Lake Winnipeg: State of the Science II
Toward the Integration of Lake Science and Management

Lake Winnipeg Research Consortium Inc.
Special Science Workshop
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Canad Inns Fort Garry
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EXECUTIVE SUMMARY

Introduction

For Lake Winnipeg, nutrient abatement in the watershed has become the predominant focus of government-led programs like the Lake Winnipeg Basin Initiative, the Watershed Systems Research Program at the University of Manitoba, and the Lake Friendly Stewards Alliance. **While eutrophication is a major water quality concern, it cannot be managed in isolation from the rest of the lake's food web or from additional stressors acting upon the system, such as climate change and exotic species.** For instance, evaluating lake indicators, such as the extent of algal blooms, in response to nutrient abatement actions being undertaken in the watershed will be challenging without a better understanding of the impact of zebra mussels on nutrient cycling within the lake, especially in the nearshore region. Similarly, understanding the response of the fishery, whether positive or negative, to changes in nutrient loading (and rainbow smelt, zebra mussels and other factors) will remain speculative without adequate food web data. Meeting the requirements of eco-certification will also remain elusive with the inevitable consequences of a vulnerable fishery and lost commercial markets and associated service industries.

The prevailing focus on nutrients and the watershed is also contributing to diminishing on-lake science capacity. Due to various constraints, LWRC science member agencies have increasingly relied on the LWRC to collect samples on their behalf. This includes most food web investigations, including a number of exotic species, such as rainbow smelt, *Bythotrephes*, and zebra mussel veligers. Most other science still conducted on board the Motor Vessel *Namao* has been focused on water quality and algal blooms. **A continued decline in the science capacity on the lake will make it difficult to justify the cost of maintaining the infrastructure that is provided by the LWRC in order to safely access and study the lake. Should this infrastructure be lost, the capacity to carry out whole lake science will also be lost, and likely not recoverable.**

Science Workshop

As facilitator of the multi-agency and multi-disciplinary monitoring and research efforts on Lake Winnipeg, the Science Program of the Lake Winnipeg Research Consortium Inc. (LWRC) has a unique vantage point from which progress toward improved "health" and impediments to progress can be observed. It was from this perspective that the Special

Science Workshop *Lake Winnipeg: State of the Science II - Toward the Integration of Lake Science and Management* was conceived.

The objective of the Workshop, held in December 2015, was:

> ***To address the issues of diminishing science capacity and persisting/emerging science gaps and management needs on Lake Winnipeg through the development of a new framework for whole ecosystem science (research and monitoring) that is more effectively integrated with lake management goals and objectives.***

Interestingly, the discussions did not reveal anything new that has not been discussed and documented in previous Workshop reports (with the exception of a discourse on what "healthy" actually means). However, **here they are presented together for the first time within the unifying context of a whole ecosystem Science Plan intended to directly support lake management efforts.** This alone will prove inadequate within the confines of the current focus on algal blooms and nutrient abatement in the watershed. Thus, coupled with the Science Plan is a proposed New Framework, which attempts to simply illustrate how multi-agency collaboration, united by clearly defined management goals and a whole ecosystem Science Plan, can actively support lake management regimes from water quality to fish through a more coordinated integration of science and management efforts.

This report describes the proposed **New Framework** and presents a draft **whole ecosystem Science Plan** developed by the on-lake science community for consideration by decision-makers in their efforts toward attaining and managing a "healthy" Lake Winnipeg, over the long term, as part of the Public Trust.

Whole Ecosystem Science Plan

The Workshop included the development of a whole ecosystem Science Plan with consideration for other stressors beyond eutrophication, such as exotic species and climate change. Particular emphasis was on ensuring that the necessary parameters are being monitored during the early stages of zebra mussel infestation.

The guiding question for the development of the Science Plan was:

> ***What are the necessary monitoring parameters and relevant research questions that will enable managers to evaluate and respond through adaptive management to changes in the lake ecosystem?***

Clear science priorities were identified in support of management obligations. They are summarized and presented within four categories for ease of discussion – **Monitoring, Modeling, Research, and Othe**r – however, there is considerable overlap and synergy among these groupings. Routine monitoring tracks trends in given parameters but also supports the development and ongoing validation of models, and can provide valuable baseline information to research programs that aim to understand more complex in-lake processes, including changes in the food web. Similarly, model output can be used to guide monitoring and research efforts.

Science Plan - Monitoring

Nearshore Monitoring

The nearshore is considered a critical and time-sensitive monitoring gap for a number of reasons. The impacts of zebra mussels are often first revealed and most strongly felt in the nearshore areas of lakes. For Lake Winnipeg, however, very little background data exist for the nearshore region because most research and monitoring since 2002 has been in the offshore region of the lake, accessed using the M.V. *Namao*. The rate of change could be rapid in areas where zebra mussels are able to thrive, followed by longer-term shifts in energy flow impacting the offshore. Baseline data are necessary to understand these spatial and temporal changes and inform management decision making.

Given these imminent in-lake changes, there is also potential for a change in the relationship between nutrient loading from the watershed and the lake's response. For instance, total phosphorus in offshore waters may decline due to zebra mussels (effectively transferring water column phosphorus to the littoral benthic community) and not to reduced loadings from the watershed. This has important implications for management, such as setting nutrient targets, evaluating progress in efforts to reduce nutrient loading, and interpreting indicator trends. Further, because the public's perception of the lake is largely based on their nearshore experience, providing relevant and meaningful water quality trends is important from a communications perspective as well.

Food Web Monitoring (nearshore and offshore)

The current status of the monitoring programs was reviewed and recommendations were discussed and summarized in this report. The response of the food web to ecosystem changes is complex and future monitoring will require a greater commitment to long-term, comprehensive monitoring across all trophic levels in both the nearshore and offshore. Understanding changes at the base of the food web due to zebra mussels is especially important in terms of early baseline data since that is usually reflected in higher trophic levels, including fish.

Based on a metadata analysis of over 700 lakes (Higgins and Vander Zanden. Ecol. Mono. 80(2), 2010. p. 179), Higgins described some of the anticipated impacts of zebra mussels within the context of informing a monitoring program on Lake Winnipeg. In general, anticipated physical changes due to zebra mussels include reductions in suspended solids and turbidity, and increases in water clarity. As the south basin of Lake Winnipeg is typically light limited due to high turbidity, increased water clarity could result in increased primary productivity in the form of attached algae (as opposed to phytoplankton) in the nearshore. In some of the Great Lakes, these attached algal mats detach and foul beaches, clog fishing nets and water intakes. High bacterial counts, including pathogens, have also been associated with attached algae in the nearshore.

Almost all groups of **phytoplankton** decline after zebra mussels invade resulting in a reduction in areal photosynthesis; the effects on **zooplankton** biomass across all groups tend to be proportional. **Zoobenthos** in the offshore profundal region tend to decline or remain unchanged, whereas in the littoral area, populations tend to increase with two notable exceptions, unionids and sphaerids (freshwater mussels). Reductions in freshwater mussels can reach 90% within 10 years of invasion. The magnitude of impacts on **fish** will depend on the extent to which energy is diverted from offshore to littoral pathways (see Research below), and on the respective species' ability to adapt or capitalize on these changes.

Fisheries Monitoring in Support of Eco-certification

From a commercial fishery perspective, eco-certified markets are becoming increasingly important as large companies such as Walmart choose to sell only seafood meeting these requirements. Eco-certification of the Lake Winnipeg fishery would allow fishers to sell into these markets. It is important to note, however, that eco-certification is not a replacement for, or pre-requisite to, sustainably managing a fishery.

Lake whitefish stock status (index-netting program). The provincial index-netting program is built around understanding walleye and sauger populations only. There is no longer an index-netting program for lake whitefish, and the only data collected (length and weight from dressed fish) are derived from the commercial catch sampling, which is not fishery-independent data. Consequently, management of lake whitefish is lacking, which renders this species extremely vulnerable. Further, ensuring an optimum balance between water quality and fisheries productivity requires information on lake whitefish.

Expanding the index-netting program to include the NE portion of the lake. The current provincial index-netting program (walleye and sauger) uses 59 net sets per year, largely on the west side of the lake. Expanding this program possibly up to 86 net sets to include the northeast corner of the lake was recommended.

Characterize and evaluate the non-quota by-catch including retained (i.e. pike) and discarded species, as well as endangered, threatened or protected species. Eco-certification requires an understanding of the impacts of a fishery not only on commercially valuable species, but also on the ecosystem itself. For example, it is necessary to have information on all non-quota species retained or discarded as by-catch. Moreover, any species (such as pike) that represents 5% or more of the total annual harvest must be brought into a management regime demonstrating that measures are in place to minimize impacts on that species.

Given the current effort of data collection, it is not possible to evaluate the impact of the fishery on non-quota species. The by-catch in the commercial fishery is not formally documented and there are no limits on by-catch of non-targeted species. As well, the by-catch from the index-netting program is bulked weighed only.

Recreational sport fishing survey for both walleye and sauger. In addition to by-catch mortality, information must be collected on the removal of fish by other sources, such as domestic consumption and recreational fishing, if shown to have an impact on the fishery.

Role of Fishers in Science and Management

The importance of the role of fishers in lake science and management is well established and has been previously discussed and documented in numerous reports, the most recent from the *2011 Lake Winnipeg Quota Review Task Force*. Indeed, three fishers comprised half of the Task Force, together with three scientists and a science Chair, and additional fisher input was sought via community visits and a fishers' knowledge survey.

Several discussions ensued during this Workshop on the need for fishers to become more involved in Lake Winnipeg science-management. Some of the salient points raised included fishers' involvement in the following areas, which are described in more detail in the report:

- Contributing to data collection;
- Contributing fishers' knowledge;
- Decision-making; and
- Being accountable by accepting some responsibility for the outcomes of collective management decisions.

Science Plan - Models

Models provide an important framework for the integration of research and monitoring data. They serve as useful management tools to help set targets, to predict or evaluate the lake's response to various management strategies, and to understand processes within the lake. The development of models also has a unifying function in that it can serve as a common goal among agencies with differing mandates, priorities, levels of funding, and commitment to the lake.

In terms of future model development, the presence of zebra mussels can profoundly impact nutrient cycling in the lake. As a result, the response of the lake becomes less predictable with models that are limited to the offshore region of the lake, such as the WASP model currently being used. To confound matters, nutrients, exotic species and climate change will likely impact the fishery. Further model development could help in understanding the implications of potentially conflicting management objectives or outcomes of a given stressor or environmental change. Recommendations for future modeling efforts included the following.

ELCOM-CAEDYM Model (or other combination) with Zebra Mussels

The ELCOM-CAEDYM model with zebra mussels will be an important addition for understanding in-lake processes. The input requirements for the zebra mussel component include density and biomass estimates and a substrate map, at least in the critical regions. Substrate becomes a dynamic parameter with zebra mussels and is discussed under Research below (Substrate Mapping).

In addition, continuation of external loading information including atmospheric loading is needed as well as information on internal loading (see Nutrients below). Forcing requirements include climate buoys for air temperature, humidity, wind speed and direction, and solar radiation. In-lake model validation requires temperature buoys, YSI moorings (at least two), and one or two current meters.

Food Web Modeling

Ecosystem models can provide a conceptual understanding of the structure and function of the ecosystem. A whole ecosystem model was identified as an essential component of the 2004 Lake Winnipeg Science Plan (EC/DFO/MB). However, due to the complexity of ecosystems and the cumbersome nature of whole ecosystem models, a more practical approach was discussed to include using the outputs of interest from one model, such as ELCOM-CAEDYM, as inputs to higher tropic level models, such as bioenergetics or fisheries models.

Bioenergetic-based food web modeling requires field data such as diet, abundance, growth, temperature (optimal, lethal) etc. and physiological information across trophic levels of interest. Such a model, or coupled models, would serve as a tool for many purposes, depending on the research or management questions being asked. See also “Energy Flow (Food Web Dynamics)” in Research below.

Science Plan - Research

Federal scientists lead most of the research that is being conducted on Lake Winnipeg, while the academic community, for various reasons, is largely absent from the on-lake research effort. This, in itself, could be considered an important gap that will require some level of leadership from within the academic community to address.

Fisheries Research in Support of Eco-certification

Fishery effects on fish behavior. A requisite for eco-certification is that information must be collected on the effects of the fishery on the lake's ecosystem. By-catch was previously discussed in Monitoring. Another area of concern is the impact of the fishery on fish behaviour, specifically spawning times.

Fish stock discrimination, movement and migration. An obstacle to achieving third party sustainable certification for Lake Winnipeg is that not all fishers are willing to participate, which hinders the ability of the other communities to move toward becoming eco-certified. A potential solution to this issue is to define units in the lake that can serve as separate areas for management purposes. This would be achieved through studies that aim to establish how far fish range and where exactly stocks go - between basins, spawning to feeding, etc. This would help determine how mixed the stocks are, and ultimately whether part of the lake could be certified in order to maintain (or gain) markets for at least the communities that are willing to work with Fisheries staff toward eco-certification.

Substrate Mapping

Substrate mapping was deemed a high priority and time sensitive project that will support numerous science-management initiatives on the lake, including:

- ELCOM-CAEDYM (or other combination) model development;
- Eco-certification (fish habitat); and
- Zebra mussel colonization potential.

Zebra Mussel Population Dynamics

Information on the population dynamics of zebra mussels, such as distribution and whole lake densities, will be necessary to understand the magnitude and extent of their infestation. This information will assist in establishing filtration capacities and potential impacts on the rest of the food web. Mussel data needed for ELCOM-CAEDYM model (or the new setup) described above includes density and biomass estimates as well as a substrate map, at least in the critical regions.

Characterizing the mussel population will not be a simple task given the size of the lake and the dynamic nature of infestations. Determining rough estimates of substrate availability was deemed a priority along with monitoring of mussel population densities.

Energy Flow (Food Web Dynamics)

"Energy flow" is a rather sprawling category that draws on multiple disciplines, multiple stressors, monitoring, models, and management, and nicely embodies the need to integrate science and management from the whole ecosystem perspective.

Ultimately, food web monitoring data, information on diet (quality and quantity) and spatial distribution of dietary resources across trophic levels are necessary to understand the flow and transformation of energy from nutrients to fish; offshore to nearshore; south basin to north basin; and how that flow can be redirected or disrupted in response to changing nutrient supply (including abatement), climate change, introduction of exotic species, commercial fishing, and as yet unrecognized emerging issues.

Given the time constraints of the workshop, the emphasis on monitoring, and the notable absence of the academic community, individual proposals for specific research questions were not developed. Instead, general types of research questions were discussed, such as the following. As well, specific areas of research, the status of that research, and its potential relevance to management efforts are summarized.

- How might changes in nutrient loading affect fisheries productivity?
- How will exotic species, such as zebra mussels or rainbow smelt, impact food web function and structure and ultimately fisheries productivity?
- What is the role of blue-green algae in the overall productivity of the lake - do they represent a trophic dead-end?
- Are the biological end-points of each trophic level a predictable function of nutrient concentrations?
- How important are heterotrophic bacteria and protozoa, relative to phytoplankton, in lake productivity, especially in the turbid south basin?

Nutrient Dynamics

To date, much of the on-lake research effort has focused on nutrients but some important research gaps remain.

Phosphorus retention and recycling (re-suspension and internal loading). Current retention estimates reveal a potentially enormous reservoir of phosphorus being stored in the lake. An accurate estimate of phosphorus retention is important since it could be recycled within the lake and potentially prolong remediation efforts if it were to become available for uptake by organisms. This will in part depend on the extent to which this phosphorus is remobilized by various means (internal loading, re-suspension, bio-turbation) into the water column, and on its bioavailability.

In shallow lakes like Lake Winnipeg, it is challenging to distinguish internal from external sources of phosphorus because the water is usually well mixed both vertically and horizontally. Direct measurements in Lake Winnipeg are required to confirm phosphorus release from sediments and to describe the processes that determine release rates. (At the time of writing, the only published estimates of internal loading were based on correlations only.)

Denitrification and nitrogen fixation. These are two important balance terms that are currently missing from the nitrogen budget. **Denitrification** is a microbial process involving the reduction of nitrate to form molecular nitrogen (N_2) or nitrous oxide, both of which are gases and could therefore represent an important but unaccounted for loss of nitrogen from the system. Because anaerobic bacteria carry out this process, anoxic conditions within the micro-zone of the sediment-water interface could enhance rates; stratification and water column oxygen depletion would not be requisite conditions for this process. No estimates of denitrification have been made for Lake Winnipeg. Although there has been enough *in situ* study of **N_2 fixation** to know that it is a significant term in the nitrogen budget of the lake, inter-annual variability and trends have not been quantified.

Silica. Silica is an important nutrient to track in both the nearshore and offshore for modeling and research purposes. On Lake Simcoe, there was a decline in silica but due to a data gap over the critical period when zebra mussels invaded, the cause of the decline is not known. A decline in silica may impact the diatom community and subsequent succession to cyanophytes. Diatoms are also a preferred source of food for some species of zooplankton, which in turn are consumed by fish fry. Any disruption to the timing, quantity or quality of these food sources in the spring could impact the young-of-the-year of some species of fish.

Outflow at Two-Mile Channel. Accurate outflow data is required to balance nutrient and sediment budgets, for estimating phosphorus retention in the sediment, and to determine nutrient targets. The total nutrients exported from Lake Winnipeg is not accurately known. Moreover, turbid water drawn from along the north shore creates a cross channel gradient of sediment and nutrient concentration that is impossible to characterize by a single water sample. This could be an issue depending on the use of the information; discussed further in the report.

Proposed New Framework for Integrating Science and Management

Coupled with the Science Plan is a proposed New Framework, which attempts to illustrate how multi-agency collaboration, united by clearly defined management goals and a whole ecosystem Science Plan (research, modeling and monitoring), can actively support lake management regimes from water quality to fish through a more coordinated integration of science and management efforts.

The New Framework has two purposes:

1. Reveal or re-establish the **roles and responsibilities** of the essential agencies integral to and responsible for the management of Lake Winnipeg; and
2. Define and/or identify clear **processes** in support of the long-term adaptive management of Lake Winnipeg based on whole ecosystem lake science, including Reporting.

The New Framework is not based on a rigid, hierarchical structure with top down governance. On the contrary, it is based on a flexible, cyclical structure that reveals the value of each component to the whole, and the consequences when even just one of those essential components is compromised or responsibilities relinquished. The New Framework also allows the integration of other knowledge systems, such as fishers' knowledge or citizen science. Perhaps most importantly, the cyclical structure is more conducive to adaptive management regimes led by the Province yet supported by multiple science agencies working on the lake.

The underlying assumptions of the New Framework, include:

- Government (provincial and federal) has a responsibility to **manage** the lake ecosystem, from water quality to the fishery, as part of the Public Trust;
- Management must include **evidence-based decision-making**;
- There is a need for **whole ecosystem science** (monitoring and research);
- **Academia** has a role, if not a responsibility, to engage in **research**; and
- **Reporting**, in its many forms, is an intrinsic component of the New Framework.

Reporting is an integral part of the Framework. In addition to the collection and management of data from multiple agencies over the long term, *Reporting* includes many deliverables that result from the collective on-lake science and monitoring effort carried out by multiple agencies, including a comprehensive State of the Lake report, plain language information (i.e. factsheets), peer-reviewed publications, annual reports, recommendations on harvest control measures, reporting adjustments to nutrient targets, among others.

The importance of timely, transparent and strategic communication to the general public, media and stakeholders cannot be over-stated and must include clear, accessible messaging on the "health" of the lake that is founded on science and management objectives. Although these more accessible information products would not stop the onslaught of misinformation touting "the lake is dying" or "the most threatened lake in the world", it would certainly help render the public and others less vulnerable to it.

Clear messaging based on whole ecosystem adaptive management outcomes also affords the opportunity to reveal to the general public and policy-makers the uncertainty and complexity that is inherent in the dynamic nature of ecosystems and stresses imposed on them: uncertainty and complexity that necessitates strong leadership and collaboration in working toward clearly articulated common goals and objectives that ultimately define a "healthy" Lake Winnipeg.

INTRODUCTION

What does a "healthy" Lake Winnipeg actually mean?

There is much talk about a "healthy" Lake Winnipeg. However, this term is very subjective and can mean something different depending on who is using it. Cottagers may consider it to be an algae-free beach, while fishers may think of an abundance of fat walleye. Scientists may view the above as conflicting since a reduction in nutrients may lead to both a reduction in algal blooms and a reduction in fish productivity. Indeed, much of the scientific community considers "healthy" to be a rather meaningless term and avoids its use altogether. Nevertheless, given the common usage of "healthy" by both government and the public, it is not likely to disappear from the vernacular any time soon, and **defining "healthy" would assist these diverse interests in working more effectively toward common goals**.

From the public's perspective:

> *What is the community consensus of a "healthy" Lake Winnipeg?*

From the science community's perspective:

> *What is the scientific consensus on how "healthy" can be translated into tangible management objectives?*
>
> *How can the progress toward better "health" be communicated back to the public, stakeholders, and decision-makers using measureable outcomes based on science?*

In Ontario, the terms "swimmable, drinkable, fishable" are in common usage as a way to communicate what a "healthy" lake means. One could add "sustainable" to this list. For beaches, the global Blue Flag Program has a symbolic blue flag as a means to simply, but effectively, communicate a "healthy" beach. There is, of course, considerable science underlying the symbolic blue flag that is available to those who wish to delve further into what contributes to a blue flag outcome. For those who don't, however, the underlying message of "health" is readily accessible, meaningful and consistent.

In Manitoba, perhaps the best example of effective messaging that is based on science in support of management is the Waterhen Lake fishery, which is now eco-certified under the Marine Stewardship Council Program. In place is a co-management system with clearly stated objectives, quantifiable targets, and a visual evaluation and reporting process based on the status (red, yellow and green) of performance indicators that collectively articulate the "health" of the fishery. This then guides a transparent decision-making process, which may or may not require the implementation of pre-established harvest control measures, with the ultimate goal of maintaining a sustainable or "healthy" fishery.

Are we on track toward a "healthy" Lake Winnipeg?

For Lake Winnipeg, nutrient abatement in the watershed has become the predominant focus of government-led programs like the Lake Winnipeg Basin Initiative, the Watershed Systems Research Program at the University of Manitoba, and the Lake Friendly Stewards Alliance. While eutrophication is a major water quality concern, it cannot be managed in isolation from the rest of the lake's food web or from additional stressors acting upon the system, such as climate change and exotic species, without significant consequences. For instance, evaluating lake indicators, such as the extent of algal blooms, in response to nutrient abatement actions being undertaken in the watershed will be challenging without a better understanding of the impact of zebra mussels on nutrient cycling within the lake, especially in the nearshore region. Similarly, understanding the response of the fishery, whether positive or negative, to changes in nutrient loading (and rainbow smelt, zebra mussels and other factors) will remain speculative without adequate food web data. Meeting the requirements of eco-certification will also remain elusive with the inevitable consequences of a vulnerable fishery and lost commercial markets and associated service industries.

The prevailing focus on nutrients and the watershed is also contributing to diminishing on-lake science capacity. Due to funding and personnel constraints, LWRC science member agencies have increasingly relied on the LWRC to collect samples on their behalf. This includes most food web investigations, including a number of exotic species, such as rainbow smelt, *Bythotrephes*, and zebra mussel veligers. Most other science still conducted on board the Motor Vessel (M.V.) *Namao* has been focused on water quality and algal blooms. A continued decline in the science capacity on the lake will make it difficult to justify the cost of maintaining the infrastructure that is provided by the LWRC in order to safely access and study the lake. Should this infrastructure be lost, the capacity to carry out whole lake science will also be lost, and likely not recoverable.

Ample guidance exists in numerous government and independent reports recommending holistic management approaches. One of these, the *2004 Federal-*

Provincial Science Workshop (Environment Canada; Fisheries and Oceans Canada; Province of Manitoba) developed science proposals and general recommendations to improve scientific support for the management of Lake Winnipeg. Acting on those proposals was expected to be the first step in the development of an ongoing *comprehensive* science program for Lake Winnipeg. In another example, the *2011 Lake Winnipeg Quota Review Task Force* evaluated the productivity and sustainability of the fishery and recommended moving toward a whole ecosystem adaptive management regime for the Lake Winnipeg fishery.

In essence, what began in 2004 with whole ecosystem science in support of management of the lake ecosystem has been reduced to a narrow focus on nutrient and algal bloom abatement. Indeed, the walleye fishery is now showing signs of decline attributed to the commercial harvest. This is a new stressor, in addition to eutrophication, climate change, and exotic species, among others. The important distinction, however, is that over-fishing is a stressor that can be largely avoided through effective fisheries management.

Moving toward a "healthy" Lake Winnipeg

As facilitator of the multi-agency and multi-disciplinary monitoring and research efforts on Lake Winnipeg, the Science Program of the Lake Winnipeg Research Consortium Inc. (LWRC) has a unique vantage point from which progress toward improved "health" and impediments to progress can be observed. It was from this perspective that the Special Science Workshop *Lake Winnipeg: State of the Science II - Toward the Integration of Lake Science and Management* (Appendix A - Agenda) was conceived in an effort to initiate a conversation with the on-lake scientific community on how to address these concerns and better support adaptive management of the Lake Winnipeg ecosystem.

To that end, the Workshop included the development of a whole ecosystem **Science Plan**, from nutrients to fish, with consideration for other stressors beyond eutrophication, especially zebra mussels. A whole ecosystem Science Plan alone will prove inadequate within the confines of nutrient abatement. Thus, coupled with the whole ecosystem Science Plan is a proposed **New Framework**, which attempts to illustrate how multi-agency collaboration, united by clearly defined management goals and a whole ecosystem Science Plan (research, modeling and monitoring), can actively support lake management regimes from water quality to fish through a more coordinated integration of science and management efforts.

This report describes the proposed New Framework and presents a draft whole ecosystem Science Plan developed by the on-lake science community for consideration by decision-makers in their efforts toward attaining and managing a “healthy” Lake Winnipeg, over the long term, as part of the Public Trust.

SCIENCE WORKSHOP OVERVIEW

Workshop Objective

The objective of the Workshop was:

> *To address the issues of diminishing science capacity and persisting/emerging science gaps and management needs on Lake Winnipeg through the development of a new framework for whole ecosystem science (research and monitoring) that is more effectively integrated with lake management goals and objectives.*

Pre-Workshop Preparation

New Framework

The proposed New Framework was developed prior to the workshop in an effort to unite the on-lake science effort in support of lake management regimes within a meaningful structure. It was presented to the science group during the Workshop for feedback and refinement, and is described in detail in Part A of this report.

Science Plan development

To maximize productivity during the short period of time together, a comprehensive summary table (Appendix B) was prepared and sent out to participants (Appendix C) prior to the Workshop. The content of the Table was structured and based on outcomes from the LWRC's 2011 *"State of the Science I. What is the scientific basis for understanding and protecting Lake Winnipeg?"* which provided a synthesis of existing knowledge and evaluated the progress made on the science priorities and research needs identified in the 2004 Federal-Provincial Science Workshop, described above. In addition, updates from the LWRC's annual workshops subsequent to the 2011 Workshop were included in the Table, as well as the most recent updates solicited prior to this Workshop. The summary table contained columns for the following:

- Where we are (previous findings and recent science updates);
- Where we need to go (remaining knowledge gaps); and
- Why (necessity and value of the above). The Why column was removed due to the prohibitive size of the Table and instead incorporated into the report's text where relevant.

This Table was intended to: provide continuity by building on previous efforts by Manitoba, Canada, and the LWRC; avoid repetition of discussions from previous workshops; update participants beyond their areas of interest/expertise; and provide structure to the Workshop discussions.

Workshop Structure

The Workshop was just under two full days (Appendix A - Agenda). Day 1, "Laying out the pieces", focused on the big picture perspective in terms of both management needs, from water quality to fish, and the status of research and monitoring from the whole ecosystem perspective (Appendix B). Day 2 aimed to "Put the pieces together" in the form of a whole ecosystem Science Plan that supports management needs.

Day 1 – Laying Out the Pieces

Introduction: Purpose and overview of the Workshop including the New Framework.

Session 1: Full-length "unifying overview" presentations from science, management and reporting perspectives.

Session 2: Recent science updates and knowledge gaps for the various components of the ecosystem, including sediment, nutrients, phytoplankton, zooplankton, benthos and fish.

Integrative Discussion: By the end of Day 1, having reviewed the state of the science and management from this big picture perspective, an integrative discussion was planned based on the following questions.

1) Do we need to integrate lake science and management more effectively in order to manage Lake Winnipeg?
2) Do we need to approach it from the whole ecosystem perspective?
3) If so, what are the main obstacles, besides funding, preventing this from happening?

Day 1 did not unfold as cleanly as outlined above; nevertheless, informative discussions took place. All told, there was affirmation for 1) and 2) above, and there followed much discussion on 3), the obstacles to integrated lake science and management and to whole ecosystem science on the lake. Day 2, therefore, proceeded as planned to move forward with the development of a whole ecosystem Science Plan.

Day 2 – Putting the Pieces Together

Session 3: Overview of the current infrastructure on Lake Winnipeg, notably the capabilities of the on-board support of the research vessels M.V. *Namao* and M.V. *Fylgja* (Appendix D) and nearshore and offshore station networks (Appendix E).

Science Plan development: Structured exercise, based on Day 1 discussions and outcomes, to identify actions on priority science needs (research and monitoring) in the form of a Science Plan that supports management responsibilities.

Session 4: Presentation and panel discussion led by Dr. Dave Barber (CEOS, University of Manitoba). The purpose of this Session was to explore the feasibility of forming a new water-related research centre for freshwater science, focusing around key elements of northern watersheds with potential for connecting it to marine science downstream in Hudson Bay (Appendix F). A committee of interested agencies was struck following this Session.

PART A

NEW FRAMEWORK FOR INTEGRATING LAKE SCIENCE AND MANAGEMENT

Figure 1 represents a conceptual diagram of the proposed New Framework for integrating science and management of the Lake Winnipeg ecosystem. The New Framework is intentionally very simple yet attempts to reflect the necessity for, and inherent complexity, associated with multiple agencies working collaboratively across multiple disciples in support of common goals and objectives.

The New Framework has two purposes:

1. Reveal or re-establish the **roles and responsibilities** of the essential agencies integral to and responsible for the management of Lake Winnipeg; and
2. Define and/or identify clear **processes** in support of the long-term adaptive management of Lake Winnipeg based on whole ecosystem lake science, including Reporting.

The New Framework is not based on a rigid, hierarchical structure with top down governance. On the contrary, it is based on a flexible, cyclical structure that reveals the value of each component to the whole, and the consequences when even just one of those essential components is compromised or responsibilities relinquished. The New Framework also allows the integration of other knowledge systems, such as fishers' knowledge or citizen science. Perhaps most importantly, the cyclical structure is more conducive to adaptive management regimes led by the Province yet supported by multiple science agencies working on the lake.

The underlying assumptions of the New Framework, agreed upon by the science group, include:

- Government (provincial and federal) has a responsibility to **manage** the lake ecosystem, from water quality to the fishery, as part of the Public Trust;
- Management must include **evidence-based decision-making**;
- There is a need for **whole ecosystem science** (monitoring and research);
- **Academia** has a role, if not a responsibility, to engage in **research**; and
- **Reporting**, in its many forms, is an intrinsic component of the New Framework.

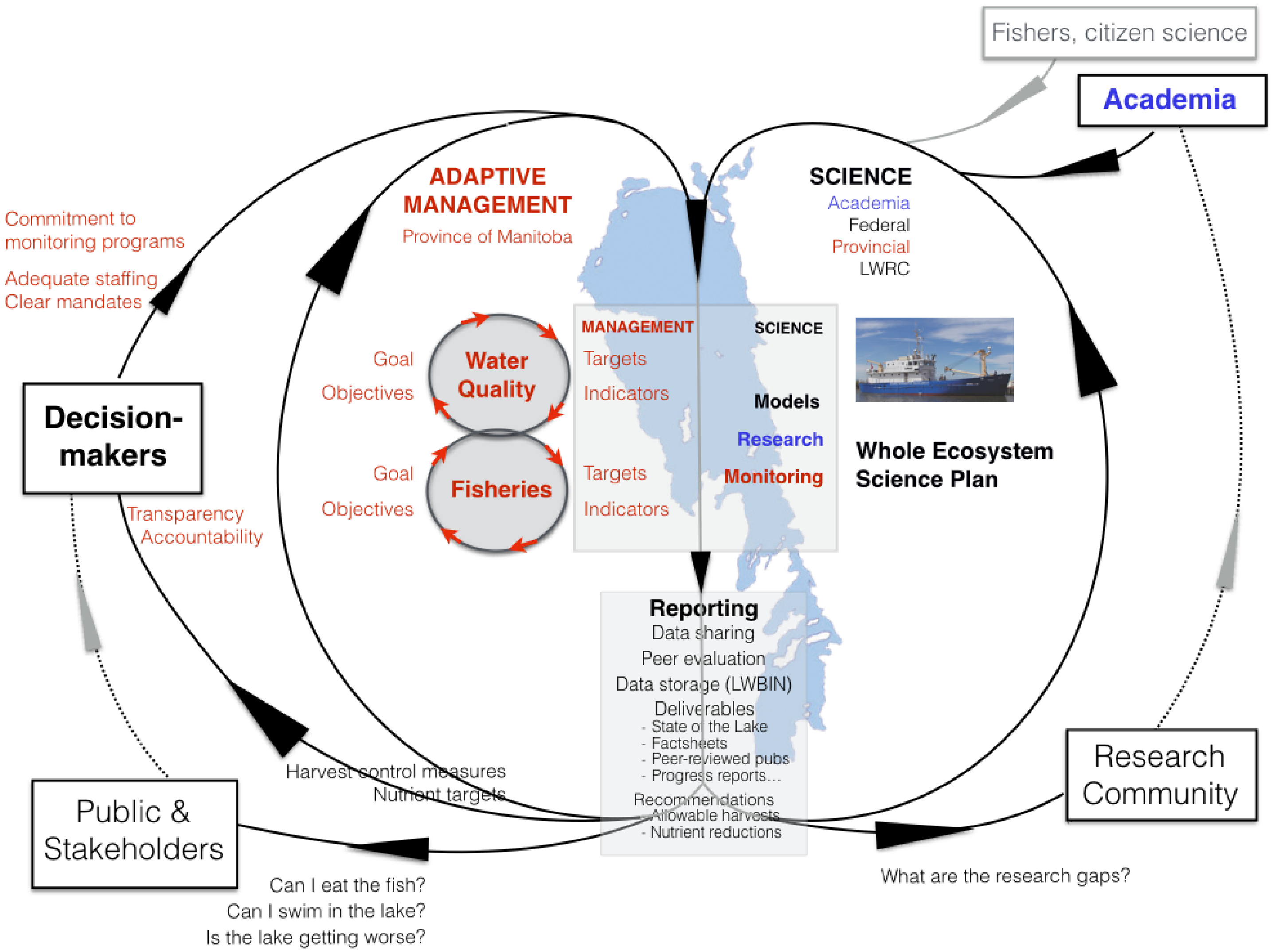


Figure 1. Conceptual diagram of the proposed New Framework that attempts to convey the integration of lake science and management of Lake Winnipeg, based on clearly defined management goals, objectives, targets and indicators within a whole ecosystem science plan.

Reporting includes many deliverables that result from the collective on-lake science and monitoring effort, including a comprehensive State of the Lake report, plain language information such as factsheets, peer-reviewed publications, annual reports, recommendations on harvest control measures, reporting adjustments to nutrient targets, among others.

In an effort to better define a more strategic and collaborative Reporting process that reflects and supports the on-lake science-management effort in its many facets, a collective agreement may be in order, which recognizes and acknowledges the importance of the following:

- Collaborative nature of data collection by multiple agencies beyond government;
- Necessity and value of peer evaluation;
- Importance of sharing data and/or other forms of information;
- Long term data storage and accessibility (Lake Winnipeg Basin Information Network);
- Diverse reporting obligations from plain language to peer-review that occur on different time scales; and
- Timely, transparent and strategic communication to the general public, media and stakeholders.

The importance of timely, transparent and strategic communication to the general public, media and stakeholders cannot be over-stated. As previously discussed in the Introduction, this must include clear, accessible messaging on the "health" of the lake that is founded on science and management objectives. In addition, regular plain language updates such as the State of the Lake Report are critical and would benefit from a more strategic and collective effort from the on-lake science group. Although these more accessible information products would not stop the onslaught of misinformation touting "the lake is dying" or "the most threatened lake in the world", it would certainly help render the public and others less vulnerable to it. Clear messaging based on whole ecosystem adaptive management outcomes also affords the opportunity to reveal to the general public and policy-makers the uncertainty and complexity that is inherent in the dynamic nature of ecosystems and stresses imposed on them.

In summary, the New Framework attempts to illustrate how monitoring, modeling and research within a multi-agency collaborative Science Plan can support adaptive management regimes from water quality to fish. Among the other key players, Academia and the federal government have a role in engaging in research to assist in understanding more complex processes in the lake, in support of management objectives. Also, the Lake Winnipeg Research Consortium requires strong governance to ensure its stability in terms of financial and succession planning to provide the on-lake infrastructure essential to whole ecosystem management over the long term.

Part B describes the outcomes of the discussion and exercise for the development of a multi-agency collaborative whole ecosystem Science Plan that is intended to directly support the management obligations of Manitoba.

PART B

WHOLE ECOSYSTEM SCIENCE PLAN DEVELOPMENT

The development of a new Science Plan was structured around the following considerations.

- The assumptions of the New Framework, if not the framework itself
- Whole ecosystem perspective
- Multiple stressors acting upon the ecosystem including
  - Commercial fishery harvest levels
  - Invasive species
  - Eutrophication
  - Climate change
  - Emerging issues (contaminants, micro-plastics etc)
- Management objectives from water quality to fisheries, notably
  - Reduction of algal blooms
  - Sustainable fishery

There is not yet a unique set of clearly defined management goals and objectives, with corresponding targets and indicators, toward which progress is aimed. Nevertheless, the two objectives selected above encompass the whole ecosystem, which served the purpose of the exercise. Nutrient targets that are both ecologically and economically relevant will be difficult to define and adaptively manage without more knowledge of the food web linkages between nutrient supply and fish productivity, and vice versa – the lake cannot be managed for a sustainable fishery without understanding the overall impact of nutrient supply on fish production. Given that additional stressors are acting on the lake ecosystem, the most recent (but certainly not last) being zebra mussels, it becomes clear that management is a complex realty that will require the engagement and coordination of multiple science agencies, and will necessitate ongoing refinement and revision over the long term.

Although the emphasis of the discussion was on monitoring, the overall guiding question for the exercise was:

> *What are the necessary monitoring parameters and relevant research questions that will enable managers to evaluate and respond through adaptive management to changes in the lake ecosystem?*

All told, clear science priorities were identified in support of management obligations. They are summarized and presented within four categories for ease of discussion – Monitoring, Modeling, Research, and Other – even though there is considerable overlap and synergy among these groupings. Routine monitoring tracks trends in given parameters but also supports the development and ongoing validation of models, and can provide valuable baseline information to research programs that aim to understand more complex in-lake processes, including changes in the food web. Similarly, model output can be used to guide monitoring and research efforts.

For each category, some additional commentary is provided in support of the recommendations made, but it is not intended to be a comprehensive synthesis. (For that, the aforementioned *State of the Lake I* report is recommended reading.) Interestingly, the discussions did not reveal anything new that has not been discussed and documented in previous workshop reports. However, here they are presented together for the first time within the unifying context of a Science Plan intended to directly support whole lake management efforts.

Science Plan - Monitoring

Appendix D briefly describes the on-lake infrastructure provided by the LWRC for both offshore (M.V. *Namao*) and nearshore (M.V. *Fylgja*) monitoring. Appendix G provides a summary of the current status and future needs of both the offshore and nearshore monitoring programs in terms of chemical, physical and biological parameters.

Monitoring recommendations included the following:

- Enhance nearshore sampling program to better reflect the offshore program;
- Greater commitment to food web monitoring, beyond phytoplankton, in the nearshore and offshore;
- Fisheries monitoring in support of eco-certification; and
- Enhanced role of fishers in monitoring.

1. Nearshore Monitoring

The nearshore is considered a critical and time-sensitive gap for monitoring for a number of reasons. The impacts of zebra mussels are often first revealed and most strongly felt in the nearshore areas of lakes. For Lake Winnipeg, however, very little background data exist for the nearshore region because most research and monitoring since 2002 has been in the offshore region of the lake, accessed using the M.V. *Namao*. The rate of change could be rapid in areas where zebra mussels are able to thrive, followed by longer-term shifts in energy flow impacting the offshore. Baseline data are necessary to understand these spatial and temporal changes and inform management decision making.

Given these imminent in-lake changes, there is also potential for a change in the relationship between nutrient loading from the watershed and the lake's response. For instance, total phosphorus in offshore waters may decline due to zebra mussels (effectively transferring water column phosphorus to the littoral benthic community) and not to reduced loadings from the watershed. This has important implications for management, such as setting nutrient targets, evaluating progress in efforts to reduce nutrients, and interpreting indicator trends. Further, because the public's perception of the lake is largely based on their nearshore experience, providing relevant and meaningful water quality trends is important from a communications perspective as well.

2. *Food Web Monitoring (nearshore and offshore)*

The response of the food web to ecosystem changes is complex and future monitoring will require a greater commitment to long-term, comprehensive monitoring across all trophic levels in both the nearshore and offshore. Understanding changes at the base of the food web due to zebra mussels is especially important in terms of early baseline data since that is usually reflected in higher trophic levels, including fish.

Based on a metadata analysis of over 700 lakes (Higgins and Vander Zanden. Ecol. Mono. 80(2), 2010. p.179), Higgins described some of the anticipated impacts of zebra mussels within the context of informing a monitoring program on Lake Winnipeg. In general, physical changes due to zebra mussels include reductions in suspended solids and turbidity, and increases in water clarity. As the south basin of Lake Winnipeg is typically light limited due to high turbidity, increased water clarity could result in increased primary productivity in the form of attached algae (as opposed to phytoplankton) in the nearshore. In some of the Great Lakes, these attached algal mats detach and foul beaches, clog fishing nets and water intakes. High bacterial counts, including pathogens, have also been associated with attached algae in the nearshore.

Almost all groups of **phytoplankton** decline after zebra mussels invade resulting in a reduction in areal photosynthesis; the effects on **zooplankton** biomass across all groups tend to be proportional. **Zoobenthos** in the offshore profundal region tend to decline or remain unchanged, whereas in the littoral area, populations tend to increase with two notable exceptions, unionids and sphaerids (freshwater mussels). Reductions in freshwater mussels can reach 90% within 10 years of invasion. The magnitude of impacts on **fish** will depend on the extent to which energy is diverted from offshore to littoral pathways (see Research below), and on the respective species' ability to adapt or capitalize on these changes.

Phytoplankton

In recent years, much of the emphasis on Lake Winnipeg monitoring and research has focused on eutrophication in the offshore region of the lake. It was recommended that comparable effort be directed to the nearshore.

Continuing the current work devoted to remote sensing for offshore bloom timing, intensity, and extent (Binding, ECCC Burlington) remains a valuable contribution to management objectives and remote sensing products are intended to serve as an indicator for reporting purposes. Defining targets for the extent of bloom formation would be a useful next step.

Algal biomass and taxonomy were identified as important components for both nearshore and offshore programs. Many of the cyanobacteria found in the lake have not yet been identified to species level. This includes *Aphanizomenon flos aquae,* which seems to occur as three or four variants that may or may not produce microcystin. Greater taxonomic resolution of some cyanobacteria to species level may reveal a shift in dominant species over time in response to changing conditions in the lake, which in turn could influence toxin production risk.

Soluble reactive phosphorus (SRP) would likely be one of the main drivers for the nearshore algal blooms, if light is not limiting. Thus, it was deemed useful to monitor the ratio of either SRP (or TDP) to total phosphorus, especially for modeling purposes if nearshore blooms start to occur.

<u>Zooplankton</u>

Nearshore. To date, data are limited to a two-year study carried out by Parker (EC Winnipeg) in the south basin. In addition, the LWRC has collected samples on behalf of Fisheries Branch at the 12 lake-wide nearshore stations for *Bythotrephes* and zebra mussel veligers only.

Offshore. Bythotrephes and zebra mussel veligers sampling is carried out at all offshore stations by the LWRC on behalf of Fisheries Branch. There is limited capacity for provincial government staff to process these samples and work up the data. The LWRC also collects offshore zooplankton samples on behalf of Hann (U. Manitoba) along a 29 station north-south transect. These samples have not been analyzed since 2006 due to lack of funds. This issue is further discussed in “Other” below. Prior to 2006, zooplankton biomass was determined and the taxonomic resolution was to species level (Salki, DFO retired).

Whether analyzed or not, the current zooplankton samples and data represent an important pre-zebra mussel invasion baseline for the offshore region that could serve many purposes in terms of food web research and modeling, including the ELCOM-CAEDYM model or other combination (described below) and bioenergetics/food web modeling.

In addition to a greater commitment to support the collection and analysis of zooplankton in both offshore and nearshore monitoring programs, night sampling for large predaceous zooplankton, such as *Mysis* and *Bythotrephes*, was recommended but not necessarily on a routine basis.

Zoobenthos

As with zooplankton, zoobenthos is a critical component of the food web that was deemed important to include in both offshore and nearshore monitoring programs.

Nearshore. At the time of writing, there was no nearshore zoobenthos being sampled.

Offshore. The provincial monitoring program currently includes collecting and processing benthos during the spring survey at the 14 long-term stations. In addition, the LWRC collects samples on behalf of Hann (UM) at all offshore stations. Benthos taxonomy is to Family level at best and only abundance is determined. This should be adequate for some food web modeling; however, the taxonomic resolution may not be of much value as an indicator. Given that samples are archived, biomass and taxonomy could be revisited at a later date. Ultimately it will depend on what questions the research and modeling communities aim to answer. Again, the existing samples represent an important pre-invasion baseline for the offshore regions of the lake.

Forage fish

Prey or forage fish populations have a key position in aquatic ecosystems representing an important link between lower trophic levels and predatory fish, such as walleye and sauger. The Lake Winnipeg pelagic trawling program (Lumb, Prov. MB) provides estimates on the species composition and biomass in the pelagic fish community, including exotic species such as rainbow smelt, in different regions of the lake. This establishes an important baseline with which future trends can be compared to evaluate ecosystem change due to zebra mussels and other stressors. In addition, data can provide an early indication of year class strength of walleye, which may help predict future walleye recruitment into the commercial fishery.

Funding for the existing offshore trawling program is not stable and in recent years, the LWRC has assumed responsibility for much of the field sampling. Despite this assistance, and the importance and value of these data to modeling, research and the commercial fishery, the program has still been reduced spatially.

Recommendations for the forage fish monitoring program included the following:

- Stable support for the pelagic trawling program;
- Introduce otter trawls to characterize the bottom fish community; and
- Nearshore surveys for anticipated changes associated with zebra mussels.

In addition, opportunity exists for collaboration with Manitoba Hydro's CAMP, which includes fish sampling using very small mesh gillnets (½", ¾" and 1") in the north basin near Grand Rapids and Dauphin River.

3. Fisheries Monitoring in Support of Eco-certification

A number of fisheries-related monitoring and research priorities that would specifically assist in meeting the requirements of eco-certification were identified. Eco-certification would allow fishers to sell into eco-certified markets, which are becoming increasingly important as large companies such as Walmart choose to sell only seafood meeting these requirements. It is important to note that eco-certification is not a replacement for, or pre-requisite to, sustainably managing a fishery - these recommendations remain relevant whether eco-certification proceeds or not.

The research studies in support of eco-certification are described in the Research section below. The monitoring-related priorities included:

- Developing an index-netting program for lake whitefish that is conducted by provincial staff or in collaboration with fishers;
- Expanding the index-netting program for walleye and sauger to include the NE portion of the lake;
- Characterizing and evaluating the non-quota by-catch, including retained (i.e. pike) and discarded species, as well as endangered, threatened or protected species; and
- Conducting a recreational sport fishing survey for both walleye and sauger to determine harvests.

<u>Lake whitefish stock status</u>

There are three commercial species in Lake Winnipeg: walleye, sauger and lake whitefish. The provincial index-netting program is built around understanding walleye and sauger populations only. There is no longer an index-netting program for lake whitefish, and the only data collected (length and weight from dressed fish) are derived from the commercial catch sampling, which is not fishery-independent data. Consequently, management of lake whitefish is lacking, which renders this species extremely vulnerable. Further, ensuring an optimum balance between water quality and fisheries productivity will not be possible without better fisheries data.

To overcome this important issue, greater capacity within Fisheries Branch will be required to either re-introduce an index-netting program run by staff or to work collaboratively with fishers to generate fishery-independent lake whitefish data. As an interim measure to glean some indication of stock status, a study that would involve ground truthing hydro-acoustics using gillnetting in key areas of the lake is also a viable option (Lumb and Klein, Prov. MB).

Expanding the index-netting program to include the NE portion of the lake

As mentioned, the provincial index-netting program is built around understanding walleye and sauger populations. The current program uses 59 net sets per year, largely on the west side of the lake. Given the size of the lake, expanding this program possibly up to 86 net sets to include the northeast corner of the lake was recommended.

Characterize and evaluate the non-quota by-catch including retained (i.e. pike) and discarded species, as well as endangered, threatened or protected species

Eco-certification requires an understanding of the impacts of a fishery not only on commercially valuable species, but also on the ecosystem itself. For example, it is necessary to have information on all non-quota species retained or discarded as by-catch. Moreover, any species (such as pike) that represents 5% or more of the total annual harvest must be brought into a management regime demonstrating that measures are in place to minimize impacts on that species.

Given the current effort of data collection, it is not possible to evaluate the impact of the fishery on non-quota species. The by-catch in the commercial fishery is not formally documented and there are no limits on by-catch of non-targeted species. As well, due to limited capacity within Fisheries Branch, the by-catch from the index-netting program is bulked weighed only.

This monitoring gap could be addressed with life history parameter data (age, growth curves and age of maturity) and demographic analysis of all by-catch species caught in the index-netting program. This would primarily include white sucker, northern pike, and yellow perch depending on the mesh size. Collection of life history parameters would require a few years of sampling. Demographics would provide an assessment to a certifying body of whether or not the fishery is impacting these species. In addition to advancing the eco-certification process, this information would inform modeling efforts. (See also Role of Fishers below.)

Recreational sport fishing survey for both walleye and sauger

In addition to by-catch mortality, information must be collected on the removal of fish by other sources, such as domestic consumption and recreational fishing, if shown to have an impact on the fishery. Again, additional capacity in Fisheries Branch staff would be required to fulfill this priority. (See also Role of Fishers below.)

4. Role of Fishers in Science and Management

The importance of the role of fishers in lake science and management is well established and has been previously discussed and documented in numerous reports including the aforementioned *2004 Federal-Provincial Science Workshop* report: the LWRC's *2011 State of the Science I* report; and the *2011 Lake Winnipeg Quota Review Task Force* report. Indeed, three fishers comprised half of the Task Force, together with three scientists and a science Chair, and additional fisher input was sought via community visits and a fishers' knowledge survey.

Several discussions ensued during this Workshop on the need for fishers to become more involved in Lake Winnipeg science-management. Some of the salient points raised included fishers' involvement in:

- Contributing to data collection;
- Contributing fishers' knowledge;
- Decision-making; and
- Being accountable by accepting some responsibility for the outcomes of collective management decisions.

For the first two points, data collection and fishers' knowledge, some of the suggested areas where this could be achieved with some effort included:

- Provincial index-netting program;
- Fishers' monitoring program or logbook program to assist in the development of a commercial index of abundance for quota and by-catch species;

- Establish commercial catch per unit effort data by reporting the number of nets, length of nets, mesh sizes of nets, and nights set for each delivery;
- Indigenous subsistence harvest and consumption surveys. The subsistence use of fish is not documented and is, therefore, a challenge to estimate. The few studies that exist are difficult to compare due to differences in data collected, such as fish harvested versus fish consumed;
- Fisher citizen science undertaken through a traditional study on communities for documenting fishery and environmental observations; and
- Include fishers, within the context of the annual LWRC Science Workshop, as contributors of knowledge and collaborators in the development of specific projects that would contribute to management decision-making.

Strong leadership as well as a willingness to work together are required to make greater fisher participation a realty on Lake Winnipeg, as was achieved for Waterhen Lake. As mentioned in the Introduction, this lake was eco-certified in 2014 under the Marine Stewardship Council Program making it the first fishery in the western hemisphere and the second inland freshwater fishery in the world to be MSC certified. This process required fishers and managers working together to develop a management plan and decision-making process. There is also a role for regulators and the science community in this process, again illustrating the value and need to work collaboratively across agencies and disciplines within a transparent framework.

Science Plan - Models

Models provide an important framework for the integration of research and monitoring data. They serve as useful management tools to help set targets, to predict or evaluate the lake's response to various management strategies, and to understand processes in the lake. The development of models also has a unifying function in that it can serve as a common goal among agencies with differing mandates, priorities, levels of funding and commitment to the lake.

Currently, there are several numerical models for Lake Winnipeg in various stages of development by Yerubandi and colleagues (ECCC Burlington). Notable among them are the following.

- **Estuary Lake Coastal Ocean Model (ELCOM)** or "physical model" is a 3-D hydrodynamic model used to simulate the thermal structure, large-scale circulation patterns, and water levels.
- **Water Analysis Simulation Program (WASP) model** or "eutrophication model" was developed for Lake Winnipeg to establish ecologically relevant nutrient targets.
- **Integrated lake-watershed model** links the WASP model to watershed models such as SPARROW or SWAT.

The use of models to test management scenarios is an important component of nutrient management. The aforementioned integrated lake-watershed model can be used to help determine the required nutrient reductions in the watershed to achieve in-lake nutrient targets. In turn, best management practice scenarios in the watershed can then be assessed and optimized to meet those targets. Currently missing, however, is an established adaptive management process to evaluate the information and change management tactics as necessary.

In terms of future model development, the presence of zebra mussels can profoundly impact nutrient cycling in the lake. As a result, the response of the lake becomes less predictable with models that are limited to the offshore region of the lake, such as the WASP model mentioned above. To confound matters, nutrients, exotic species and climate change will likely impact the fishery. Further model development could help in understanding the implications of potentially conflicting management objectives or outcomes of a given stressor or environmental change. The following was proposed for future modeling efforts.

- Model development to include the nearshore processes with zebra mussels (i.e. ELCOM-CAEDYM or other combination); and
- Bioenergetics and fisheries models to better understand how various changes in the ecosystem could affect fisheries productivity.

1. *ELCOM-CAEDYM Model (or other combination)*

The ELCOM-CAEDYM model with zebra mussels will be an important addition for understanding in-lake processes. As no modelers were present during the discussion, information on data requirements was acquired after the workshop (Leon and Yerubandi, ECCC). Water quality parameters needed to run the Lake Winnipeg ELCOM-CAEDYM model are listed in Appendix G. Some are currently being collected, while others will need to be added to the suite of parameters, especially for the nearshore region.

The input requirements for the zebra mussel component include density and biomass estimates and a substrate map, at least in the critical regions. Substrate becomes a dynamic parameter with zebra mussels and is discussed under Research below (Substrate Mapping). The addition of zooplankton (likely to species level) may also be considered.

In addition, continuation of external loading information including atmospheric loading is needed as well as information on internal loading (see Nutrients below). Forcing requirements include climate buoys for air temperature, humidity, wind speed and direction, and solar radiation. In-lake model validation requires temperature buoys, YSI moorings (at least two), and one or two current meters.

2. *Food Web Modeling*

Ecosystem models can provide a conceptual understanding of the structure and function of the ecosystem. A whole ecosystem model was identified as an essential component of the 2004 Lake Winnipeg Science Plan (EC/DFO/MB). However, due to the complexity of ecosystems and the cumbersome nature of whole ecosystem models, discussion turned to more practical approaches. One suggestion was to use the outputs of interest from one model, such as ELCOM-CAEDYM, as inputs to higher tropic level models, such as bioenergetics or fisheries models.

Although this approach may not account for top-down effects in the food web, it was deemed computationally less cumbersome than one massive model, which may take days to run a short scenario. Bioenergetics-based food web modeling requires field data such as diet, abundance, growth, temperature (optimal, lethal) etc. and physiological information across trophic levels of interest. Such a model, or coupled models, would serve as a tool for many purposes, depending on the research or management questions being asked. See also "Energy Flow (Food Web Dynamics)" in Research below.

Science Plan - Research

Federal scientists lead most of the research that is being conducted on Lake Winnipeg, while the academic community, for various reasons, is largely absent from Lake Winnipeg research. This, in itself, could be considered an important gap that will require some level of leadership from within the academic community to address and rectify.

The following knowledge gaps were identified as important in terms of supporting management objectives:

- Fisheries research in support of eco-certification;
- Substrate mapping;
- Zebra mussel distribution;
- Energy flow/food web (multiple and diverse projects); and
- Nutrient dynamics.

1. *Fisheries Research in Support of Eco-certification*

Fishery effects on fish behaviour

A requisite for eco-certification is that information must be collected on the effects of the fishery on the lake's ecosystem. By-catch was previously discussed in Monitoring. Another area of concern is the impact of the fishery on fish behaviour, specifically spawning times. There is currently some indication that the spawning date of walleye has advanced eight days, more than would be expected from the effect of climate change alone, and believed to be due to the way the fishery opens in the spring. The underlying concern is if the walleye spawn is pushed too far ahead in time, walleye fry would not have access to a supply of zooplankton in the water column. Thus, the fishery could be damaged as a matter of how the fishery is managed by causing disconnects in time between these two important biological events.

Fish stock discrimination, movement and migration

An obstacle to achieving third party sustainable certification for Lake Winnipeg is that not all fishers are willing to participate, which hinders the ability of the other communities to move toward becoming eco-certified. A potential solution to this issue is to define units in the lake that can serve as separate areas for management purposes. This would be achieved through studies that aim to establish how far fish range and where exactly stocks go - between basins, spawning to feeding, etc. This would help determine how mixed the stocks are, and ultimately whether part of the lake could be certified in order to maintain (or gain) markets for at least the communities that are willing to work with Fisheries staff toward eco-certification.

Fish movement studies, led by Watkinson (DFO Winnipeg), will use internal tags and acoustics for the three main commercial species plus channel catfish and sturgeon. There is excellent potential for partnerships between multiple agencies in support of this management requirement.

2. *Substrate Mapping*

Substrate mapping was deemed a high priority and time sensitive project that will support numerous science-management initiatives on Lake Winnipeg, including:

- ELCOM-CAEDYM model (or other combination) development;
- Eco-certification (fish habitat); and
- Zebra mussel colonization potential.

How exactly to map the substrates in Lake Winnipeg will prove challenging and costly due to its size and remote north basin.

South Basin

The SHIM study (Lake Winnipeg Foundation) produced a substrate map that goes approximately 3 m offshore in the south basin and has some littoral materials associated with it. It was suggested that this be used in the interim.

Using a single beam system and a suitable vessel, Watkinson (DFO Winnipeg) is developing proposals to acquire funds to map the south basin and narrows, but not the north basin. At most, the nearshore of the north basin could be mapped but it would introduce some safety issues that need to be considered. It was estimated that about 30 days would be needed to do a 1 km grid in the south basin, made up of a couple hundred km of transects, although in places with homogeneous substrates fewer transects would be needed. Another approach may be to start with a coarse grid and do the whole south basin, then focus more on littoral zone surveys. It would allow for better resolution where appropriate although it might still take the same amount of time since the density would be higher in the nearshore.

North Basin

Needless to say, it will take an enormous amount of time to do substrate mapping by sonar in the north basin, at any level of resolution. An alternate approach would be to map the shoreline itself using remote sensing and deduce the littoral substrate. For example, a sandy shoreline is likely related to a sandy littoral: similarly, for a rocky shoreline. This would of course serve as an interim measure in the event the resources to map the littoral of the whole north basin in a systematic way are not readily available.

3. Zebra Mussel Population Dynamics

Information on the population dynamics of zebra mussels, such as distribution and whole lake densities, will be necessary to understand the magnitude and extent of their infestation. This information will assist in establishing filtration capacities and potential impacts on the rest of the food web. Mussel data needed for ELCOM-CAEDYM model (or the new setup) described above includes density and biomass estimates as well as a substrate map, at least in the critical regions.

Characterizing the mussel population will not be a simple task given the size of the lake and the dynamic nature of infestations. Rough estimates of substrate availability (see above) was deemed a priority along with monitoring of mussel population densities.

Some thoughts put forward during the discussion included the following.

- For the south basin, it was suggested to at least include a coarse cut for the offshore densities. (Sonar could be used for mapping soft sediment densities and for distinguishing hard from soft bottom materials.)
- An approach for the more challenging north basin would be to do some littoral zone ground-truthing surveys from diverse shorelines and combine with remote sensing.
- Mapping the turbid waters in the south basin could be extremely difficult. Developing a method to measure CO_2 activity in the water column, either continuously or while cruising, was discussed. The premise behind this idea is that between zebra mussel respiration and decomposing fecal material, there would likely be a large amount of CO_2 output from the sediment. CO_2 transects may be a way to gauge activity where they are not visible. This method could be used to begin looking at CO_2 levels in appropriately suspected substrate based on the SHIM substrate mapping (described above) in the littoral zone of the

south basin. One drawback to this approach is that the signal of metabolic activity could disappear on a windy day. *In situ* instrumentation that includes CO_2, turbidity, chl-a etc. may be useful if an academic partner could be found to lead the work.

- There may be a concomitant decline in calcium concentrations that could be related to mussel population.

4. Energy Flow (Food Web Dynamics)

"Energy flow" is a rather sprawling category that draws on multiple disciplines, multiple stressors, monitoring, models, and management, and nicely embodies the need to integrate science and management from the whole ecosystem perspective.

Ultimately, food web monitoring data, information on diet (quality and quantity) and spatial distribution of dietary resources across trophic levels are necessary to understand the flow and transformation of energy from nutrients to fish; offshore to nearshore; south basin to north basin; and how that flow can be redirected or disrupted in response to changing nutrient supply (including nutrient abatement), climate change, introduction of exotic species, commercial fishing, and as yet unrecognized emerging issues.

Given the time constraints of the workshop, the emphasis on monitoring, and the notable absence of the academic community, individual proposals for specific research questions were not developed. Instead, general types of research questions were discussed, such as the following. As well, specific areas of research, the status of that research, and its potential relevance to management efforts are summarized below.

- How might changes in nutrient loading affect fisheries productivity?
- How will exotic species, such as zebra mussels or rainbow smelt, impact food web function and structure and ultimately fisheries productivity?
- What is the role of blue-green algae in the overall productivity of the lake - do they represent a trophic dead-end?
- Are the biological end-points of each trophic level a predictable function of nutrient concentrations?
- How important are heterotrophic bacteria and protozoa, relative to phytoplankton, in lake productivity, especially in the turbid south basin?

Stable isotopes and diet

Stable isotope analysis is an important tool that allows the examination of food web structure and dynamics at multiple levels, depending on the analytical approach taken, data available and models used. Isotope and diet studies would help trace the flow of energy from phytoplankton to fish, and to evaluate spatial and temporal changes in diet and productivity. Coupled with a bioenergetics model, the potential impacts of zebra mussels on specific fish species could be explored, as could the impact of the decline in rainbow smelt (the "smeltdown") on walleye in the north basin.

Muscle tissue samples or aging structures can be used for stable isotope analyses, although muscle is preferred. The Freshwater Fish Marketing Corporation does permit Fisheries Branch staff to sample fish provided it is not the muscle tissue. Otoliths can be sampled from lake whitefish since they are dressed, but only fin clips can be sampled from walleye and sauger since they arrive headless and dressed. Whole fish would have to be purchased to sample otoliths from the latter species, and muscle tissue from any other fish. There is good potential for collaboration between management, science/academia, industry, commercial and recreational fishers.

Spatial interactions (nearshore vs. offshore; north basin vs. south basin)

A potential consequence of high densities of zebra mussels in the nearshore of the lake is the diversion of energy from the offshore to the nearshore benthic area. Over time, this could result in less offshore productivity and potential behavioural changes in fish in search of food. In addition, if the narrows becomes heavily colonized by zebra mussels, there may be an even greater disconnect between the south and north basins, which could have implications for management decisions, such as setting nutrient targets.

Consequences of environmental change/stress on fish physiology and production

Physiology. A brief discussion took place on metabolic and physiological response of fish to multiple stressors such as climate change, micro-plastics pollution, changes in nutrient availability/quality, or habitat degradation. The work of Lemoine (U. Brandon) combines biochemical, molecular and whole animal biological techniques to investigate how organisms modify their metabolism in response to various ecological stressors.

Fish production. There is a limit to fish productivity and those limits are imposed by the ecosystem in which the fish live. What are the relationships between environmental variables, such as an earlier ice-out, *Diporeia* declines, the "smeltdown", or increased or decreased phosphorus loading on potential fish production? What is the productive capacity of the ecosystem? What are the drivers of this productivity? Again, there is tremendous potential for various collaborative research and monitoring projects.

Under ice diatom bloom and winter sampling

There is evidence suggesting that during years of low snow cover, light conditions appear to be adequate to allow the growth of diatoms under the ice. It is believed that this early and extensive diatom growth could deplete silica levels, a nutrient that is required for diatom growth. This, in turn, can result in shorter spring diatom blooms and an earlier succession to cyanobacteria and accompanying undesirable consequences. In addition, diatoms are considered an excellent source of food for some consumers and the timing of their bloom formation and termination may influence the subsequent energy transfer to lower level consumers, such as zooplankton and fish fry.

How to approach characterizing the under-ice environment will depend on the research questions being asked. For the diatom bloom, additional winter sampling was recommended to include the entire winter and spring under differing snow packs, in order to achieve enough fine scale resolution. Satellite images can also be used to determine whether ice is clear and to describe snow cover.

Winter sampling will also help to address issues associated with monitoring in a changing climate. For example, in many lakes, ice cover is breaking up earlier and forming later, leaving a longer open water season. Where changes in the biota are observed, we will need to understand to what extent they are due to sampling at a different time in seasonal biological cycles, to responses of the community to the earlier breakup or longer season, or to independent stresses.

Under ice algal blooms also have the potential to create areas of low oxygen. Thus far, however, low oxygen in the water column is a seemingly rare event in Lake Winnipeg at least during the open water season. In winter, no anoxic events have been measured based on four years of winter mooring data. What remains an unknown, however, are redox conditions at the sediment/water interface, and the implication on other processes like denitrification and internal phosphorus loading (discussed below).

Primary production

There is currently a ship-board algal incubator/analyzer system that records major algal taxa (cyanobacteria, diatoms, chlorophytes and cryptophytes) and measures algal productivity and respiration continuously in transit (Stainton, DFO Winnipeg). It can be used to demonstrate carbon limitation and measure Pmax with and without carbon limitation. This instrumentation is a tool to study algal productivity and to establish relationships with other variables in the lake (e.g. nutrients, water clarity) and with biomass mapping by satellite remote sensing. To maximize its potential, it will need to be integrated into a research and/or a monitoring program. Given the systematic coverage of the lake three times per year during the M.V. *Namao* surveys, it could be used as a reproducible, spatio-temporal record of primary productivity. There is interest in developing a similar system to measure nearshore productivity (described in "Zebra Mussels" above).

Papakyriakou (U. Manitoba) proposed work includes a flux tower on the M.V. *Namao* and another deployed by the Hecla lighthouse. The objectives of this work would be to further understand evaporation and CO_2 fluxes using eddy covariance, characterize surface surfactant film, and develop parameterization for transfer/exchange coefficients for use in bulk-type flux models. Overall, this research would assist in balancing budgets for water and carbon, understanding the lake's carbon source/sink status and determining its metabolic balance (net autotrophic vs heterotrophic).

Secondary production / Microbial loop

It was suggested, without elaboration, that dissolved organic carbon (DOC) be added to the suite of water chemistry as a measure of allochthonous carbon inputs to the lake. It is assumed (by the author) that this interest in DOC is related to it being a source of carbon for heterotrophs, such as bacteria and protozoa.

Increased nutrient loading that supports primary productivity also directly supports the creation of autochthonous (algae-derived) carbon, the most visible symptom of concern in eutrophic lakes. Under light-limited conditions, however, such as in the south basin of Lake Winnipeg, nutrients could support secondary production via the microbial loop thereby increasing lake productivity without the development of algal blooms. Understanding the relative importance of heterotrophs and the microbial loop in lake productivity and energy transfer is especially important if nutrient abatement measures are successful.

5. Nutrient Dynamics

To date, much of the on-lake research effort has focused on nutrients and some important research gaps remain. However, all have been discussed at previous meetings and included in various reports, including the *Federal – Provincial State of Lake Winnipeg report (1999 to 2007)* and the LWRC's *2011 State of the Science I* report. For this reason, a very brief synopsis follows.

Phosphorus retention and recycling (re-suspension and internal loading)

Retention estimates reveal a potentially enormous reservoir of phosphorus being stored in the lake. An accurate estimate of phosphorus retention is important since it could be recycled within the lake and potentially prolong remediation efforts if it were to become available for uptake by organisms. This will in part depend on the extent to which this phosphorus is remobilized by various means (internal loading, re-suspension, bio-turbation) into the water column, and on its bioavailability.

In shallow lakes like Lake Winnipeg, it is challenging to distinguish internal from external sources of phosphorus because the water is usually well mixed both vertically and horizontally. At the time of the Workshop, the only published estimates of internal loading had been recently released by Nurnberg and LaZerte (JGLR 42(1), 2015. p.18) who calculated the internal load in the north basin of Lake Winnipeg to be high, ranging from 70% to 130% of the total annual loading, or roughly equal to the total load. Concern was expressed over these estimates, especially since they are based on correlations and not direct measurements. Direct measurements in Lake Winnipeg are required to confirm phosphorus release from sediments and to describe the processes that determine release rates.

Denitrification and nitrogen fixation

Denitrification and nitrogen (N_2) fixation are two important balance terms that are currently missing from the nitrogen budget. *Denitrification* is a microbial process involving the reduction of nitrate to form molecular nitrogen (N_2) or nitrous oxide, both of which are gases and could therefore represent an important but unaccounted for loss of nitrogen from the system. Because anaerobic bacteria carry out this process, anoxic conditions within the micro-zone of the sediment-water interface could enhance rates; stratification and water column oxygen depletion would not be requisite conditions for this process. No estimates of denitrification have been made for Lake Winnipeg.

Although there has been enough *in situ* study of N_2 *fixation* to know that it is a significant term in the nitrogen budget of the lake, inter-annual variability and trends have not been quantified. To address this need, a number of methods were discussed including acetylene reduction assay, ^{15}N stable isotopes, heterocyst model (ballpark estimates), and membrane inlet mass spectrometry. All methods are considered fairly straight forward; however, the acetylene reduction assay will require establishing its ratio with ^{15}N stable isotopes, which has not yet been done on Lake Winnipeg.

The expertise and/or analytical equipment to address these nutrient balance terms include Ramlal (DFO Winnipeg), Higgins (IISD-ELA) and Baulch (U. Saskatoon).

Silica

Silica is an important nutrient to track in both the nearshore and offshore for modeling and research purposes. On Lake Simcoe, there was a decline in silica but due to a data gap over the critical period when zebra mussels invaded, the cause of the decline is not known. As mentioned above, a decline in silica may impact the diatom community and subsequent succession to cyanophytes. Diatoms are also a preferred source of food for some species of zooplankton, which in turn are consumed by fish fry. Any disruption to the timing, quantity or quality of these food sources in the spring could impact the young-of-the-year of some species of fish.

Outflow at Two-Mile Channel

Accurate outflow data is required to balance nutrient and sediment budgets, for estimating phosphorus retention in the sediment, and to determine nutrient targets. Jenpeg is over 80 km downstream of Warren's Landing, the original/true outlet of the lake. Between these two sites, numerous factors can impact the chemistry of the water, such as the flooding of forest and peatland. Considerable sediment is also generated from erosion of the north shore of Lake Winnipeg, which flows through 2-Mile Channel to Playgreen Lake without significant interaction with offshore waters in Lake Winnipeg. Beyond that, 8-mile Channel was constructed in permafrost and has also experienced very severe erosion. Both sources add to the sediment-associated fraction of nutrients measured at Jenpeg.

Consequently, the total nutrients exported from Lake Winnipeg is not accurately known. Moreover, turbid water drawn from along the north shore creates a cross channel gradient of sediment and nutrient concentration, which are impossible to characterize by a single water sample.

A rather lengthy conversation ensued regarding the need for, and challenge associated with, sampling the outlet of the lake given this plume of sediment. In sum, this could be an issue depending on the use of the information. For a simple mass balance model, one could use concentrations from stations in the northeast part of the north basin to calculate the flux out of the lake. Better estimates, however, may be required for sediment budgets or the ELCOM-CAEDYM model, especially if the channel is resolved in the model. Also, if interest lies downstream, and not in the lake itself, better outflow data would be required. A dedicated field study could involve sampling transects across the channel and determining velocity distribution. As an interim measure, taking two samples, one in the turbid plume and the other in the clear flow, would at least provide a high and low range until a field study can resolve the issue more accurately.

Science Plan - Other

1. Emerging Issues

Brief mention was made of emerging issues that may not be of immediate concern but for which background data would be of value to collect. These include micro-plastics (which have already been detected in the lake), wastewater contaminants and other emerging contaminants.

National Fish Contaminants Monitoring and Surveillance Program (McGoldrick, ECCC Burlington) continues to be interested in obtaining fish opportunistically from Lake Winnipeg. Rennie (Lakehead U.) will continue work on micro-plastics.

2. Sample Backlog

This discussion focused on the zooplankton and benthos sample backlog but could also include calculating settled net volumes. The samples for these parameters continue to be collected but not analyzed. Zooplankton samples from 2007 onwards have not been analyzed - similarly, for benthos from 2013 onwards. Settled net volumes require additional lab work, which has not been carried out since 2006.

It was suggested that samples be composited prior to analysis to address this backlog, especially given the number of samples that are collected annually. Aggregating samples in appropriate proportions would provide a means to capture rough changes over time. However, this would not be recommended as a final solution to the backlog, as it would limit the value and use of the data. It would, nevertheless, provide sufficient information to address the bigger picture questions.

3. eDNA Technology

A brief mention was made about using (or contributing to the development of) eDNA technology to estimate fish species densities, and presence or absence of endangered, protected or threatened species. eDNA technology would also be applicable to other aquatic biota, such as zooplankton or benthos.

Biodiversity Genomics at the Biodiversity Institute of Ontario (U. Guelph) is a leader in this field. Docker and Gingera (U. Manitoba) have used eDNA technology for zebra mussels in Lake Winnipeg and a publication is in preparation.

4. *Existing Datasets*

There are existing datasets in various institutions, government to academic, which could support current efforts if they were identified, worked up and made available. Fisheries Branch in particular has some datasets that could be used to advantage, and indeed they are to a certain extent, but only as an add-on to the current workload of staff. This was considered an excellent place for linking with academia, notably graduate students who may be looking for a project or additional data in support of their work.

5. *Field Program*

Some suggestions were made regarding the field program. They included introducing more night sampling and possibly more frequent sampling of a subset of stations to better understand detailed seasonal effects. These suggestions are certainly possible provided an integrated and collaborative project is developed to justify the costs associated with running the research vessel(s).

Additional considerations include the challenge associated with working in the nearshore region as it is often a high-energy environment. The main criterion for the current network of 12 stations was widespread geographical coverage. However, the littoral stations should also be representative of the range of substrate types. Thus, there may be a need to revisit and possibly modify this network.

APPENDIX A

AGENDA
Lake Winnipeg Research Consortium Inc.
Science Workshop

Canad Inns Fort Garry, Ambassador A
1824 Pembina Highway, Winnipeg
December 1st & 2nd, 2015
Teleconference Call-In: 204-261-7450 (then press 0 & ask for ext 6300)

Lake Winnipeg – State of the Science
Toward the Integration of Lake Science and Management

Science Workshop Objective: *To address the issues of diminishing science capacity and persisting/emerging science gaps and management needs on Lake Winnipeg through the development of a new framework for whole ecosystem science (research & monitoring) that is more effectively integrated with lake management goals and objectives.*

DAY 1

Integrating Lake Winnipeg Science and Management - Laying Out the Pieces

8:30 AM	Workshop purpose, structure & anticipated outcomes	**K. Scott**

Session 1 – Unifying Overviews

8:45 AM	Ecological impacts of zebra mussels	**S. Higgins**
9:15 AM	Modeling update & future needs	**R. Yerubandi**
9:45 AM	Ecologically relevant nutrient objectives	**E. Page**
10:15 AM	**Break**	
10:30 AM	Eco-certification update & future needs	**B. Galbraith/G. Klein**
11:00 AM	Quota Review Task Force recommendations	**B. Ayles**
11:30 AM	Lake indicators update & future needs	**D. Lindemann**
Noon	**Lunch (buffet lunch on site at Aalto's)**	

Session 2 – Science and Management Status Updates and Discussions

To include: status updates; review of knowledge gaps; management needs; clarifying linkages; and identifying impediments or obstacles to progress.*

1:00 PM **Sediment, Nutrients & Producers** **Panel**

- Nutrient budgets – fluvial influxes; climate; nitrogen fixation & denitrification; outflows; north shore erosion; phosphorus retention and recycling: in-lake nutrients; water balance
- Carbon – metabolism (R:P); sequestration (algal carbon)
- Phytoplankton – biomass; composition; diatom to cyanobacteria succession (silica, ice transparency); taxonomy; cyanobacterial toxins; dissolved oxygen

Benthos & Zooplankton (native & exotics) **Invert. Panel**

- Benthos community characteristics – changes, causes & consequences

- Zooplankton community characteristics
- Zebra mussels & *Bythotrephes* – possible changes & consequences to lower food web

2:45 PM **Break**

3:00 PM **Fish** **Fish Panel**

- Commercial – stock status; mortality; thermal-optical habitat; population structure
- Forage community – offshore
- Fish diets – sauger, walleye, smelt, cisco; micro-plastics
- Local knowledge
- Spatial considerations – migrations; habitat classification; nearshore; tributaries & reefs; wetlands; critical habitat for SAR

4:15 PM **Integrative Discussion** on achieving *ecologically* relevant nutrient objectives and a sustainable fishery (in an increasingly complex ecosystem).

4:45 PM **Wrap up**

DAY 2

Integrating Lake Winnipeg Science & Management - Putting the Pieces Together

Session 3 – Science Plan Development within a New Framework

Structured discussion, based on Day 1 outcomes, to identify actions on priority science needs (research, monitoring & reporting) that support management goals and objectives.

8:30 AM **LWRC Lake Science Infrastructure** **K. Scott**

Science Plan within a New Framework **SciMan Group**

- *Whole Ecosystem Monitoring Plan* – requirements
- *Special Projects* – nearshore bathymetry; 2-Mile Channel transects etc.
- *Research Questions* – to include Strategic Partnership NSERC development
- *Reporting* – streamline processes from data sharing and peer evaluation to reporting (State of the Lake, lake indicators, etc.)

12:30 PM **Lunch (buffet lunch on site at Aalto's)**

Session 4 – Proposed Northern Watershed Research Centre

Panel discussion to explore the feasibility of forming a new 'Northern Watersheds Research Centre across the breadth of freshwater science in Manitoba, focusing it around key elements of the northern watersheds of Manitoba and the potential for connecting it to marine science downstream in Hudson Bay.

1:30 PM Northern Watershed Research Centre **D. Barber**

1:50 PM Panel comments (5 minutes each) & group discussion **Panel**

3:30 PM **Break**

3:45 PM Workshop - unfinished conversations & next steps

4:45 PM **Wrap up**

APPENDIX B

Summary Table – "Where we are" and "Where we need to go"

DAY 1 - SESSIONS 1 & 2

This summary table is intended to provide a starting point & structure for the conversations that will take place on Day 1 during Sessions 1 & 2. In addition to providing science updates on previous findings (WHERE WE ARE – column 2), and identifying where the knowledge gaps remain (WHERE WE NEED TO GO – column 3), the discussions will identify the nature of the science needed (Research, Monitoring or Other – column 4) in preparation for Day 2 Science Plan development. Perhaps most importantly, Day 1 will help establish whether there is a true need to integrate adaptive management and whole ecosystem science (WHY? – column 5). To that end, there are three questions at the end of this table that we will consider at the end of Day 1, having just discussed the status of both science and management on Lake Winnipeg from the big picture perspective. NOTE: Columns 4 & 5 were removed due to space limitations.

For continuity and to build on previous efforts by Manitoba, Canada and the LWRC, this table is largely based on outcomes from the 2011 LWRC Science Workshop, which aimed to synthesize existing knowledge and evaluate the progress made on the science priorities and research needs identified in the 2004 Federal-Provincial Science Workshop. The 2004 Science Workshop resulted in the development of priority science proposals and general recommendations to improve scientific support for the management of Lake Winnipeg. That said, this table also contains information that has not yet been discussed and is, therefore, not intended to be a source of information for reference purposes.

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
Session 1: Unifying Overviews -- from science, management & reporting perspectives		
Zebra mussels (Higgins)	Zebra mussels & the Great Lakes experience - what we can expect & prepare for in LW.	
Modelling Update (Yerubandi)	**Physical Model** - 3-D hydrodynamic model (ELCOM) used to simulate the thermal structure, large-scale circulation patterns, & water levels in 2007. - Performance satisfactory as verified against field data (Zhao *et al.*, 2011). - Used to study impact of 1997 RR flood on the circulation & dispersion of contaminants in LW (Rao & Zhao, 2010). Accuracy of simulations suggested the model is capable of describing flow & transport of material required for detailed water quality simulations during the flood. **Eutrophication Model** - Developed for LW by applying the WASP to simulate the N & P cycles & the dynamics of three phytoplankton groups, using nutrient loadings to the SB & NB (Zhang & Rao, 2011).	**Physical Model** – Sub-surface currents were not predicted well, possibly due to the complex morphometry & bottom topography of the lake, which may not have been adequately resolved by the coarse horizontal resolution of the model, or by the coarse resolution of available bathymetric data itself. **Eutro Model** - Silica balance & seasonal variability of zooplankton not included - Uniform sediment re-suspension velocities used throughout the simulation period due to a lack of information relating to their inter/intra-annual variability. - The N & P sediment flux rate was also set to zero for the dissolved nutrient fraction released from sediment. - Both approximations above need to be validated by field research. Running the model for longer than a six-year scenario is recommended (a longer period

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
		may be required to reach a new P equilibrium) **Ecosystem Model** – data requirements QRTF - 5f. Ecological model for LW
Ecologically relevant nutrient objectives (Page)		
Eco-certification (Galbraith & Klein) Quota Review Task Force (Ayles)	http://www.seachoice.org/wp-content/uploads/2015/11/MBA_SeafoodWatch_Manitoba_freshwater_lakes_Report.pdf https://www.gov.mb.ca/waterstewardship/fisheries/commercial/pdf/lwtf2011.pdf	- Requirements on eco-certification to be provided at workshop - TF recommendations to be provided at workshop.
Lake indicators (Lindemann)	2010 – list of 35 indicators developed (by TriStar) 2011 – Canada & MB refined list to 18 indicators 2012 – EC prepared an internal draft report describing the development of individual draft indicator profiles and assessment criteria for indicator prioritization 2013 – "*Lake Winnipeg Eutrophication Indicators Workshop*" to assess proposed indicators through a peer-review process	- Nearshore indicators - Relevant to public & science?
Session 2: Science & Management Status Updates & Discussions - Sediment, Nutrients and Producers		
Fluvial influxes	- Increased P concentrations & onset of large cyanobacterial blooms in LW starting in the mid-1990s was driven almost entirely by increased P loading from the RR. - The hydrology in the RR Basin (annual runoff & frequency & extent of flooding) is a major determinant of the magnitude of P loading - Other tributaries contribute comparatively little (Winnipeg & Dauphin rivers) or have a negative (Saskatchewan River) effect on this loading. - Most of LW's enormous watershed is currently not an important contributor of nutrients to the lake, & P abatement efforts should be aimed largely at the RR Basin.	- East side stream monitoring?
Precipitation & Run-Off		

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
Climate		
Wetfall/dryfall	No work has been done to improve estimates of wetfall & dryfall specific to LW. The current value being used was derived from the ELA in NW Ontario. There are also two values from Alberta, one higher & one lower than the ELA, & one from an imprecise study done in RMNP.	Determining wetfall & dryfall estimates is a complex task & the current estimates are accurate enough to model the concentration in the lake, which is among the more important things to accomplish.
Nitrogen Fixation	- N_2 fixation rates have been estimated for LW between 1999 & 2001 using the acetylene reduction method (Hendzel unpub). - Roughly 9,300 t/yr of N was introduced into LW via this process. - Kling (unpubl) compared heterocyst numbers to the amount of N_2 fixation & found a strong correlation between the two. The ultimate goal of this work was to develop a model for LW that would predict how much N_2 is fixed using heterocyst counts in water samples, rather than direct measurements of N_2 fixation.	- N_2 fixation rates require refinement - There was some concern with the acetylene reduction method used to generate the LW data. The ratio of acetylene reduction to N_2 fixation as measured by N^{15} or some other N tracer approach, varies between 2-3 up to a factor of 8. To validate the LW data set, it would be useful to do some N^{15} analyses in conjunction with acetylene reduction to look at how widely this ratio might range in LW. - Heterocyst model?
Denitrification	No work has been done	- No measures of denitrification have ever been made - Sediment-water interface
Outflow	- Yearly outflow P concentration data from the lake surface are consistently lower in the spring & summer than P measured in the river at Jenpeg 80 km downstream. In the fall, this difference is not as apparent. - Provincial long-term data set uses a sampling site at Jenpeg - 2012 - Warren Landing sampling (chem) began. 2014 - 2-Mile sampling (chem) began (Hydro) - **McCullough 2015 update on north shore erosion study**: annual sediment load by bank erosion along north shore is similar in magnitude to the load carried in by the RR, the other major source of sediments to LW. The erosion is a large source of P; however, the net effect is probably to remove P from the water column by adsorption and sedimentation. A large but unquantified fraction of the eroded sediments is carried through the outlet channels, effectively bypassing the lake. Status ongoing - **Welch & Stadnyk 2015 update on stable water isotopes NB & outlets**: suggests a seasonal change in the portion of the lake contributing the majority of the outflow.	- All season record of P concentrations in the outflow - Transects required across 2-Mile due to sediment plume & consequent difference in nutrient concentrations - **McCullough – future plans include**: remote sensing (Landsat TM) & environmental data (wind, lake level and discharge records) will be used to describe forcing & southward extent of the sediment plume, & sediment to quantify sediment transport through the outlet channels. Sediment collected in 2014 along transects north shore to centre of NB to be analyzed for particle size and tracer gradients. - Due to possible bifurcation of flow velocities between turbid and clearer water it may be necessary to measure currents in the channel directly - dedicated field study required.

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	Mixing within the lake is also suggested by the variation in evolution of the isotopic signatures at different sites throughout the year. (More info to be presented at workshop)	
Phosphorus Retention	- P retention estimates in the sediment of the lake range from 60 to 70%, largely unchanged since the 1970s. - However, due to the increased nutrient load, the *net* sedimentation (loading – outflow flux) is estimated to have nearly doubled from roughly 3,200 to 5,500 Mg P/a.	- Outflow data required (see above) - These estimates would benefit from field data that include annual sampling at the true outlet of the lake, winter included & sedimentation rates under different flow regimes.
Internal Recycling (re-suspension & internal loading)	- **Anecdotal observation** from remote sensing that when a severe storm event occurs in the NB, it produces an area of turbidity followed by a cyanobacterial bloom with the same pattern of distribution. - **EC sedimentation/re-suspension** examined at a couple of sites under different mixing conditions using automated sediment traps. The results showed very high variability & additional studies are needed. - **EC Watson**: found distinct differences in sediment particle size between basins that may have implications for re-suspension events; & little relationship between grain size & TP (no update provided in 2015) - **Molot *et al.*:** study examining anoxic P release & role of Fe (sediment cores) completed - **Nurnberg study (2015) internal loading**	- Remote sensing & correlation analyses to establish relationships between suspended sediments & algal blooms. - The internal loading vs higher algae explanation of higher autumn TP may be resolved by looking at seasonal trypton (non-organic particles) in the DFO database. - Data requirements to understand/model nearshore re-suspension associated with zebra mussel pseudo-feces ?
Bioavailable Phosphorus	**Watson (EC)** - Preliminary studies of bioP in surface sediments indicate that: - The proportion of the TP pool that is bioavailable is greater in the SB than in the NB; - Smaller particle size was associated with higher bioavailability of P (no update provided)	- Would SRP be an easier parameter to monitor on a routine basis? - Nearshore SRP - Additional studies are needed to determine what factors control the bioavailability of P in the water column
In-Lake Nutrients	- **Watchorn (MB)** to provide update on N, P & chlorophyll concentrations in NB & SB - **Watchorn (MB)** to update group on interlab interagency in-lake P comparison	**Provincial monitoring** is ongoing & will continue to include: - general chemistry; physicals; & nutrients (all stations); metals; phytoplankton; benthos; & sediment chemistry at (W stations); bacteria (opportunistic sampling)
Water balance	Evaporation term of water budget has only been estimated. In one study, evaporation off the lake was based on evaporation as a residual term in the water balance (McCullough *et al.*, 2012). In another, the evaporation data was scaled from	- Evaporation term not yet determined - Groundwater input not known - To improve upon the current water balance for LW, direct measurements of

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	the estimation of monthly evaporation off Dauphin Lake (Zhang & Rao 2011).	evaporation should be estimated independently (see Papakyriakou below)
Carbon	**Bunting *et al.*, (2011)** - study of the sedimentary record from three cores in the SB of LW showed that C content (~1.5%) was very stable from about 1800 to 1900, then increased, first gradually (by 50%), then rapidly to 2006. Concentrations of most algal pigments increased 300 to 500%, & the C:N mass ratios (~10:1) were characteristic of algal-derived material. This suggests that considerable autochthonous C is being buried. **Wassenaar (2011)** - spatial & temporal patterns of dissolved oxygen & its $^{18}\partial O$ from 2006 to 2010 showed that, despite the high nutrient loadings & large algal bloom formation, LW was under-saturated in dissolved oxygen & largely heterotrophic with a R:P > 1.1. One partial explanation was that lake heterotrophy is largely driven by allochthonous C subsidy from the watershed. In further support of this, the mean $^{13}\partial C$ value of –27.2 +/- 2.1 for LW is highly indicative of allochthonous terrestrial C inputs. **Stainton (DFO) 2015 update** – in sum: - Ship-board incubator accurately reflects *in situ* Pmax & R - Incubator can be used to demonstrate C limitation & measure Pmax with & without C limitation. - Pelagic areas of LW considerably more productive than Lake Erie. - There is a usable correlation between surface chlorophyll levels & Pmax but relationship different between N & S basin. There is apparent remote sensing potential. - More details will be provided at workshop	- Interpretation of existing diurnal CO_2 data for productivity estimates - Effect of reservoir management unknown on sequestration of algal C - Characterize protozoan community **Stainton** – future plans include: - Instrumentation is operational but still under development - Needs integration with mixing model to estimate water column P & R & whole lake P & R - Interest in developing similar system to measure nearshore benthic productivity **Papakyriakou (UM)** proposed work includes a flux tower on the *Namao* & deployed by the Hecla lighthouse. Objectives will be: - Shore up understanding of evaporation & C dioxide fluxes using eddy covariance; - Sample/characterize surface surfactant film; - Develop parameterization for transfer/exchange coefficients for use in bulk-type flux models that accounts for the lake's particularly pronounced summertime surface surfactant film. - An ancillary monitoring program for lake micrometeorology, pCO2 & other C system parameters would be put in place. – Would improve our ability to balance budgets for water & C, understand its C source/sink status & contribute to the understanding of its metabolic balance (net autotrophic vs heterotrophic).
Phytoplankton	**Two remote sensing projects underway:** - Real-time data for bloom timing, intensity & extent (Binding, EC) - Operational internet service for distribution of near-time maps of Chl & surface phytoplankton blooms (McCullough & NOETIX) **Kling (previous findings):** - Algal community has experienced an increase in biomass & a shift from diverse, meso-eutrophic species to primarily eutrophic species.	- Additional winter sampling – the entire winter & spring, under differing snow packs, in order to achieve enough fine scale resolution. - Silica – to help understand the role of silica & temperature on diatom growth & cyanobacterial succession. - **MWS** conducts winter sampling (algae & a full suite of chemistry) 1x/year at 14 stations usually as close to ice-out as possible to capture the low oxygen events - Should sampling be adjusted to reflect an

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	- Seasonal shifts in the community composition are also apparent. Spring diatoms have become dominated by eutrophic taxa, & the summer algal community has become less diverse with a predominance of nitrogen-fixing cyanobacteria- - Important differences observed between low & high snow depth over ice **Kling 2015 update** – at workshop	earlier ice out?
Cyanobacterial toxins	- Microcystins deemed a low risk to human health. - Provincial monitoring of blooms continues at beaches (SB) & offshore - Watson (EC) - genetics study (no update provided)	- Range of toxins unknown - Species level identification of some cyanobacteria recommended - What triggers toxin production? - Fate & effects in food web unknown - How will zebra mussels impact toxins?
Dissolved oxygen	- Since 2002, low oxygen events in bottom waters measured in 2003, 2006 & 2007 in the central NB. - The SB had no hypoxic events in any year with the exception of one station, & no dissolved oxygen concentrations below 5.5 mg/L were recorded in either basin between 2008 & 2010 - Based on the current findings, it appears that LW does not experience persistent & frequent low oxygen events but they do nevertheless occur under certain conditions.	- Due to the size of the lake, the spatial & temporal extent of low oxygen events remains poorly understood - Effort thus far has been directed at understanding water column oxygen levels only. - Little is known about oxygen dynamics at the sediment/water interface - Winter sampling for DO - Some QA/QC of Seabird data
Benthos & Zooplankton		

Changes	- **ECs** 2 year nearshore SB data on portal
	- **Hann/Watson** – previous findings include: an overall increase in the density of zoobenthos since 1969, especially in the NB; considerable annual variability in densities with the highest in 2006 & the most notable declines in 2008; hotspot in benthos density in the area north of Long Point, moving from Grand Rapids to Warren's Landing; substantial increase in the density of oligochaetes & chironomids in the NB & a decrease in the density of *Diporeia*.
	- Limitations of benthic data:
	  ○ Abundance only, not biomass
	  ○ Taxonomic resolution generally at the Family level, if not lower.
	  ○ Inconsistent methods MWS & Hann
	- **Hann 2015 update** at the workshop
		- Biomass estimates
		- Nearshore data
		- Higher taxonomic resolution to the species or genus level - focus on groups like the chironomids & oligochaetes as indicators.
		- Indices for oligochaetes & chironimids specific to LW could be developed
		- Implementation of these indices would rely on intensive & frequent sampling & ability to identify to genus &/or species level.
		- Indices could then be used to produce better spatial maps for a given time period. In addition, sediment cores could be used to determine more accurate historical spatial & temporal patterns such as when & where changes started to occur.

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
Causes	Interpretation limited by limitations above	- Diet o To clarify the role (edibility & nutritionally) of cyanobacteria versus phytoplankton o Relative importance of heterotrophs vs autotrophs - Oxygen dynamics at sediment/water interface unknown - Relate spatial patterns for turbidity & consequent bloom formation in the NB to benthic response
Consequences	Unknown	- Commercial & forage fish diets - Littoral to pelagic transects – use CABIN methods for L Erie by EC
Zooplankton	- *Bythotrephes* detected in 2011 - Pelagic sampling continues (at 29 sites) but many samples remain un-analyzed - **EC 2-year nearshore study in the SB** included zooplankton: o The shoreline & littoral sites show higher diversity than the offshore sites since both littoral & pelagic species are found there. o No nearshore sampling in NB - **Hann/Salki 2015** update at workshop	- Nearshore both basins - Relative importance of zooplankton vs zebra mussels on phytoplankton grazing - Winter/spring
Zebra Mussels	2012 - the LWRC introduced 2 nearshore stations in the NB 2013 (October) - zebra mussels arrived 2014 - a nearshore network of 12 stations established **Janusz (MB) 2015 update**: - Adults - Substrate samplers deployed in harbours. Densities of settled zebra mussels on plates have increased substantially since 2014. - Spawning frequency – monthly basis, removed the top layer of substrate samplers (3 layers total) that were deployed in a number of harbours in the SB. Data not analyzed but there were clear spatial differences in settling rates - Veligers - sampled at all stations, offshore & nearshore. As of the end of the 2015 open water season, found at an increasing number of stations in the SB, one within the channel & at one station in the NB. Also, generally found at greater numbers than in 2014. - Red River update will be included at	- What parameters need to be included in order to assess the impacts of zebra mussels on primary production, energy flow changes, consequences on benthic & fish communities, fish habitat, algal toxins… - What parameters are needed to validate an ecosystem model? - Bathymetric surveys & substrate mapping to: characterize the structural composition character of the lake bottom (may prove useful if hindcasting used to determine temporal correlations); identify habitat suitable for quagga mussels (next in line…) - Nearshore P shunt - Water clarity: Secchi depth or other measures of water clarity; remote sensing may be an effective means to map water clarity. - What defines the littoral zone within the context of zebra mussels: depth, nearness to shore or something else?

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	workshop.	- Adult distribution, densities
Bythotrephes	- *Bythotrephes* detected in 2011 - Monitoring continues by MB at all stations, offshore & nearshore - Samples from the summer & fall *Namao* cruise in 2014 & 2015 have not been analyzed.	- Seasonal diet & nutrition studies of pelagic forage fishes like cisco & emerald shiner, in addition to the work done on rainbow smelt diets - Consequence on growth rates & condition - SWF sampling uncertain due to limited funds
Fish		
Index-netting	- Walleye mortality estimates are high - Lake whitefish is not sampled in the index-netting program. No mortality estimates available - An "avoid" ranking by Seafood Watch on sustainability (walleye, whitefish & pike) - Interpretation & use of data for management decision-making is not evident **Geisler 2015 update on thermal-optical habitat of walleye:** post-invasion water clarity can be accurately predicted based on few readily available lake parameters**;** observed declines in walleye yield in some systems in Ontario & New York can be partly attributed to increased water clarity with dreissenid invasion but also to concurrent declines in TP & angler effort**;** when developing a walleye production model in Manitoba the importance of ecozone was highlighted, along with the different indicators of primary productivity in each ecozone	- Acoustic surveys - species-specific biomass, abundance, distribution - Non-quota, by-catch species characterization (currently only bulk weighed & counted by mesh) - Sampling NB pelagic & east side of lake - FFMC data could be better used to advantage - QRTF 4a. Commercial fisheries harvest & effort monitoring program – to establish commercial fisheries catch per unit effort (CPUE) for each species - QRTF 4b. Index gill netting monitoring program – see hand-out - QRTF 4c. Commercial catch sampling program – see hand-out - QRTF 4d. Sentinel fishers monitoring program or fishers' logbook program – see hand-out - QRTF - 5h Management changes should be the subject of systematic evaluation
Other sources of mortality - Subsistence - Unrecorded commercial harvest (special permits, bushing) - Recreational - Other (toxins, hypoxia)	**Subsistence** - a rough estimate for the LW subsistence harvest has been calculated to be between 10 & 28 kg per capita, or 3.2% to 9.3% of the average total commercial harvest between 2000 & 2007 (LWQRTF, 2011) **Environmental** - given the seemingly rare & fleeting episodes of hypoxia in the NB, mortality due to low oxygen is likely rare. The frequency of such occurrences is not known, nor is the cause.	- QRTF 4g. Comprehensive domestic (subsistence) survey – see hand-out - QRTF 4f. Recreational sport fishing survey – see hand-out
Sub-Population Structure (F3)	**Moles *et al.* (2010)** showed that the two growth forms for walleye (normal & dwarf) share common juvenile habitat but the normal form	- Tagging studies required - The CLAs used as part of the Quota Entitlement system on LW imposes limits

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	shifts into an alternate adult niche. Also suggested that selective fishing by the gill net fishery might be an important mechanism favouring the dwarf form & thereby contributing to polymorphism in walleye. **Backhouse *et al.* (2011)** - used mitochondrial & microsatellite DNA variation. Results indicated that very little population structure was detected possibly indicating a low degree of natal homing, migrations or historical & current stocking, all of which could obscure genetic structure. **Hobson *et al.* (2011)** - using stable isotopes of N & C showed that small-bodied fishes (<350 mm) exhibited fidelity to the lake basins, & possibly even to regions within each basin. The study did not include adult fish. Smaller fish turn over their tissues faster & will reflect what they have been in recently, whereas larger fish may have turnover rates of several months.	on the area a fisher can set nets, & has, in effect, created restrictions in fishers' movements on a much finer scale than any stock specific management system would. This is with the exception of Dauphin River, which would be fishing a single stock. - *QRTF - 5c. Genetic stock structure* – to effectively manage & protect stocks
Trawling	**EC otter trawls** - offshore bottom trawls, although limited, showed a distinctly different deepwater pelagic fish community made up primarily of freshwater drum & troutperch. **Fishers (pre-2010)** – from NHCN have observed large die-offs of smelt following the spring spawn. Also observed that smelt used to be bigger & fewer, but now they are small & more abundant. There has been a large increase in rainbow smelt over the years, including down the Nelson River system. The increase was particularly noteworthy on the west side of the Lake since about 2000 (LWQRTF, 2011). **Lumb 2015 update** - Large differences in species composition & biomass in the pelagic fish community in different regions of LW. The pelagic fish community in the NB is made up of predominantly non-native Rainbow Smelt, while in the channel & the SB, native Emerald Shiner & Cisco are the dominant species. - Results from pelagic surveys suggest a decrease in Rainbow Smelt biomass in recent years. White Bass & Yellow Perch biomass in the offshore waters were greatest in the summer in the SB, while biomass of juvenile Walleye was greatest in the SB, followed by the channel, & the NB during both summer & fall.	- Recruitment indices for walleye. LOTW summer sampling of YOY walleye & sauger proven to be an effective way to predict year class strength by the end of the first summer. A similar such recruitment index could be developed for LW walleye. - Further comparisons with when fish are recruiting to the index-netting program could establish if there is a good translation between strong YOY classes & what is showing up in the gillnets, thus provide another predictive tool. - Otter trawls - Night trawls – to reduce trawl avoidance in the NB due to water clarity & the bias that this might introduce to biomass estimates. Greater activity at night? (feeding) Changes in water clarity due to zebra mussels over time. - **Lumb - offshore hydroacoustics** - to assess the fish community, including basin wide estimates of rainbow smelt biomass. - **Lumb/Klein - nearshore acoustics & index gill netting** to work on developing a way to assess large-bodied fish species including whitefish - QRRTF 4e. Offshore small fish trawling program

<table>
<tr><th>TOPIC</th><th>WHERE WE ARE
Recent Findings and Updates</th><th>WHERE WE NEED TO GO
Knowledge Gaps</th></tr>
<tr><td>Fish Diets</td><td>Observations by fishers & Fisheries Branch biologists indicate that whitefish are also eating smelt in the NB.
Hann 2015 update on the recent diet work of 2 graduate students (details at workshop):
- Sheppard - Sauger & walleye diet study (3 manuscripts - publ, accepted & in review, JGLR)
- Olynyk - Smelt & cisco diet study (manuscript submitted JGLR, in revision)
- Bioenergetics model for LW has been initiated
Rennie – microplastics are in the lake. Possible next phase of study - are they in the fish?</td><td>- Whitefish data needed (diet, length, weight
- Diet at different life stages
- QRTF 5b. Diets of lake whitefish, walleye & sauger – to evaluate the quality of & changes in diet & productivity
- Rennie & Hanson – possible study looking at quantity, source, & dietary exposure of microplastics</td></tr>
<tr><td>Traditional & Local Knowledge (F5)</td><td>- QRTF (2011) sought input from fishers (other than those on the TF) by developing a fishers' survey that was administered in various communities around the lake in 2009. The survey questions were diverse encompassing subjects related to catch effort, exotic species & climate change, among others.
CIER (2006) carried out a study in FRCN that involved the collection of indigenous knowledge related to climate change, LW & changes in the fishery, as well as the social, cultural & economic impacts of these changes (Maclean 2007). A constrained domestic fish consumption survey was carried out. Interviews (13 fishers) & community input.
- Mclean (2010) addressed how successful government was at establishing a level of trust & interaction with commercial fishers. The thesis included a lot of verbatim information from fishers about attempts that were made in the past & that had failed.</td><td>- Fisheries Branch visits roughly 12 to 15 communities per year in conjunction with the FFMC community visits. At that time, biologists & fishers are able to interact & discuss concerns, observations & expectations. This has proven effective in building a rapport with communities. One drawback, however, is that information is not formally recorded.
- One framework within which the collection of local knowledge could be standardized is through a co-management board where information is managed within the co-management framework, including how the collection of local knowledge could be built into a reference indicator system that would be used to adjust quotas on an annual basis.- described QRTF.</td></tr>
<tr><td colspan="3">Spatial Considerations - Fish movement & fish habitat</td></tr>
<tr><td>Spatial Considerations
Habitat & fish movement</td><td>Fishers knowledge on migration: whitefish movements included travelling down the east side, off Reindeer Island, & back up to Long Point. This was believed to be a quest for food, which ended in the fall, inshore where they spawned; migration of walleye from the NB south.
Studies conducted over 40 years ago: whitefish tagging studies (1950s to 1970s) show evidence of discrete populations of whitefish driven by fidelity to a spawning area; in another study, tagged whitefish were recaptured together a few years later, indicating that they</td><td>- Additional tagging studies for all commercial species
- QRTF 5d. Seasonal migrations of walleye, sauger & whitefish – studies would include a fishers' knowledge study, combined with scientific tagging & genetic studies</td></tr>
</table>

TOPIC	WHERE WE ARE Recent Findings and Updates	WHERE WE NEED TO GO Knowledge Gaps
	stick together. Not published & data not readily available	
Fish Habitat Classification (H2) Nearshore	**SHIM (2012) by LWF**: aimed to identify & map sensitive habitats along southern shoreline using Sensitive Habitat Inventory Mapping; did not include tributaries. The intention was offer a set of shoreline management guidelines to government & regulators to guide development decisions **Littoral sampling program 2010-2011 (EC): b**each seines (nearshore), gillnets (five sites in the SB) & otter trawls (offshore)**;** length frequency & age were determined; two years limited to SB only	Proposal H2 - Fish Habitat Classification SB (2004 science workshop). Collect necessary data to apply existing fish habitat models developed for the Great Lakes in support of a fish-habitat management plan Data required: bathymetry & substrate mapping (both basins); fetch (from GIS-based maps); cover (from aerial photos, sonar, & stratified field surveys). Would also involve the development of a good fish habitat suitability database based on the current literature & includes: depth preferences by life stage of critical species; thermal preferences; habitat structures etc
Use of Tributaries & Reefs by Fish (H3)	**QRTF (2011)** included a map question on the location of important spawning sites for the three commercial species in both basins. Response was high. NHCN fishers expressed concerns over a number of spawning habitats that have become degraded due to build-up of sand, which either blocks fish passage or covers spawning habitat	Original intention of 2004 proposal was to determine which tribs & reefs are important habitats for fishes, especially SAR, & to develop a habitat-use inventory as a water & land management tool for protecting tributaries & reef fish habitats. (see above) Zebra mussels are now part of the picture.
Decline in Wetland Habitat (H4)	- **Wetland Restoration Group** exists - **EC (Parker)** conducted surveys of Netley-Libau Marsh in 2009 & 2010 & found that the greatest fish species richness was on the east side, which is not affected by diversion of RR waters	Netley-Libau - Potential effect of seiches & the resulting variations in lake level, - Isostatic rebound
Critical Habitat for SAR (H6)	- Sturgeon Working Group	

1) Do we need to integrate lake science and management more effectively in order to manage Lake Winnipeg?

2) Do we need to approach it from the whole ecosystem perspective?

3) What are the main obstacles, besides funding, preventing this from happening?

APPENDIX C

Workshop Participants

Agency	Name
Environment Canada	Joanne Volk
	Ram Yerubandi
	Les Rutherford
	Kristina Farmer
	Dorothy Lindemann
	Kim Ruttan
	Paul Klawunn
Manitoba	Brian Parker
	Bill Galbraith
	Chelsey Lumb
	Geoff Klein
	Laureen Janusz
	Justin Shead
	Elaine Page
	Elise Watchorn
	Alexandra Goodman
	Desiree Stratton
Fisheries and Oceans Canada	Mike Stainton
	Doug Watkinson
	Patricia Ramlal
	Jeff Moyer
Lakehead University	Mike Rennie
U. Manitoba & U. Winnipeg	Greg McCullough
	Brenda Hann
	Mark Hanson
	Marianne Geisler
	Claire Hebert
	Charles Wong
Brandon U.	Christophe Lemoine
IISD-ELA	Scott Higgins
	Mike Paterson
Manitoba Hydro	Ainslie Chaze
	Gary Swanson
Salki Consultants Inc.	Alex Salki
Independent	Ray Hesslein
Independent	Burt Ayles
Lake Winnipeg Foundation	Alexis Knispel Kanu
Session 4 (U. Manitoba)	Dave Barber
	David Lobb
	Genevieve Ali
LWRC	Al Kristofferson
	Mo Tipples
	Karen Scott

APPENDIX D

On-Lake Infrastructure

Motor Vessel *Namao*

Motor Vessel *Namao* provides whole lake offshore access
and nearshore and outflow access by workboat.

Specifications

- 327.91 tons gross tonnage
- 103.82 tons net tonnage
- 12 knots cruising speed
- 34.5 tonnes fuel capacity
- Accommodates 15 persons (9 crew; 7 science)
- 33.62 m length
- 8.53 m breadth
- 2.13 m draft
- 2 laboratories
- Meteorological tower (no instrumentation) on bow
- Seabird rosette (turbidity, dissolved oxygen, temperature, PAR, conductivity, chlorophyll)
- Tow body hydroacoustic
- On board Evos microscope

APPENDIX D continued

Motor Vessel *Fylgja*

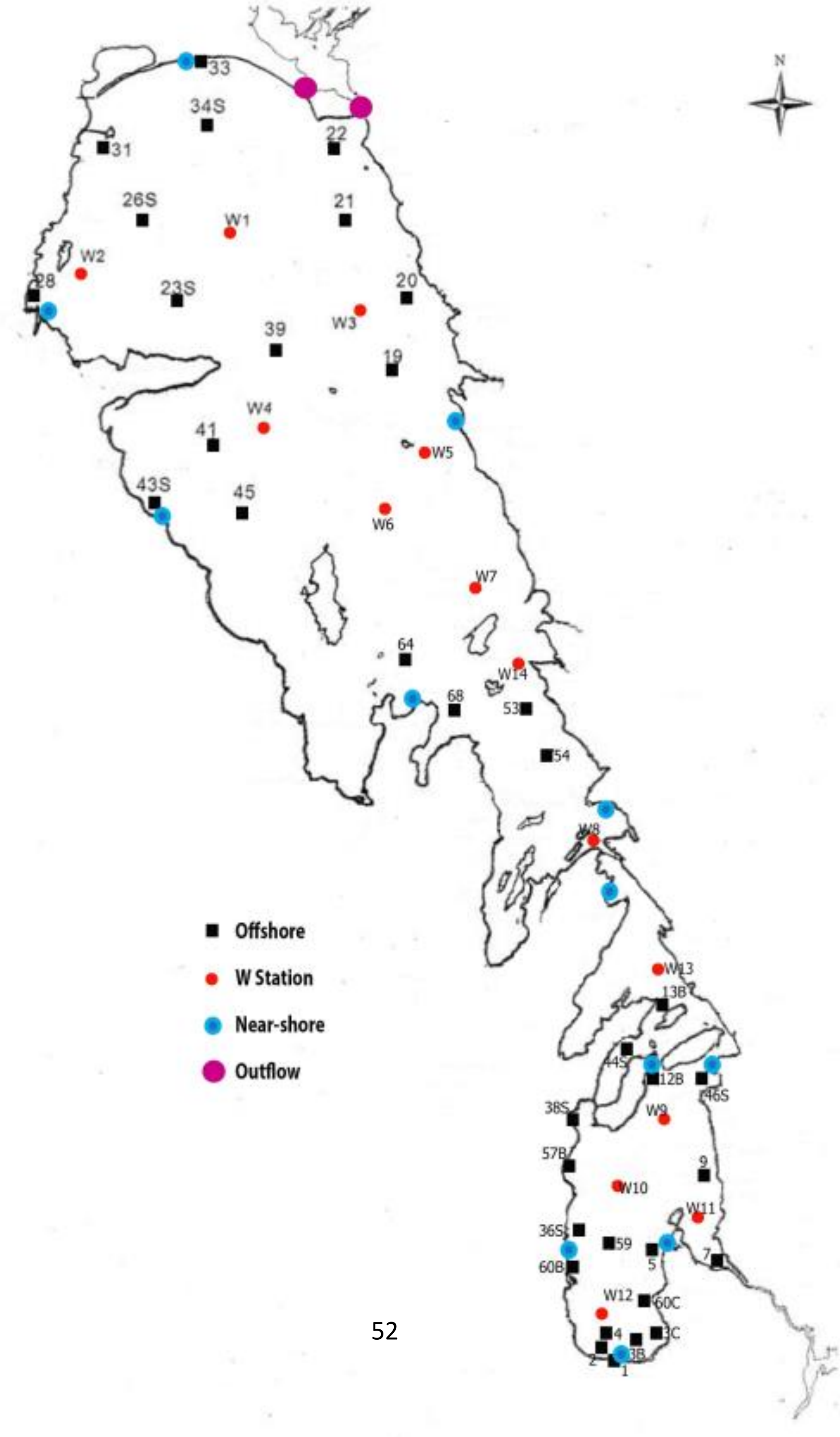
M.V. *Fylgja* provides nearshore access for special projects
in the south basin and narrows of Lake Winnipeg.

Specifications

- 42’ length overall
- 12’ beam
- 3.5’ draft
- Steel hull & cabin
- Aluminum wheelhouse
- Detroit diesel motor (3 cylinder, 53 cu. In.)
- Horsepower
    - 73 Continuous Shaft hp (at 2400 rpm)
    - 92 Rated Shaft hp (at 2800 rpm)
    - 101 Rated Brake hp (at 2800 rpm)
- Cruising speed 8 knots
- S-L 555 windlass & chain (manual)
- No winch but could be installed
- 150 L fresh water tank
- Sleeps maximum of six but only four recommended (2 crew; 2 science)

APPENDIX E

Station Networks – Nearshore, Offshore & Outflows



APPENDIX F

Northern Watershed Research Centre Panel Discussion

A concept whose time has come?

Research on freshwater systems in Manitoba is a critically important element at the local, provincial and national levels. Currently the coordination of freshwater science is somewhat ad hoc with a number of organizations working collaboratively within subgroups of the system, but with little or no overall coordination. This is particularly true of the University of Manitoba where expertise exists in watershed science, lake science and freshwater-marine coupling but little coordination amongst the elements of these scientific foci.

The purpose of this panel discussion is to explore the feasibility of forming a new 'Northern Watersheds Research Centre' (NWRC) across the breadth of freshwater science in Manitoba, focusing it around key elements of the northern watersheds of Manitoba and the potential for connecting it to marine science downstream in Hudson Bay. The University of Manitoba is interested in playing a role in this new centre and the benefits of having a strong academic core to this initiative could be a significant benefit to overall coordination of freshwater science.

The Centre for Earth Observation Science (CEOS) has a strong track record in scientific coordination and a 'systems' approach to understanding complex systems. Towards this end CEOS is interested in exploring how freshwater science in the Province can be coordinated in a way similar to how marine science has developed within CEOS. **In particular the session will reflect on whether there is a need for such a centre, the geographic and scientific scope of the centre and what governance form this centre should take.** The session will in particular address how this proposed NWRC would:

1) Provide leadership, visibility and coordination of FW science in Manitoba.

2) Make more effective use of existing major scientific infrastructure (e.g., LWRC, ELA, etc.)

3) Provide coordinated access to standardized water quality laboratories.

4) Develop new and highly integrated research infrastructure through new coordinated proposals (e.g., CFI)

5) Coordinate watershed, river and lake science providing a more 'systems' level approach.

6) Examine the relative contributions of water regulation and climate change to the system.

7) Determine downstream effects through FW-marine coupling.

At the upcoming LWRC Science Workshop, a Session is scheduled on Day 2 in the afternoon to discuss the structure and functioning of such a Centre. Panelists would reflect on the key questions above and from their particular perspectives as representatives of key stakeholders of a new centre focused around coordination of FW science in Manitoba.

Order of Presentation:

- David Barber (CEOS/UM) – 20 min
- Invited panelist perspectives
- Group discussion – 1 hour

APPENDIX G

Current and proposed parameters for a whole ecosystem monitoring program on Lake Winnipeg. Frequency of proposed sampling is not yet established.

Parameter	Current Surveys spring, summer, fall, winter	Stations	Agency Lead	Status of Effort	Proposed
pH	Offshore only Spring, Summer, Fall	All stations, Seabird profiles	ECCC	Ongoing	CONTINUE
DO					
% saturation					
Conductivity					
PAR					
Temperature					
Turbidity					
pH, Temperature, PAR, Secchi	Offshore & Nearshore Spring, Summer, Fall	All stations (surface & bottom) unless noted	MB	Ongoing	CONTINUE
Conductivity					
BOD		Surface only			
TSS					
N - NH3 dissolved					
N – NO3NO2 diss					
N – TKN					
Chl-a		Surface only			
P – total					
P – total dissolved					
P – ortho					
P – acid hydrolyable					
P – total particulate					
C – total		Surface only			
C – total inorganic		Surface only			
C - organic		Surface only			
Above chem. + below	Offshore Spring, Summer, Fall, Winter (1x/yr near ice-out)	W stations only Euphotic & bottom	MB	Ongoing	ADD NEARSHORE
DO (Winkler)					
TDS					
Turbidity					
Colour – true					
Cl – dissolved					
SiO2 – reactive diss					
SO4 dissolved					
ALK (various)					

Metals (various)					
Sediment chemistry	Offshore Spring, Summer, Fall,	W stations only Euphotic & bottom	MB	Ongoing	ADD NEARSHORE
Pesticides	Summer only	Euphotic - W12, W11, W2			ADD NEARSHORE
Organic N – partic & diss'd					NEEDED FOR MODEL
Inorganic N – partic					NEEDED FOR MODEL
P – particulate (org'c & inorg'c)					NEEDED FOR MODEL
Phytoplankton	Spring, Summer, Fall Winter (1x/yr near ice-out)	W stations	MB	Ongoing	ADD NEARSHORE
Zooplankton	Spring, Summer, Fall	29 stations S/N transect	UM	Uncertain	ADD NEARSHORE
Zebra mussel veliger	Offshore & Nearshore Spring, Summer, Fall	All stations	MB	Ongoing?	ADD NEARSHORE
Bythotrephes	Offshore & Nearshore Summer, Fall	All stations	MB	Ongoing?	ADD NEARSHORE
Benthos	Spring, Summer, Fall	All stations	UM	Ongoing?	CONTINUE
Benthos	Spring, Summer, Fall	W stations	MB	Ongoing	ADD NEARSHORE
Zebra mussel adult Presence/absence	Open water season	Harbours	MB	Likely not ongoing	DISCONTINUE
Zebra mussel adult abundance					ADD LAKEWIDE
Zebra mussel adult biomass					NEEDED FOR MODEL
Forage fishes	Spring, Summer, Fall (when funds available)	Sub-set of station network	MB	Uncertain	ADD NEARSHORE
Forage fishes					ADD OTTER TRAWLS
Walleye	Spring	6 sites - Index Netting Program	MB	Ongoing	ADD NE PART OF LAKE
Sauger	Spring	6 sites - Index Netting Program	MB	Ongoing	ADD NE PART OF LAKE
Whitefish	N/A	N/A	MB	Not sampled	ADD NEW PROGRAM

APPENDIX H

Additional perceived challenges or impediments to progress identified during the Science Workshop discussions

General

A unique set of goals, objectives, targets and indicators should be developed in support of the adaptive management of water quality and the fishery, with or without eco-certification. Multiple goals and objectives from multiple agencies simply create confusion and are counter-productive to the ultimate goal of effective ecosystem management.

In an effort to more effectively fulfill its obligation to manage Manitoba's natural resources as part of the Public Trust, the Government of Manitoba is encouraged to: define and support clear mandates for Sustainable Development (formally known as Conservation and Water Stewardship) for the work on Lake Winnipeg; establish clear reporting processes from staff to senior decision-makers and stakeholders, to enhance accountability, transparency, and support of decisions made; address capacity to allow for adequate sample collection and processing, data analysis and interpretation, additional training, development and implementation of adaptive management plans, and collaborations with partner agencies; and ensure appropriate capacity to meet requirements of monitoring programs, communications, and eco-certification and auditing costs.

The limited contribution of academia to the research on Lake Winnipeg must change. Large scale, system level collaborative research is required to explicitly investigate complex interconnected, ecosystem-level processes in support of management obligations. The University of Manitoba is providing leadership in initiating the coordination of existing and new water-related integrated research through the development of a Centre for Water System Science.

Lake Winnipeg Basin Information Network

Lack of engagement by government. Even though both the provincial and federal governments have contributed significant funding to the LWBIN, neither agency has contributed data or reports to the network since. The current federal ACBIS dataset (of which the LWBIN holds an older set of records for) is still not publicly available. These 2 organizations provide funding to many other groups in the Lake Winnipeg/Nelson River and Arctic Watersheds yet still have no documented strategy for their data management. The GOC does have an open data strategy and web site where they can post data but it does not yet allow documents/data to be viewed or provide any means of interaction. It also does not allow mapping data files to be visualized.

Need better strategy to engage a broader user base. *As* more citizen scientists, conservation districts and other widely located organizations become involved in sampling in the watershed, educating them on options they have for sampling, analysis and storage of their data is important. The LWBIN needs to make better connections with these organizations to help work with researchers and other organizations to facilitate this.

Standardized strategy for data management. An extension to the above, as organizations move forward in sampling and data analysis, providing users with templates (data management plan, metadata template) that can guide them through documentation is needed to minimize data issues at the collection stage and to maximize data value. These strategies should be developed at the BEGINNING of a project and not after the data has been collected.

Funding. Properly developing and managing a data warehouse/delivery site is expensive. It is not just putting together a website and loading data. For long-term stability, data backup and archiving, data management and storage takes strategic development and planning. Server storage space becomes expensive. The LWBIN still needs an easier to use front facing interface and some development at the back end.

Eco-certification Process

Stakeholders and government must work together to develop new science-based management plans for Manitoba's commercial fisheries.

Government must be supported and encouraged to implement new management plans, research plans and other elements required to meet identified weaknesses.

Appropriate steps will need to be taken to meet certification and auditing costs.

Partnerships with other government departments/agencies, industry and academic institutions must be established and maintained to meet certification requirements/program criteria, as well as, changing consumer/market demands.