises: Koops attributed ecological surprises to uncertainty, nonlinearities and non-equilibrium dynamics. He argued that ensembles of ecosystem models may be a means to attack the vexing issues of ecological surprises. Here, he suggested that ensembles of approaches can help understand or manage the uncertainty about decision-making. Further, such approaches balance the implicit trade off in model complexity and tractability (Geary et al. 2020). Answers that are robust across this spectrum increase our confidence as they show a robustness to both overly complex models and simple models that do not harness all the available data.

Dr. Len Hunt, Research Scientist (Ontario Ministry of Natural Resources and Forestry)

Dr. Len Hunt started by noting he was a researcher specializing in human dimensions and the environment, or the study of people and their behaviour in a natural resource setting. He then expressed that he wanted to discuss two general aspects to this research that are likely important for management in general and ecosystem management specifically:

i. Human Population Change into the Future

First, Hunt covered the fact that human population dynamics will change under global change and with these changes we necessarily alter the behavioural landscape of humans on natural resources. Within this framework he felt that while climate change is critical, it may be more relevant to consider all aspects of global change, all multi-stressors or cumulative effects as it is this suite of changes that alter human dimensions. These multi-stressors may act additively, synergistically or even antagonistically when coupled together.

He went on to say that these changes may alter the way humans benefit from the environment and that this changing "benefit" is what we need to manage. As an example, he argued that while we largely manage now for consumptive benefits (e.g., fisheries) we may see an increasing shift towards "appreciative" benefits that come from the maintenance of fish and wildlife or more generally biodiversity. With this idea, he then pointed out that we expect Ontario to change significantly in the next 25 years with a 40% increase in population that will load on major urban centers like Toronto and Ottawa and increase the diversity of the people we manage.

These changing human population dynamics alter the demand for key ecosystem services thereby making them critical to ecosystem management. This changing landscape means that currently under-represented or under-considered groups may suddenly influence the socio-politics more and alter management; what is relevant to manage now may not be as relevant in the future. This will inevitably lead to new demands for ecosystem management.

ii. The Need for Interdisciplinary Socio-Ecological Research and Management Perspectives

Hunt believes that it is not enough to look at human dimensions and ecological research and management in isolation but rather integrate these perspectives. This will lead to

unified theoretical and conceptual frameworks that can be used to view the Great Lakes through a socio-ecological lens. This, he argued, holds a great deal of potential for moving our ability to manage ecosystems and he encouraged this as a growing area of research and application.

To help people understand what he meant by socio-ecological dynamics and implications he discussed an example: Take a fishery where a given harvested recreational fish decreases which in turn, materializes as reduced catch rates for fishers who then may alter their behaviour. As some examples of altered behaviour fishers may: i) stop fishing; ii) shift to another species; or iii) they may simply change their fishing tactics. Regardless, this cascade of effects then feedbacks to impact the fisheries and so this behavioural connection between human dynamics and fish responses may be critical to understand sustainability. Numerous examples of these complex socio-ecological interactions with implications are emerging.

Finally, he ended by encouraging collaboration and recognizing challenges. One of the primary challenges being the ability to recognize and respect each other's different scientific approaches. As an example, ecologists often employ strict empirical approaches that are quantitative while sociologists may take a more qualitative tract. Regardless, to collaborate we need to overlook our differences.

Dr. Erin Dunlop, Research Scientist (Ontario Ministry of Natural Resources and Forestry)

Dr. Erin Dunlop introduced herself as a researcher who does a lot of work on ecosystem change (biotic and abiotic) and how it affects fish populations and what this in turn means for management. Much of her work focuses on lake whitefish and overlaps with Ryan Lauzon's area of expertise.

She then noted that the meeting had yet to discuss the role of evolution and argued that this is an underappreciated aspect of these systems that needs to be considered more. Fish populations and other organisms are responding evolutionarily to anthropogenic change, and this can be critical to sustainability.

To give us ideas of how evolution may impact ecosystems and their management, Dunlop laid out two broad cases. Evolution can be thought of as occurring sometimes "too fast" and sometimes "too slow". Evolution occurs potentially rapidly in harvested fish populations as harvesting can selectively remove certain members of the population which then alters life history traits and behaviour of the population. Some examples from research include harvesting-induced selection reducing the age of maturation, increasing reproductive investment, altering the speed of the population, changing fisheries yield and stock-recruitment relationships. All of these can alter the speed of recovery of a population to perturbations and their adaptability to global change and can have negative management implications.

As an example of "too fast" evolution, she noted research on lamprey potentially becoming more resilient to a pesticide used to control their populations. Such a rapid evolutionary response has clear implications for lamprey control and fish populations in the Great Lakes.

She then considered the case of "too slow" evolution with species not able, for example, to keep up with climate change and potentially collapsing or altering their distribution in the face of such change. She noted that because evolutionary responses impact key attributes, an important area for research is multi-species eco-evolutionary models and hoped the CEM would play a role in promoting this type of research and application.

Here, Dunlop pointed out the significant challenge of bringing in evolution to an already complex system. She cited a cod example that used a bio-economic model with harvest-induced evolution to study the implications of harvest-induced change on economics to translate evolution into a clear management currency. This example suggesting that evolution is important to management and that there are clear ways to make the presentation of evolution relevant.

Dr. Andrew Honsey, Fisheries Biologist (USGS Great Lakes Science Center)

Dr. Andrew Honsey started by telling the audience he acts as a science support researcher to restore coregonines, or ciscos and whitefishes, across the Great Lakes. His projects under this broad area include:

i) Cisco and lake whitefish recruitment dynamics.
ii) Spawning habitat use by various coregonines.
iii) Understanding the impacts of hatchery rearing on coregonine morphology and fitness.

Honsey then told the audience that he was approaching this talk through tools the CEM and ecosystem management in general may benefit from using, as well as research areas that have not yet been well integrated into the practice of ecosystem management.

The first thing suggested was that genetics (with genomics) may offer important advances including identification. Here, identification is beyond fishes but even in this guild environmental DNA (eDNA) aids in the identification of species, as coregonines, for example, are frequently misidentified by even long-term experts. These approaches can also help stock assessment and population structure and further can help us understand the fisheries productivity of critical habitats or areas impacting nutrient and energy flux that will feed into ecosystem-level models.

eDNA offers a lot of potential to be further harnessed, clearly aiding identification but also in some cases allowing us preliminary ideas of abundance; both of which can allow us to create and monitor around key baselines.

He then touched on the potential role of data collection systems that are bringing large amounts of novel data to the Great Lakes. These data present opportunities to tie data and information to both large-scale highly parameterized complex models, as well as more general simple models that still require broad swaths of data. Here, he gave examples of data collection systems including the "goby bot" and telemetry both of which present opportunities for novel use of large quantities of data for ecosystem models. His message was that the CEM can help Great Lakes research in the synthesis of this large - often real time - data and the implementation of these data collections by parameterizing models that can assess management strategies.

Honsey referred to an earlier comment by Ludsin that had resonated with him: models that connect land modification and nutrients to the food web in the Great Lakes do not exist. That is, a full ecosystem scale model that connects processes across land and water and thus intimately connect different aspects of sustainability (water quality, fisheries). Here, that he is aware of, very little work has operated at this scale although pieces of this puzzle exist. Honsey felt that the CEM could play a significant role in moving towards such a holistic framework that can aid big picture management.

Finally, Honsey then reiterated the idea that the CEM needs to make real connections to management, stakeholders and Indigenous groups to make sure the development of research and

applications are on and around the needs of these groups. Doing this ensures buy-in for CEM but also makes sure research products are useful from a societal perspective. He ended by emphasizing that this foundation is critical.

Due to time constraints, questions did not occur after these talks.

1.7 Breakout Groups Responses (Science Opportunities)

Again, as in the morning sessions, in response to the breakout groups, the following notes were summarized from all groups. Below we include the compiled list of issues that came out in the "bear pit" (i.e., summarized responses to group discussions) under four categories.

i. Gaps in what we heard.

- Bigger issue is what are the societal issues we need to address and what is CEM going to do about it. First need to define what issue you are going to look at, then find the right disciplines and people to work on it. Human dimensions would be part of this and may be a prerequisite to determining what the priorities are.
- Work done more on marine systems – portfolio effects. E.g., BC salmon and not all streams are performing the same way at the same time so a "portfolio" of streams can be stabilizing. This seems to have potential for Great Lakes system: e.g., Cisco versus other prey species or multiple species of ciscoes to provide a more consistent prey base.
- Uncertainty – provide more structured ways to incorporate uncertainties in ecosystem management. E.g., Eco path with Ecosim that could be used to describe different ways of energy flow.
- Not much discussion of trade-offs, e.g. egg fish passage – dams provide a useful lamprey control method but have the obvious negative effect on fish migrations.
- How do we provide advice on trade-offs or management options?
- Understanding the function of the current state is critical.
- Human dimensions – can we influence the value and expectations of users. E.g., Walleyes are highly valued but perhaps the expectations are not reasonable given the current state of the ecosystem and maybe there are better options. Is this a marketing issue? Do we have a role here?
- Coproduction of question development. Managers being at the table with researchers but also including users and Indigenous rights holders.
- Portfolio effects – Atlantis model could be used to explore nutrient inputs and match this with knowledge of fisheries data to improve (optimize?) where nutrient management decisions are being made.
- For things like human dimensions, what species people choose, these choices seem to be hard-wired so they are not always something we can change.
- Need some science-based communications NOT coming from an agency (which may be perceived to have a self-interest); maybe the CEM could be viewed to have an objective perspective and be more credible.
- Is there potential for use of AI in ecosystem modelling? Could the CEM be the caretaker for ecosystem models for each of the Great Lakes?
- Use of SEM (structured equation models). This is like a pathway analysis and would provide a structured method to assist managers in visualizing (projecting?) possible outcomes from management actions.
- CEM really need to get to know the partners over the next few years. This will lead to drumming up funding opportunities, finding priorities and projects to work on. Get a quick win to get started and build momentum.

ii. Science Advances

- Ecosystem models (several options here – Eco path, Atlantis, others)
- SEM
- AI to help with understanding ecosystem complexity and big data.

iii. Tools

- Coproduction as a method for how to identify major issues and prioritize for work to be done.
- Formal gap analysis should be undertaken to inform about work to be done.
- Leverage the expertise of the QFC which is well established and has long-term connections while the CEM is getting rolling.

iv. Disciplines

- Fisheries Science and management
- Nutrients
- Climate change