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FEATURE

Standardized Broad-Scale Management and Monitoring of Inland Lake Recreational Fisheries: An Overview of the Ontario Experience

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NOT a happy Walleye *Sander vitreus* caught at Wabakimi Provincial Park, Ontario, Canada. Photo Credit: OakleyOriginals

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There are ~250,000 lakes in Ontario that support important cultural, recreational, and economic fisheries. In 2005, the Ontario Ministry of Natural Resources and Forestry adopted the Ecological Framework for Recreational Fisheries Management to tackle the heterogeneity of lake resources and angler mobility across the landscape, increase public participation in fisheries management, and streamline an ever-growing list of regulations. The Broad-Scale Monitoring Program for Inland Lakes began in 2008 to meet these goals. Essential elements of the program are: clear objectives, standardized sampling methods, operational implementation, diagnostic indicators, standardized reporting, a multidisciplinary team, and adaptive monitoring. Fishes, zooplankton, habitat, and angling activity are measured at each lake and provide the data needed to make evidence-based fisheries management decisions. The data have benefited other provincial initiatives and provided significant contributions to the science of freshwater ecology. Recommendations are provided for other jurisdictions considering the implementation of a standardized broad-scale monitoring program.

INTRODUCTION

Freshwater inland fisheries are important sources of animal protein and income to millions of people worldwide (Welcomme et al. 2010; Lynch et al. 2016). A significant portion of these inland fisheries are recreational with at least 220 million recreational anglers worldwide (World Bank 2012; Arlinghaus et al. 2015). The sustainable management of these resources requires an understanding of their ecosystems, population dynamics, and use. This information can be collected through monitoring programs that evaluate not only the populations but also track the ecosystem conditions that may impact stock status (Francis et al. 2007).

The province of Ontario, Canada, has ~250,000 inland lakes (>0.05 km^2) distributed over ~1,076,000 km^2 (OMNR 1984). These lakes and their fishes are culturally, recreationally, and economically important. This paper focuses on the management of recreational fisheries that support 1.2 million anglers and contribute Can$1.6 billion annually to the provincial economy (OMNRF 2015). In 2005, the Ontario Ministry of Natural Resources (now Ontario Ministry of Natural Resources and Forestry [OMNRF]) instituted the Ecological Framework for Recreational Fisheries Management (EFFM) to address the need for a management approach that streamlines fishing regulations and balances the spatial and temporal variation of resources with the needs of communities and anglers (Lester et al. 2003; OMNRF 2015). The EFFM and overarching Ontario Provincial Fish Strategy: Fish for the Future aim to improve the conservation and management of fisheries and their ecosystems, and increase public participation in fisheries management (OMNRF 2015).

Elements of (1) landscape-level, (2) ecosystem-based, and (3) adaptive management have been incorporated into the EFFM to support these objectives. Landscape-level management recognizes that broad-scale forces such as environmental variation, the mobility of anglers, and stresses such as spreading invasive species distributions can render traditional lake-by-lake approaches inadequate for effective management (Lester et al. 2003; Deroba et al. 2007). A landscape approach is especially necessary in jurisdictions like Ontario, where thousands of lakes dotted across a massive geographic area would be impossible to manage individually. Ecosystem-based fisheries management, on the other hand, acknowledges the complex ecological and socioeconomic pathways that lead to dynamic states of fisheries (Larkin 1996; Pikitch et al. 2004). It has been adopted as a guiding policy by the United Nations Food and Agriculture Organization Committee on Fisheries (FAO 2003; Patrick and Link 2015). Including ecosystem-based fisheries management in the EFFM acknowledges the ecological and human elements of recreational fisheries. Adaptive management, which involves an iterative process of learning, has been endorsed for natural resources for decades (Holling 1978; Walters 1986). Inclusion of this concept in the EFFM establishes a process by which learning through monitoring within management cycles can be used to evaluate management effectiveness and fine-tune future management decisions. Ultimately, the integration of these three management approaches in the EFFM recognizes that recreational fisheries are complex and dynamic.

The Broad-Scale Monitoring Program for Inland Lakes (BsM) was designed to support the EFFM and provide the data necessary to make evidence-based management decisions. Key elements of three management approaches are incorporated into the monitoring design. First, hundreds of lakes are selected for monitoring to understand the heterogeneity of lake types and resource distributions across the landscape. Second, the physical, chemical, and biological ecosystem conditions, and angler activities on each lake are monitored. Third, it was established from the outset that the monitoring would be cyclical and flexible to accommodate changing management questions, environmental conditions, and stresses.

This paper describes the recreational fisheries management framework in Ontario with particular emphasis on the BsM monitoring component. The benefits of this program to other business areas within MNRF and windfall of scientific insights gained about fish and fisheries ecology, food web dynamics, and climate change are highlighted. The lessons learned are synthesized to provide recommendations for other jurisdictions considering the implementation of a standardized broad-scale monitoring program.

LANDSCAPE AND FISHES OF ONTARIO

Ontario spans 41–57°N and has significant latitudinal gradients in climate, human activities, and fish species richness (Chu et al. 2015; Figure 1). Mean annual air temperatures range from −5 to 9°C and mean annual total precipitation ranges from 240 to 1,150 mm with more in the lee of the Great Lakes (Crins et al. 2009). Most of Ontario's population (14.5 million people in 2019) is concentrated along the border of the Great Lakes, while the northern region of the province (>50°N or 42% of the total landmass) is home to only 24,000 people (Crins et al. 2009; OMNRF 2019).

Ontario has the highest diversity of fishes in Canada (128 native and 17 naturalized species) with species richness in lakes ranging from 1 to 49 species (Chu et al. 2015; OMNRF 2015). The commonly targeted recreational sport fishes are cold-water (prefer ≤ 19°C) Lake Trout *Salvelinus namaycush* and Brook Trout *S. fontinalis*, cool-water (prefer > 19 < 25°C) Walleye *Sander vitreus*, Northern Pike *Esox lucius*, and Yellow Perch *Perca flavescens*, and warm-water (prefer ≥ 25°C) Smallmouth Bass *Micropterus dolomieu* and other Centrarchids (DFO 2015).

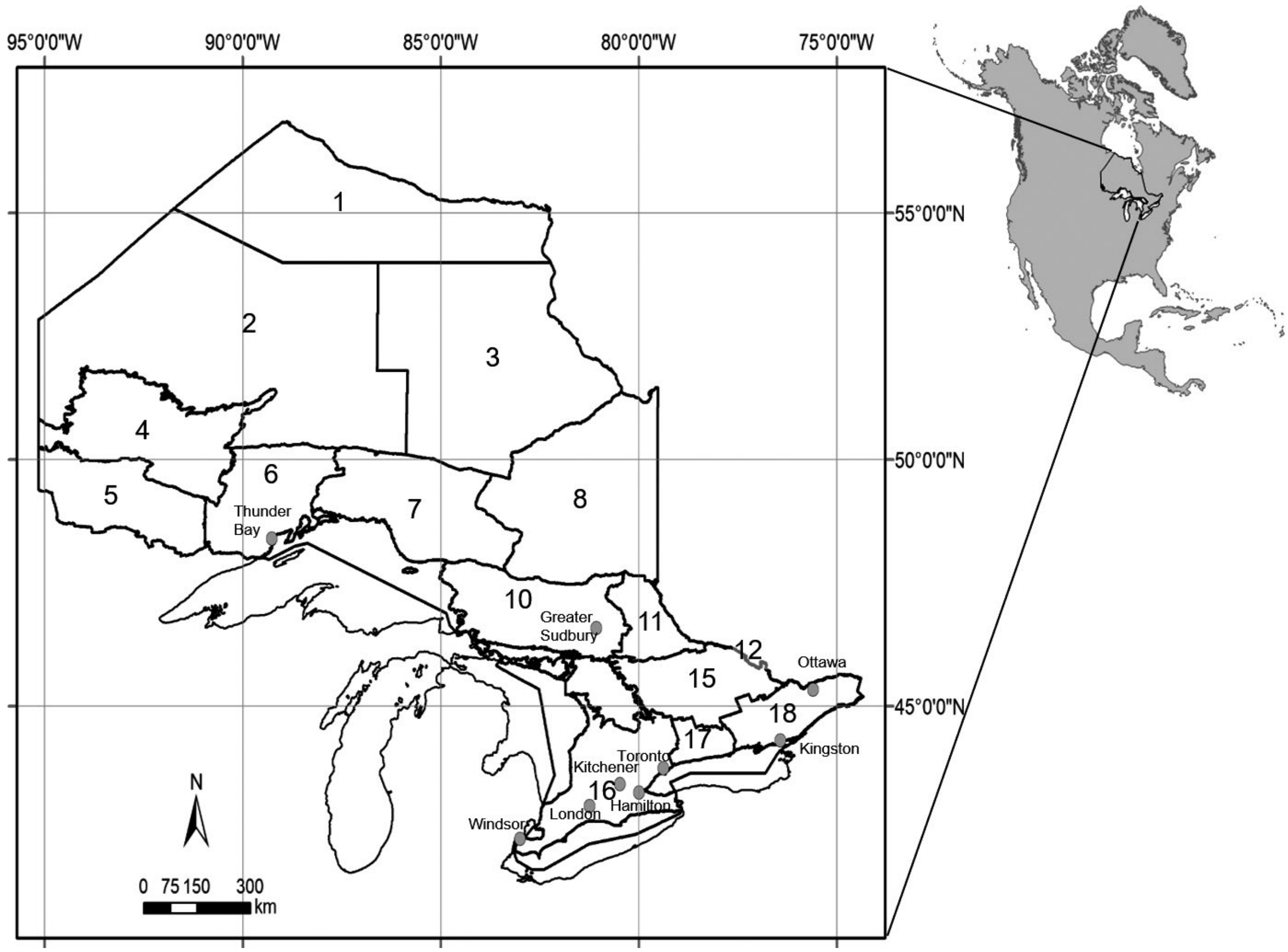

Figure 1. Cities and inland Fisheries Management Zones in Ontario, Canada.

MANAGEMENT CYCLE

With delegated authority from the federal government of Canada, MNRF is responsible for fisheries management decision making, and the administration and enforcement of fishing regulations. The ministry also has a legal duty to consult Indigenous communities when any proposed activity or decision may adversely impact treaty rights (*Constitution Act 1982*). Under the EFFM and using existing knowledge of the environment and angling pressure, 20 Fisheries Management Zones (FMZs) were established as the primary units for management (OMNRF 2015; Figure 1). Zone-specific regulations aim to benefit regional recreational fisheries needs while incorporating community and angler interests.

Fisheries goals and objectives for each FMZ are set within fisheries management plans by MNRF after engagement with FMZ Advisory Councils (Figure 2). Councils can include Indigenous community members, academia, conservation groups, resource stakeholders (e.g., angling groups, outfitters, cottagers), retail businesses, and the general public (OMNRF 2015). Councils and MNRF discuss the goals, objectives, monitoring results, and options for management actions (Figure 2) but the monitoring and decision-making program authority lies with MNRF.

Fisheries management plans are written using historical information collated in background documents and BsM reporting products. They include goals, objectives, indicators, benchmarks, and timelines for achievement (Table 1). Goals are the long-term ecological and socioeconomic targets for each FMZ. Objectives are more specific than goals and must have measurable indicators, benchmarks, and realistic timelines for achievement. Indicators are quantifiable metrics (e.g., fish abundance) that can be used to track progress towards the goals and objectives. Values for the indicators are often derived from the BsM data, but other indicators, e.g., number of public meetings hosted to raise awareness of best fisheries practices, may be generated and tracked by MNRF staff (Table 1). Benchmarks are reference values associated with each indicator and can be based on historical information or on data from the first cycle of BsM. Management actions include harvest regulation changes, public education, rehabilitation and protection plans, stewardship, stocking, and enforcement that are applied to achieve the goals and objectives for each zone (Table 1).

The FMZ background documents and draft plans are presented to councils through a series of information sessions. Further public engagement is facilitated via open houses, posts to the provincial environmental registry, and social media. During open houses, people meet at a specific time and location to speak with MNRF staff to review and discuss plan objectives and proposed regulation changes. The ministry uses feedback from these engagements when preparing the final plan and seeking Ministerial approval for decisions on management actions and regulatory changes.

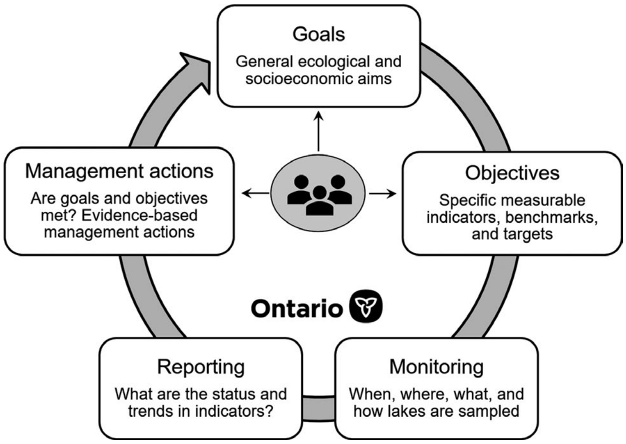

Figure 2. Adaptive fisheries management cycle outlined in Ontario's Provincial Fish Strategy: Fish for the Future.

The iterative process of planning and monitoring under EFFM provides the data necessary to evaluate the effectiveness of different management actions as data become available (Figure 2). Adaptive management in Ontario is passive. That is, the consequences of management are repeatedly evaluated (through monitoring), but no attempt is made to impose experimental management actions specifically with the intention of learning (McDonald-Madden et al. 2010). For example, in 2010, Lake Trout regulations in FMZ 10 were changed from three fish any size (January 1 to September 30) to two fish (only 1 > 40 cm; January 1 to the first Monday of September). The Cycle 2 BsM data (2012–2017) indicated that the status of Lake Trout improved since the regulation was implemented. Zones 10 and 11 have similar landscapes, lake characteristics, fish communities, and FMZ goals and objectives. Therefore, the seemingly effective FMZ 10 Lake Trout regulations were implemented in FMZ 11 in 2020.

BROAD-SCALE MONITORING DESIGN

Rigorous monitoring designs should include: (1) clearly defined objectives, (2) standardized sampling methods, (3) operational implementation, (4) science development, (5) standardized information management and reporting, (6) a multidisciplinary team, and (7) adaptive monitoring (Hayes et al. 2003; Legg and Nagy 2006; Field et al. 2007). Each element is described here for the BsM program.

Objectives of the BsM Program

The four objectives of the program are to: (1) estimate, with known confidence, the current status and trends in selected indicators (e.g., abundance, body size; see OMNRF 2016) of Ontario's fishery resources in lakes; (2) describe the geographic distribution, extent, and characteristics of aquatic resources in Ontario lakes; (3) identify natural and anthropogenic stresses affecting the condition of aquatic resources, and (4) provide reports on the state of fisheries and aquatic environments.

Standardized Sampling Methods

Standardized methods that define when, where, what, and how to sample are crucial to ensure comparisons can be made among multiple lakes within and among FMZs (Bonar and Hubert 2002; Bonar et al. 2009; Smith and Blackwell 2019). In Ontario, approximately 100–150 lakes are sampled annually with FMZ reporting occurring on a 5-year cycle. At the time of this publication, two cycles of sampling have occurred, 2008–2012, 2013–2017, and the second year of Cycle 3 is complete.

Where and How Many Lakes to Sample

Lakes are selected using a stratified-random, spatial sampling design. The first level of stratification is FMZ. The second level is lake surface area. Five lake size categories were defined (20–100, 100–500, 500–1,500, 1,500–5,000, and 5,000–250,000 ha, respectively) to ensure that small lakes, which are

Table 1. Examples of the goals, objectives, indicators, benchmarks, and actions that can be included in Fisheries Management Zone (FMZ) plans.

Description and examples of plan content
Examples of FMZ goals, which can reflect ecological or socioeconomic interests:
• Manage for the improvement of fisheries, including healthy natural fish populations, beyond a minimally sustainable condition, enhance urban opportunities, and provide a safe food source.
• Protect ecosystem, species, and genetic diversity within FMZ into the future.
• Improve the general public's respect for natural resources, their awareness of ethical practices around aquatic ecosystems, and their knowledge of regulatory principles and practices.
Examples of objectives that are more specific targets than goals because they include indicators and benchmarks used as comparators to evaluate status:
• Increase the number of self-sustaining Lake Trout lakes in FMZ 10 above abundance benchmarks to 50% (from 32%) within 20 years.
• Maintain the abundance of mature Walleye measured in Cycle 1 of broad-scale monitoring.
• Increase the number of Walleye ≥ 45 cm per North American gang to greater than the 2009 value within 10 years.
• Develop a strategy to protect and improve fish habitat within management cycle.
• Minimize the introduction and spread of aquatic invasive species within management cycle.
• Promote awareness of the principles of species management and invasive species by producing a number of fact sheets and distributing via websites, social media, stakeholder distribution networks, and hard copy.
Examples of management actions that are the interventions implemented to potentially meet the goals and objectives:
• Allowable harvest of two Lake Trout (only 1 > 40cm) from January 1 to the first Monday of September.
• Allowable harvest of four Walleye (None between 43 and 60 cm, and one fish >60 cm) between January 1 to the third Sunday in March, and third Saturday in May to December 31.
• Maintain existing fish sanctuaries.
• Continue to apply provincial regulations, guidelines, and permit conditions to protect fish habitat, particularly with respect to flows and levels in regulated waterbodies where it affects Walleye recruitment and productivity.
• Increase communication with stakeholders by conducting regular outreach activities focused on fisheries and compliance issues and by producing literature (fact sheets, status reports) suitable for posting to the web or for handing out at public meetings.

more abundant in each FMZ, are not the majority of lakes selected for monitoring. Very large lakes (e.g., Lake Nipigon and Lake of the Woods, which are >250,000 ha) are not included in BsM and are monitored individually. The third stratification for selection is the presence of three recreationally important fish species: Walleye, Lake Trout, and Brook Trout. With knowledge of the number of lakes with each species in each FMZ (Table 2), it was decided that ~10% of the lakes with each species would be sampled each cycle (every 5 years) to measure trends in the populations through time (Figure 3). An equal number of lakes are randomly selected each cycle as "state lakes" for one-time sampling (Table 2). Although not mutually exclusive, the data from "trend lakes" can be used to report on the status of trends of fisheries populations through time while the state lake data can be used to understand the distribution and characteristics of aquatic resources, and the state of stresses (e.g., invasive species) across the landscape.

The proportional approach standardized how many lakes were allocated for sampling among zones and recognized that the number of lakes with Walleye, Lake Trout, and Brook Trout differ among zones (Table 2). However, proportional approaches to determine sample sizes for these types of monitoring designs may lack the statistical rigor required to detect change (Cohen 1988; Legg and Nagy 2006; Field et al. 2007). To address this issue, power analyses were conducted to determine the minimum number of lakes necessary to detect a trend in abundance in the zones (Appendix S1). The minimum number of lakes needed to detect a 1.5-fold change in abundance were 20 lakes for Walleye and 10 lakes each for Lake Trout and Brook Trout. This minimum was applied in FMZs that did not have many lakes with the target species (Table 2).

What to Sample

Fishes, zooplankton, habitat, and angling activity are measured for each BsM lake (Figure 4). Counts and lengths are recorded for all fish species; weight, aging structures, and tissue samples are collected for genetic and contaminant analyses for recreationally important species. Lake bathymetry, water chemistry, water clarity, and temperature and dissolved oxygen profiles are measured to describe lake habitat. Aquatic Invasive Species (AIS) are documented, and angler activity is measured using aerial angler counts.

How to Sample

The sampling methods are standardized across the program (Sandstrom et al. 2008). Large-bodied fishes are caught using the standard North American (NA) multi-mesh benthic gillnets that target species >20 cm (Bonar et al. 2009). Small-bodied fish species and young of the larger-bodied species are caught using standard Ontario (ON) multi-mesh gillnets (Sandstrom et al. 2008). Both nets are deployed using a depth-stratified, random sampling design. Zooplankton samples are collected using plankton nets and examined in the laboratory for AIS, such as spiny water flea *Bythotrephes longimanus*, and veligers of Dreissenid mussels. Water samples for chemical analysis and Secchi disc measurements are collected in the spring. All gillnetting, summer Secchi measurements, temperature and dissolved oxygen profiles, and zooplankton sampling occurs when surface water temperature is greater than 18°C, after the onset of thermal stratification (Sandstrom et al. 2008). To estimate angler activity, the number of boats (recreation vs. angling), number of anglers in a boat (where discernable), ice huts, and open ice fishermen are counted via aerial flights (Chu et al. 2016).

Operational Implementation

During Cycle 1 (2008–2012) and 2 (2014–2018), 726 and 688 lakes were sampled, respectively, with 570 being repeated trend lakes. Sampling at this scale requires 15–20 field crews per year trained in the standard sampling methods and safety practices. The sampling program also requires significant operational logistics: equipment purchases, rentals, and

Table 2. Original design of the number of lakes monitored as part of the Broad-scale Monitoring Program for Inland Lakes in Ontario.

		Known Walleye, Lake Trout, and Brook Trout lakes			10% sample (minimum)			Total number of lakes	
FMZ	n lakes	Wa	LT	BT	Wa (20)	LT (10)	BT (10)	*Trend* sample	*State* sample
1	107	3	4	3	3	4	NA	7	3
2	11,930	504	101	9	50	10	NA	60	281
3	407	28	0	4	20	NA	NA	20	10
4	4,456	842	126	4	84	13	NA	97	105
5	3,497	782	468	0	78	47	NA	125	82
6	2,066	288	136	105	29	14	11	54	49
7	2,058	290	113	144	29	11	14	54	48
8	2,986	401	61	28	40	10	NA	50	70
10	3,230	123	561	649	20	56	65	141	76
11	984	115	140	53	20	14	NA	34	23
15	2,133	146	391	428	20	39	43	102	50
16	362	22	2	20	20	NA	NA	20	9
17	134	29	0	1	20	NA	NA	20	3
18	613	103	56	3	20	10	NA	30	14
Total	34,972							823	823

FMZ=Fisheries Management Zone; BT=Brook Trout; LT=Lake Trout; Wa=Walleye.

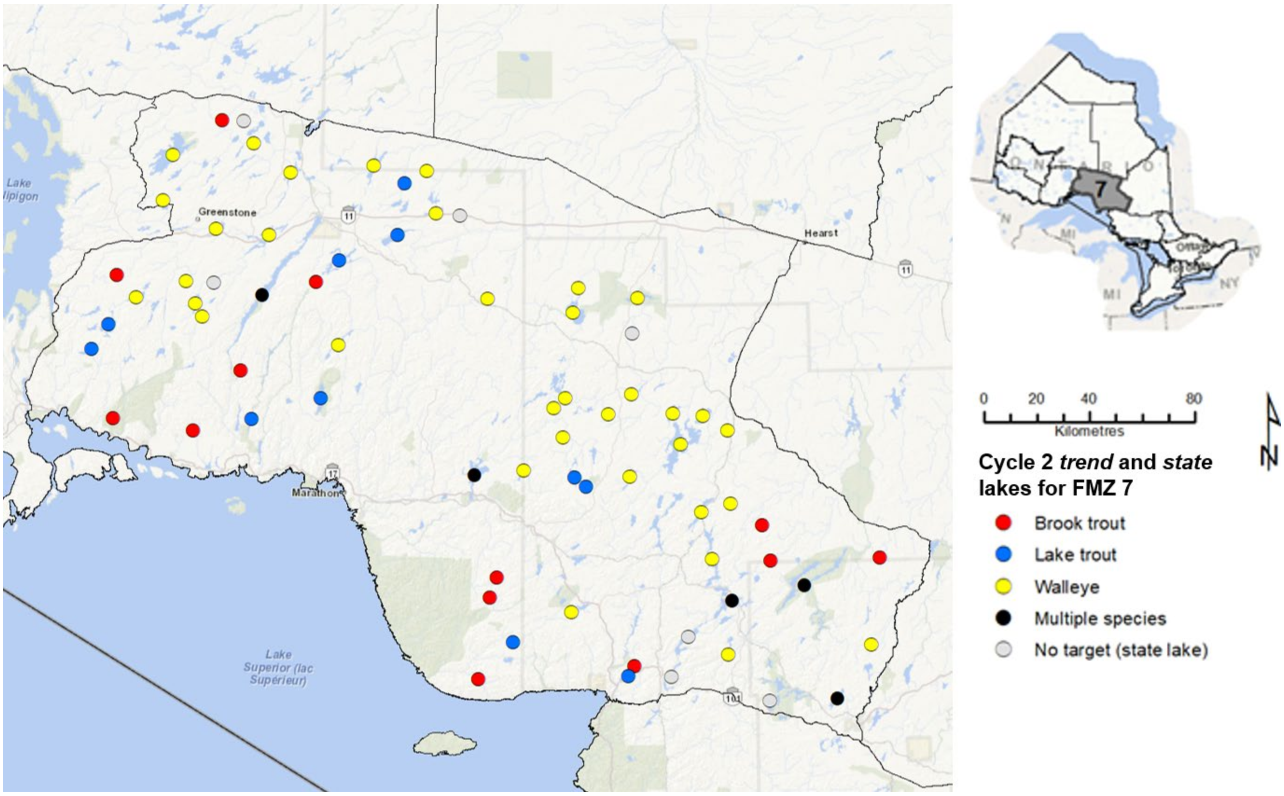

Figure 3. Example of lakes selected for "trend" and "state" monitoring in Fisheries Management Zone (FMZ) 7 during Cycle 2 (2013–2017) of the Broad-scale Monitoring Program for Inland Lakes in Ontario.

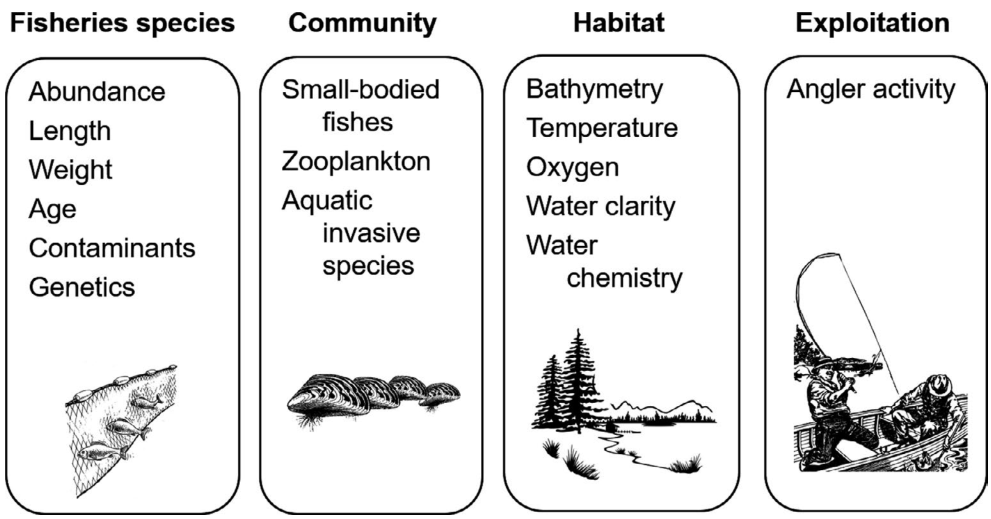

Figure 4. Fish, zooplankton, habitat, and angler activity data collected for each lake surveyed as part of the Broad-scale Monitoring Program for Inland Lakes in Ontario.

maintenance, hiring of crews, organization of travel, food, and accommodations, and aerial flight coordination. These tasks require a team of operational supervisors, technicians, and biologists and emphasizes the importance of sufficient staffing for program delivery.

Science Development

Science development is an integral part of the program and requires an ongoing commitment to fund and conduct the research necessary to develop diagnostic indicators and improve the efficiency of the design. Several biological and ecological indicators are calculated using the BsM data, e.g., trophic status, abundance estimates of different species, and species diversity indices (OMNRF 2016). Mortality and biomass reference points that are standard indicators for stock assessments worldwide (Caddy and Mahon 1995) have been developed for Walleye (Lester et al. 2004; Lester et al. 2014) and are being developed for Lake Trout, Brook Trout, Northern Pike, and Smallmouth Bass. Ultimately, these reference points will be used to populate Kobe (phase) plots that describe the status of populations within each FMZ (Maunder and Aires-da-Silva 2011).

Other examples of science development efforts include calibrations of the NA nets to netting protocols and configurations used in the past (e.g., Giacomini et al. 2020). Development of a contact retention selectivity tool for the NA nets (Walker et al. 2013). Evaluations of double-gang versus single-gang ON net configurations, and the addition of a pelagic netting component to improve netting efficiency.

Standardized Information Management and Reporting

Standardized information management and reporting is just as important as the standardized methods used to collect the data. This includes management of fundamental (e.g., geographic data), field, and post-field (e.g., water chemistry and aging results) data. A centralized database is maintained to store data as well as automate some of the data quality assurance/quality control, and queries for standardized reporting. Reporting products are crucial for transferring field results and diagnostics to planners, the public, and councils. Standardized BsM reports scale from individual lake to provincial summaries and have different schedules for release (Table 3).

Multidisciplinary Team

Program delivery requires (1) field crews and supervisory staff for coordinating field work, (2) data clerks, data analysts, database developers, and geographic information system specialists for information management, (3) policy analysts, fisheries biologists, and research scientists for scientific design, diagnostic indicator development, and reporting standards, and (4) biologists for planning, management, and engagement with the FMZ advisory councils. External partnerships were also established with the Ministry of Environment, Conservation, and Parks to process the water chemistry samples and share results, and the Arnott Lab at Queen's University to search the zooplankton samples for invertebrate AIS.

Adaptive Monitoring

The field component of BsM is an adaptive process responding to knowledge gained during each field season and funding realities (Figure 5). For example, during the first years of Cycle 1, it became apparent that surveys in remote northern lakes (FMZ 1, 2, and 3; Figure 1) were beyond the financial scope of the program. Access to these remote lakes required long-distance aerial transport of crews and equipment and was not sustainable in the long-term. The decision was made to exclude those zones from the program, but to encourage community-based monitoring of lakes near Indigenous communities with MNRF's Far North Branch.

After Cycle 1, the small lake size categories were changed from 20–100 ha and 100–500 ha to 5–50 ha, 50–500 ha, because lakes <50 ha were difficult for crews to access. It was decided that lakes ≥50 ha would be selected for Walleye and Lake Trout trend lakes. However, lakes 5–50 ha with Brook Trout would still be used as trend lakes for that species, because they are typically found in these small lakes and rarely coexist with Walleye or Lake Trout.

After Cycle 2, a 10-year design review was conducted to determine where modifications could be made given two cycles of monitoring. The original minimum target of 20 Walleye and 10 Brook Trout lakes were not met in some zones. As there are no additional funds to sample more lakes in the under-sampled zones, it was decided that a new, equitable minimum sample size of lakes was required for the program. The new minimum was set at 25 trend lakes per species, based on achieving an effect size of 0.5, alpha = 0.1, and power = 0.8 for a two-tailed paired *t*-test (Steidl et al. 1997; Lougheed et al. 1999; Di Stefano 2003).

The status of the state lake monitoring was also scrutinized during the 10-year review. During Cycle 1 and 2, 113 and 183 state lakes were surveyed, respectively. This effort fell well below the original target of 823 state lakes per cycle. However, state lakes are needed to meet the objectives of the program. Additionally, examination of the fish abundance data indicated that most trend lake populations were reasonably stable between 5-year cycles. Therefore, it

Table 3. Standard reporting products and their content generated from the Broad-scale Monitoring Program (BsM) for Inland Lakes in Ontario.

Reporting standard	Description of content	Target audience and reporting timeline
Field work communications	Flyers notifying the public of upcoming BsM survey activities and can describe the lake(s) to be sampled, the methods used for sampling (e.g., gillnets), and or how the data are used to inform management decisions	Local communities; released annually
Lake Bulletins	Web-based documents posted to Fish ON-line (Available: https://bit.ly/34bzYRl); Ontario Ministry of Natural Resources and Forestry (MNRF)'s interactive public website that can be used to search for lake information including fishing regulations, lake-specific BsM results, access points, and bathymetric maps	Public; released annually
Lake Synopses	Documents containing lake-level summaries of fisheries population, fish community, habitat, and angler activity data collected during BsM surveys (OMNRF 2016). These documents can be used to inform Fisheries Management Zone (FMZ) planning	MNRF staff for FMZ planning; released per cycle
Data Reports	Documents containing the raw data for all ecological and angler activity data collected for each lake surveyed within each FMZ per cycle. These documents can be used to inform FMZ planning.	MNRF staff for lake-specific and FMZ planning; released per cycle
Zone Reports	FMZ level summaries of all ecological and angler activity data. These documents can be used to inform FMZ planning	MNRF staff and Councils for zone planning; released per cycle
Provincial summaries	Inform state of the resource reports such as the State of Ontario Biodiversity Report (OBC 2015)	MNRF and public; release dependent on provincial reporting timelines

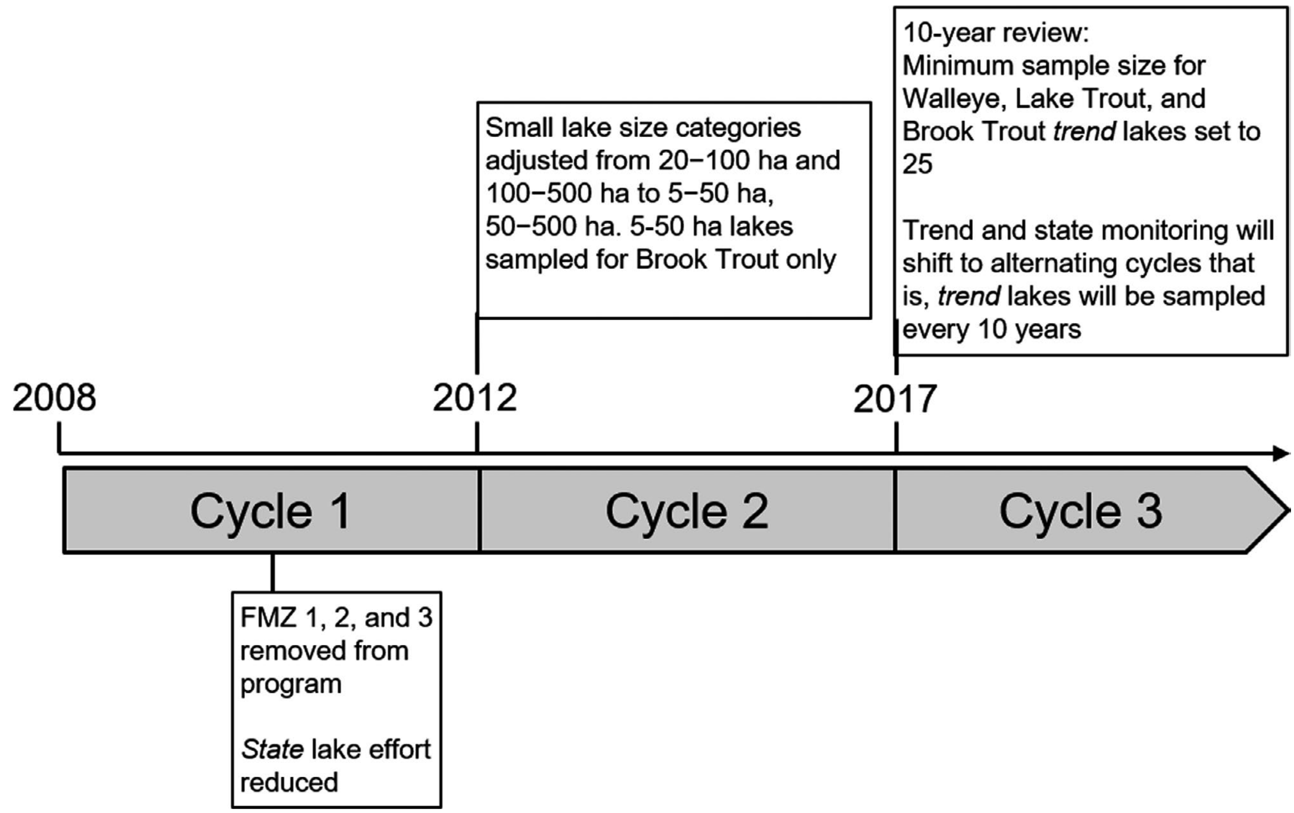

Figure 5. Timeline of adaptive monitoring changes to the Broad-scale Monitoring Program for Inland Lakes in Ontario.

Table 4. Number of lakes sampled as part of the Broad-scale Monitoring Program for Inland Lakes in Ontario. Some lakes were sampled for more than one species so values in the columns may not add up to totals.

	Cycle 1				Cycle 2				Cycle 4	Cycle 5		
	Trend				Trend					Trend		
FMZ	Wa	LT	BT	State	Wa	LT	BT	State	State	Wa	LT	BT
1	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	NA	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4	76	16	NA	6	65	14	NA	41	50	25	25	NA
5	84	49	NA	1	53	36	NA	25	50	25	25	NA
6	30	15	10	38	24	10	10	21	75	25	25	25
7	31	14	10	NA	40	16	13	10	75	25	25	25
8	36	10	NA	18	38	10	NA	28	50	25	25	NA
10	20	53	55	NA	23	35	53	30	75	25	25	25
11	20	14	NA	8	21	12	NA	13	50	25	25	NA
15	29	22	11	15	18	13	10	NA	75	25	25	25
16	19	1	NA	8	18	NA	NA	2	20	20	NA	NA
17	22	NA	NA	6	20	NA	NA	1	25	25	NA	NA
18	24	15	NA	13	20	12	NA	3	50	25	25	NA
Total				726				688	595			595

BT=Brook Trout; FMZ=Fisheries Management Zone; LT=Lake Trout; Wa=Walleye.

was decided that the program will shift to alternating trend and state cycles. Cycle 3 (2018–2022) is a transitional cycle during which trend lakes sampled in Cycle 1 and 2 would be re-surveyed to meet reporting commitments to councils, and lakes will be added to meet the 25 lake minimum in FMZs where 25 lakes were not sampled in Cycle 1 and 2. Cycle 4 (2023–2027) will be a state cycle and Cycle 5 would be a trend cycle (Table 4).

INFORMING BSM PROGRAM OBJECTIVES, AND PROVINCIAL AND INTERNATIONAL INITIATIVES

In addition to fisheries objectives met by the program, BsM has significantly improved our understanding of fish species distributions. Netting data confirmed extant and new populations for three species being considered for assessment by the Committee on the Status of Endangered Wildlife in Canada: Pygmy Whitefish *Prosopium coulterii*, Northern Sunfish *Lepomis peltastes*, and Deepwater Sculpin *Myoxocephalus thompsonii*. Additionally, the discovery of Threespine Stickleback *Gasterosteus aculeatus* in a northern lake represents a range extension of more than 350 km. The data also indicated that either our understanding of some species distributions is incorrect or there have been losses in some lakes. For example, Brook Trout were expected to be found in 98 and 80 lakes during Cycles 1 and 2, respectively, but were not detected in 18 and 5 of those lakes, respectively.

In response to the global Strategic Plan for Biodiversity 2011–2020 (CBD 2010), many jurisdictions regularly report on the state of their biodiversity. Cycle 1 BsM data were used to generate alien aquatic species, water quality, and state of fisheries indicators included in the 2015 State of Ontario's Biodiversity Report (OBC 2015). Alien species (species not native to Ontario or species introduced beyond their native range) were detected in 46% of the lakes sampled in Cycle 1 (Figure 6), and mortality estimates generated from BsM data indicated that Walleye fishing mortality exceeded predicted sustainable levels in southern FMZs (Figure 7).

The BsM data have also been analysed to show that terrestrial protected areas confer some benefits to lake fish communities (Chu et al. 2018; Lamothe et al. 2019). This has implications for the design of freshwater protected areas to meet the Convention on Biological Diversity targets to protect at least 17% of terrestrial and inland water areas around the globe by 2020 (CBD 2010). Chu et al. (2018) also demonstrated that community size spectra can be used to measure ecological integrity (composition, function, and structure); the maintenance and restoration of ecological integrity is an overarching goal for protected area management within MNRF and internationally (Parrish et al. 2003; *Provincial Parks and Conservation Reserves Act 2006*).

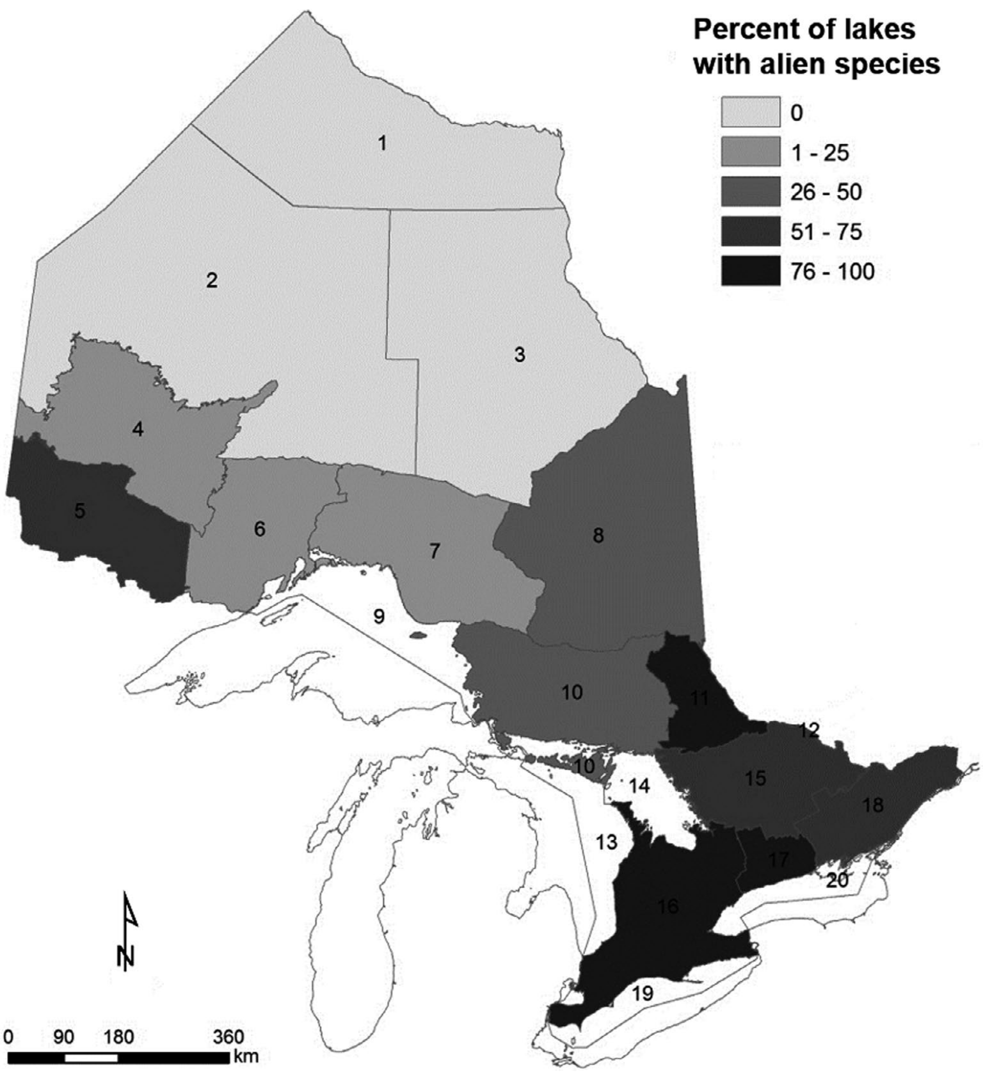

Figure 6. Percent of lakes with alien (aquatic invasive species and native species introduced outside of their range) species surveyed as part of the Broad-scale Monitoring Program for Inland Lakes in Ontario.

ADVANCEMENTS IN SCIENCE WITH BSM

Between 2012 and 2020, 27 scientific primary publications have been produced using BsM data (Appendix S2). These publications span a variety of disciplines, e.g., Tunney et al. (2012) used BsM data to explore food web responses to changing climatic conditions. Alofs et al. (2014) found a reduction in the distributions of small-bodied prey fishes coincident with the northward expansion of Centrarchids in Ontario. Gutowsky et al. (2019) examined the interactions among multiple pressures impacting Walleye populations. Nienhuis et al. (2014) found that the presence of zebra mussels *Dreissena polymorpha* affected the condition, growth, and relative abundance of some game fish species. Given the range in environmental conditions and lake types, the findings from Ontario likely improve our understanding of lakes in other temperate and boreal regions of the world.

RECOMMENDATIONS FROM LESSONS LEARNED

The key lessons learned since BsM was initiated are presented here as they may inform the implementation or continuation of similar monitoring programs in other jurisdictions. The lessons are ranked from most to least important from the perspective of what is required to sustain BsM.

Clearly communicate the objectives and deliverables of the monitoring program and do not overcommit. From the outset, communicate within the agency how policy, management, and monitoring are linked, what is in and out of scope of the monitoring program, and how it informs other agency initiatives. The ecosystem-based monitoring approach applied in BsM has spillover benefits for other business areas (e.g., protected areas and land use planning, and biodiversity reporting). However, BsM is not a panacea to understand every lake issue that may arise across the province. Individual lake-level monitoring and management happens for nine lakes and two lake chains (Ottawa River [FMZ 12] and Winnipeg River) where there are significant pressures from commercial and recreational fisheries and/or human development within their watersheds. Lakes with impending anthropogenic pressures, e.g., industrial development, or lakes identified for protection or restoration can also be managed locally (OMNRF 2015). Hayes et al. (2003) noted a similar situation in Michigan where local-scale needs may arise and conflict with larger-scale monitoring. They suggest

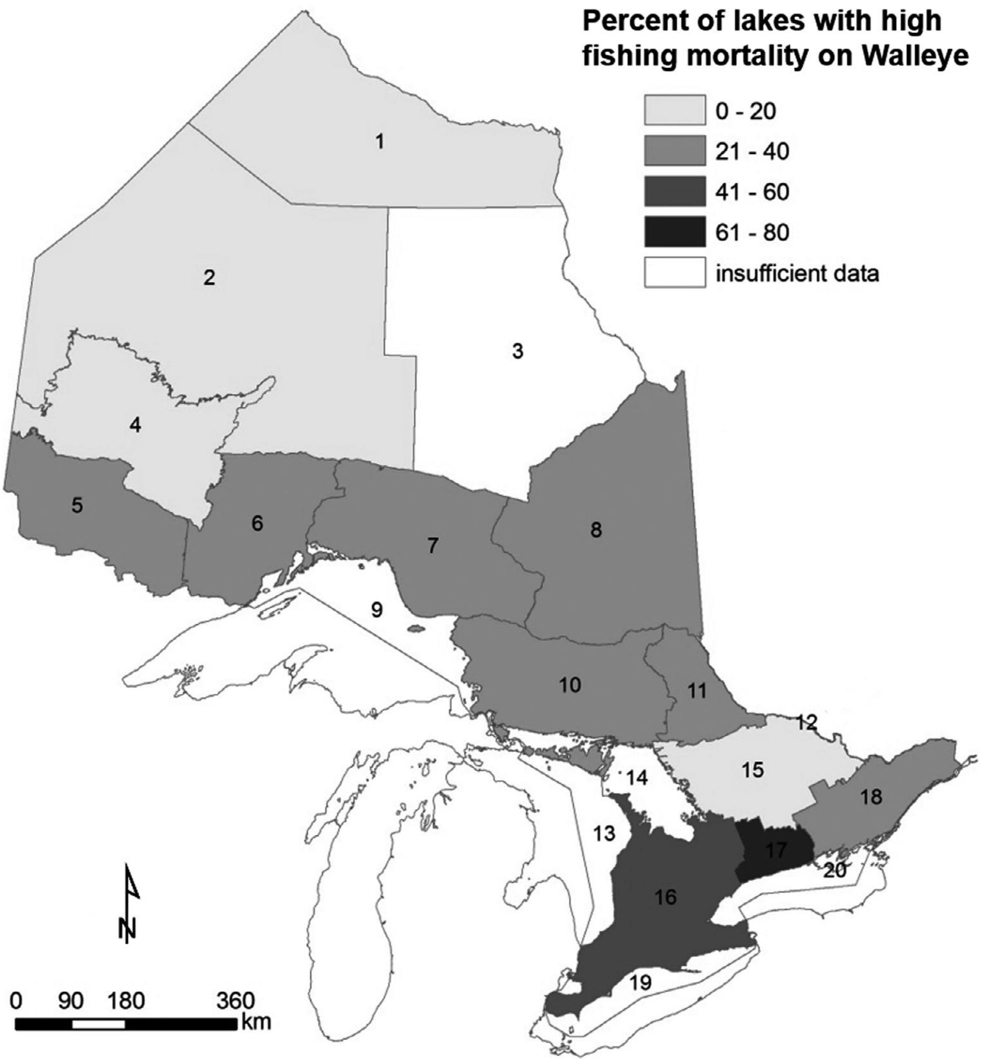

Figure 7. Percent of sampled Walleye lakes in each Fisheries Management Zone with Walleye fishing mortality equal to or greater than natural mortality based on the first 5-year cycle of Ontario's Broad-scale Monitoring Program for Inland Lakes.

that for these cases, discussions among affected organizational levels should produce a rational basis for deciding the allocation of sampling resources. In Ontario, separate allocations exist, but the feedback loops where local studies may inform broad-scale efforts or vice versa have not been established and require continual discussions among different arms of the agency.

Synchronization of the monitoring and management cycles takes time. Data reporting, soliciting council membership engagement, and decision making are not impulsive processes. After 10 years, FMZ plans are either complete or in progress for 10 of the 12 FMZs. Agencies initiating or maintaining these broad-scale programs have the responsibility to encourage and maintain engagement with interested parties.

Investment and internal and external support are key to maintaining the monitoring program. Dedicated stable and long-term funding is required to support these types of monitoring programs, but vocalized internal and external support are equally important. Within the agency, continual downward and upward communication, and upper management support are necessary to uphold the value of the program. Partnerships with other agencies, public groups, and academic partners maximize the potential utility and value of the monitoring data, and contribute to the viability of the program.

A clear governance structure will improve program efficiency. In agencies where the monitoring and science section may be separate from the management and regulatory section, terms of reference defining roles and responsibilities of staff and lateral communication between sections will contribute to the effective use and interpretation of the data while ensuring the data also meet the original and shifting management needs.

CONCLUSION

Inland freshwater fisheries have been important to humans for generations. Maintaining these resources requires evidence-based decisions that have been encouraged for decades in natural resource management and conservation (Holling 1978). Evidence-based management has been practiced in Ontario for some time (OMNR 1983). The EFFM and BsM are an integration of science, monitoring, reporting, and management that aims to maintain sustainable recreational fisheries that address cultural, ecological, and socioeconomic needs for generations to come.

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.

Supplementary Material AFS