Lake Simcoe
Monitoring Report

2014

Ontario

PIBS 9823e

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LAKE SIMCOE
MONITORING REPORT

2014

Résumé

En 2008, le gouvernement de l'Ontario a instauré la Loi sur la protection du lac Simcoe. Cette loi a pour objet « de protéger et de rétablir la santé écologique du bassin hydrographique du lac Simcoe ». En 2009, le Plan de protection du lac Simcoe a été publié. Ce plan traite d'enjeux clés pour la santé du lac Simcoe, notamment :
Lake Simcoe including:

- le rétablissement de la santé de la vie aquatique;
- l'amélioration de la qualité de l'eau;
- la protection et le rétablissement des rives et des zones naturelles;
- l'examen des effets des espèces envahissantes et du changement climatique.

L'approche de gestion est adaptive et intègre des données scientifiques et de surveillance continues afin de s'améliorer et de s'adapter.

Le rapport de surveillance du lac Simcoe de 2014, élaboré par le ministère de l'Environnement et de l'Action en matière de changement climatique, présente les résultats de tous les programmes de surveillance écologique du lac Simcoe et de son bassin hydrographique. Il comprend les contributions de l'Office de protection de la nature de la région du lac Simcoe et du ministère des Richesses naturelles et des Forêts. Le rapport décrit les tendances à long terme jusqu'en 2012 qui sont disponibles et fournit des renseignements sur les agents de stress et la santé écologique du lac Simcoe et de son bassin hydrographique.

Les résultats du rapport indiquent que des agents de stress continuent d'affecter la santé écologique du lac Simcoe et de son bassin hydrographique, notamment :

- la croissance démographique et l'urbanisation;
- les activités agricoles;
- la couverture naturelle restante pour soutenir les espèces fauniques;
- le changement climatique;
- les espèces envahissantes.

Le rapport cerne plusieurs améliorations au niveau de la qualité de l'eau et de la vie aquatique du lac Simcoe. Le phosphore total a beaucoup baissé dans la plupart des affluents et dans certaines stations près du rivage du lac. L'oxygène dissous en eau profonde de la fin d'été s'est nettement amélioré, et la biote aquatique sensible, comme les poissons indigènes d'eaux froides, montre des signes de rétablissement.

Cependant, certains indicateurs montrent encore des effets d'agents de stress. Les concentrations de phosphore dans certains affluents et dans les stations en eau libre du lac durant l'été sont encore plus élevées que les objectifs fixés, et l'oxygène dissous en eau profonde de la fin de l'été n'est pas à 7 milligrammes par litre de manière constante comme le prévoit le Plan de protection du lac Simcoe. Aussi, les concentrations de chlore ont nettement augmenté dans le lac et l'ensemble du bassin hydrographique.

Il est important de continuer à surveiller et à étudier les effets des agents de stress existants et émergeants pour protéger et rétablir la santé écologique du bassin hydrographique du lac Simcoe.

Summary

In 2008, the Ontario government passed the Lake Simcoe Protection Act, whose purpose is to "to protect and restore the ecological health of the Lake Simcoe watershed." This was followed by the Lake Simcoe Protection Plan in 2009. The Plan focuses on key issues critical to the health of Lake Simcoe including:

- restoring the health of aquatic life
- improving water quality
- protecting and rehabilitating shorelines and natural areas, and;
- addressing the impacts of invasive species and climate change.

The management approach is adaptive, incorporating ongoing science and monitoring to improve and adapt.

The 2014 Lake Simcoe Monitoring Report compiled by the Ministry of Environment and Climate Change presents the results of all ecological monitoring programs for Lake Simcoe and its watershed. It includes contributions from the Lake Simcoe Region Conservation Authority, and the Ministry of Natural Resources and Forestry. The report describes long-term trends up to 2012 where available that provide background information on stressors, and the ecological health of Lake Simcoe and its watershed.

The report results indicate that there continues to be a number of stressors affecting the ecological health of Lake Simcoe and its watershed. These include:

- human population growth and urbanization
- agricultural activities
- the amount of natural cover available to support wildlife species
- climate change, and;
- invasive species.

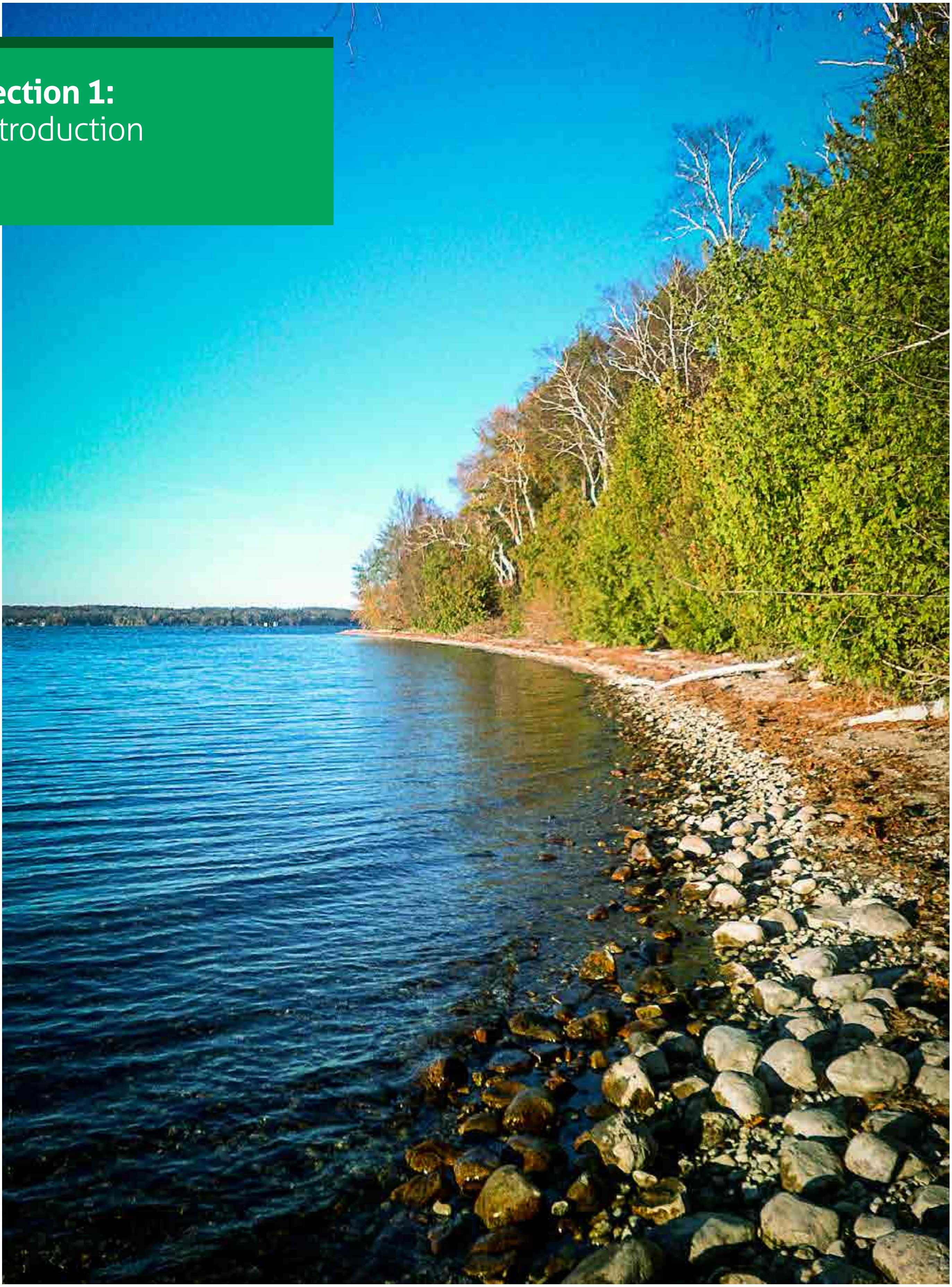
Several improvements in the water quality and aquatic life of Lake Simcoe were detected. Total phosphorus has decreased significantly in most of the tributaries and at some nearshore lake stations. The end of summer deepwater dissolved oxygen has significantly improved, and sensitive aquatic biota, such as native coldwater fish, have shown signs of recovery.

However, some indicators are still showing the effects of stressors. Phosphorus concentrations in some tributaries and at the open water lake stations during the summer were still above objectives, and the deepwater dissolved oxygen at the end of summer was not consistently at the Lake Simcoe Protection Plan target of 7 milligrams/litre. Another example is chloride concentrations, which have significantly increased across the watershed and in the lake.

It is important to continue to monitor and study the effects of existing and emerging stressors in order to protect and restore the health of the Lake Simcoe watershed.

Lake Simcoe, Ontario, Canada

Section 1:
Introduction



Introduction

Lake Simcoe and its watershed are essential components of the Ontario landscape, due to their size and southern location. Over the past two centuries, human activity has significantly affected the ecological health of the watershed and subsequently the lake. Starting in the 19th century, settlers began changing the watershed by clearing land for agriculture and urbanization (MacCrimmon and Skobe, 1970), which resulted in negative effects to the lake that became apparent around the 1930s (Hawryshyn et al., 2012). By the 1970s, citizens around the lake were concerned about the water quality, excessive aquatic plant growth (Veal and Clark, 1970), and the decline in the coldwater fishery (MacCrimmon and Skobe, 1970). Intensive water quality monitoring studies in the 1970s identified that issues in the lake were a result of high amounts of phosphorus (P) entering the lake from the watershed (Ralston et al., 1975). Numerous studies, recommendations and actions of multiple agencies followed under the umbrella of the Lake Simcoe Environmental Management Strategy (LSEMS) in an effort to reduce P loads (Palmer et al., 2011). In more recent years, however, Lake Simcoe and its watershed have been subjected to a number of new stressors, such as the introduction of invasive species and the effects of climate warming (Fig. 1).

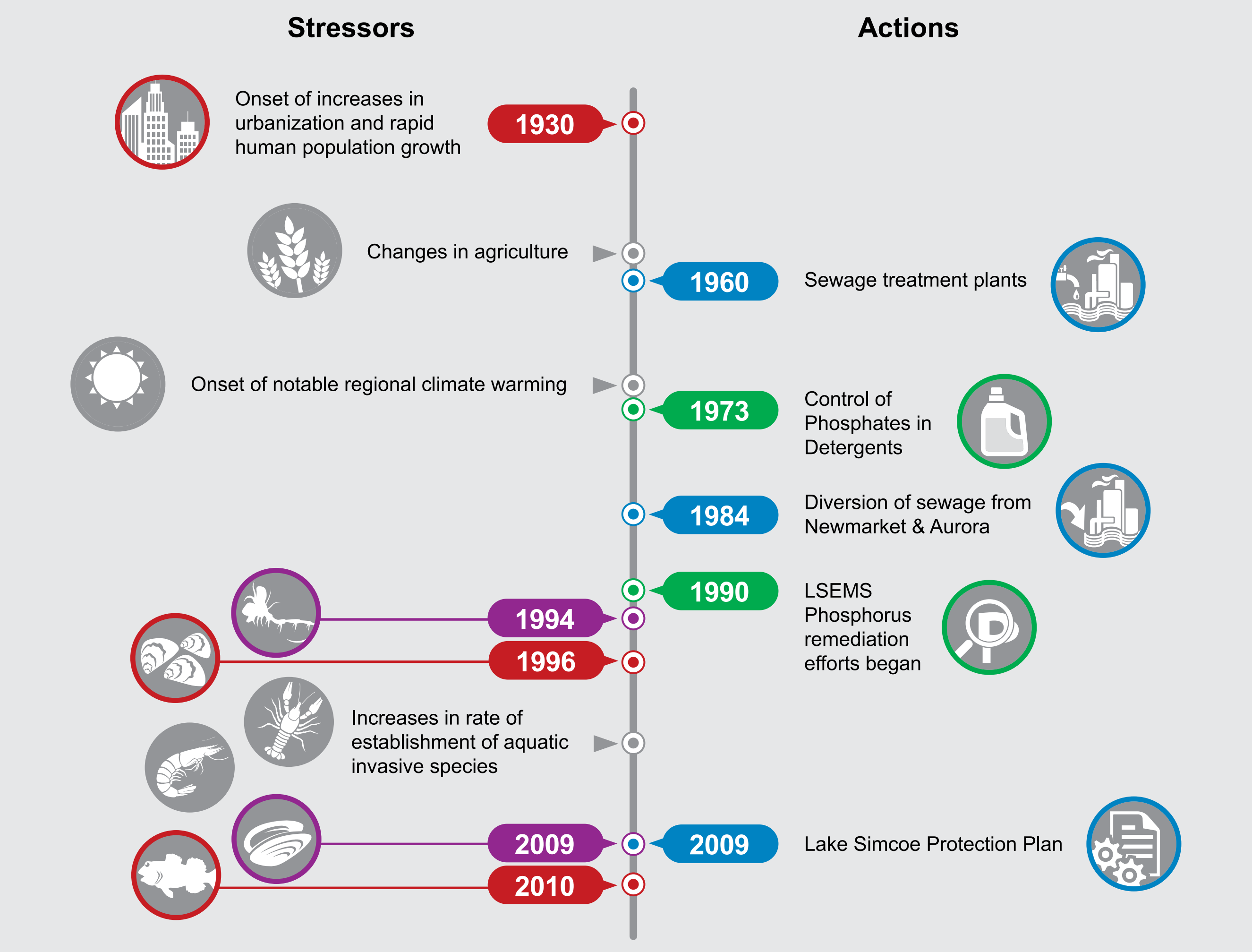


Figure 1: Timeline of key stressors and actions for Lake Simcoe

Ecological indicators and targets that inform the ecological health of Lake Simcoe and its watershed are identified throughout the Lake Simcoe Protection Plan (LSPP). The indicators and targets were determined during the development of the LSPP through consultation with Ministry experts as well as the Science Advisory Committee, a Minister appointed committee that is now called the Lake Simcoe Science Committee (LSSC). The LSSC is composed of leading scientific experts in watershed protection from academia, the LSRCA, the MOECC and the MNRF.

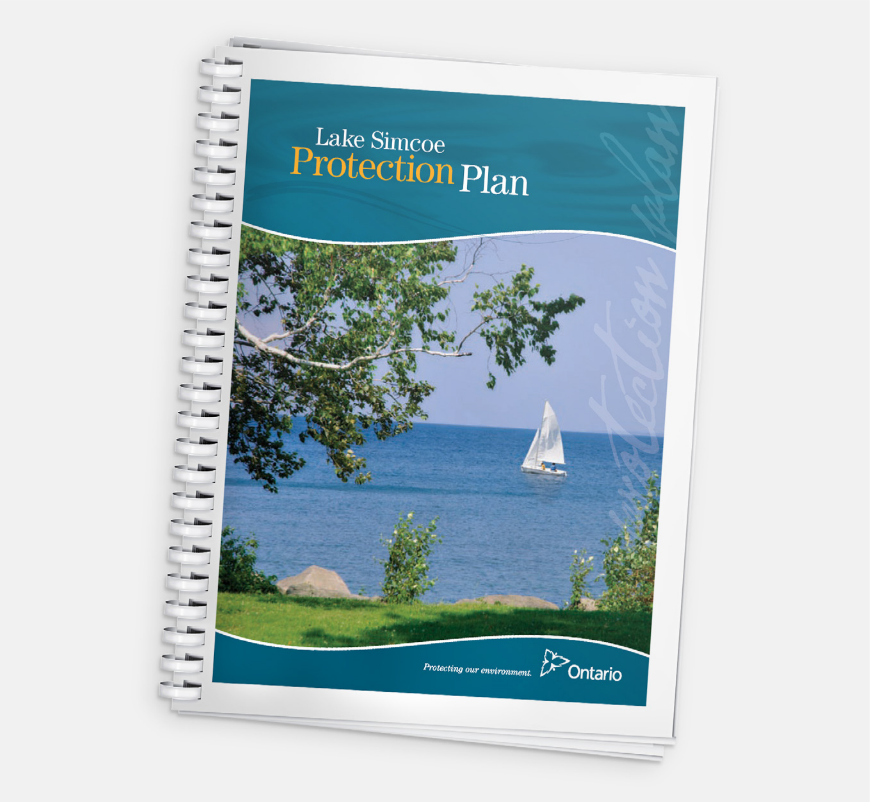
In 2008, the Ontario government passed the Lake Simcoe Protection Act (LSPA), with its primary purpose "to protect and restore the ecological health of the Lake Simcoe watershed". The LSPA was followed in 2009 by the Lake Simcoe Protection Plan (LSPP), the first plan of its kind in Canada for an individual lake and watershed. The LSPP is based on an adaptive management approach, which allows continuous adaptation of the management of the lake and its watershed as new understanding is gained from ongoing research and monitoring. A crucial component of adaptive management is to monitor and report on indicators of ecological health so that the effectiveness of management actions can be evaluated. The need to report on the lake's ecological health was highlighted in the LSPA, Section 12.2:

The Minister shall, at least once every five years, prepare a report that,

(a) describes the results of any monitoring programs;
(b) describes the extent to which the objectives of the Lake Simcoe Protection Plan are being achieved.

The information in the present report provides the background technical information for Section 12.2(a) of the LSPA, giving the long-term trends of all ecological monitoring programs for Lake Simcoe and its watershed. Some recent and ongoing research is also highlighted that helps fill in gaps in our understanding of the trends and their interactions. An upcoming 5-year Minister's report will highlight the key monitoring results of this technical report.

In 2011 and 2012, a multi-agency comprehensive monitoring strategy (CMS) working group listed ecological indicators, targets and monitoring policies in the Lake Simcoe Protection Plan (LSPP), whether or not these are monitored on the Lake Simcoe watershed, and, if so, under which monitoring programs. The list developed by the CMS working group provided the basis for what is presented in this report. The CMS findings illustrate, as will the results in this report, that many important indicators identified in the LSPP are monitored. The CMS working group developed recommendations for monitoring, as well as management and reporting, of ecological data. The CMS was released in 2015 as a companion to this monitoring report.

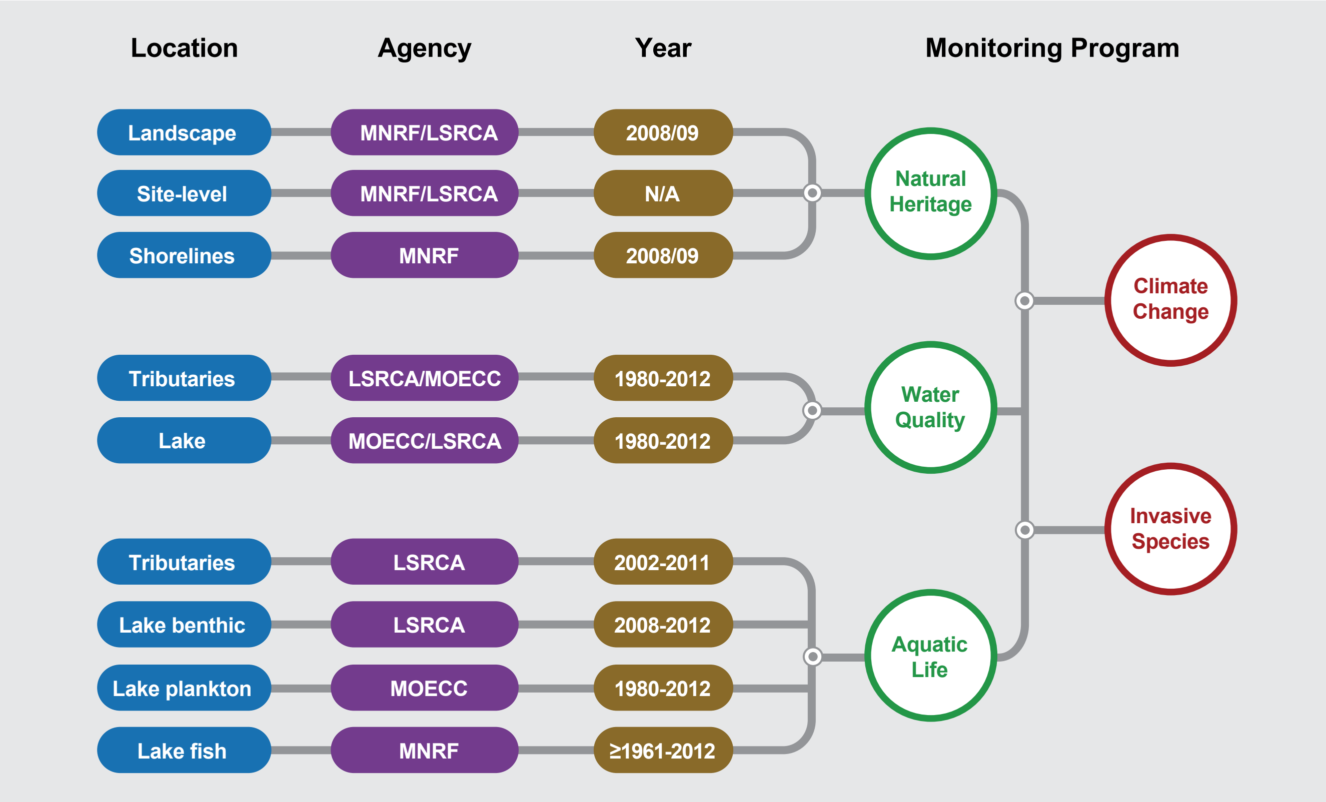


Cover of the Lake Simcoe Protection Plan

Monitoring Programs and Agencies

The monitoring of Lake Simcoe's ecological health is a collaborative effort. The primary agencies involved are the Ministry of Natural Resources and Forestry (MNRF), the Lake Simcoe Region Conservation Authority (LSRCA) and the Ministry of the Environment and Climate Change (MOECC). The Lake Simcoe monitoring programs can be classified into three main areas — Natural Heritage, Water Quality and Aquatic Life — which in turn provide monitoring information on Invasive Species and Climate Change. Each area is made up of a collection of smaller programs carried out by the three key agencies (Fig. 2).

Site-level natural heritage monitoring. *Credit: MNRF*



Location	Agency	Year	Monitoring Program
Landscape	MNRF/LSRCA	2008/09	Natural Heritage
Site-level	MNRF/LSRCA	N/A	
Shorelines	MNRF	2008/09	
Tributaries	LSRCA/MOECC	1980-2012	Water Quality
Lake	MOECC/LSRCA	1980-2012	
Tributaries	LSRCA	2002-2011	Aquatic Life
Lake benthic	LSRCA	2008-2012	
Lake plankton	MOECC	1980-2012	
Lake fish	MNRF	≥1961-2012	

Figure 2: The locations, agencies and years of data collection for Lake Simcoe monitoring programs

Small yellow lady's slipper (*Cypripedium parviflorum var. makasin*)

The Natural Heritage results in this report were provided by Science and Research Branch and Regional Operation Division's Southern Region of the MNRF. Currently, there is no implemented monitoring program for Natural Heritage so the data presented provide baseline information collected when the LSPA and LSPP were created (2008/2009). Water Quality is monitored collaboratively by the LSRCA and the Environmental Monitoring and Reporting Branch of the MOECC at permanent sites in the tributaries and the lake, as well as the intakes of three water treatment plants (WTPs) (Fig. 3). The MOECC also monitors groundwater quality through the Provincial Groundwater Monitoring Network, which was presented in the LSRCA's recent report (LSRCA, 2013). Aquatic life monitoring in the tributaries is performed by the LSRCA in collaboration with municipalities, and in the lake by the LSRCA, MOECC and the Lake Simcoe Fisheries Assessment Unit (LSFAU) of the MNRF. Some additional information provided in the Climate Change section was obtained from Environment Canada (EC).

Tributary	**Code**
Atherley Narrows	ATH
Black River	BL
Beaver River	BV
Hewitts Creek	HEW
East Holland River	HL
Hawkestone Creek	HS
Hotchkiss Creek	HTK
Kettleby Creek	KB
Leonards Creek	LEN
Lovers Creek	LV
Mount Albert Creek	MAC
Maskinonge River	MSK
North Schomberg River	NS
Pefferlaw Brook	PFR
West Holland River	SHLC
Talbot River	TAL
Tannery Creek	TC
Uxbridge Brook	UB
Upper Schomberg	US
Whites Creek	WC

Water Treatment Plants (WTPs)	**Code**
Keswick	KSWK
Sutton/Georgina	SUTN
Beaverton	BVRT

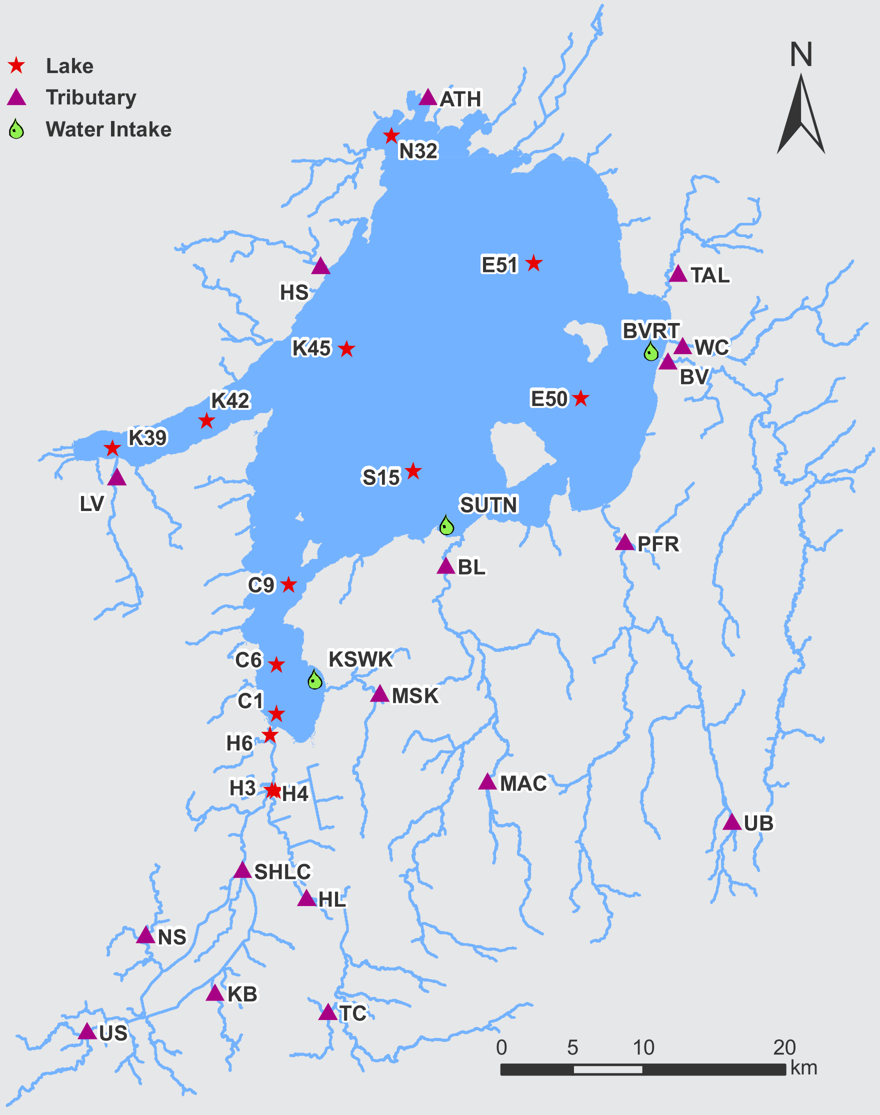


Figure 3: Water quality monitoring sites. *NOTE: only 3 of the 6 WTPs on Lake Simcoe are part of the intake monitoring program*

METHODS

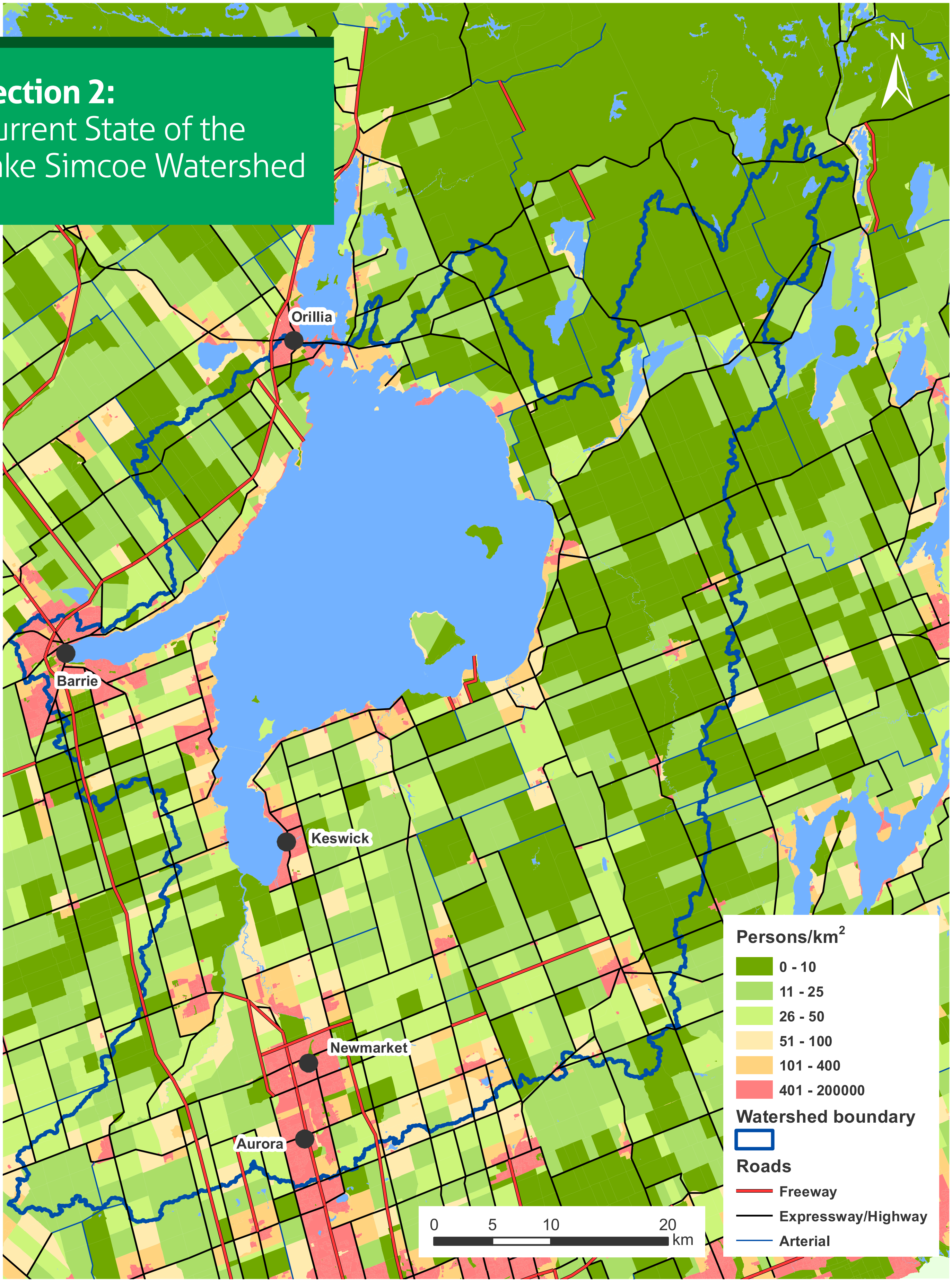
The primary focus of this report is on long term changes; thus, when long term data were available, they were presented as annual trends that were tested for significant changes over time with a non-parametric test (Mann-Kendall). A significance level of 0.05 was used that was adjusted by a correction for False Discovery Rate as it is more likely to obtain a significant result when repeatedly testing the same variable on a number of stations (Yan et al., 2008); the results are presented as no significant change (↔), or significantly increasing (↑) or decreasing (↓). It is important to keep in mind that a significant pattern may not be detected when less than 10 years of data were available for testing (Yue et al., 2002).

(Top) Monitoring river hydrology.
Credit: LSRCA

(Middle) Monitoring lake water quality.

(Bottom) Monitoring nearshore fish.
Credit: MNRF

Section 2:
Current State of the Lake Simcoe Watershed



Current State of the Lake Simcoe Watershed

The Lake Simcoe watershed has a total land area of approximately 2,899 km^2 with 35 tributaries. Currently, the Lake Simcoe watershed is made up of 45% agricultural and 7% urban areas (LSRCA and MOE, 2013). The percent of agricultural land has decreased slightly in recent years, while urban populations and areas have increased, a trend that is projected to continue (MOI, 2012). There were 435,500 permanent residents in the watershed based on the 2011 census, a significant increase from approximately 185,000 in 1981 (Fig. 4). The population is concentrated along major transportation corridors, such as Newmarket and Aurora along Yonge Street, and in Barrie along Highway 400 at the western tip of Kempenfelt Bay (Fig. 5). Around the lake there are also areas of high population density, particularly in the communities in and around Barrie, Orillia and Keswick, while the north-east part of the watershed is more sparsely populated.

METHODS

These population values are estimated from Canada Census data at the Census Subdivision (CSD) level. For CSDs that were partially contained in the watershed, population was estimated as the CSD total population in proportion to the area of the CSD falling within the watershed boundary; thus these values are slight underestimates (<5% of the true values).

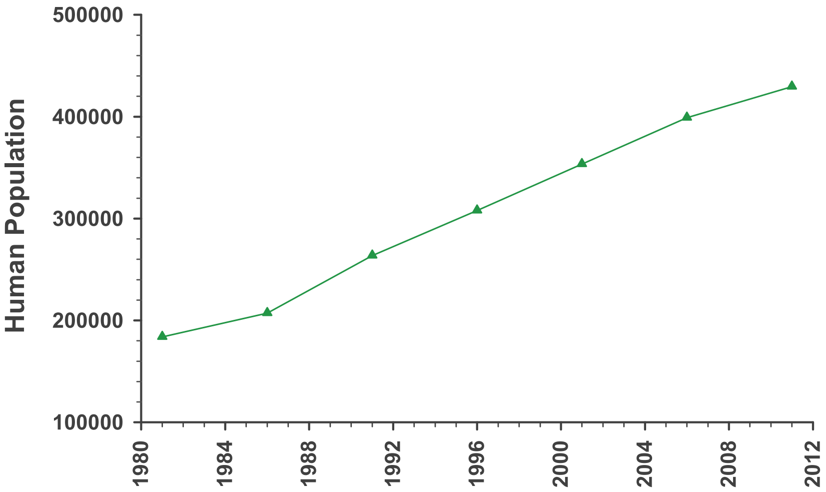


Figure 4: Human population numbers for the Lake Simcoe watershed

Looking northwest towards Bradford. *Credit: Nick Wilson*

Figure 5 *(Opposite page)*: Human population density in 2011: Census dissemination blocks

Lake Simcoe has over 300 km of shoreline, and several islands in its main basin and two large bays: Kempenfelt Bay that extends west from the main basin and Cook's Bay, which extends south (Fig. 6). The lake has a surface area of 722 km^2, with maximum depth of 42 m and a mean depth of 14 m. Water leaves Lake Simcoe through a single outlet at Atherley Narrows, which is located at the north end of the lake near Orillia. The amount of time a molecule of water remains in the lake (i.e., the average annual flushing time) is 11.3 years (O'Connor et al., 2013).

METHODS

Bathymetry information derived by the MNRF from Canadian Hydrographic Service original depth sounding field sheet, 1957, scale 1:36,000. This map should not be relied on as a precise indicator of routes or locations, nor as a guide to navigation. The MNRF shall not be liable in any way for the use of, or reliance upon, this map or any information on this map.

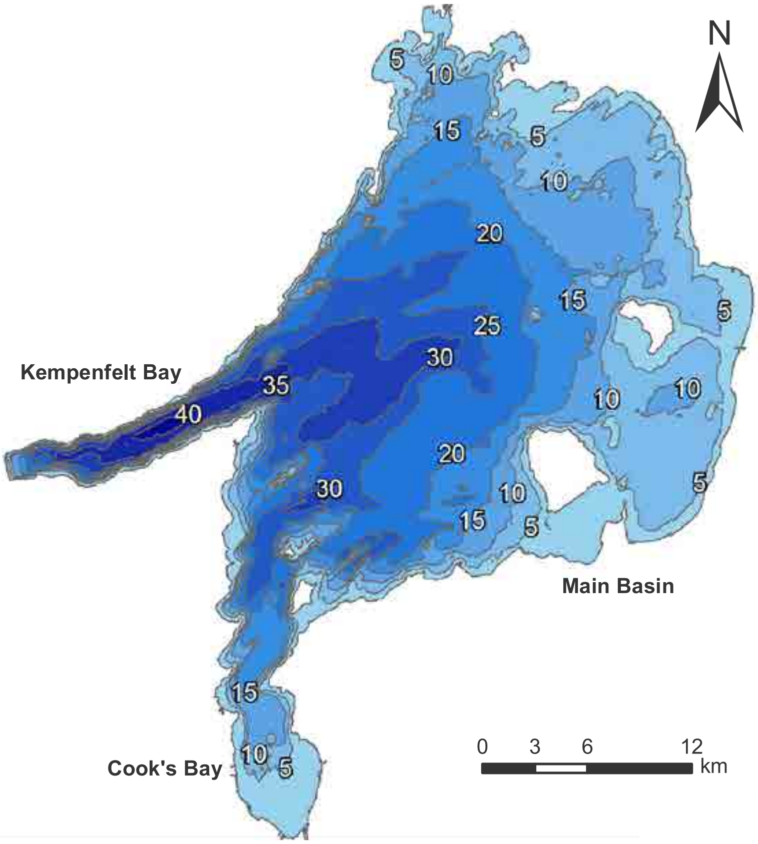


Figure 6: Bathymetric map of Lake Simcoe showing depth contours in metres

Trent-Severn Waterway, Lock 41.
Credit: Jim Eddie

The lake and watershed provide many services to Lake Simcoe residents. Six WTPs draw water from the lake, providing clean drinking water for several communities, while 14 municipal and one industrial water pollution control plants (WPCPs) discharge treated wastewater. Seven of the WPCPs discharge directly into Lake Simcoe, while the other eight discharge into rivers that flow into the lake. The lake and watershed also provide diverse recreational opportunities, from ice-fishing and snowmobiling in the winter to boating, fishing and hiking in the summer. For example, each summer, many recreational boaters make their way across Lake Simcoe as part of the Trent-Severn Waterway that connects Lake Ontario to Georgian Bay. The trends discussed in this report are directly and indirectly related to the many services provided by the lake and watershed.

Natural Heritage and Shorelines

With a large human population and significant growth planned, it is important that the watershed also continues to support high quality natural heritage and shoreline areas. Natural vegetative cover, which is composed of woodlands, wetlands and riparian areas, provides many ecological and social functions, and is closely linked with water quality in the tributaries and the lake. The indicators for natural heritage and shorelines from the LSPP presented in this report are:

1. The proportion of land in overall natural cover, woodland, wetland, and riparian vegetation, taking into account habitat quality
2. The degree of fragmentation of natural cover and features, and;
3. The integrity of natural shoreline, i.e., the amount of shoreline that is either undeveloped or maintained in a naturalized state

Credit: MNRF

METHODS

Both landscape and site-level monitoring programs are needed to monitor the natural heritage indicators in the Lake Simcoe Protection Plan (LSPP) (Fig. 7). Landscape level monitoring is based on regular large-scale mapping of natural cover and land use activities in the watershed, and allows the measurement of two types of indicators: amount of natural cover and its fragmentation. Site-level monitoring is the measurement of the composition and structure of vegetation at chosen sites across the watershed. These detailed measurements enable us to assess the quality of natural cover at the site level and make inferences about the quality of natural cover at landscape scales. The landscape level indicators presented here were based on 2008/2009 orthophotography, representing a single point in time. Both the LSRCA and MNRF map land cover for the Lake Simcoe watershed; for the purpose of this report, only the MNRF results are presented, which do not consider cultural thickets and meadows as natural as they are a result of anthropogenic activities. The percent of overall natural cover, woodlands, interior forests, wetlands, as well as the percent of natural cover within riparian areas 30 m and 120 m from streams were calculated for the whole watershed and for each subwatershed using Geographic Information Systems. These data are interpreted based on the LSPP target for high quality natural cover, and Environment Canada's Habitat Guidelines (EC, 2013) for other types of cover, which provide minimum thresholds for supporting populations of wildlife.

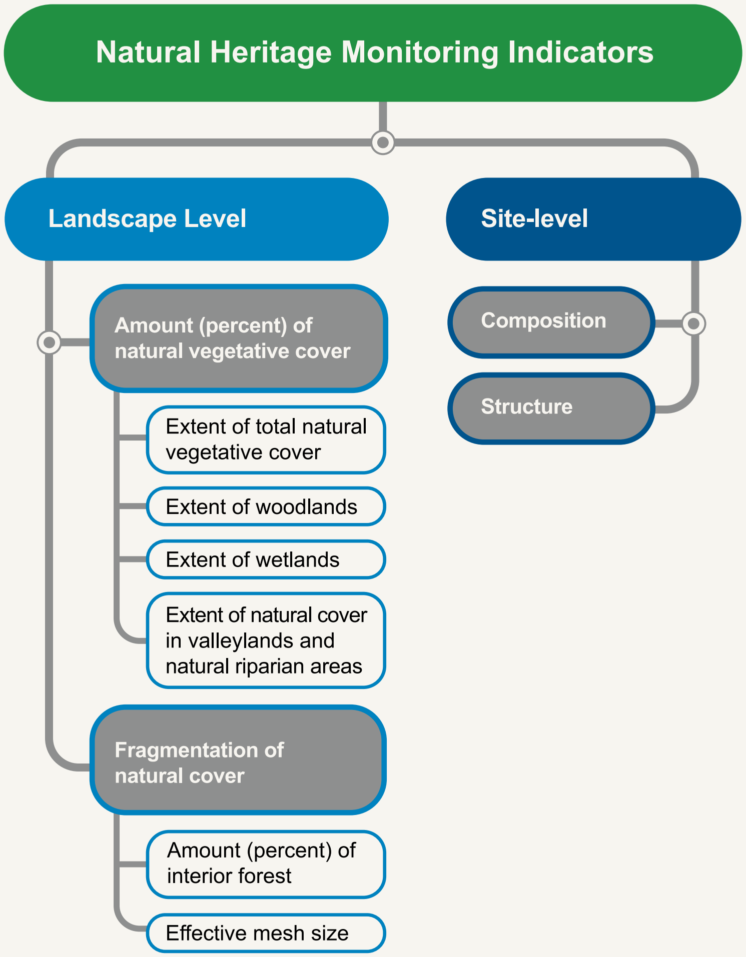


Figure 7: Natural heritage monitoring: Landscape and site-level indicators for determining the status and trends of natural vegetative cover in the Lake Simcoe watershed.

Natural vegetation

For LSPP monitoring purposes, overall natural vegetative cover was identified as woodlands, swamps, non-treed wetlands, grasslands, and other natural vegetation cover, which includes alvars, prairie grasslands, sand barrens and savannah. As a whole, the watershed had 35% overall natural cover in 2008/2009, which was below the LSPP's target of 40% high quality natural cover (Table 1; Fig. 8). Three subwatersheds had less than 20% natural cover: Maskinonge River, and Hewitts and Barrie Creeks. These subwatersheds were at higher risk, as a minor decline in the amount of natural cover may result in dramatic changes in biodiversity and ecological functions of vegetation, including impacts on water quality. At the moment, it is not possible to determine how much of the existing 35% of natural cover was high quality. To define high quality natural cover, both structural and compositional vegetation indicators are required, which can only be obtained from a carefully designed site-level monitoring program (see text box).

Table 1: Percent cover of natural heritage areas in 2008/2009. *NOTE: Red text indicates when cover was below Guidelines*

Subwatershed	Abbreviation	Natural Cover (%)	Woodland Cover (%)	Wetland Cover (%)	Riparian (30 m) Natural Cover (%)	Interior Forest Cover (%)
Barrie Creeks	BC	13	12	3	25	0
Lovers Creek	LV	29	25	16	65	5
Hewitts Creek	HEW	19	16	9	48	1
Innisfil Creeks	INN	29	27	12	43	6
West Holland	WH	25	21	11	42	4
East Holland	EH	27	22	11	48	3
Maskinonge River	MSK	18	14	9	45	1
Georgina Creeks	GC	36	33	16	41	9
Black River	BL	45	41	25	66	13
Pefferlaw River	PFR	38	35	17	66	9
Beaver River	BV	28	21	19	59	3
Whites Creek	WC	32	26	23	42	7
Talbot River	TAL	45	36	22	63	10
Ramara Creeks	RAM	35	28	26	44	10
Oro Creeks North	OCN	39	35	13	68	7
Hawkestone Creek	HS	50	45	23	74	12
Oro Creeks South	OCS	41	37	12	63	6
Fox Island	FOX	69	69	1	39	3
Snake Island	SNK	74	74	26	21	36
Georgina Island	GI	80	77	58	62	40
Thorah Island	THI	61	60	40	74	16
Simcoe Watershed		35	30	18	55	7
Guideline		**40**	**30**	**6**	**75**	**10**

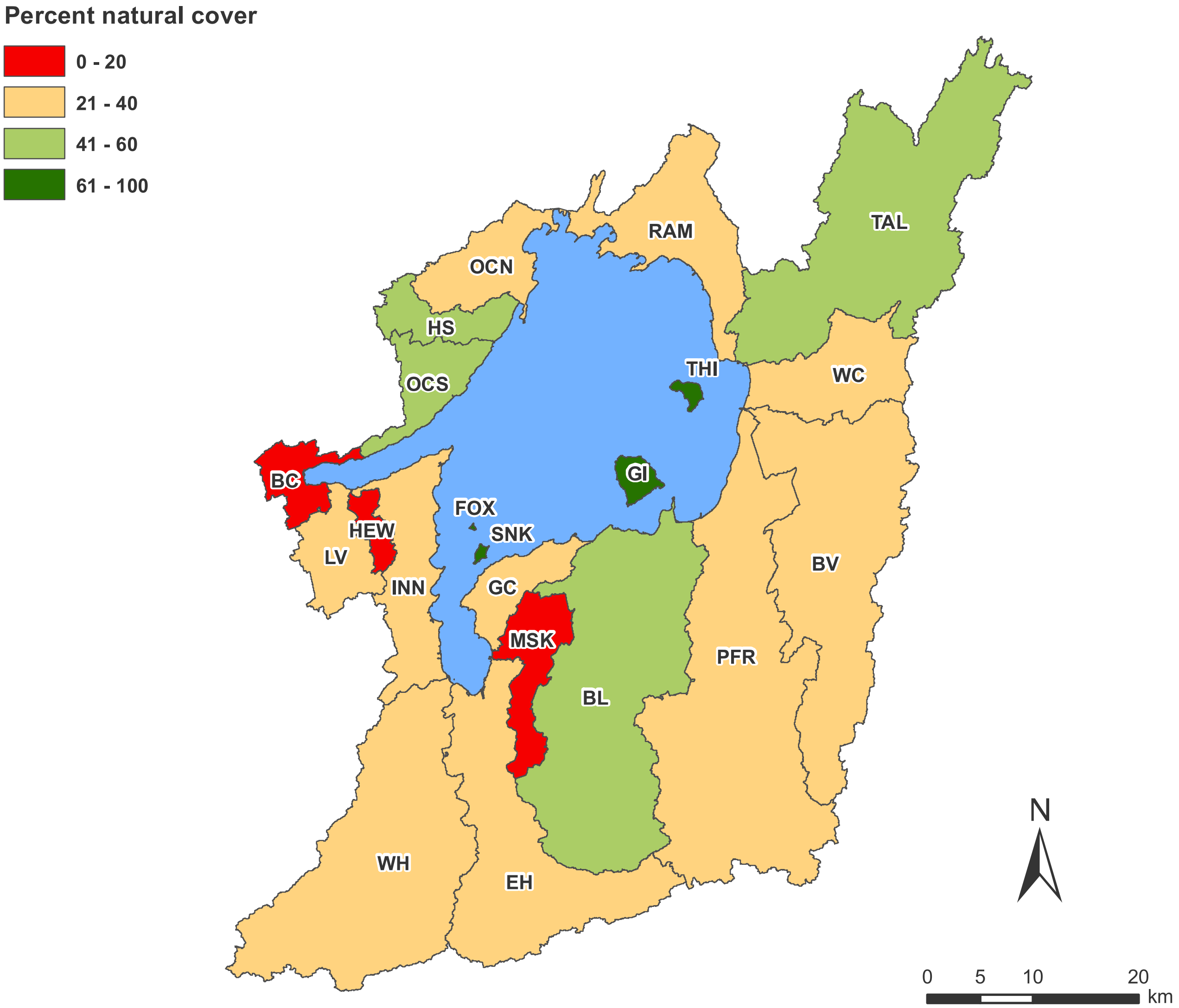


Figure 8: Extent and distribution of natural cover. *See Table 1 for subwatershed abbreviations*

RESEARCH

Credit: MNRF

As a step toward developing a site-level natural heritage monitoring program, a pilot study was undertaken in 2011 by Dr. Danijela Puric-Mladenovic. This study sampled 106 sites in the watershed to adapt the Vegetation Sampling Protocol (VSP), which was developed by the MNRF and the University of Toronto's Faculty of Forestry, for monitoring the Lake Simcoe watershed. Plots were set up on public lands and covered woodland areas. The data were used to develop a working, site-level definition of high quality. Data from the VSP plots initially were used to calculate over 30 criteria and indicators of terrestrial ecosystem condition. Of these, up to seven individual and independent indicators are included in the calculation of a composite measure of ecosystem quality, depending on the habitat type being examined (i.e., forests, wetlands or other natural vegetative cover). The criteria are 1) natural areas index, 2) weed index, 3) above ground biomass, 4) standing dead trees, 5) forest regeneration, 6) vertical forest structure, and 7) wetness index. A second more expansive pilot study was initiated in 2014 with the goal of expanding the network of plots to a watershed-wide terrestrial monitoring program. Once implemented, the data generated will provide more detailed site-level information to better analyze the quality of the natural cover in the watershed.

The Environment Canada Habitat Guidelines provide three thresholds for the amount of woodland areas, each dependent on the amount of risk:

- 30% woodland threshold is high-risk as it may only support up to half of the potential animal and plant species, and thus is vulnerable to even minor habitat loss, degradation and fragmentation;
- 40% woodland threshold is medium risk; and,
- 50% woodland threshold is low risk, ensuring increasing or stable biodiversity, and improved ecological functions, such as healthy aquatic systems.

Woodlands

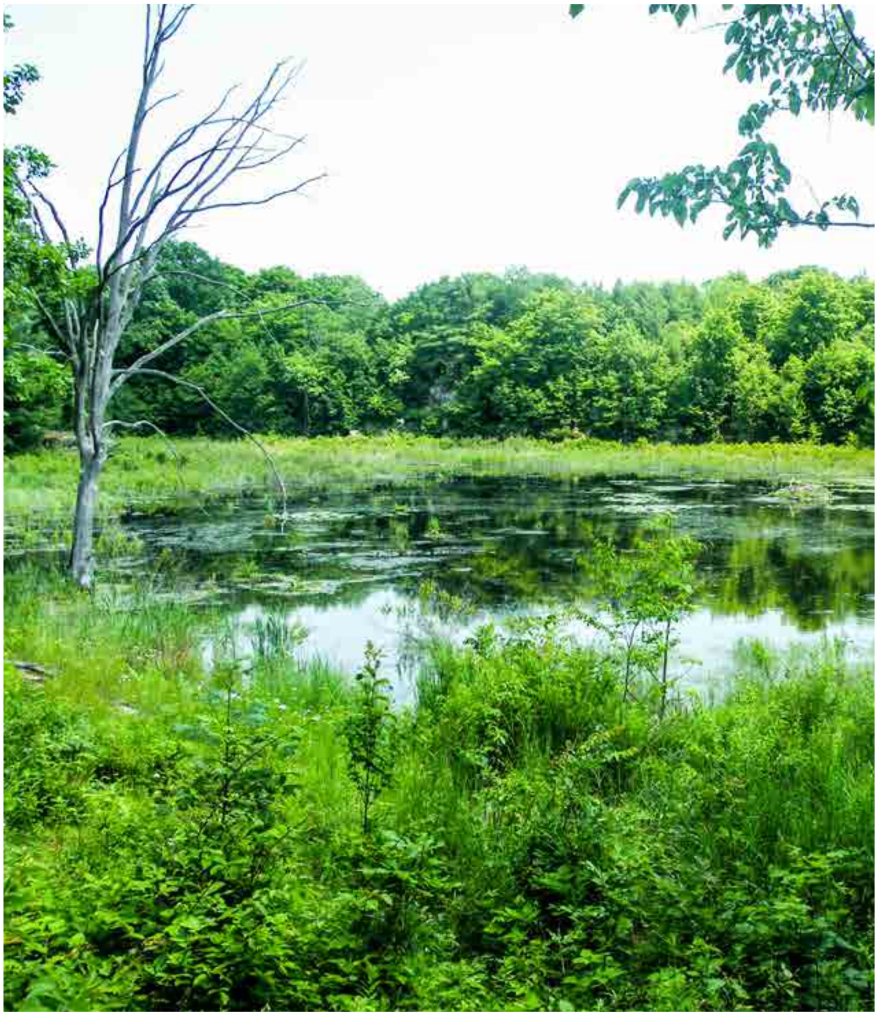
Woodland areas include natural treed areas on both upland and wetland sites (treed swamps), hedgerows, and plantations that are 0.25 ha or larger and that have a tree crown cover of over 60% of the ground. The entire Lake Simcoe watershed had 30% woodland cover in 2008/2009 (Table 1), which is the riskiest woodland cover threshold of the EC Habitat Guidelines. This indicates high vulnerability to any potential changes (e.g., climatic or land use) on the biodiversity and ecological functions of the Lake Simcoe watershed.

In 2008/2009, only the islands, where woodland cover exceeded 60%, were at low risk. Two subwatersheds (Black River and Hawkestone Creek) were above 40% woodland cover, and can be classified as medium risk, while Barrie Creeks and the Maskinonge River were below 15%, which places them at the extreme end of the high risk woodland cover.

Hewitts Wood. *Credit: Jim Eddie*

Wetlands

Wetlands, such as swamps, fens, bogs and marshes, are types of natural vegetation that represent the transition between aquatic and terrestrial ecosystems. The wetland cover in the Lake Simcoe watershed as a whole was 18% in 2008/2009, meeting the EC Habitat Guidelines of a minimum 10% wetland cover for a major watershed (Table 1). However, wetland cover was distributed unevenly between subwatersheds, ranging from two subwatersheds (Fox Island: 1%, and Barrie Creeks: 3%) that were below the 6% recommended minimum for a subwatershed, to 58% on Georgina Island. It is well recognized that wetlands serve numerous ecological functions; recent research in quantifying ecological goods and services outline their critical role as a sink for pollutants, nitrogen, P and sediments (Troy and Bagstad, 2009). As such, wetland conservation is a cost effective way to reduce loading of P and other pollutants to tributaries and the lake. For example, capacity of about 25% of the existing riparian wetlands (2,088 hectares) in the Black River subwatershed removed the same annual amount of P as the Sutton WPCP based on a study by Ducks Unlimited (Pattison et al., 2011).



Onoclea sensibilis

Lake Simcoe wetlands. *Credits: MNRF*

Whites Creek. *Credit: Jim Eddie*

Riparian vegetation

Riparian vegetation also has a positive impact on hydrology and other ecological functions. Natural vegetation in riparian areas supports hydrological processes by controlling runoff and improving water quality (Tabacchi et al., 2000). To provide and protect aquatic habitat, the EC Habitat Guideline recommends that a minimum of 75% of the stream length is vegetated (i.e., natural cover). The riparian areas were identified based on a 30-m width on each side of all watercourses. This is also consistent with the natural heritage policies of the LSPP, which require a 30-m vegetative protective zone around aquatic habitats. The watershed as a whole had only 55% natural cover in the 30-m riparian zone in 2008/2009 (Table 1). By subwatersheds, the amount of natural cover in the riparian zone ranged from far below the threshold at 25% in Barrie Creeks to almost meeting the threshold at 74% in Hawkestone Creek and on Thorah Island.

While a 30-m wide buffer may be suitable for shading, and erosion and sediment control, wider vegetated riparian areas within 120 m of a stream provide additional and prolonged stream quality and hydrological benefits, and serve as high functioning wildlife habitats and corridors. The Lake Simcoe watershed had 44% natural cover within a 120-m riparian zone. Strategic increases of natural vegetation within riparian zones can be achieved through active restoration, which includes tree planting and stabilizing banks, and/or passive restoration that allows natural succession to occur.

Leonard's Woods. *Credit: Jim Eddie*

Habitat fragmentation

Habitat fragmentation occurs when natural cover and features are broken down into smaller patches due to various human activities, such as land development, agricultural expansion and urbanization. The degree of fragmentation is another important indicator of ecosystem health, the condition of natural cover and landscape connectivity. Fragmentation has many negative impacts on vegetation structure and composition, wildlife and insect populations, species at risk habitats, seed dispersal, and the spread and abundance of invasive species. A target in the LSPP is "to achieve a greater proportion of natural vegetative cover in large high quality patches". Two measures of fragmentation are percent of interior forest and effective mesh size.

Talbot River subwatershed.
Credit: Lew Molot

Interior forests provide critical habitat to animal and plant species that depend on and prefer interior forest conditions that provide shelter from other non-forest areas and influences. Typically, interior forest is considered to be at least 100 m within the forest edge. The amount of interior forest helps identify important habitat areas for specific species that depend on interior conditions. As a whole, the watershed had 7% interior forest cover in 2008/2009, which was lower than the minimum of 10% suggested by EC Habitat Guideline (Table 1). Seven subwatersheds (Hawkestone and Ramara Creeks, Black and Talbot River, and Georgina, Snake and Thorah Island) met the minimum standard. The more agriculturally based subwatersheds, such as Hewitts Creek, West and East Holland Rivers, and Beaver River, had less than 5% of interior forest, and the highly urbanized subwatershed of Barrie Creeks had no interior forest.

Credit: MNRF

METHODS

Effective mesh size quantifies the probability that two random points (i.e., representing the locations of a pair of animals or plants) occur in the same patch of natural cover and are not separated by intervening land use (e.g., developed and urban lands, roads or agricultural fields). The fewer barriers among natural cover patches, the higher the effective mesh size. The effective number of meshes per unit area of 10 km^2 (known as S_{eff}) is the inverse of the effective mesh size, thus decreasing where there is less landscape fragmentation. S_{eff} is presented here by subwatersheds and within the Talbot subwatershed by catchment, and compared spatially for 2008/2009, as there is no threshold for S_{eff} nor do we currently have measurements over time.

The other measure of natural cover fragmentation calculated for the Lake Simcoe watershed is effective mesh size (Jaeger et al., 2007; 2008). This is a method of measuring landscape fragmentation in relative terms for areas of different sizes. This measure enables monitoring fragmentation across the watershed and detecting trends through space and time.

S_{eff} of the entire watershed was 7.2 meshes/10 km^2 in 2008/2009 but S_{eff} in the subwatersheds varied substantially (Fig. 9). Barrie Creeks was the most fragmented subwatershed with a S_{eff} of 545 meshes/10 km^2, which was 150 times more than the least fragmented watershed, Talbot River, at S_{eff} of 3.6. All of the islands (except Fox Island), as well as Black River, Ramara Creeks and Pefferlaw River, had very low S_{eff}.

Examining all subwatersheds by catchment, there was also significant variation in the amount of fragmentation, even within Talbot River, the least fragmented subwatershed. Fragmentation measurements by catchment can identify where within a subwatershed to set priorities for restoring connectivity; catchments with high S_{eff} values would be given higher priority for increasing natural cover connectivity.

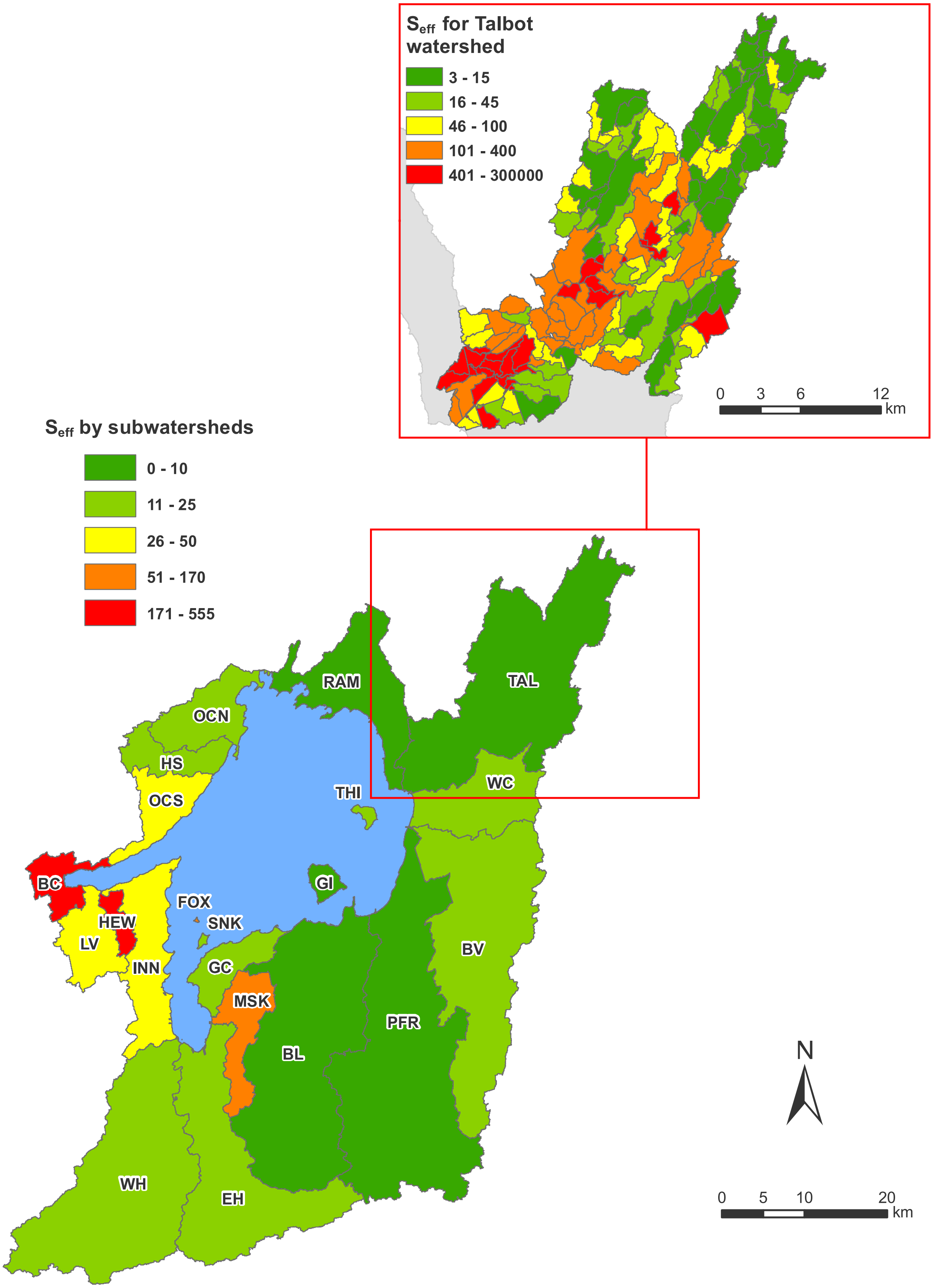


Figure 9: Measure of fragmentation (S_{eff}) for Lake Simcoe subwatersheds, with a detailed breakdown for the Talbot subwatershed. *See Table 1 for subwatershed abbreviations*

Shorelines

There is more than 300 km of shoreline around Lake Simcoe, with natural substrates ranging from stone and sand to nutrient rich organics with diverse wetland and aquatic plant communities. However, an increase in urban and rural development and recreational uses in the watershed has caused significant alteration to the shoreline. A comprehensive inventory of the Lake Simcoe shoreline was undertaken by the MNRF to enhance the capacity of management agencies to make sound decisions by providing a better understanding of the current state of the shoreline and assist in identifying priority areas for restoration.

Near Beaverton Beach

METHODS

The shoreline inventory was created with the 2008/2009 orthophotography, and was designed to be adaptable for the incorporation of other sources of information as they become available. The inventory was compiled by categorizing shoreline types and alterations around the lake, with a focus on the visible shoreline (i.e., above the water level), and digitizing structures on or near the shoreline (Fig. 10). The shoreline groups were classified as natural vegetative cover, open beach/bar, altered or undetermined. The land within 20 m of the shoreline was also examined on orthophotographs for tree cover and infrastructure. The amount of tree cover for the different shoreline groups confirmed the location of natural cover along the shore, and identified natural shoreline areas that were too small to be included in the wetlands or woodlands layers.

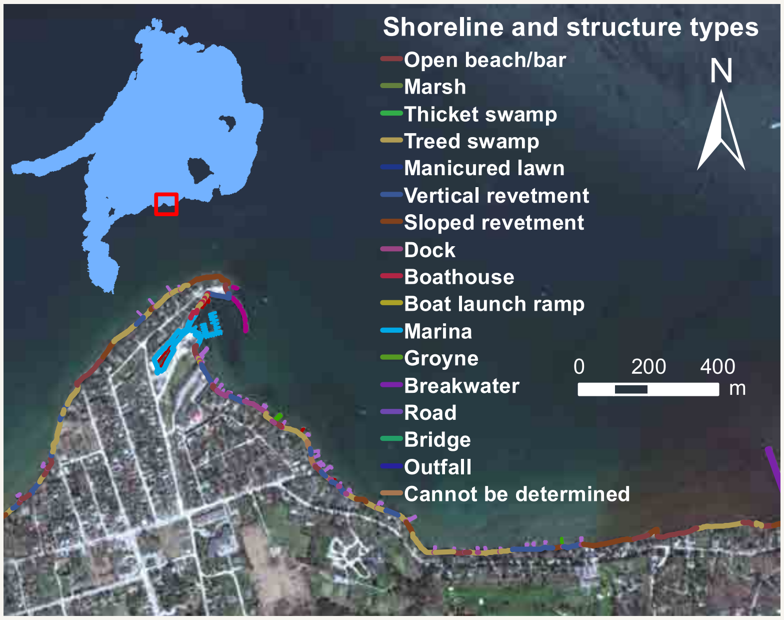


Figure 10: Shoreline inventory: Digitized shoreline of Jacksons Point

Of the 358 km of shoreline classified, over half was found to be in an altered state, with 36% sloped and vertical revetments (i.e., shoreline stabilization structures), 6% marinas, 3% docks, and the remaining 6% breakwaters, boat houses and launches, manicured lawns, groynes, and roads. The rest of the shoreline was a mix of natural vegetative cover (39%), open beach/bar (10%) and undetermined (Fig. 11). In total, there were over two thousand shoreline and nearshore structures in Lake Simcoe. The majority of these structures were docks followed by marinas and boathouses, with boathouses having the largest footprint within the lake.

Within the onshore zone (i.e., 20 m inland from the waterline), altered shorelines and open beach/bars had the least amount of tree cover, with almost all having less than 25% (Fig. 12). Over half of the natural shoreline reaches had more than 60% tree cover, although close to 20% of the natural shorelines had no tree cover at all, and instead had mainly naturalized grassy areas or marshes. Infrastructure (e.g., roads) was present in over 80% of both altered areas and open beach/bars, while areas with natural vegetative cover had one or more structures in just over half. In all three shoreline classification groups, manicured lawn was by far the most reported land cover followed by wooded area and ornamental plantings.

This inventory provides a baseline for the state of the Lake Simcoe shoreline when the LSPP was released. To report on the targets and indicators of the LSPP, this inventory should be repeated at a regular interval of 5–10 years to allow for the monitoring of land use change and shoreline naturalization over time. A Shoreline Management Strategy is currently being developed, which will address best management practices for the shoreline including restoration, protection and land use planning. The inventory supports the strategy by assisting in identifying high priority areas for restoration and protection, as well as detecting changes in natural cover on the shoreline.

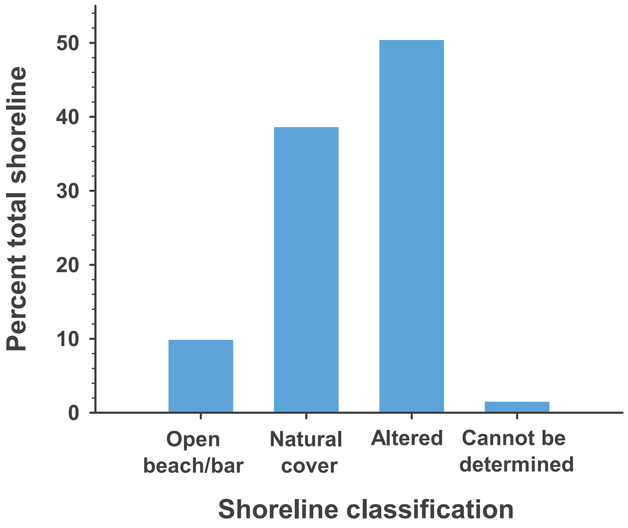


Figure 11: Overall classification of the Lake Simcoe shoreline

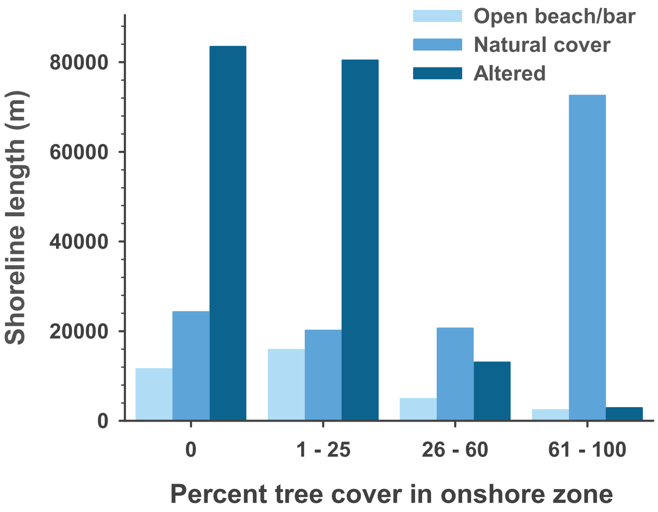


Figure 12: Onshore tree cover of the Lake Simcoe shoreline (within 20 m of waterline)

Section 3:
Invasive Species

Invasive Species

Another stress to the Lake Simcoe watershed has been the establishment of invasive species. These are species that are not native to the watershed and cause significant disruption to its ecosystem. The only indicator in the LSPP for invasive species is the presence of newly introduced species.

There are 48 known species in Lake Simcoe watershed that are considered invasive, with 32 generally living above water or on land (Table 2) and the rest (16) in the water (Table 3).

Table 2: Terrestrial invasive species on the Lake Simcoe watershed

Scientific Name	**Common Name**	**Taxonomic Group**
Acer negundo	Manitoba maple	Vascular Plants
Acer platanoides	Norway maple	Vascular Plants
Alliaria petiolata	Garlic mustard	Vascular Plants
Berberis vulgaris	European barberry	Vascular Plants
Cynanchum rossicum	Dog strangling vine	Vascular Plants
Cynanchum louiseae	Black dog strangling vine	Vascular Plants
Elaeagnus umbellata	Autumn olive	Vascular Plants
Fallopia japonica	Japanese knotweed	Vascular Plants
Heracleum mantegazzianum	Giant hogweed	Vascular Plants
Impatiens glandulifera	Purple jewelweed	Vascular Plants
Iris pseudacorus	Yellow iris	Vascular Plants
Lonicera tatarica	Tartarian honeysuckle	Vascular Plants
Lonicera spp.	Exotic bush honeysuckles	Vascular Plants
Lythrum salicaria	Purple loosestrife	Vascular Plants, Aquatic
Miscanthus sacchariflorus	Japanese silver grass	Vascular Plants
Pastinaca sativa	Wild parsnip	Vascular Plants
Phragmites australis ssp. australis	European reed	Vascular Plants, Aquatic
Pinus sylvestris	Scotch pine	Vascular Plants
Pistia stratiotes	Water lettuce	Vascular Plants, Aquatic
Rhamnus cathartica	Common (European) buckthorn	Vascular Plants
Frangula alnus	Glossy buckthorn	Vascular Plants
Robinia pseudoacacia	Black locust	Vascular Plants
Aegopodium podagraria	Goutweed	Vascular Plants
Alnus glutinosa	European alder	Vascular Plants
Hemerocallis g.	Daylily	Vascular Plants
Vicia cracca	Tufted vetch	Vascular Plants
Sirex noctilio	Sirex wood wasp	Insects, Forest pest
Agrilus planipennis	Emerald ash borer	Insects, Forest pest
Sirococcus clavigignenti-juglandacearum	Butternut canker	Forest Disease
Myrmica rubra	European fire ant	Insects
Trachemys scripta elegans	Red-eared slider	Reptiles
Cygnus olor	Mute swan	Birds

METHODS

An MNRF-led working group compiled the first comprehensive list of known invasive species for Lake Simcoe and its watershed that included aquatic and terrestrial plants, animals and diseases.

The original sources of information were the invasive species database of the Ontario Federation of Anglers and Hunters (OFAH), Ontario Streams' monitoring report, Lake Simcoe Protection Plan (LSPP) Invasive Species, and the LSPP. The species on the list were confirmed to be an invasive species and present in the Lake Simcoe watershed by an expert review panel consisting of MNRF biologists (including Natural Heritage Information Centre and forest health specialists), the OFAH Invasive Species Awareness Program, members of the Ontario Invasive Plant Council, and Ontario Streams. Monitoring programs on the lake and watershed also continue to aid in the detection of new invasive species.

The proposed site-level monitoring program outlined in the natural heritage section and the ongoing water monitoring programs assist in the rapid identification, tracking of abundances, and assessing of risk of terrestrial and aquatic invasives.

(Opposite page) **Giant hogweed.**
Credit: Ken Towle

Terrestrial (land based) Invaders

The terrestrial or land-based invasive species that are threatening the ecological health of the Lake Simcoe watershed include a variety of vascular plants, animals (including insect forest pests) and disease. The Lake Simcoe watershed has a history of terrestrial invasive species becoming established, starting in the 1960s or earlier. The following is a synopsis of species already established within the watershed, some newly introduced and some watch list species (i.e., species not yet discovered in the Lake Simcoe watershed).

Several invasive species are well-established and widespread within the Lake Simcoe watershed; invasive tree species include common buckthorn (*Rhamnus cathartica*), manitoba maple (*Acer negundo*) and norway maple (*Acer platanoides*), and invasive vascular plant and shrubs species include garlic mustard (*Alliaria petiolata*), dog strangling vine (*Cynanchum rossicum*), and giant hogweed (*Heracleum mantegazzianum*).

Credit: Ken Towle

Approximately six sightings of giant hogweed have been confirmed across the Lake Simcoe watershed following its initial confirmation in Ontario in 1949, and in the Lake Simcoe watershed near Uxbridge in April of 2010. Originating from Southwestern Asia and Europe, this perennial plant can grow 5 m tall, and can pose a significant threat to human health. Once exposed to sunlight, the sap contained in its leaves and stalks can cause severe burns and blisters, and has also been known to cause permanent blindness following eye contact. One single plant can produce up to 100,000 seeds, which can remain viable for up to seven years. This species has since been added to Ontario's Noxious Weed List.

Black locust. *Credit: Richard Dickinson*

The target in section 7.1 of the LSPP is to prevent new invaders from entering the Lake Simcoe watershed where possible; the indicator of success is no newly introduced invasive species. One strategy to support this is the development of a watch list to identify the species with the greatest potential to be introduced or to spread into the watershed. Two terrestrial invasive species now considered on this list are kudzu vine and oak wilt. Kudzu (*Pueraria montana*) is native to eastern Asia and was first introduced into the United States in 1876 for an exhibition and later used as a forage crop and for planting along roads as a form of erosion control. The first discovery of kudzu in Ontario was in Leamington in 2009. This aggressive invader can grow an astonishing 30 cm in a single day, blanketing almost anything (e.g., fences, hydro poles, entire trees, houses and highway signs), hence its nickname "the vine that ate the south". Currently, this species is not controlled or restricted in Ontario, and as such it is important that people know the threat this species poses to our natural environment and should not plant it. Oak wilt is caused by the invasive fungal pathogen *Ceratocystis fagacearum*, and is a serious and fatal disease of oaks (*Quercus* spp.), especially red oaks. Oak wilt was first recognized in North America in 1944 and has since been confirmed in 24 eastern, midwestern and southern states, with recent confirmations in New York State in 2008. Currently, this invasive fungal pathogen is not known to Canada.

Credit: Ed Czerwinski

A new introduction of particular concern is the emerald ash borer (EAB). The EAB is a metallic green D-shaped insect that lays its eggs on native ash trees. EAB larvae bore tunnels that cut the flow of nutrients and water to the leaves, causing the tree to die typically within two to three years of infestation. Originating from China and first discovered in Windsor, Ontario, this flying insect has since been spreading throughout Canada and the United States.

In Ontario, the EAB has been steadily spreading north and was first discovered in the Lake Simcoe watershed in 2011. As of the 2013 monitoring season, EAB has been observed as far north as the Town of Georgina and is predicted to continue to spread aggressively within this area in particular due to the dense ash population. Currently, certain municipalities are considering treatment options for infected and uninfected trees as a part of a maintenance and preventative approach.

(Top left) **Manitoba maple.**
Credit: Hayley Anderson

(Top right) **Norway maple.**
Credit: Ken Towle

(Bottom left) **Garlic mustard.**
Credit: Ken Towle

(Bottom right) **Dog strangling vine.**
Credit: MNRF

Rusty crayfish. *Credit: MNRF*

Aquatic Invaders

Most of the invasions by aquatic species into Lake Simcoe have been relatively recent; all species except for common carp and rainbow smelt (*Osmerus mordax*) have invaded since the early 1990s. The proximity of Lake Simcoe to the Great Lakes, as well as the Trent-Severn Waterway that connects these water bodies, results in the Great Lakes being a principal source. Some of these aquatic invasive species can be especially disruptive to the health and function of lake ecosystems, as seen in the Great Lakes. Additionally, species originating from the same region can produce an "invasional meltdown" in an invaded lake (Ricciardi, 2001), when one invasive species facilitates the success of subsequent invaders. Some of Lake Simcoe's aquatic invasive species already co-exist in other areas, having originated from the Ponto-Caspian region of Eastern Europe and Western Asia. They arrived in the Great Lakes in ballast water of transoceanic ships returning from the Baltic Sea. Through some of the ongoing aquatic monitoring programs and/or research efforts, detailed information is available for Lake Simcoe on four Ponto-Caspian invaders: dreissenid mussels (zebra; *Dreissena polymorpha* and quagga; *Dreissena rostriformis bugensis*), round goby and the spiny water flea (*Bythotrephes longimanus*).

Aquatic invasive species outreach and education has been successful in raising awareness on invasive species, promoting best practices regarding the disposal of bait, and encouraging the reporting of new species encounters back to the Invasive Species Hotline maintained by the Ontario Federation of Anglers and Hunters (OFAH). Aurora District MNRF, in collaboration with OFAH, has conducted 'Operation Bait Bucket' each winter since 2011, talking to almost 4,000 angling groups. With this program, anglers recognize themselves as the 'eyes on the water' and share their observations with district and OFAH staff.

Table 3: Aquatic Invasive Species and fish diseases in Lake Simcoe and its tributaries

Scientific Name	Common Name	Taxonomic Group
Neogobius melanostomus	Round goby	Fish
Osmerus mordax	Rainbow smelt	Fish
Cyprinus carpio	Common carp	Fish
Pomoxis nigromaculatus	Black crappie	Fish
Carassius auratus	Goldfish	Fish
Pimephales promelas	Rosey red minnow	Fish
Bythotrephes longimanus	Spiny water flea	Invertebrates (Non-insects)
Dreissena rostriformis bugensis	Quagga mussel	Invertebrates (Non-insects)
Dreissena polymorpha	Zebra mussel	Invertebrates (Non-insects)
Orconectes rusticus	Rusty crayfish	Invertebrates (Non-insects)
Echinogammarus ischnus	Eurasian amphipod	Invertebrates (Non-insects)
Hydrocharis morsus-ranae	European frogbit	Vascular Plants, Aquatic
Myriophyllum spicatum	Eurasian watermilfoil	Vascular Plants, Aquatic
Potamogeton crispus	Curly-leaf pondweed	Vascular Plants, Aquatic
Novirhabdovirus sp.	Viral hemorrhagic septicemia	Fish Disease
Cyprinid herpesvirus 3	Koi herpes virus	Fish Disease

Dreissenid mussels

Zebra mussel. *Credit: United States Geological Survey*

The first dreissenid detected in North America was the zebra mussel, initially sighted in the Great Lakes in 1988. A monitoring program set up in advance of the zebra mussel invasion allowed for the documentation of this event. The first sign of reproduction in Lake Simcoe occurred in August 1992 with the collection of six zebra mussel larvae (i.e., veligers) in Kempenfelt Bay but the first zebra mussel cohort occurred in the Main Basin in 1994 followed by a much larger spawn in 1995 (Evans et al., 2011). By 1996, adult mussels were widely established and abundant in the Main Basin; average total zebra mussel abundance was 32,529 mussels/m^2 on rocky littoral zone substrates, with 98% being juveniles from the 1995 year class (Evans et al., 2011). Over the next decade, the dynamics of the zebra mussel were not monitored, but by 2005 its density had declined to 5,101 mussels/m^2 (Stantec, 2006). Its biomass, however, did not change significantly from 1996, likely because there were fewer juveniles in the 2005 population. In 2005, the zebra mussel was abundant in the nearshore and even found along the shoreline but was rarely observed in the deeper part of the Main Basin, which is unsurprising given its preference for warmer water (Baldwin et al., 2002).

Quagga mussel. *Credit: United States Geological Survey*

The quagga mussel was first detected in Lake Simcoe in 2004 by the MNRF, but it was not observed in the 2005 benthos survey, and was apparently still at very low densities in 2008 (Ozersky et al., 2011a; LSRCA, 2013). Since 2009, dreissenid dominance has possibly been shifting toward the quagga mussel; zebra mussel abundance appears to be declining and the quagga mussel has apparently increased. The LSRCA's whole lake density estimate for dreissenids in 2009 was 4015 mussels/m^2, with quagga mussels making up approximately one-quarter. As described in the Aquatic Life section, LSRCA's monitoring data suggest that the quagga mussel has recently been increasing on soft substrate at nearshore and deepwater

METHODS

Dreissenid mussels have been monitored in Lake Simcoe by various research programs over the years. The first program was initiated in 1990 by the MNRF to monitor the zebra mussel invasion until 1996 (for more details, please see Evans et al., 2011). The next dreissenid survey was not conducted until 2005 (Stantec, 2006), followed by annual benthic monitoring starting in 2008 by the LSRCA at 19–45 sites/year, with a whole lake survey performed in 2009/10 at 747 sites (LSRCA, 2013).

sites, especially in 2012. A decline in the zebra mussel followed by replacement by the quagga mussel has been observed in other lakes (Nalepa, 2010), usually following about nine years of co-existence (Karatayev et al., in press). Possible mechanisms for the switch are predation by round goby (as discussed below) and differences in their life history strategies.

Dreissenid mussels have had significant effects on invaded lakes, primarily through mechanisms summarized by the "nearshore shunt hypothesis"; because dreissenids are high volume filter feeders, it was hypothesized that they redirect the flow of nutrients and phytoplankton away from the offshore and into the shallower, nearshore zone where they are most abundant (Hecky et al., 2004). In other invaded lakes, dreissenid mussels have been shown to increase water clarity, decrease total P, increase silica and decrease phytoplankton, thus indirectly affecting other levels of the food web (Higgins and Vanderzanden, 2010). Dreissenids are likely contributing to changes in Lake Simcoe and its food web. For example, nearshore benthic invertebrates and warmwater fish were significantly more dependent on resources in the nearshore area in the years following the invasion of the zebra mussel (Ozersky et al., 2012; Rennie et al., 2013). Continued monitoring is clearly needed to confirm whether there's been a shift in dreissenid dominance, its cause and the potential ecological effects.

Differences in dreissenid mussel life history strategies

Zebra mussel has a keel-shape and strong byssal threads that allow it to attach tenaciously to hard substrates. This makes it better at laying claim to the lake bottom, especially rocky and frequently disturbed areas, but worse at competing, especially in low food conditions.

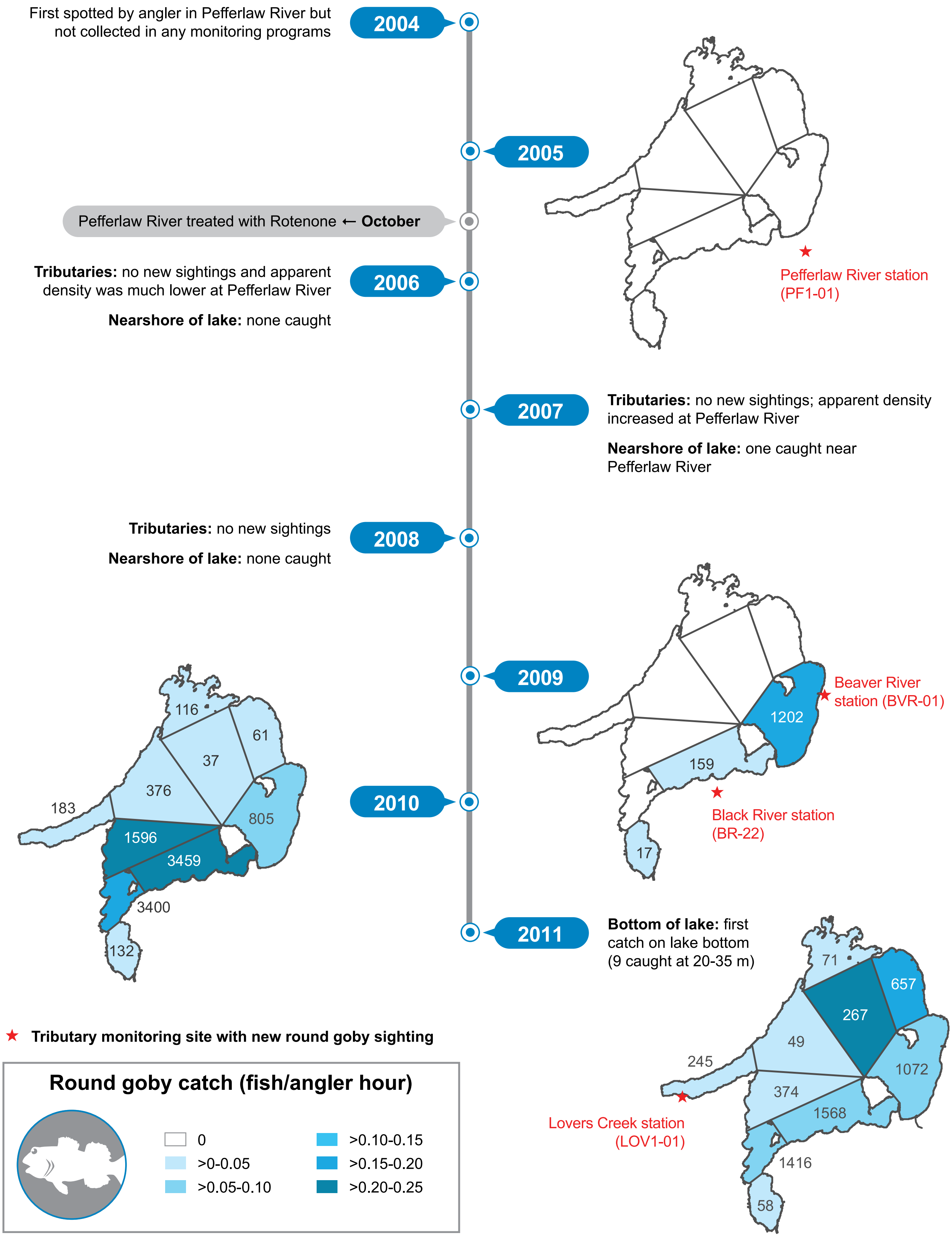
Quagga mussel invests energy toward a larger size, making it much more efficient at assimilating food, and thus more competitive in low food conditions. Therefore, in conditions that reduce zebra mussel abundance, the quagga mussel tends to slowly and steadily take over. In addition, it can thrive in cooler waters than zebra mussels, allowing it to begin feeding and reproducing earlier in the spring, as well as in deeper water.

Round goby

The next Ponto-Caspian invader, the round goby, is a small, bottom-dwelling fish that became established in the Great Lakes sometime after its first observation in the 1990s. It was first spotted in the Lake Simcoe watershed by an angler in the Pefferlaw River in 2004, and its presence was confirmed nearby in 2005 when 33 were collected by the LSRCA in routine tributary fish monitoring at the mouth of the Pefferlaw River (Fig. 13). In the fall of that year, the pesticide Rotenone was applied to the Pefferlaw River in hopes of preventing the round goby from further establishment in the Lake Simcoe watershed. The LSRCA only captured two round goby at that site in 2006; however, 65 were caught at the Pefferlaw River the next year (2007), and one was also caught nearby in the lake by the LSFAU's small fish biodiversity program. By 2009, it was collected at the mouth of two more tributaries (Black and Beaver River), and its average catch increased in nearby sections of the lake. By 2010, it appeared to be firmly established in Lake Simcoe, as it was collected in high abundance in LSFAU's nearshore netting and in every surveyed section of the lake. In 2011, its establishment expanded to the mouth of Lovers Creek on the west end of Kempenfelt Bay, and at deeper depths in the lake, with nine fish caught in the LSFAU's benthic trawling program at 20–35 m.

METHODS

Information on the spread of round goby into Lake Simcoe was compiled using data from LSRCA's tributary fish monitoring, and three of MNRF's LSFAU lake monitoring programs (summer recreational fishery, nearshore small fish biodiversity netting and benthic trawling), which are described in more detail in the Aquatic Life section. Note that the LSFAU programs were not performed in each year: small fish biodiversity netting began in 2006, summer fishery surveys were not performed from 2006 to 2008, and there was no benthic trawling in 2006.



2004 First spotted by angler in Pefferlaw River but not collected in any monitoring programs

2005

Pefferlaw River treated with Rotenone ← **October**

2006 **Tributaries:** no new sightings and apparent density was much lower at Pefferlaw River

Nearshore of lake: none caught

2007 **Tributaries:** no new sightings; apparent density increased at Pefferlaw River

Nearshore of lake: one caught near Pefferlaw River

2008 **Tributaries:** no new sightings

Nearshore of lake: none caught

2009

2010

2011 **Bottom of lake:** first catch on lake bottom (9 caught at 20-35 m)

★ **Tributary monitoring site with new round goby sighting**

Figure 13: The sequence of the round goby invasion within the Lake Simcoe watershed. Colours on maps show catch-per-unit effort by anglers by sector. Numbers on maps show estimated catch by anglers by sector.

Round goby. *Credit: MNRF*

RESEARCH

Round goby diet data were collected in the nearshore and offshore by the LSFAU in the summer of 2009 using gillnets, trapnets, minnow traps and seine nets. Nearshore diet data were also collected in August of 2011 by MNRF's Aquatic Research and Monitoring Section using minnow traps (D.O. Evans, MNRF, personal communication).

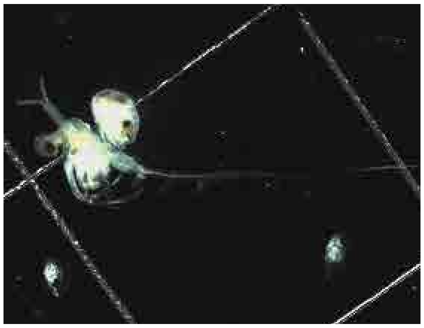
The round goby can negatively affect native fish species by outcompeting for food as well as eating their eggs and young. From observations of round goby stomach contents in 2009 and 2011, it appears to be a generalist predator in Lake Simcoe, consuming some fish but mostly invertebrates, including other Ponto-Caspian invaders (dreissenids and spiny water flea) (Table 4). The round goby can also become a common prey to lake trout (*Salvelinus namaycush*), as was observed in Lake Ontario (Dietrich et al., 2006); however, the round goby was not part of the summer lake trout diet in Lake Simcoe up to 2012 (Adkinson, 2013).

Table 4: Percent prey occurrence in the 2009 and 2011 summer diet of the round goby

Prey item	**2009 (%)**	**2011 (%)**
Chironomids (midge larvae)	30.2	27
Dreissenids (zebra mussels)	30.2	11
Other cladocerans (*Daphnia*)	15.1	-
Spiny water flea	13.2	<13
Unknown fish	9.4	<13
Native bivalves	9.4	-
Amphipods	7.5	-
Hydracarina (water mites)	5.7	15.5
Trichoptera (caddisflies)	5.7	-
Debris	3.8	30
Unknown invertebrates	3.8	-
Gastropods (snails)	3.8	-
Round goby	1.9	-
Nematodes (round worms)	1.9	-
***n* (non-empty stomachs)**	**53**	**129**

Nearshore fish monitoring. *Credit: MNRF*

Spiny water flea



Spiny water flea

The spiny water flea was detected in the Great Lakes in the early 1980s. It is a species of zooplankton, which are small crustaceans that inhabit the open water of lakes. The spiny water flea was first observed in Lake Simcoe during MOECC's routine zooplankton sampling in October 1993, and while only five were recorded, many more were collected in the following summer, suggesting that it was well established in the lake by 1994.

Since 1999 when the spiny water flea sampling began, its abundance has shown an apparent decrease (Fig. 14). This decrease was significant at two of the stations (C9 and K42), where abundances have been consistently low since 2006 (≤ 4 per m^3). While more research is necessary to determine the cause of this decline, one possibility is predation by planktivorous fish, such as the native cisco (*Coregonus artedi*), which increased in abundance in Lake Simcoe in 2006, and the invasive round goby.

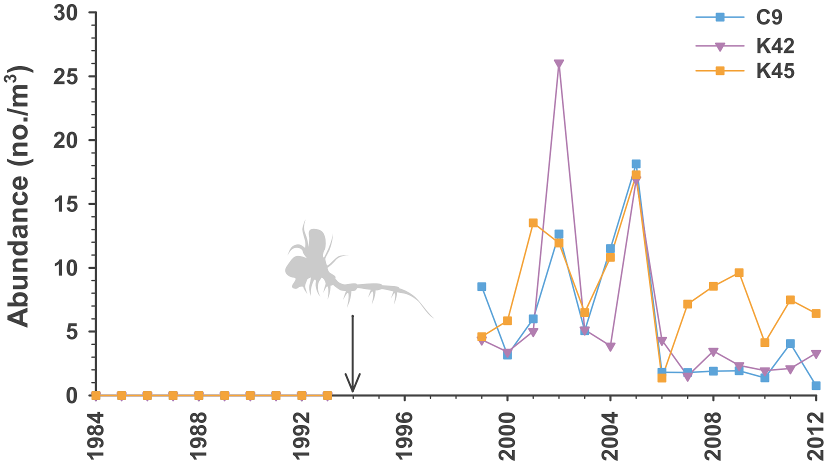


Figure 14: Spiny water flea (*Bythotrephes*) abundance (monitored from 1999–2012) at three lake stations

Unlike most zooplankton that are primarily grazers, the spiny water flea feeds on other zooplankters, especially cladocerans, and thus can significantly alter a zooplankton community (e.g., Yan et al., 2002). As described in the Aquatic Life section, significant changes occurred in the Lake Simcoe zooplankton community, especially for cladocerans, after the establishment of the spiny water flea and preceding the establishment of the zebra mussel.

METHODS

The zooplankton net that first detected the spiny water flea was too small to accurately estimate the abundance of this large zooplankter. Therefore, in 1999, the MOECC began monitoring the spiny water flea abundance with a specially designed, very large net (diameter of 0.75 m and 2.5 m long). The spiny water flea was sampled through the ice-free season at three of the routine open lake stations (C9, K42 and K45; see Fig. 3).

Spiny water flea abundance	**Trend**
C9	↓
K42	↓
K45	↔

RESEARCH

Research done by Dr. Michael Rennie and Dr. David Evans at MNRF's Aquatic Research and Monitoring Section illustrated that the diet of planktivores in Lake Simcoe changed following the introduction of the spiny water flea. Relative stomach composition (by weight) of lake whitefish, cisco and yellow perch was compared with samples collected during August in 1983 and 2009. Cisco and yellow perch switched from a summer diet composed mostly of chironomids, cladocerans and diptera larvae in 1983 to mostly the invasive spiny water flea in 2009, while the lake whitefish summer diet in 2009 included some spiny water flea but remained highly benthic and more diverse (Fig. 15).

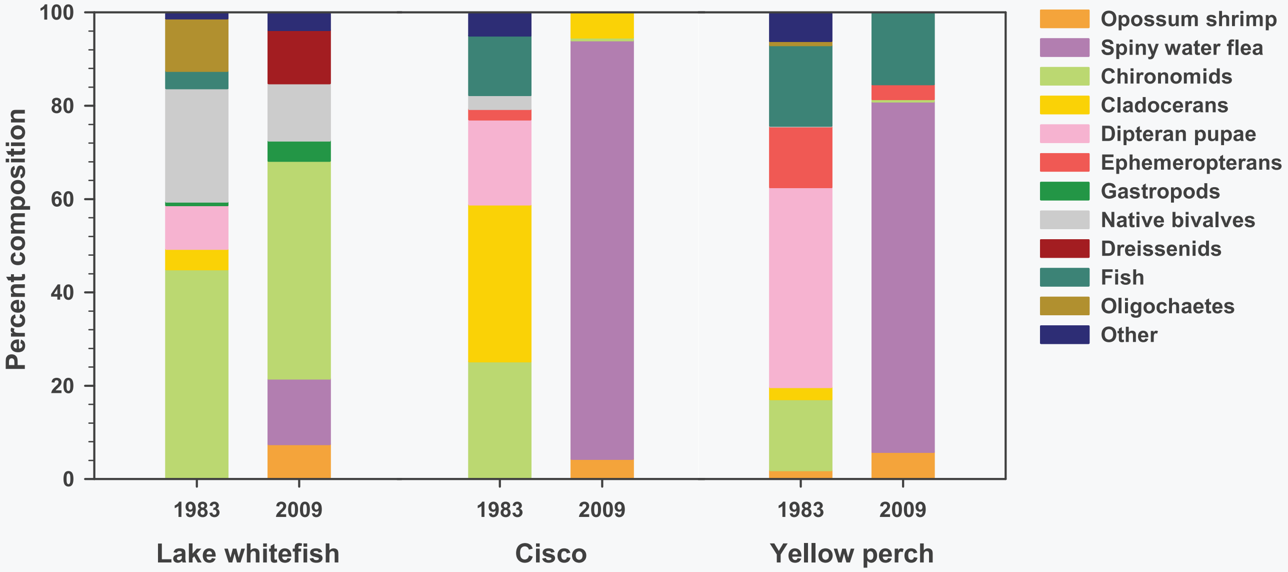


Figure 15: Percent prey composition in the 1983 and 2009 summer diet of planktivorous fish

Credit: MNRF

Fish disease

The invasion of fish diseases is also relatively new to Lake Simcoe; these viruses have become apparent in recent years and have resulted in fish die-offs in the lake. In the early summer of 2008, vast numbers of dead fish, primarily carp (*Cyprinus carpio*), were reported in Lake Simcoe. The dead carp tested positive for koi herpes virus (KHV), thus the most likely cause of death was identified as a combination of the presence of the virus and the stress from spawning and warm temperatures.

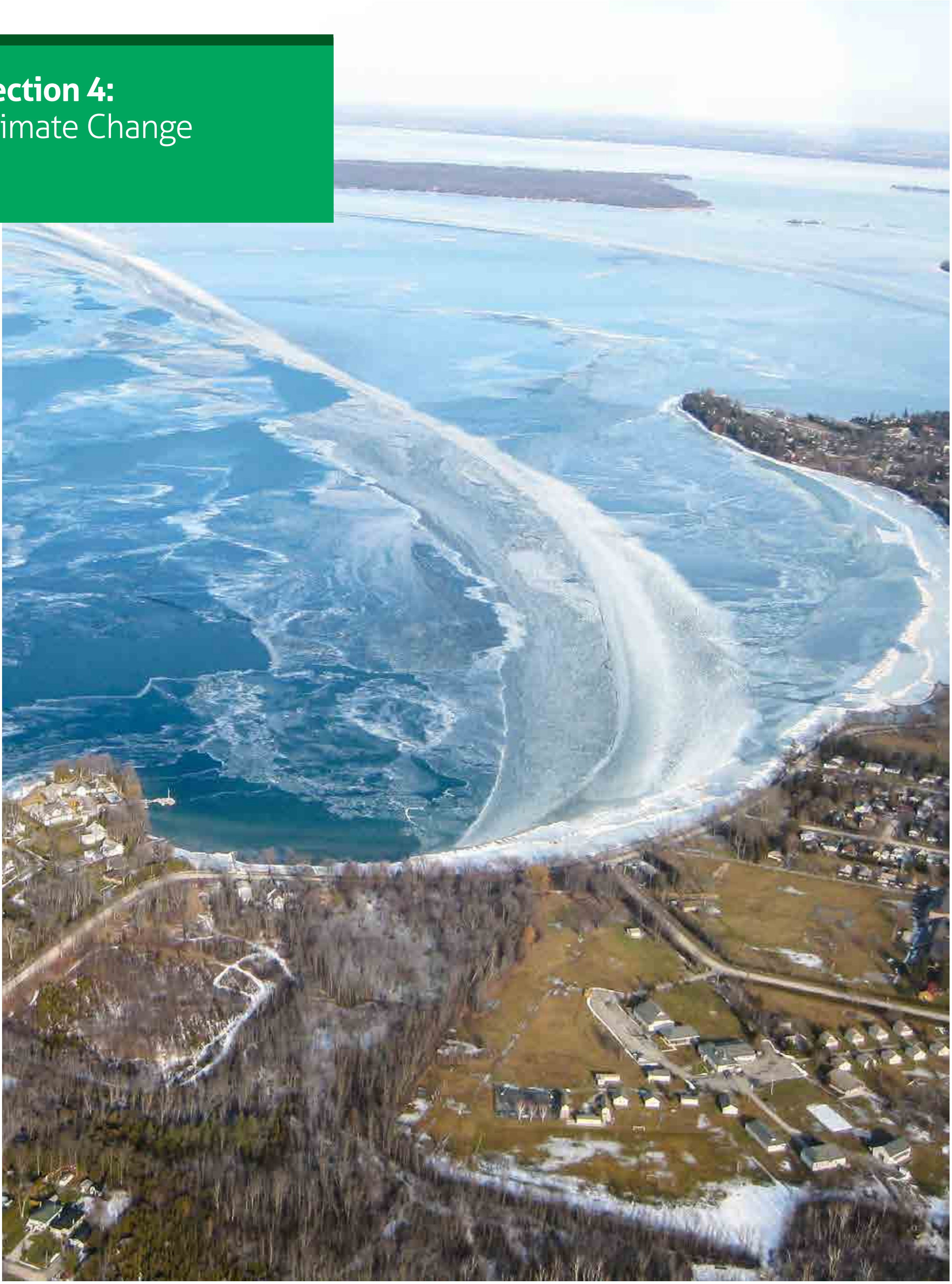
In 2011, the Canadian Food Inspection Agency announced that pumpkinseed (*Lepomis gibbosus*), rock bass (*Ambloplites rupestris*), brown bullhead (*Ameiurus nebulosus*) and round goby (*Neogobius melanostomus*) tested positive for viral hemorrhagic septicemia (VHS) in Lake Simcoe. VHS was historically found in European freshwater trout but is known to affect 28 freshwater fish species in North America. It first appeared on the West Coast of the United States in 1988 in marine trout and salmon, was noticed in marine fish off of New Brunswick in 2000, and was detected in the Great Lakes in 2005. While unpleasant for fish species, aesthetics and anglers, these fish viruses do not infect humans.

Following the detection of viral hemorrhagic septicemia (VHS) in the lake, and to slow its spread in Ontario, the Lake Simcoe Management Zone (LSMZ) was created by the MNRF in 2011. This management zone works in tandem with the Great Lakes' VHS management zone that includes the waters of Lakes Ontario, Erie and Huron, and prohibits live baitfish transfer out of these zones. To aid in the prevention of the further spread of invasive species, the transfer of live or dead baitfish in or out of the LSMZ is prohibited.

Carp infected with KHV. *Credit: MNRF*

Rock bass infected with VHS. *Credit: MNRF*

Section 4:
Climate Change



Climate Change

The effects of climate change have been reported around the world. In the Lake Simcoe watershed, annual average air temperatures could rise 2 to 6 °C by the 2070s compared to the 1980s, with additional yet less predictable changes to patterns in precipitation (Crossman et al., in press; based on IEESC, 2012, and EC, 2014, data). These alterations to the Lake Simcoe climate can directly and indirectly affect many components of the lake and its watershed, and the following trends indicate that the Lake Simcoe watershed is already seeing the effects of climate change. Climate change indicators in the LSPP are meteorological trends (e.g., precipitation, air temperature), lake thermal trends (e.g., timing of stratification), river hydrology and timing of seasonal processes like fish spawning.

(Opposite) Franklin Beach in winter of 2012

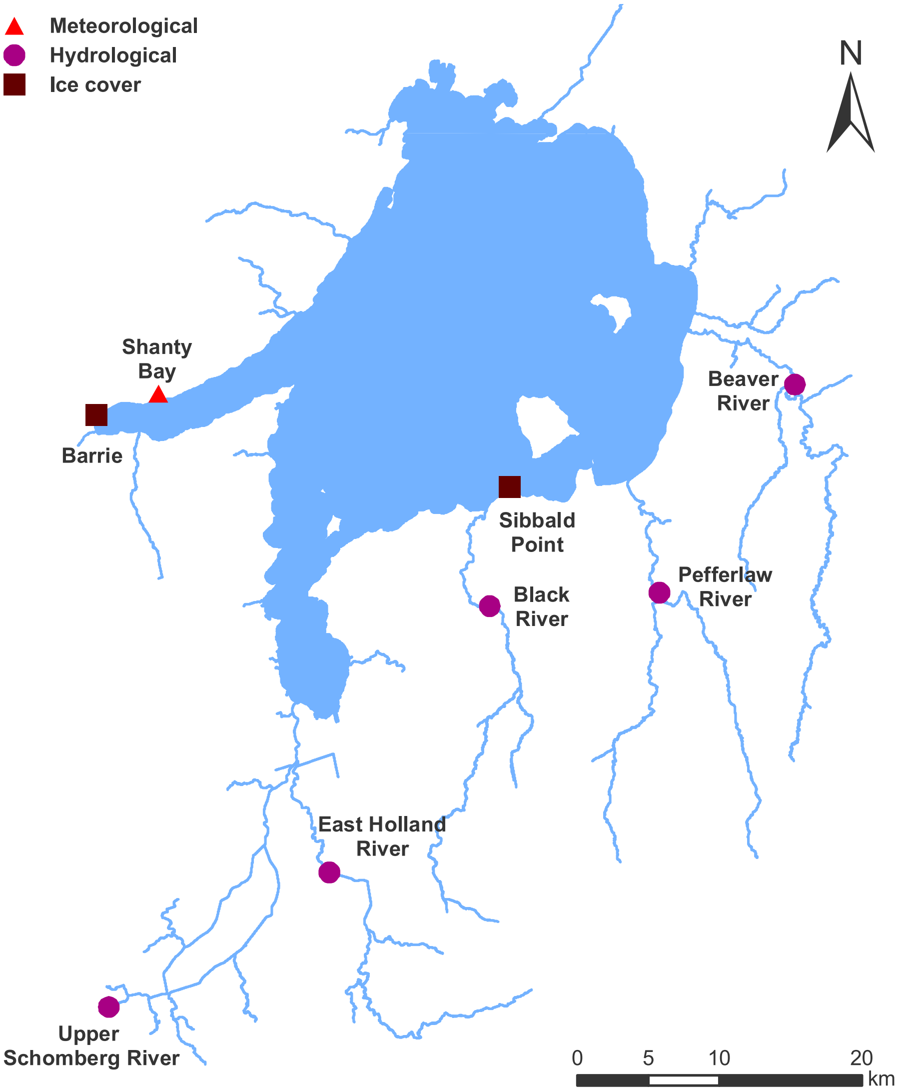


Figure 16: Locations of Environment Canada's (EC) Shanty Bay meteorological station, hydrological stations and ice cover observation points

Meteorological Trends

Annual air temperature from 1980 to 2012 measured at Shanty Bay has increased by 0.05 °C/year, resulting in an average increase of 1.6 °C. By month, significant increases occurred only in June (0.07 °C/year) and September (0.06 °C/year) (Fig. 17). On the other hand, there was no significant trend detected for annual or monthly precipitation, analyzed as rain, snow or both, over the 32-year period at the Shanty Bay station (Fig. 17). Precipitation, however, can vary considerably across the watershed, especially considering that the Shanty Bay station is in the snow belt (LSRCA, 2013).

METHODS

Meteorological data (air temperature and precipitation) were collected at Environment Canada's station at Shanty Bay (Fig. 16). Trends were analyzed using annual and monthly averages, and presented as the amount of change per year (i.e., Sen's slope) (Hirsch et al., 1991).

Meteorological data	Trend
Air temperature (Annual, June and September)	↑
Annual precipitation	↔

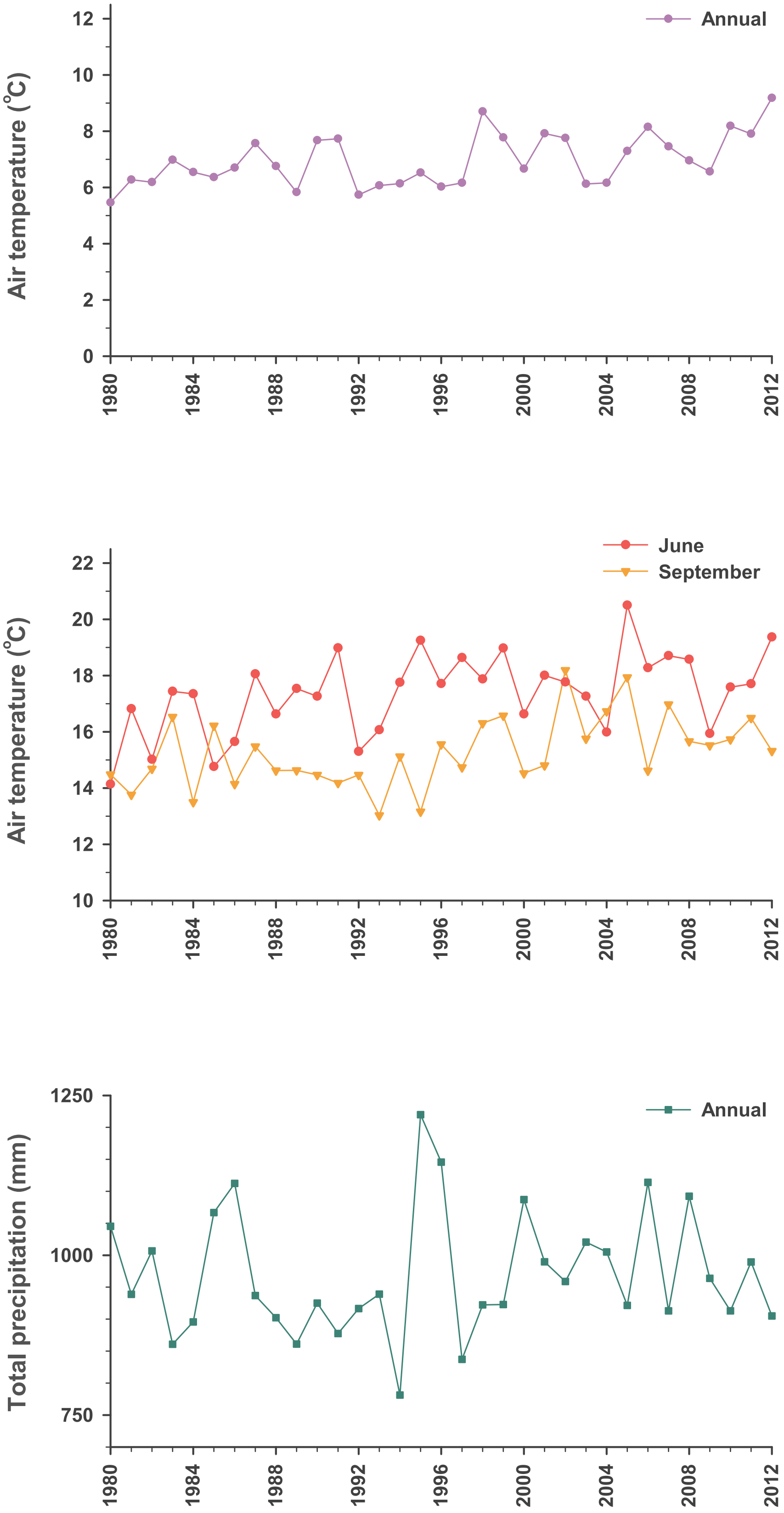


Figure 17: Meteorological trends from the Shanty Bay weather station: Air temperature (annual, June and September) and annual precipitation (snow + rain)

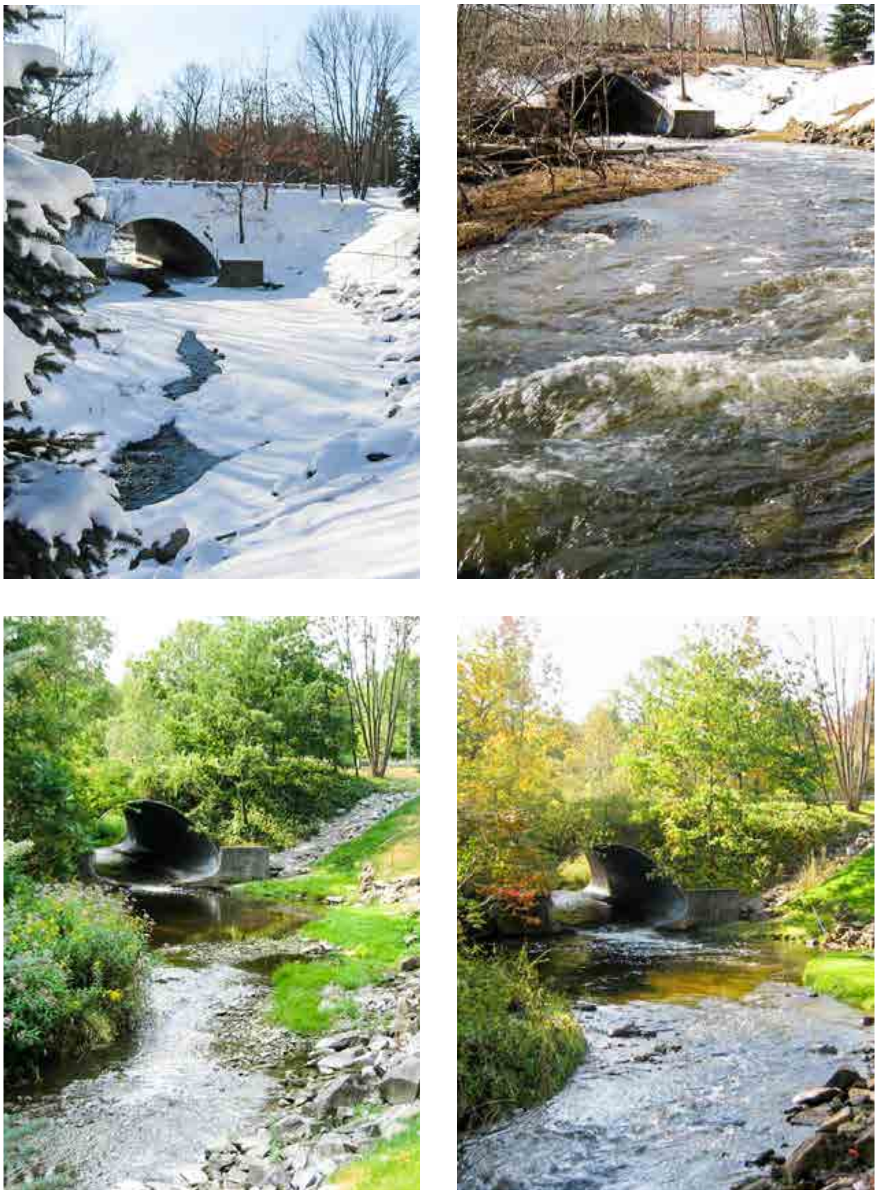
River Hydrology

River hydrology is the flow (or discharge) of water in a river, which can be affected by climate change, and is also an important indicator of water quantity. There are generally two types of flow: quickflow, which is quite variable as it comes from precipitation and is dependent upon climate, land use and topography; and baseflow, which comes primarily from groundwater and is generally more stable. Climate change may affect both types of flow through changes in winter and spring precipitation, and/or air temperatures, but the effects to flow may be complex (Jykrama and Sykes, 2007). After a "cold" winter, the snow typically melts all at once in the spring resulting in high flows (the spring freshet) and the recharging of groundwater stores. Alternatively, warmer winter temperatures can result in an earlier occurrence of the freshet, several smaller snow melt events, or short-lived "rain-on-snow" incidents when water falls on frozen ground.

METHODS

Credit: LSRCA

Discharge (m^3/s) is derived from water level measurements that are recorded by EC and LSRCA in tributaries across the watershed. Presented here are trends since 1980 at sites in five of the tributaries (Fig. 16) for each season. Seasons represent the hydrological year (June 1 to May 31); for example, spring 2008 is March, April and May of 2007.



Four seasons at Lovers Creek. *Credit: Jim Eddie. (Top left)* **Winter.** *(Top right)* **Spring.** *(Bottom left)* **Summer.** *(Bottom right}* **Fall.**

River Hydrology	All seasons
All five tributaries	↔

From 1980 to 2012, the greatest discharge occurred in the spring, with the second highest occurring in the winter. The temporal discharge trends did not change significantly in the five tributaries for any season (Fig. 18). This would be expected given there have not been any seasonal changes in precipitation, and air temperature changed only in June and September. However, changes in hydrology may be occurring that currently cannot be detected by trend analyses. Reports to date have indicated that flows at four of these sites appear to be increasing in the winter and decreasing in the spring (LSRCA, 2013), but these trends were not statistically significant. Changes in winter and spring flows may be due to more frequent rain-on-snow events, such as the very large event observed in December of 2008 (O'Connor et al., 2013), causing very high discharge in most tributaries. Because the nutrient loads to the lake from tributaries are largely dependent on the amount of flow, more analysis is required to better identify these trends, such as examining the trends in the ratio of baseflow to quickflow, and the timing of snow melts.

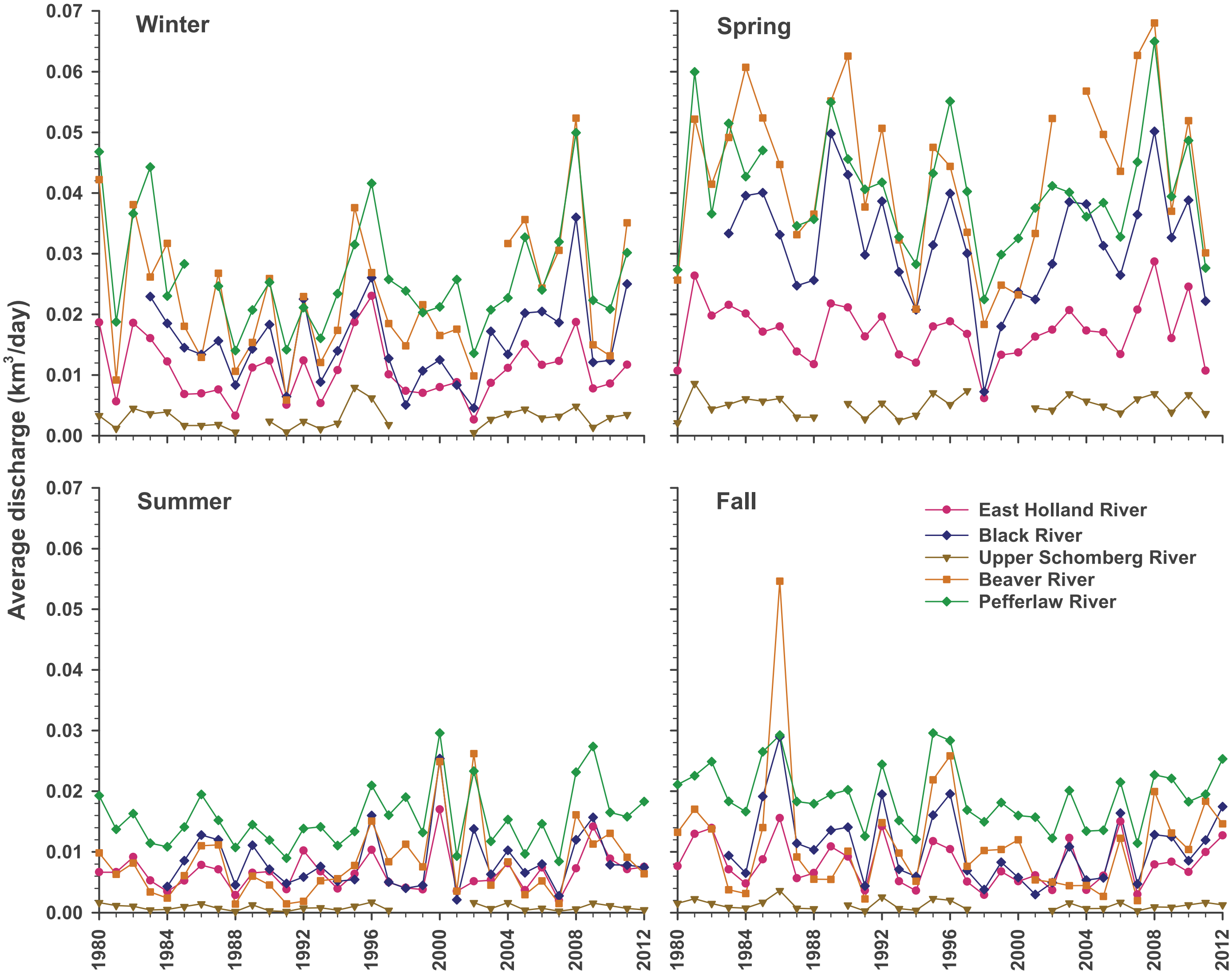


Figure 18: Seasonal river hydrology in five tributaries. *See Fig. 16 for site locations.*
NOTE: Seasons represent the hydrological year, which goes from June 1 to May 31; for example, Spring 2008 is March, April and May of 2007

RESEARCH

Dr. Jill Crossman, a postdoctoral fellow in Dr. Peter Dillon's lab at Trent University, is modelling the likelihood and extent of future climate change impacts on river hydrology of six Lake Simcoe subwatersheds, and the subsequent effects to nutrient loading. Given the uncertainties of climate projections, this modelling includes an assessment of uncertainties in rainfall and discharge predictions, and the potential consequence of that uncertainty on water quality projections. They found that although projections and uncertainties in climate were very similar, future responses in hydrology and water quality differed significantly among subwatersheds. Subwatersheds with higher clay content, such as in Beaver River and Whites Creek, responded most drastically to changes in climate as precipitation rapidly transports phosphorus (P) to rivers via overland flow. In these subwatersheds, larger reductions in flow and P concentrations were predicted, resulting in annual P load reductions. The Holland and Pefferlaw River subwatersheds were less responsive to climate change, due to a combination of precipitation filtering more slowly through the soil matrix and seasonal variability in soil P saturation, which controls the concentration of nutrients transported in soil water. In contrast to Beaver River and Whites Creek, projected flow reductions were associated with increases in P concentrations in spring months, which, combined with winter flow increases, resulted in projections of small increases in annual P loads. This work highlights the importance of tailoring P reductions to individual watersheds.

Whites Creek. *Credit: Jim Eddie*

Pefferlaw River. *Credit: Jim Eddie*

Lake Ice Cover

The direct effects of climate change are most apparent on the lake itself. For example, the timing of surface freezing (ice-on) and thawing (ice-off) is being directly affected by climate change, as well as local climatic factors (Yao et al., 2013). Higher temperatures can delay freezing in the late fall or early winter, and promote earlier thawing in the late winter or early spring.

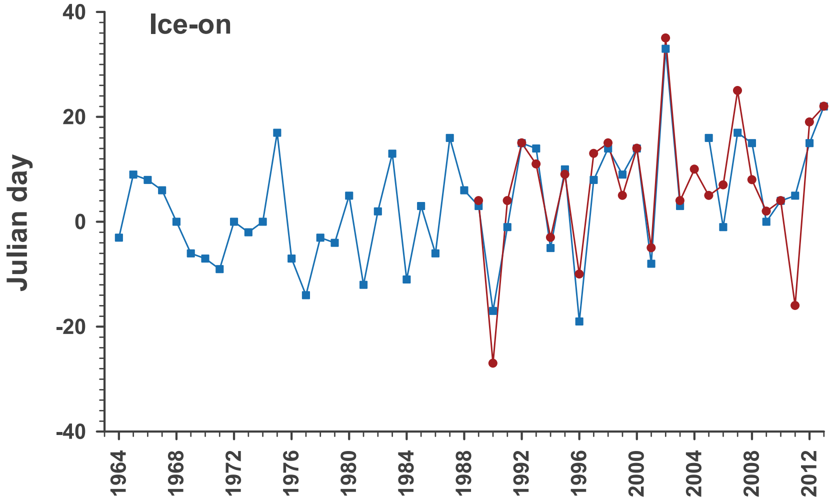
Big Bay Point

The independently made observations provided very similar results for ice-on, ice-off and total duration of ice cover (Fig. 19). The similar observations from different on-shore locations provide assurance in this type of data, and demonstrate the importance of citizen scientist programs. According to these observations, the lake was covered in ice every winter, with the longest ice cover period observed from Sibbald Point in 1996 (137 days), and the shortest period, also observed from Sibbald Point, in 2002 (38 days). Over these time periods, the lake has been freezing later, thawing earlier and thus has had a shorter duration of ice cover. These changes were significant from the Barrie location from 1964–2012 but not from Sibbald Point from 1989–2012.

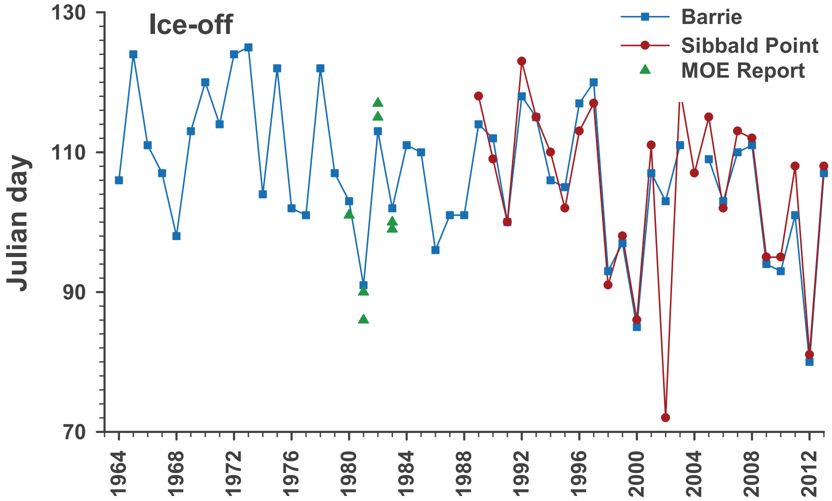
Some additional patterns may be occurring, although more years of data are necessary to confirm. Firstly, the decrease in ice cover duration appears to have sped up over the past couple decades, possibly due to warmer temperatures. Over the entire period of record presented (1964–2012) from the Barrie location, ice cover duration was approximately half a day shorter each year. Since 1989 (when Sibbald Point observations began), ice cover duration at both locations has been a full day shorter each year. Secondly, the timing of ice-off might be changing more dramatically than ice-on; for example, at Sibbald Point, ice-off was 16 days earlier in 2012 compared to 1989, while ice-on was only 4.5 days later (Fig. 19). An earlier ice-off can have subsequent effects on lake processes due to an earlier exposure to light, heat and wind, resulting in earlier stratification (see next section). These factors can affect the timing of seasonal processes for biota, such as phytoplankton, zooplankton and fish.

METHODS

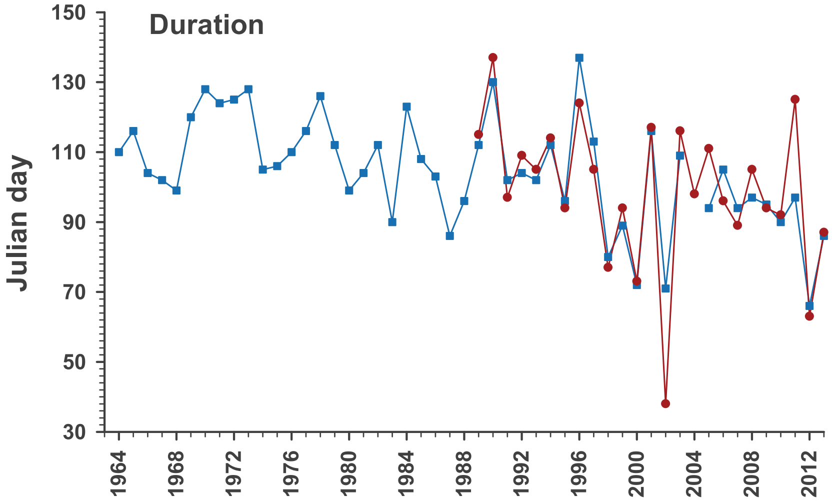
Observations of ice-on and ice-off are relatively easy to do from shore, and are of interest to those that live around the lake. There are private citizen records for Lake Simcoe ice cover observed from Barrie that go back to the mid-1850s. To ensure that consistent methods were used to determine ice-on and ice-off from Barrie, we present observations made by the same private citizen who began in 1964. Also presented are ice cover data from MNRF's LSFAU staff at Sibbald Point, beginning in 1989, and ice-off data for 1980–1983 from Table 1 of an MOE report (1984; observation location not provided). Ice cover duration is the number of days from ice-on to ice-off. The number of days difference between when observations began (1964 and 1989) and ended (2012) was estimated based on the rate of change per year (i.e., Sen's slope; Hirsch et al., 1991). When referring to a winter, the year containing January is used (e.g., winter of 2001/2002 is 2002). See Fig. 16 for site locations.



Ice-on	Trend	No. days difference
Barrie (1964–2012)	↑	12
Barrie (1989–2012)	↔	8
Sibbald Point (1989–2012)	↔	4.5



Ice-off	Trend	No. days difference
Barrie (1964–2012)	↓	-14
Barrie (1989–2012)	↓	-17
Sibbald Point (1989–2012)	↔	-16



Duration	Trend	No. days difference
Barrie (1964–2012)	↓	-26
Barrie (1989–2012)	↓	-27
Sibbald Point (1989–2012)	↔	-24

Figure 19: Lake ice cover observations: Ice-on, ice-off and total duration.
NOTE: The y-axis for ice-on figure is Julian day based on January 1

Lake Temperature

Immediately after ice-off in the spring, surface waters are warmed by solar energy, and the wind mixes the surface waters with the bottom waters. As surface waters warm, it takes more wind energy to mix vertically because greater temperature differences create greater density differences. When these density differences are large enough, the lake stratifies into three horizontal layers: epilimnion (warm surface layer), metalimnion (middle layer with rapid temperature decrease) and hypolimnion (cooler bottom layer).

The large surface area of Lake Simcoe relative to its depth provides substantial wind energy for mixing, and thus stratification can be fairly weak compared to lakes with a smaller surface area to depth ratio. Nonetheless, the lake stratified at the deeper lake stations (e.g., K42) (Fig. 20). This additional energy for mixing in the spring also resulted in a much warmer summer hypolimnion compared with lakes of similar depth.

With an earlier ice-off and warmer temperatures, the surface waters of Lake Simcoe are getting warmer in the summer. As a result, the timing of stratification appears to have changed in all three lake basins. The onset of stratification occurred earlier in spring and the lake turned over later in fall; therefore, the total duration that the lake was stratified was longer. For example, in Kempenfelt Bay (K42), the duration of thermal stratification was approximately 28 days longer in 2012 compared with 1980 (Fig. 21). The longer period of stratification was correlated with increases in air temperature, especially in June and September (Stainsby et al., 2011). Increases in water clarity (as described later) can also contribute to increased stratification as they allow solar energy to penetrate to deeper depths in the lake. Increased stratification along with shorter ice cover duration and warmer water temperatures could have significant implications on the lake biota, from phytoplankton to fish.

METHODS

Temperature was measured by the MOECC at 1-m increments from surface to bottom at all open lake stations throughout the ice-free season, but only K42 profiles are presented. The timing of stratification was calculated from temperature profiles at stations K42, K45 and C9 using the Schmidt Stability Index (see Stainsby et al., 2011, for details).

RESEARCH

Climate change effects on the phytoplankton community are currently being investigated by Jiahua Li, an MSc student in Dr. Lewis Molot's lab at York University. Climate change is expected to promote algal growth, which could contribute to algal blooms. Jiahua is working with long-term data from the MOECC to identify how climate affects lake warming and mixing, and how this in turn affects the algae. Knowledge on how climate affects algal communities will inform climate change predictions and help to mitigate detrimental impacts of future climate change such as algal blooms.

Ice breaking up on Lake Simcoe

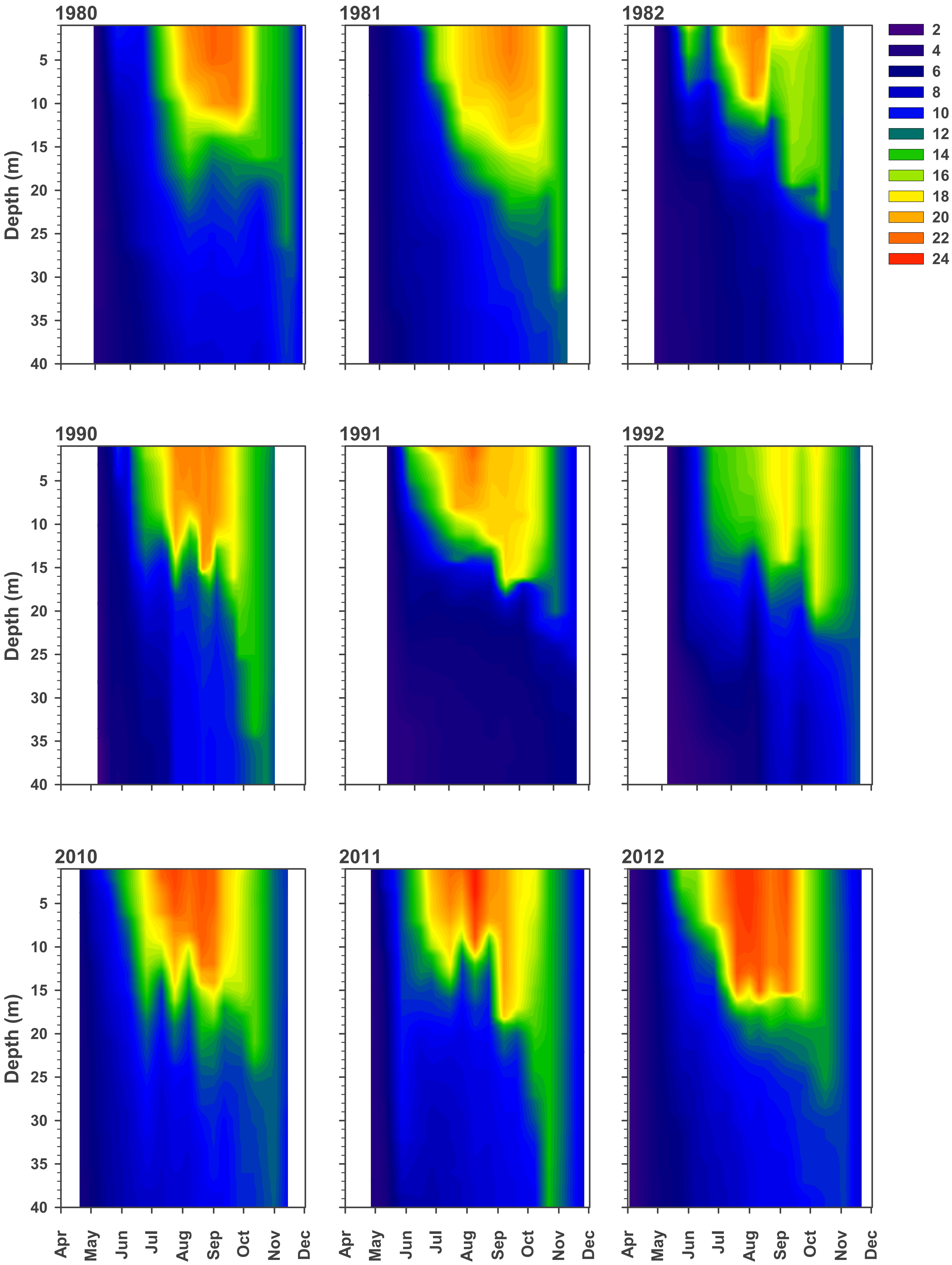


Figure 20: Thermal profiles (°C) at station K42 in Kempenfelt Bay over nine summers

Onset	Trend	No. days difference
C9	↓	-22
K42	↓	-18
K45	↓	-13

Overturn	Trend	No. days difference
C9	↑	20
K42	↑	12
K45	↑	14

Duration	Trend	No. days difference
C9	↑	47
K42	↑	28
K45	↑	27

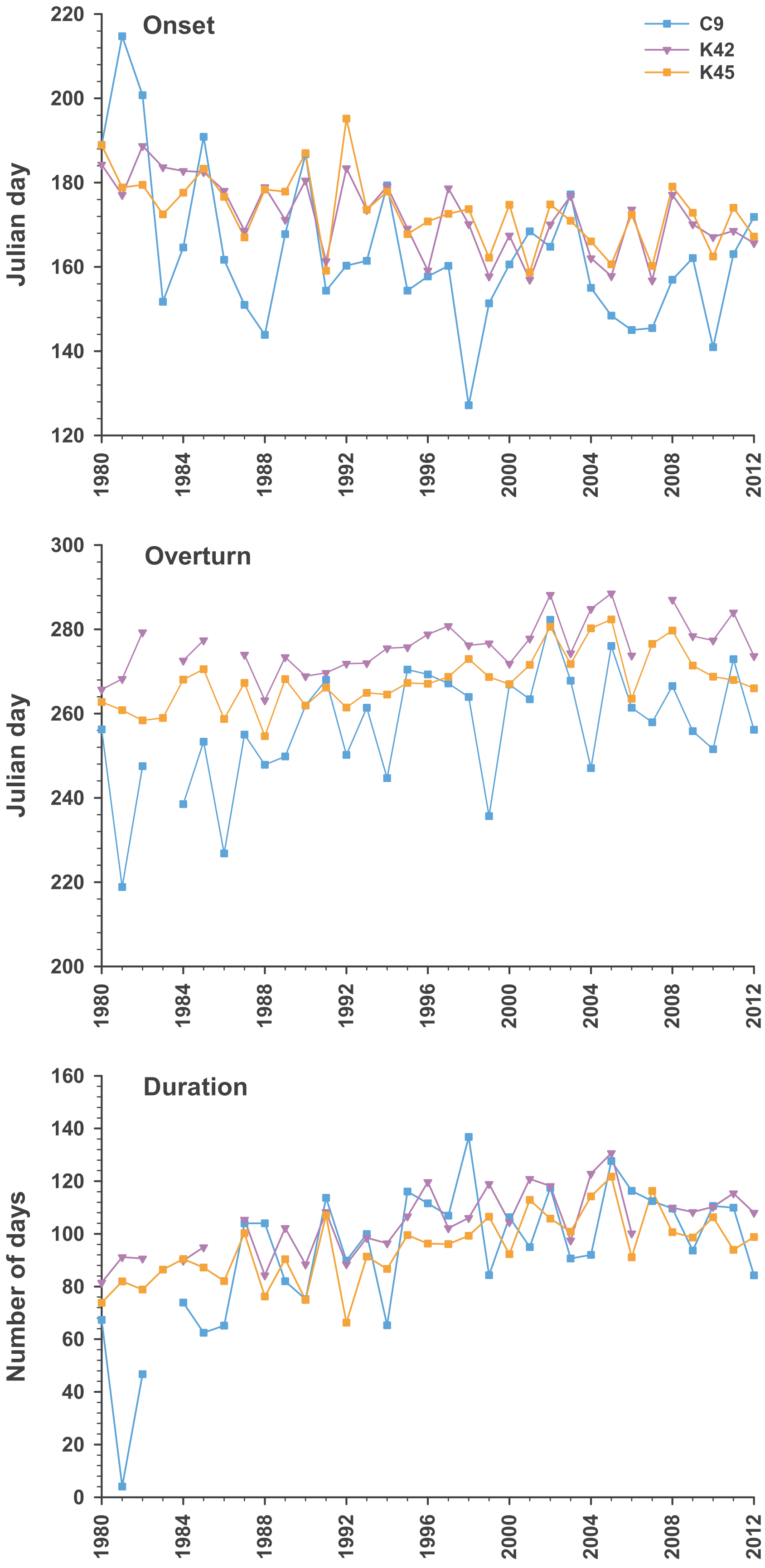


Figure 21: Timing of lake thermal stratification at three lake stations: Onset, overturn, and total duration

RESEARCH

Lake trout spawning shoal at Sibbald Point. *Credit: MNRF*

An indicator of climate change in the Lake Simcoe Protection Plan is the changes in the timing of seasonal processes like fish spawning. The lake trout spawns in the fall along shoals, but its timing of spawning would be expected to be delayed due to warmer water temperatures and a longer duration of stratification. To study whether this has occurred, Dr. David Evans' lab at the MNRF's Aquatic Research and Monitoring Section examined water temperature and lake trout spawning on two shoals of Lake Simcoe (off of Georgina and Strawberry Islands) from 1978 to 2003 that were monitored by MNRF's LSFAU. The results suggest that lake trout was spawning later in more recent years (Fig. 22), which was positively correlated with average water and air temperatures.

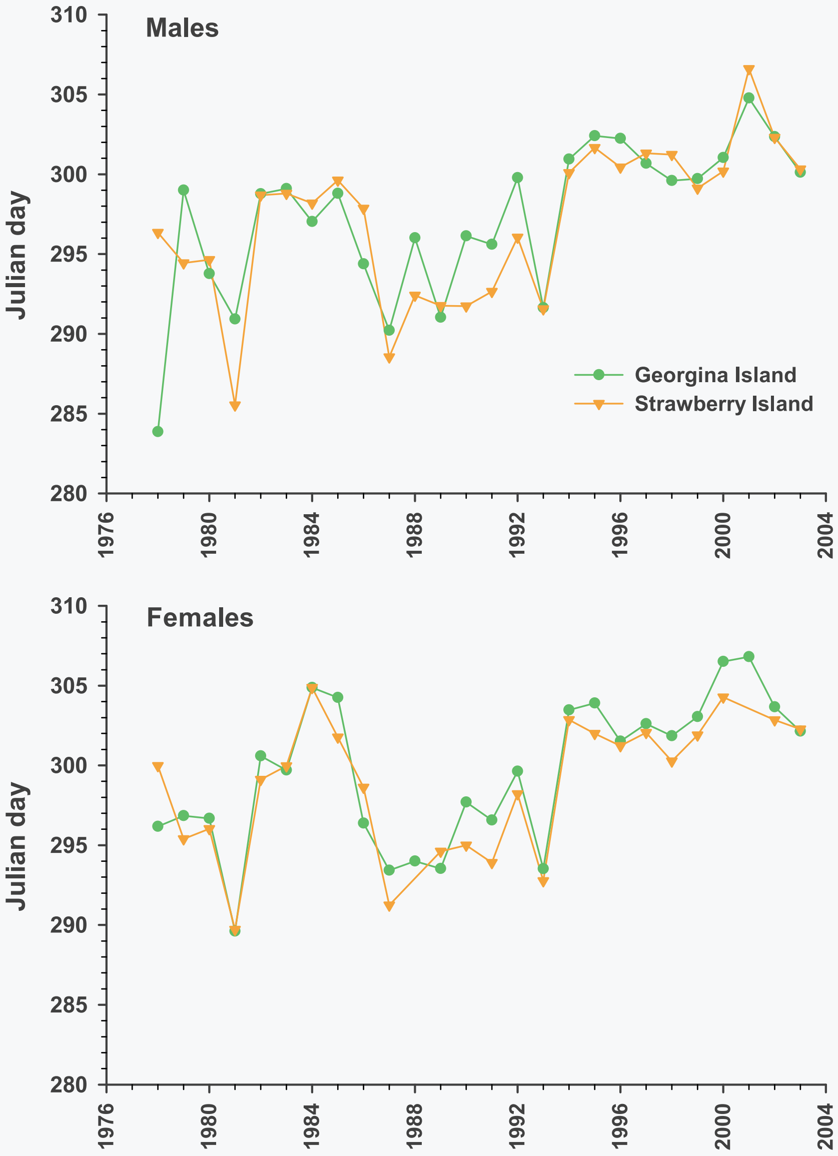


Figure 22: Timing of lake trout spawning: The estimated day when half of the mature lake trout arrived at the spawning shoals of Georgina and Strawberry Islands

RESEARCH

Daphnia galeata mendotae.
Credit: Lynne Witty

Stephanodiscus Diatoms

Climate change has affected lower trophic levels in North American lakes by causing a mismatch in the timing of seasonal processes of diatoms, a key phytoplankton group, and *Daphnia*, a key herbivorous zooplankton group (Winder et al., 2004). The MOECC are investigating whether this has occurred in Lake Simcoe. For example, in 1997 (a cool year) and 2006 (a warm year) at station K42, *Daphnia* abundance peaked on similar dates; however, the spring diatom bloom appeared to happen earlier in 2006 causing a mismatch in this warmer year (Fig. 23). When *Daphnia* miss the bloom of an important food source, their summer population abundance may be reduced, which could have consequences at higher trophic levels because *Daphnia* are food for planktivorous fishes. Further analysis will be performed to determine whether changes in timing of lower trophic levels have indeed occurred in Lake Simcoe.

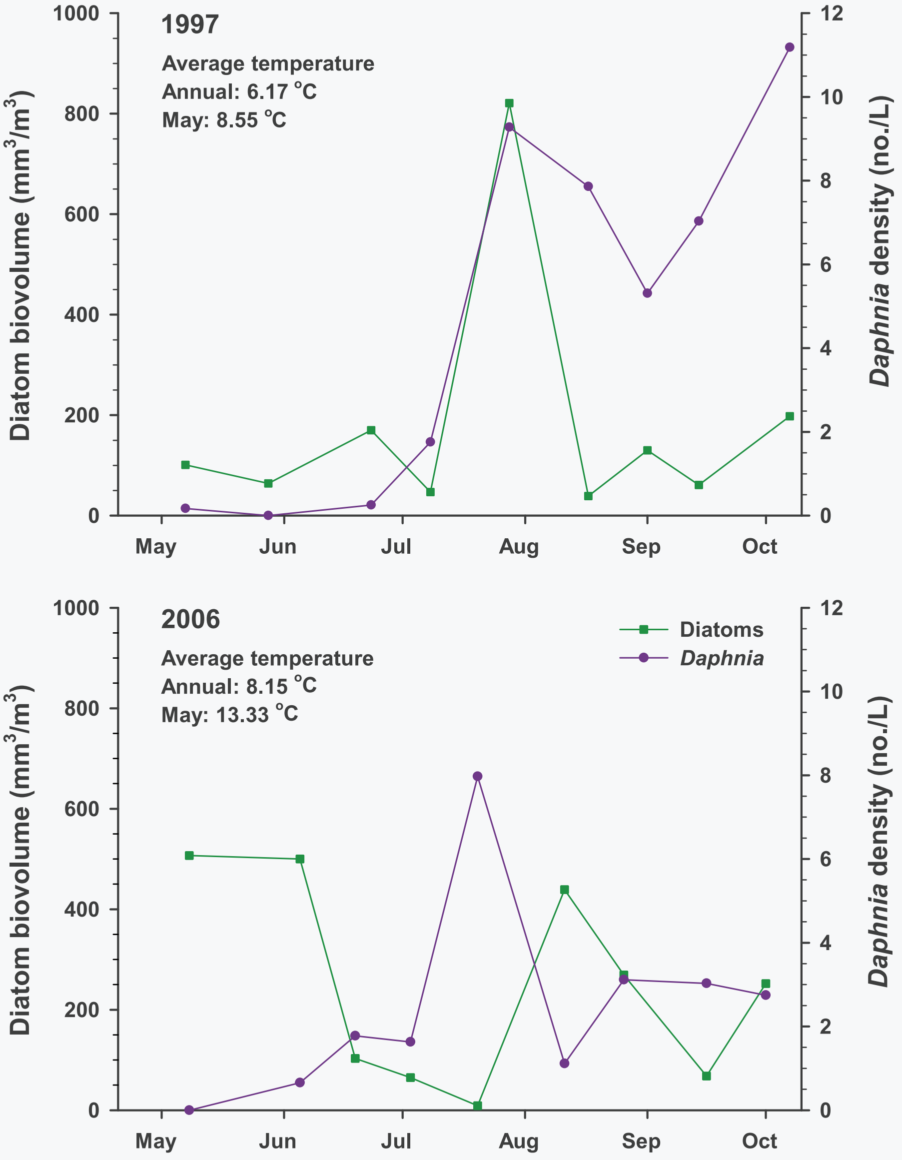


Figure 23: Timing of seasonal abundances of key phytoplankton (diatoms) and herbivores *(Daphnia)* in a cool (1997) vs. warm year (2006)

What we are doing

With effects of climate change already apparent on the Lake Simcoe watershed and further effects expected, it is important to be prepared and able to adapt to the changes. Vulnerability assessments of many aspects of Lake Simcoe have been performed, and the MOECC will soon be releasing the Climate Change Adaptation Strategy (CCAS). To inform the implementation of the CCAS, additional assessment of the adaptive capacity of the watershed to respond to the impacts of climate change on agriculture, water quality and water quantity were performed by Al Douglas of the Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR, 2014). They also developed a Lake Simcoe Watershed Community of Practice (LSWCoP), which is an online community for climate change adaptation within the Lake Simcoe watershed.

Section 5:
Water Quality

Water Quality

The quality of the water in Lake Simcoe and its tributaries is of critical importance to the human population as well as aquatic biota. Water quality is closely tied to changes described in the previous sections, such as land use and natural heritage areas, climate change, and invasive species. The following indicators of environmental health relating to water quality for the lake and its tributaries were identified in the LSPP: total P concentration and loading, dissolved oxygen, other nutrients, and contaminants (e.g., chlorides and metals). These indicators can be used to evaluate changes in water quality resulting from the implementation of the LSPP.

(Opposite) Claredon Beach Park, Keswick

METHODS

The monitoring of water quality in Lake Simcoe and its tributaries is performed in partnership by LSRCA and MOECC (Fig. 2) across the lake and watershed (Fig. 3). Monitoring of tributaries representing a variety of land use types in the Lake Simcoe watershed began in 1993 as part of the LSEMS program, with earlier monitoring through Ontario's Provincial Water Quality Monitoring Network. Long-term trends of six LSEMS sites with samples collected year round at least once per month are presented from 1980 onward. In the lake, water samples have been collected from the euphotic zone (i.e., the surface of the lake to approximately 15 m depth) of eight or more open lake stations biweekly through the ice-free season since 1980, and the MOECC has received weekly untreated water samples from three water treatment plants (WTPs) throughout the year since the mid-1980s, as part of the MOECC's Great Lakes intakes program. Untreated water samples are collected from the water intake pipes, which are nearshore and at a discrete depth. For the long-term trends, tributaries are presented as annual medians, open lake stations as ice-free means, and WTPs as annual means. Spatial distributions of phosphorus, nitrogen and chloride are provided for all stations as four-year (2009–2012) averages of mean ice-free lake, and annual tributary and WTP concentrations. Note that water quality parameters sometimes were at very low concentrations that were below the detection limit of the laboratory equipment; in those cases, a non-invasive analysis technique was used to estimate means (for more information, see Helsel, 1990).


Lake water collection


Lake water collection


Tributary water collection. *Credit: Jim Eddie*


Tributary water collection. *Credit: Jim Eddie*

Black River. *Credit: Jim Eddie*

Total Phosphorus Concentration

The greatest effects on the water quality of Lake Simcoe have resulted from excess P, most of which enters the lake through tributaries that receive run-off from agricultural areas, urban centres and natural areas. Phosphorus is a limiting nutrient of algal and aquatic plant production, and therefore more P in a tributary or the lake means more plant growth and hence more plant decomposition. Historically, excess P loading caused increased P and algal growth in the lake. This in turn depleted the hypolimnetic dissolved oxygen, because oxygen was consumed as plant matter decomposed on the lake bottom. To reach the LSPP's dissolved oxygen target of 7 mg/L, a P loading goal of 44 tonnes/year was established, which, under current hydrological conditions, has a corresponding whole-lake ice-free P lake concentration goal of 8.1 µg/L (Fig. 24).

RESEARCH

The phosphorus (P) load goal in the Lake Simcoe Protection Plan (LSPP) of 44 tonnes/year was established to meet the main objective of the LSPP, which is a dissolved oxygen target of 7 mg/L. The P load goal was estimated through a model that linked P load to minimum volume-weighted hypolimnetic dissolved oxygen (MVWHDO) (Nicholls, 1997). The relationships linking dissolved oxygen and P load (Fig. 24) were re-evaluated in the years following invasion by dreissenids and the spiny water flea (Young et al., 2011) and recently by the MOECC using the most up-to-date P load (2005–2009) data. In all analyses, the empirical relationships linking dissolved oxygen to total P were still valid following the invasions, suggesting that a P load goal of 44 tonnes/year is appropriate to meet the 7 mg/L dissolved oxygen target.

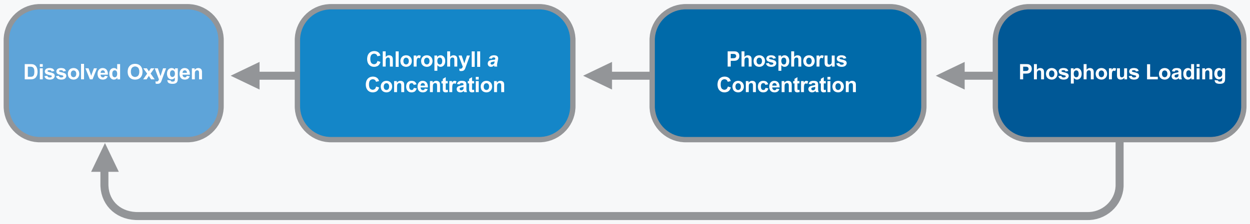


Figure 24: Relationships connecting lake dissolved oxygen with total phosphorus loading

Annual total P concentration in the tributaries varied considerably across the watershed (Fig. 25). In general, subwatersheds with more urban (East Holland River: 155 µg/L) or agricultural (Maskinonge River: 121 µg/L and West Holland River: 120 µg/L) land use had higher total P concentrations in recent years (2009–2012). Only two tributaries were below the provincial water quality objective (PWQO) of 30 µg/L (Hawkestone Creek: 20.5 µg/L and Talbot River: 18.6 µg/L), and these subwatersheds had the highest amount of natural cover in 2008/2009 aside from the islands. Across the lake, there was less variation in P concentration, likely due to lake processes such as mixing and sedimentation. Unsurprisingly, though, total P concentration was greatest in Cook's Bay (17–24 μg/L), into which the Maskinonge, and East and West Holland Rivers flow, gradually decreasing northward toward the open lake. The lowest total P recorded in the lake was at Atherley Narrows (9.0 μg/L) and the Beaverton WTP (9.8 μg/L). These concentrations met the PWQO of 10 μg/L, but were above the LSPP's P goal of 8.1 μg/L for Lake Simcoe. Atherley Narrows is where the water eventually exits the lake, thus the P had already cycled and sedimented out of the lake water before reaching this site, and therefore had lower P concentrations.

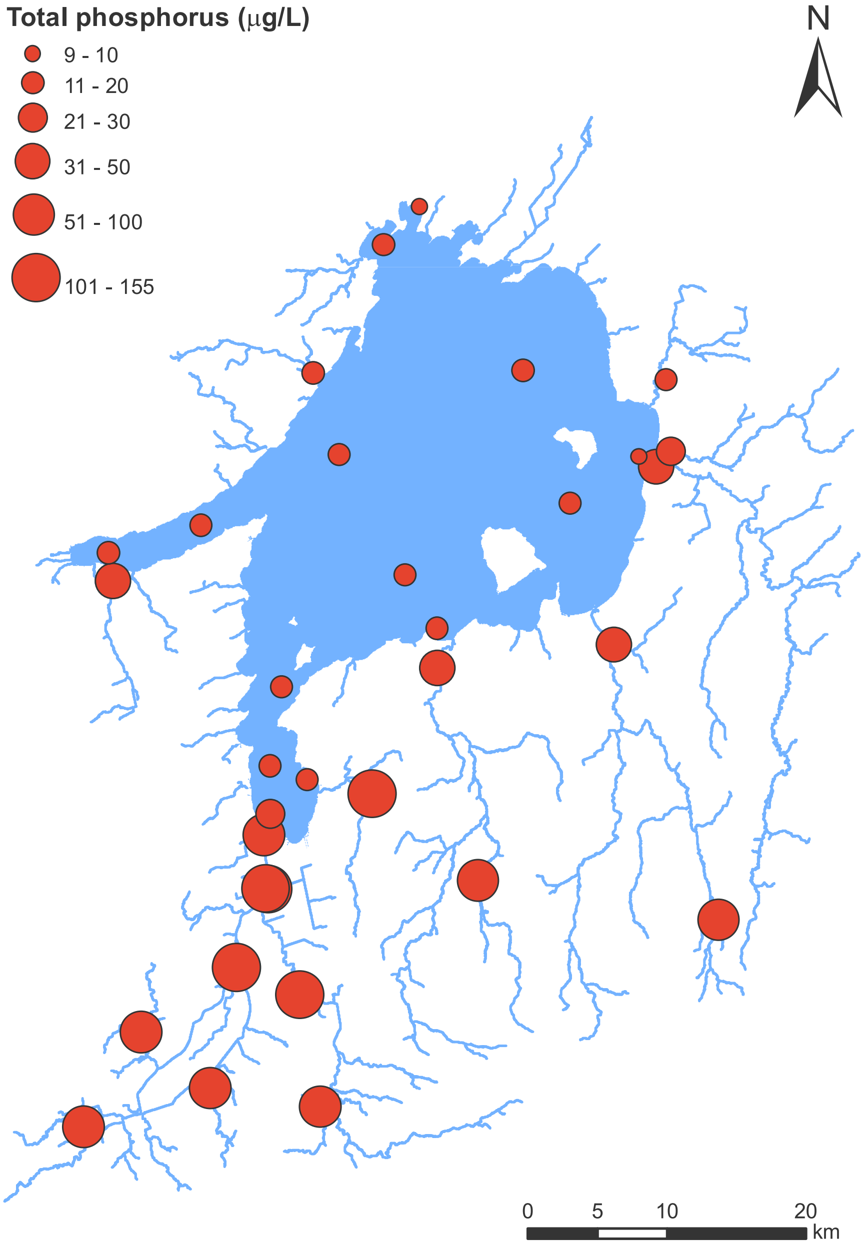


Figure 25: Recent total phosphorus concentrations (average of 2009–2012).
See Fig. 3 for station names

RESEARCH

Reduction of phosphorus (P) loading is a key action to restore and protect the water quality of Lake Simcoe, and meet the requirements of the Lake Simcoe Protection Plan. One of the principal approaches that has been taken to reduce P loading is the use of best management practices (BMPs), including planting trees and shrubs, upgrading septic systems, managing manure, restricting livestock from watercourses, planting cover crops, upgrading stormwater management ponds and diverting runoff from sources of contamination.

The effectiveness of BMPs in reducing nutrient loads is being studied by Dr. Peter Dillon at Trent University. Dr. Jill Crossman, a postdoctoral fellow in Dr. Dillon's lab, is comparing water quality at sites with and without BMPs. The monitoring data are being used in a model to determine a) how effective BMPs have been since their implementation, and b) the most effective areas for implementation. Climate change scenarios are also being used to determine the robustness of current BMPs under possible changes in temperature and precipitation.

Over the long term, there have been decreases in the total P concentration in most tributaries (Fig. 26). Since 1980, total P concentrations have decreased in the Beaver, Pefferlaw, East Holland and Upper Schomberg Rivers. Notably, the greatest declines occurred in the East Holland River, following the 1984 diversion of sewage from the upstream cities of Newmarket and Aurora. No significant change was detected in Hawkestone Creek, where monitoring started in 1993. The only site analyzed for this report that showed an increase was in Lovers Creek, where P concentration was among the lowest in the 1980s but has become slightly higher over the past two decades, coinciding with increases in urbanization.

At the eight open lake stations, there were no significant changes in ice-free P trends (Fig. 26). A report analyzing trends up to 2003 detected decreases in total P at lake stations (Eimers et al., 2005); however, these decreases primarily occurred in the 1980s, and since then P concentrations have been variable. At all stations with the exception of the most southern in Cook's Bay (C1), the trends in P concentrations appeared synchronous with periods of low P concentrations. An early period of low P concentrations (1987–1992) likely reflected P reductions in the tributaries, especially in the East Holland River after the sewage diversion. More recently (2010–2012), lower P concentrations could indicate recent improvements, as well as variation in precipitation and run-off. Similar to trends recorded at the lake stations, total P declined through the 1980s and early 1990s at the WTPs, and there was a significant decreasing trend in total P overall at two of the WTP stations (Beaverton and Keswick) (Fig. 26). The total P concentrations in the 1980s were higher at the two WTPs and station C1 at the bottom of Cook's Bay compared with the other open lake stations. This was likely due to their location in the nearshore, which is closer to the tributaries where P is received and before it is cycled and mixed throughout the lake.

RESEARCH

Phosphorus (P) retained in the sediments is a sink for P; however, certain circumstances can result in P being released from the sediments. The primary cause of internal loading is anoxia (i.e., very low dissolved oxygen levels) in the lake sediment. Recent research has estimated the internal P loading in Lake Simcoe. Nürnberg et al. (2013) used a variety of methods that suggested internal loading has decreased significantly since 1980; for example, total lake internal P loading was estimated at 84.5 tonnes/year from 1990–1997 and 37.4 tonnes/year from 1998–2006. The decreases in internal load were likely due to decreases in external P loading, which lead to fewer anoxic periods. Therefore, as total P in the sediments becomes diluted from further reductions of external P loading, internal loading will continue to decrease. However, according to Dittrich et al. (2013), and also shown by Gudimov et al. (in press; see other text box), Nürnberg's internal load evaluations may be overestimated.

Looking south towards Cook's Bay

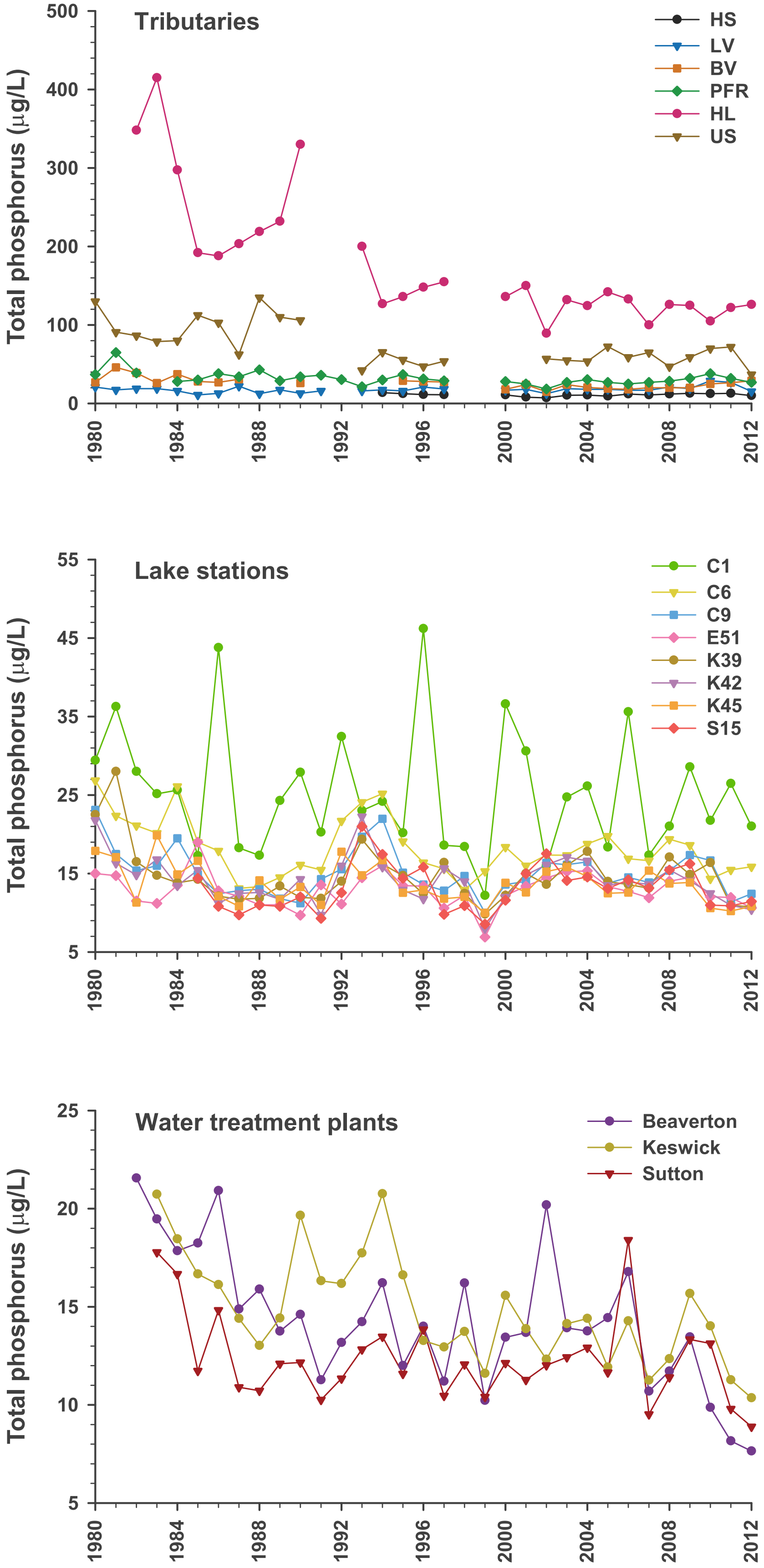


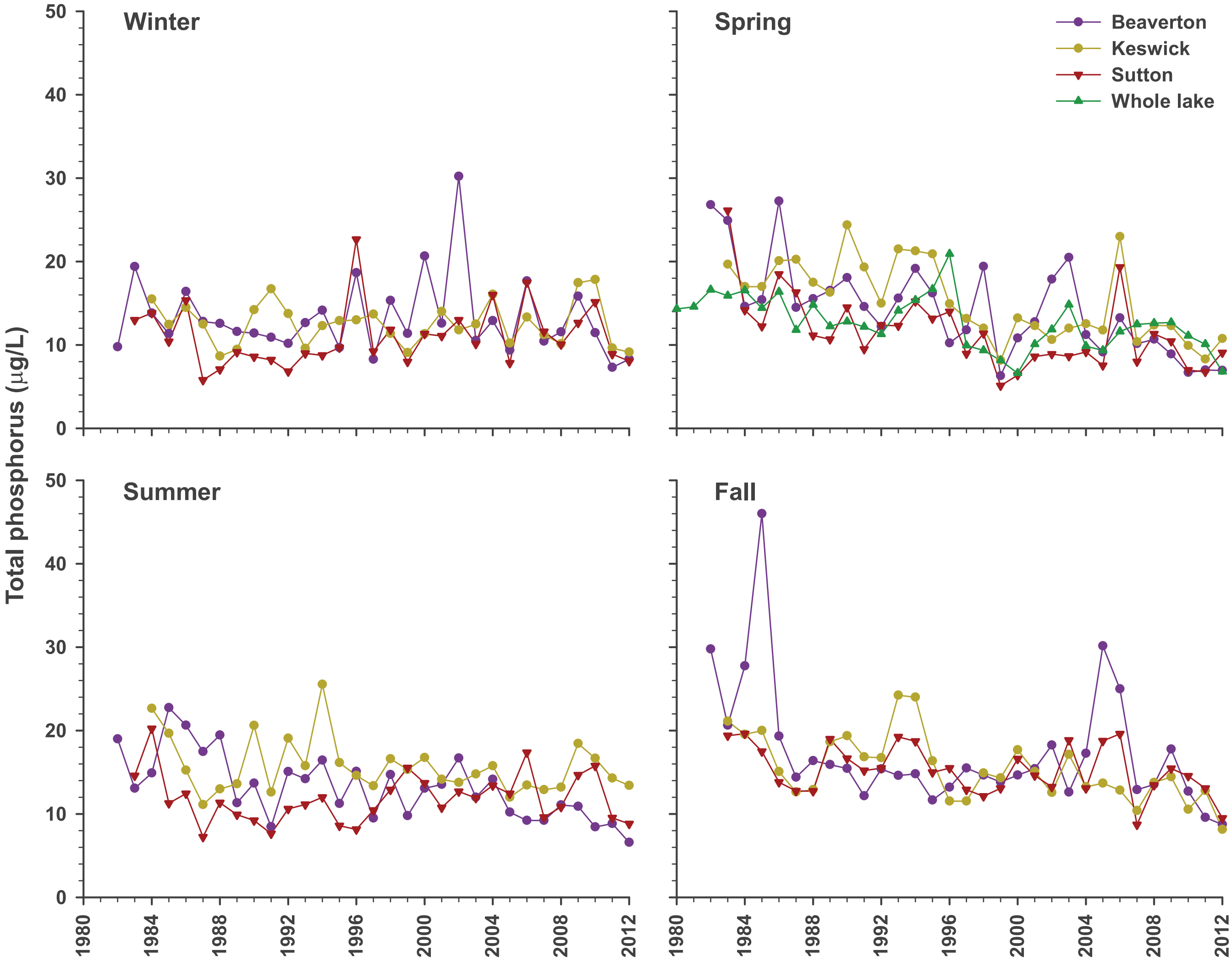
Figure 26: Total phosphorus concentration in tributaries, the lake and at water treatment plant (WTP) intakes

Total phosphorus	Trend
Hawkestone Creek (HS)	↔
Lovers Creek (LV)	↑
Beaver River (BV)	↓
Pefferlaw River (PFR)	↓
East Holland River (HL)	↓
Upper Schomberg River (US)	↓
All lake stations	↔
Beaverton WTP	↓
Keswick WTP	↓
Sutton/Georgina WTP	↔

→ RESEARCH

There are approximately 3700 septic systems surrounding the Lake Simcoe shoreline, a majority of which are located within 100 m of the lake. Phosphorus (P) loading from septic systems is estimated to contribute 4.4 tonnes/year of P to Lake Simcoe. The movement of P from septic systems to the lake can vary depending on the age, type and integrity of the septic system, as well as the type of soil surrounding the septic system. The mobility of P from septic systems is being studied by Dr. Will Robertson at the University of Waterloo. Dr. Robertson is using monitoring wells, and groundwater and sediment analysis to investigate P mobility in soils with different permeability and whether failing septic systems are a larger source of P. Knowledge of P movement from septic systems will help inform P loading calculations for Lake Simcoe and provide guidance on managing sources of P in the watershed.

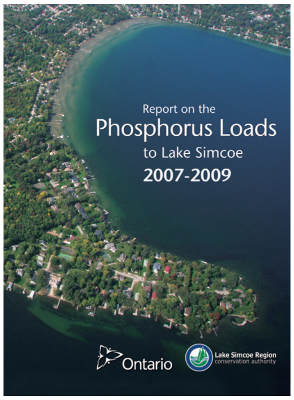
While annual or ice-free total P did not decrease at all stations, springtime P has decreased significantly across the lake at all WTPs, across the open lake stations (volume-weighted) (Fig. 27), and at all sites on the watershed except Lovers Creek (not shown). Some significant decreases were also observed in summer and fall, but very few were observed during the winter. The only increasing total P trend was observed during the summer in Lovers Creek. The greatest P inputs to lakes typically enter during the spring melt of snow and ice. Decreases in spring total P could be related to overall decreases in source inputs of P through remedial actions, but also could be linked to changes in climate if the timing of run-off has become more spread out and gradual as opposed to all at once during the spring freshet.



Seasonal total phosphorus	Spring	Summer	Fall	Winter
Beaverton	↓	↓	↓	↔
Keswick	↓	↔	↓	↔
Sutton/Georgina	↓	↔	↔	↔
Whole lake	↓	n/a	n/a	n/a

Figure 27: Seasonal total phosphorus concentration at the water treatment plant (WTP) intakes, as well as the whole lake (volume-weighted) in the spring

Aside from the tributaries, sources of P to Lake Simcoe are the atmosphere, septic systems and WPCPs, and polders. Estimated P loads from each of these sources up to 2009 were released in a joint report by the MOE and LSRCA (LSRCA and MOE, 2013). The total average P load into Lake Simcoe from 2005–2009 was 86 tonnes/year, which increased from the previous 5-year (2002–2007) average of 72 tonnes/year. This increase was primarily due to an increase in tributary P loads from 43 tonnes/year to 54 tonnes/year; tributary loads were especially high in 2007 and 2008 because of unusually high winter and spring flows in these hydrological years (see Fig. 18).



Cover of the Report on the Phosphorus Loads to Lake Simcoe (2007–2009)

Of the total 86 tonnes/year of P that entered Lake Simcoe from 2005–2009, 9 tonnes/year (11%) exited through the lake outflow (Fig. 28). The remaining 89% of P has historically been assumed to be retained in the sediments; however, in recent years, a significant portion of this P was likely taken up into dreissenid mussel tissues and shells (Ozersky et al., submitted).

➔ RESEARCH

Modelling of phosphorus (P) dynamics in Lake Simcoe from 1999 to 2007 was performed by Dr. Alex Gudimov in Dr. George Arhonditsis' lab at University of Toronto, Scarborough. He modelled the role of zebra mussels, macrophytes and sediments on P concentration in the lake basins, and found substantial recycling of P by zebra mussels and macrophytes, and P from the sediments accounted for ~30–35% of external loading. Active P recycling by the zebra mussel means that its overall clearance rate of P may be low, as much (>85%) of the P ingested was returned to the water column (Gudimov et al., in press).

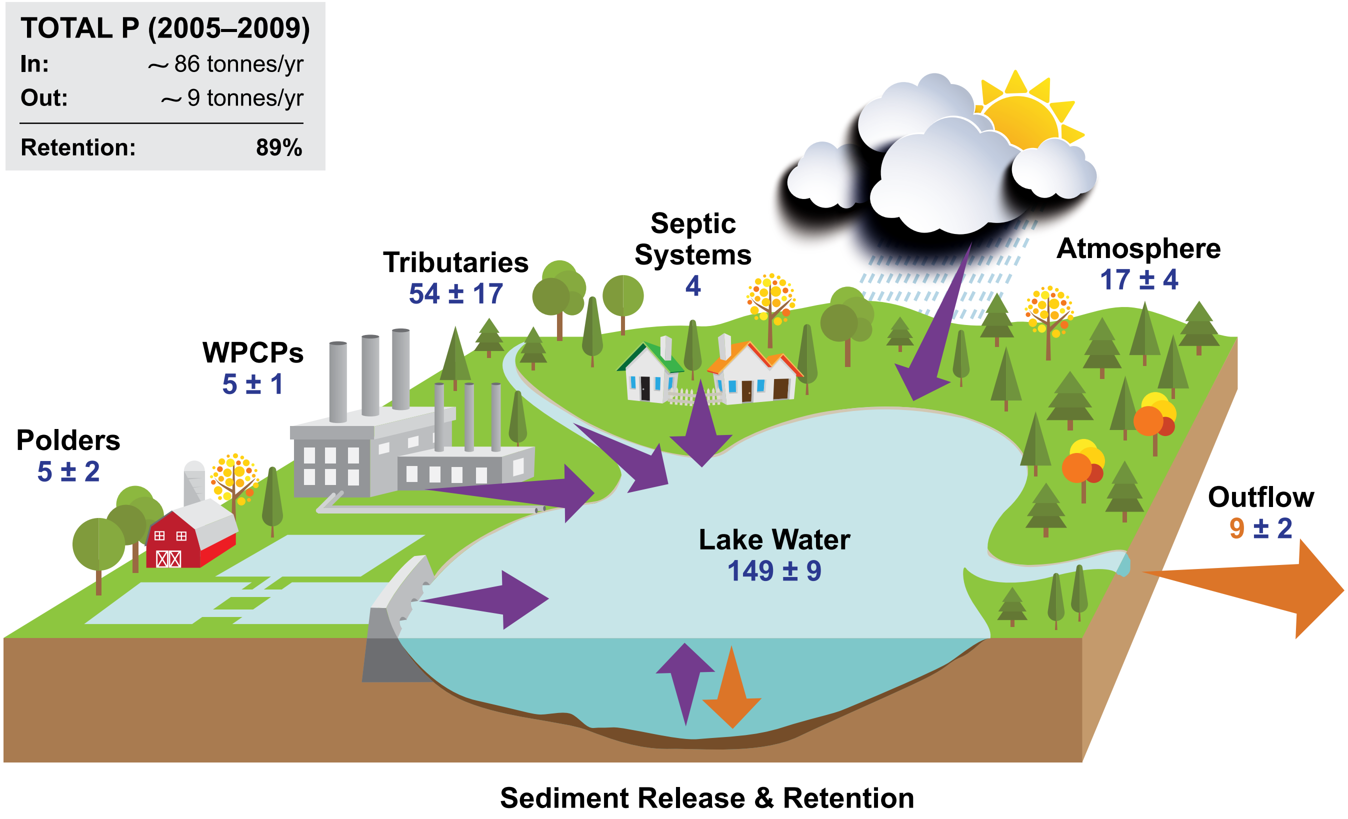


Figure 28: Average annual total phosphorus mass balance for Lake Simcoe (2005–2009)

Dissolved Oxygen

Dissolved oxygen is essential for aquatic animals, especially coldwater fishes, which have high oxygen demands yet are restricted by temperature to the hypolimnion during summer stratification. Therefore, dissolved oxygen in the hypolimnion of the lake is a key indicator of the LSPP, and, as described in the previous section, is directly linked to P loading. The main sources of dissolved oxygen to the lake are the atmosphere and photosynthesis from aquatic plants. Starting in the spring, dissolved oxygen is at a maximum (>10 mg/L), and is distributed evenly from the lake surface to bottom (Fig. 29). However, after the lake stratifies, dissolved oxygen is slowly used up in the hypolimnion as it is consumed by animals and the decomposition of settled organic matter on the lake bottom. Hypolimnetic dissolved oxygen usually reaches its minimum level just before the lake turns over in the fall.

In the LSPP, the target minimum volume-weighted hypolimnetic dissolved oxygen (MVWHDO) before September 15 is 7 mg/L, as this is the optimal amount of oxygen required for sensitive coldwater fish species, such as lake trout. By September 15, it is assumed that the temperature in the surface waters has cooled enough that coldwater fish can migrate upwards to access oxygen.

METHODS

Dissolved oxygen was measured by the MOECC at 1-m increments from surface to bottom on all ice-free sample dates and at all open lake stations; however, only K42 is presented here, as it is the deepest station in the lake and thus prime habitat for coldwater fishes. Minimum volume-weighted hypolimnetic dissolved oxygen (MVWHDO) was estimated as either the lowest VWHDO concentration from 18 m to the lake bottom before September 15 or the interpolated VWHDO on September 15, whichever was less. The mean monthly rate of VWHDO depletion (ΔDO) were estimated as the slope of the linear regression of June to September VWHDOs, and were normalized to 4 °C with mean summer temperatures.

Monitoring dissolved oxygen and temperature

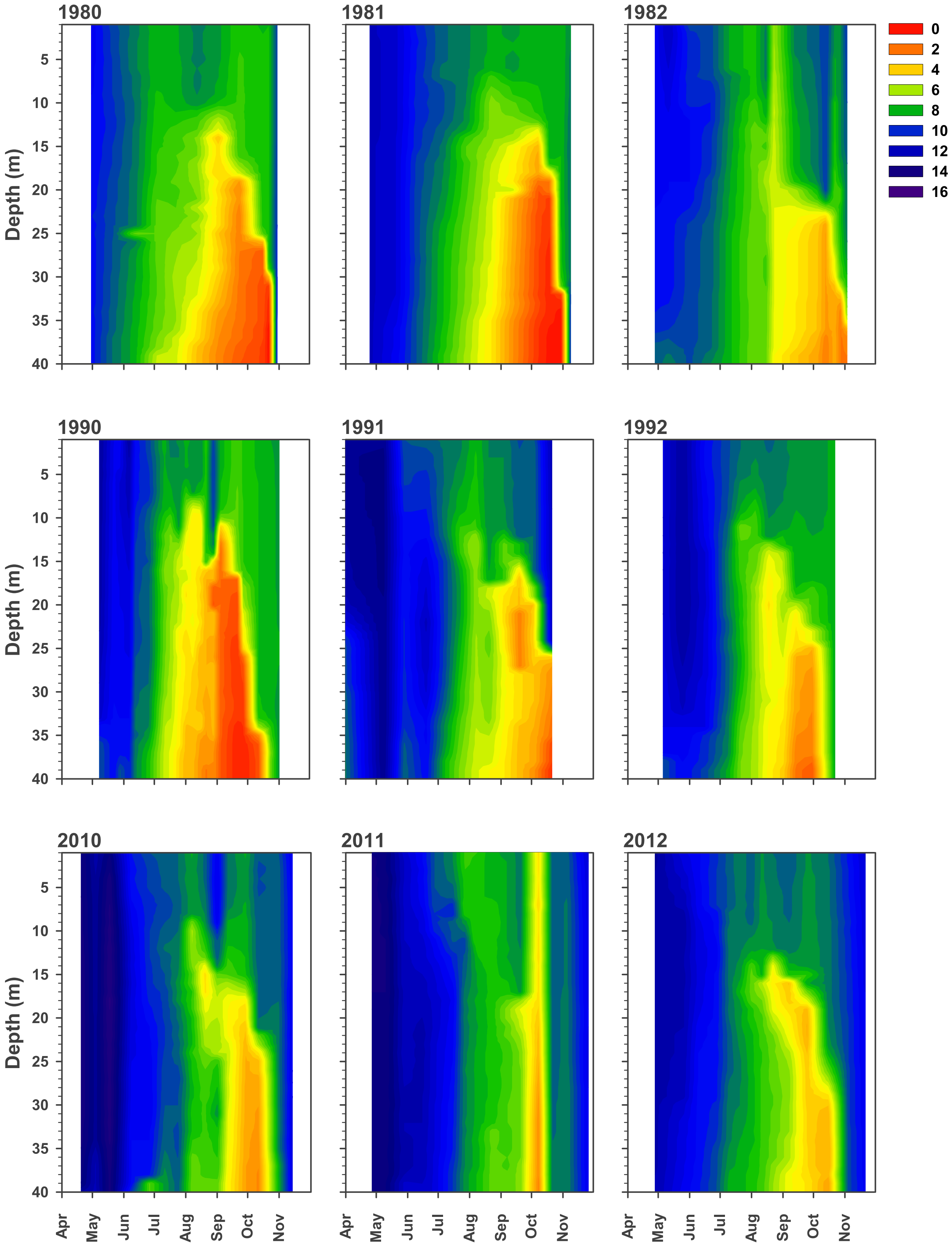


Figure 29: Dissolved oxygen (mg/L) profiles at station K42 in Kempenfelt Bay over nine summers

➔ RESEARCH

A reduced summer dissolved oxygen depletion rate since 1985, and additional spring volume-weighted hypolimnetic dissolved oxygen (VWHDO) have likely countered the negative effect of climate warming on minimum VWHDO. Some of the recent research from Dr. Lewis Molot's lab suggests that, due to the earlier stratification of the lake, dissolved oxygen depletion is starting earlier each year, which lengthens the duration that dissolved oxygen is depleted in the hypolimnion. Without starting with the higher springtime dissolved oxygen and having a slower depletion rate through water quality improvement, dissolved oxygen conditions in the hypolimnion may have been worse due to climate warming.

MVWHDO has significantly increased from an average of ~3 mg/L in the 1980s to ~5 mg/L in 2012, surpassing the LSPP target in 2005 (Fig. 30). Prior to the LSPP, the LSEMS MVWHDO target was 5 mg/L, which has been reached or exceeded in most years since 2002. Although 5 mg/L was acknowledged as sub-optimal for coldwater fish recruitment, it is a definite improvement in hypolimnetic conditions over the 1980s. We will see in the Aquatic Life section that this improvement has led to encouraging indications of sensitive species. As the MVWHDO continues to move toward the optimal target of 7 mg/L, further improvements of coldwater species are expected.

For MVWHDO to increase, it would be assumed that the rate of hypolimnetic dissolved oxygen depletion (ΔDO) was slowing down; however, a decreasing trend was not detected in our analysis of the 1980 to 2012 data (Fig. 30). To investigate further, we performed an additional analysis that looked for significant changes in the ΔDO trend direction over the time period (i.e., a segmented regression). The analysis detected a significant shift in the ΔDO trend in the mid-1980s; ΔDO increased from 1980 to 1984 and then slowly decreased from 1985 to 2012. This shift in ΔDO relates to early actions that were taken to decrease P in the lake, particularly the 1984 diversion of Newmarket and Aurora sewage from the Lake Simcoe watershed, which was a major source of P.

An additional explanation for the significant increase in MVWHDO is that the ice-free season appeared to be starting out with more oxygen in the hypolimnion, as there has been a significantly increasing amount in the spring since the 1980s (Fig. 30). It remains uncertain as to why springtime dissolved oxygen has been increasing, although it is possible that the remedial efforts, especially those during the 1980s, have led to a decrease in winter and early spring algal peaks, and therefore less algae is decomposing and using up oxygen in the spring.

Lake Simcoe in the spring

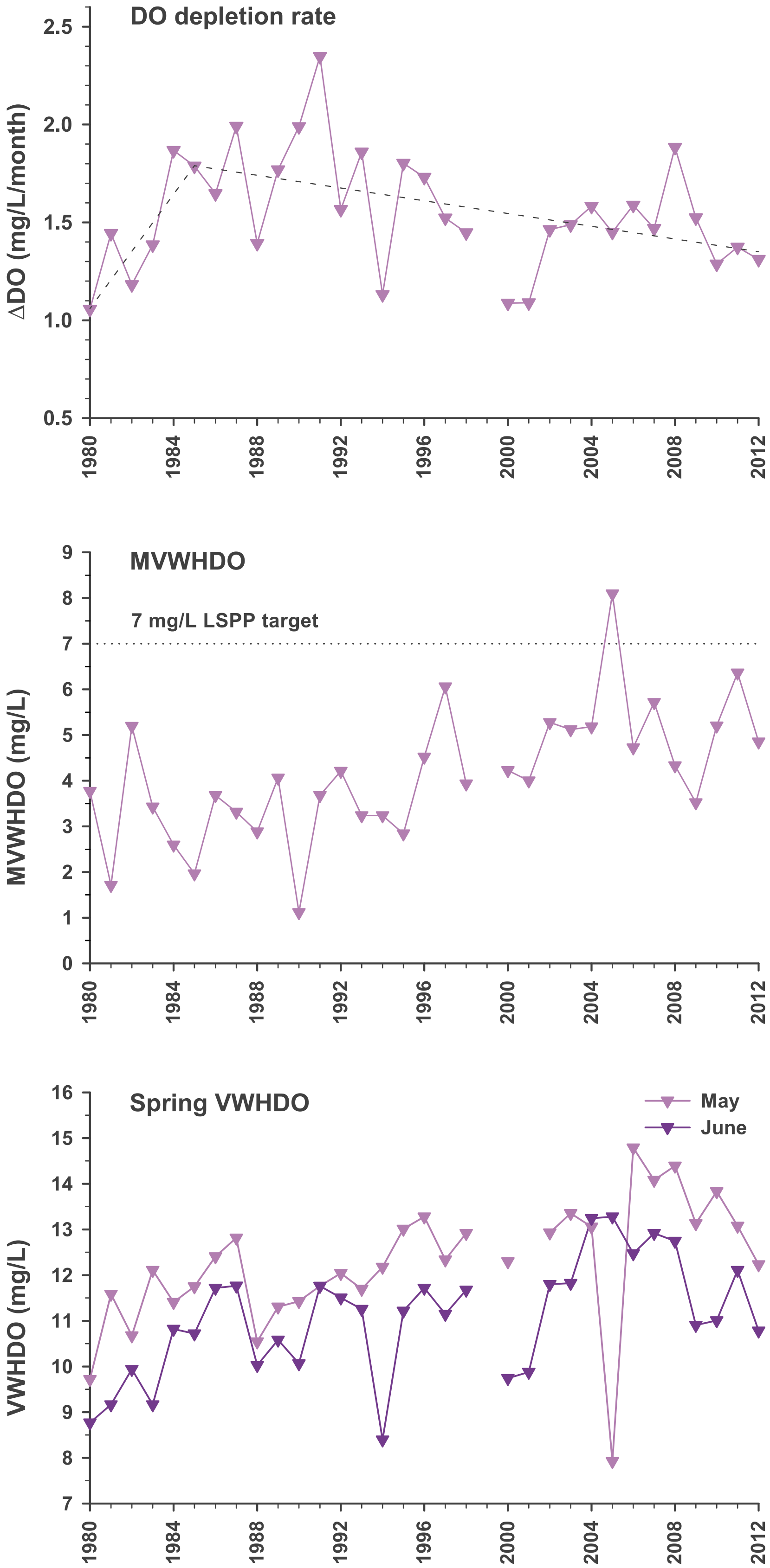


Figure 30: Dissolved oxygen (DO) at station K42 in Kempenfelt Bay: Minimum volume weighted hypolimnetic dissolved oxygen (MVWHDO), DO depletion rate (ΔDO) and spring VWHDO. *NOTE: 1999 was removed as described in Nicholls (2001). The dashed lines on the ΔDO figure were the result of a significant segmented regression analysis*

Dissolved oxygen	Trend
ΔDO	↔
MVWHDO	↑
VWHDO (May)	↑
VWHDO (June)	↑

→ RESEARCH

Some of the interannual variation in dissolved oxygen depletion rates may be caused by variation in wind speeds during the summer, as shown by research done by Mijanur Chowdhury in Dr. Mathew Wells lab at the University of Toronto Scarborough. In 2011, their lab placed Acoustic Doppler Current Profilers at station S15 in Lake Simcoe and calculated internal turbulent mixing at the thermocline (i.e., the depth of greatest temperature change). They found that, even during strong summer stratification, some dissolved oxygen was transported through the thermocline by turbulent mixing; on average, turbulent dissolved oxygen flux in August–September was 0.15 mg/L/month, which was ~10% of the hypolimnetic depletion rate (Fig. 30). When there were persistent strong winds (wind speed > 5 m/s), turbulent mixing increased by an order of magnitude, which in turn increased the rate that dissolved oxygen was transported through the thermocline. This research suggests that stormier summers on Lake Simcoe might lead to a lower hypolimnetic dissolved oxygen depletion rate.

Duckweed and cattails

Other Nutrients and Water Quality

Many other nutrients are essential for aquatic plant growth and can affect ecosystem functioning. One important nutrient is nitrogen (N), which is available in many forms in aquatic ecosystems. Total N includes nitrate plus nitrite, ammonium and organic N. As with P, total N concentrations were variable across the watershed from 2009–2012, and less variable and in lower concentrations in the lake (Fig. 31). North Schomberg River, Uxbridge River and Mount Albert Creek have the highest tributary total N concentrations (all > 2 mg/L), and Cook's Bay has the highest lake total N concentrations (C1: 0.52 mg/L; Keswick WTP: 0.47 mg/L).

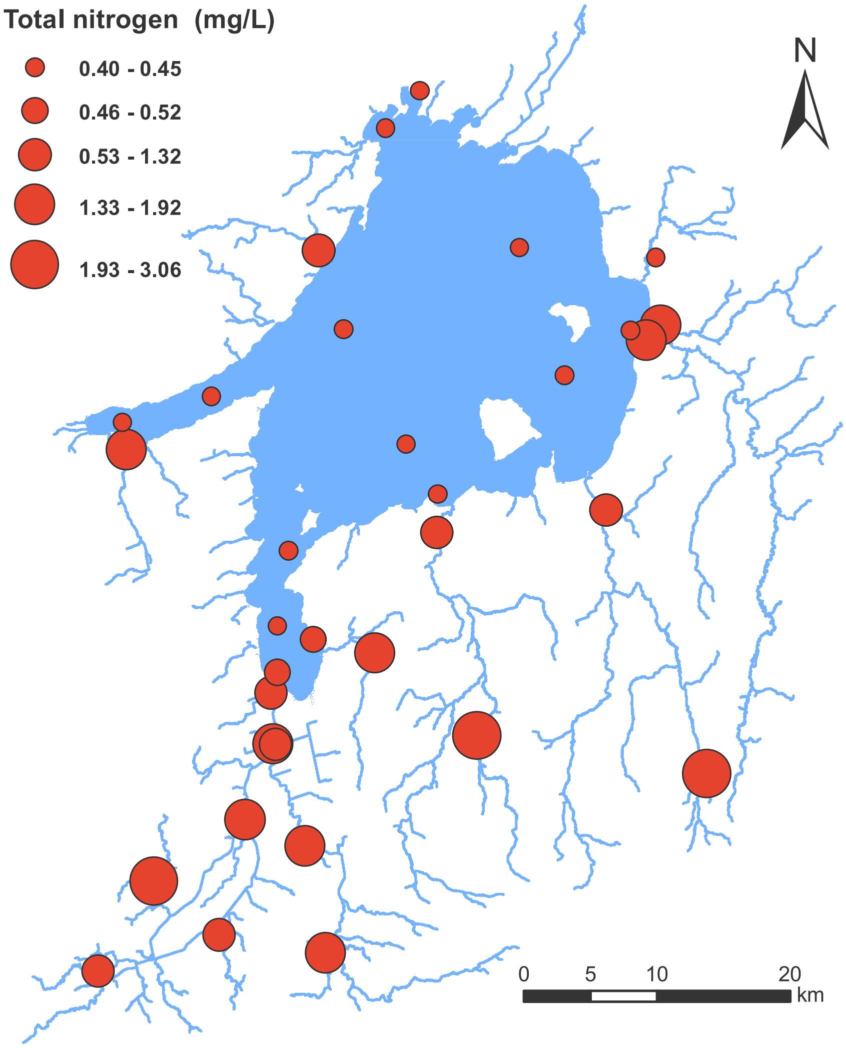


Figure 31: Recent total nitrogen concentrations (average of 2009–2012). *See Fig. 3 for station names*

The long-term trends in total N in the tributaries were also quite variable (Fig. 32). Total N in the East Holland and Upper Schomberg Rivers, and Lovers Creek significantly decreased, while Pefferlaw River significantly increased, and there was no significant change in the Hawkestone and Beaver Rivers. Interestingly, the total N and P patterns in Lovers Creek were very different; in the 1980s, N concentrations were highest, while P concentrations were the lowest. Total N declined substantially in the 1990s in Lovers Creek but remains at a higher concentration than any other tributary.

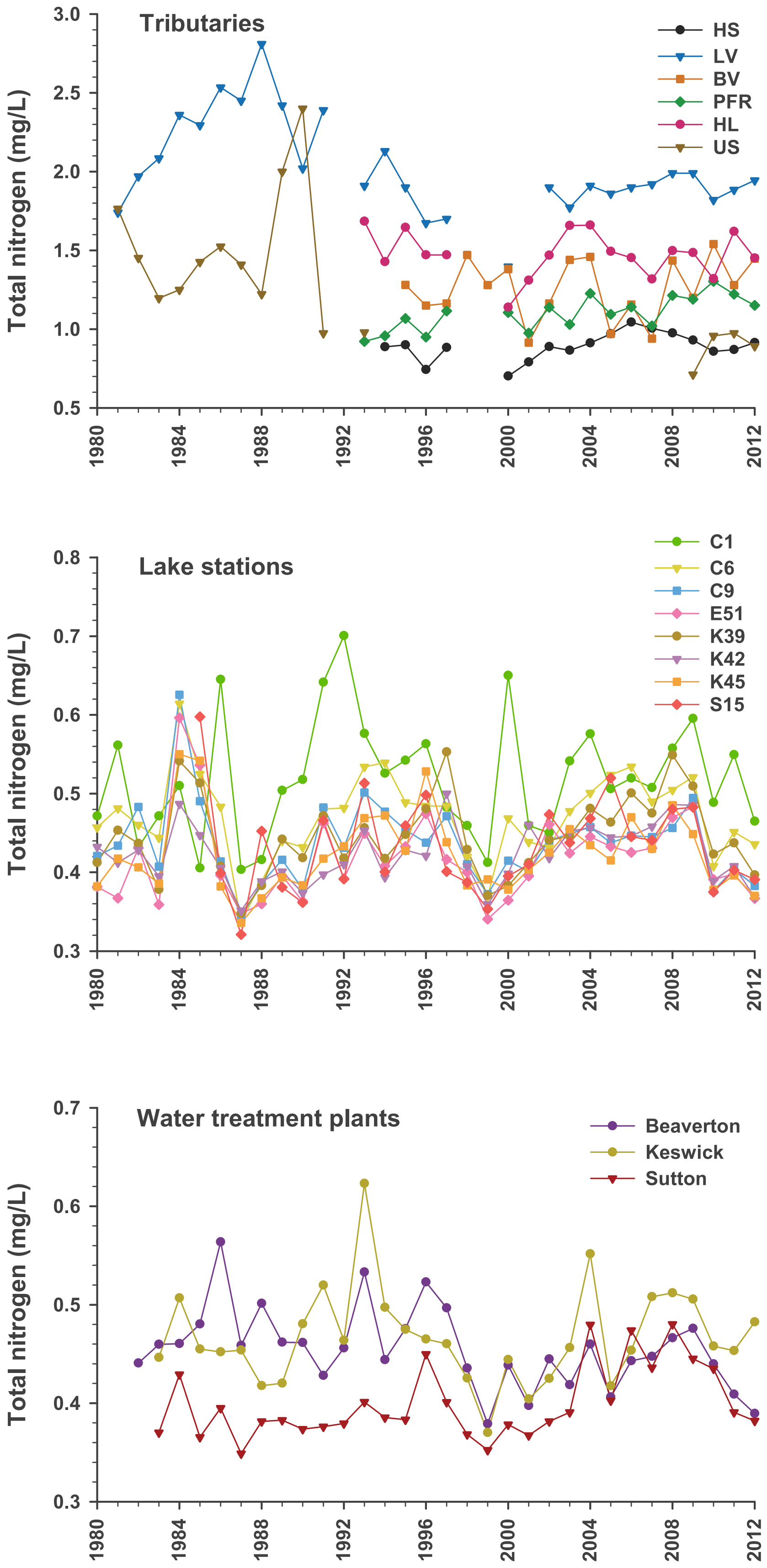


Figure 32: Total nitrogen concentration in tributaries, the lake and at water treatment plant (WTP) intakes

Total nitrogen	**Trend**
Hawkestone Creek (HS)	↔
Lovers Creek (LV)	↓
Beaver River (BV)	↔
Pefferlaw River (PFR)	↑
East Holland River (HL)	↓
Upper Schomberg River (US)	↓
All lake stations	↔
Beaverton WTP	↓
Keswick WTP	↔
Sutton/Georgina WTP	↑

Across the open lake there have been no significant changes in total N, while at the WTPs it decreased at Beaverton and increased at Sutton (Fig. 32). Total N concentration at the lake stations were synchronous and varied similarly to P, with lower concentrations occurring in the same years (1987, 1999, 2010–2012). The large peaks at C1 also occurred in similar years to P. This synchrony suggests that the primary source of both nutrients is run-off from the watershed, with fluxes driven by external factors such as weather. There were also no significant changes in nitrate plus nitrite and total ammonia at any of the open lake stations (Fig. 33).

Other nitrogen	Nitrite + nitrate	Total ammonia
All lake stations	↔	↔

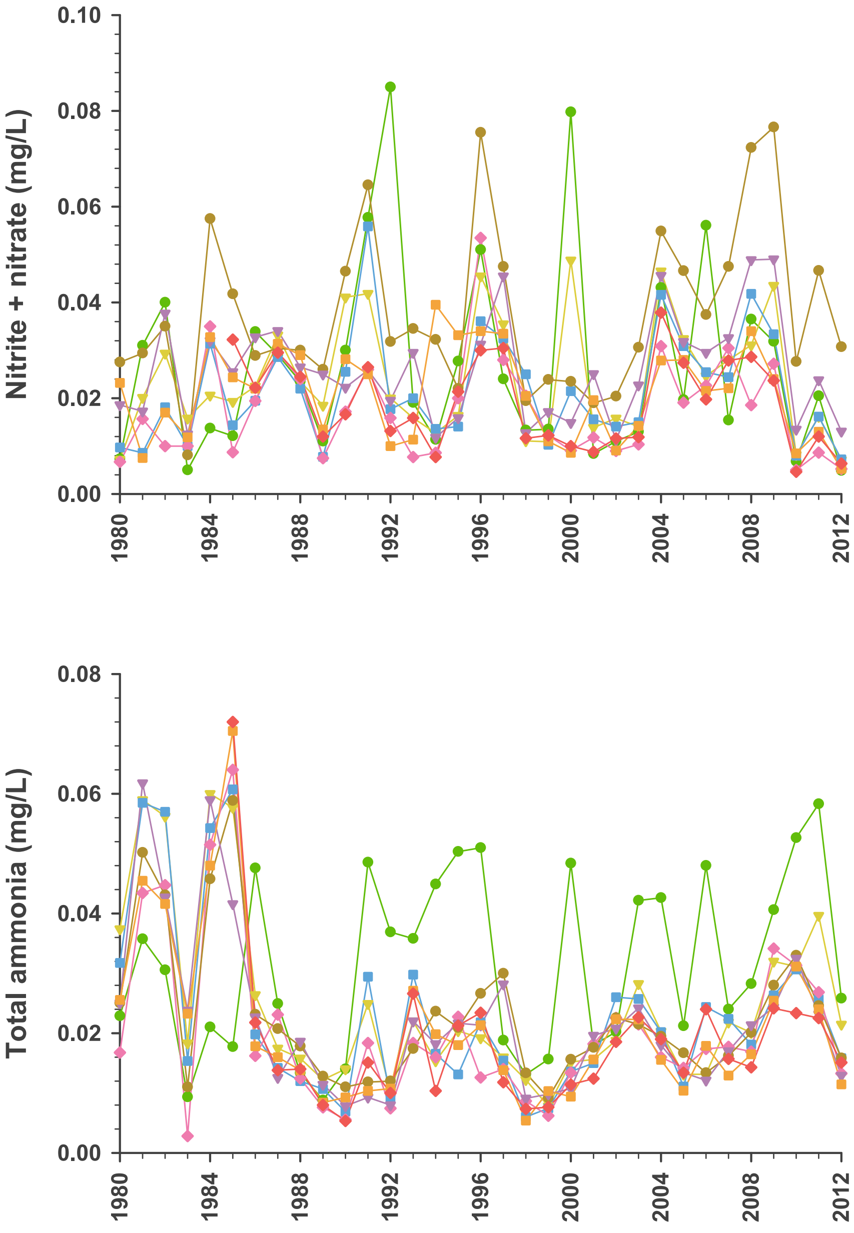


Figure 33: Nitrite plus nitrate and total ammonia concentration at the lake stations

Another dissolved nutrient in aquatic ecosystems is silica. Silica comes from the weathering of rocks and is an essential nutrient for diatoms, which is an important algal group in Lake Simcoe. There have been significant increases in silica at all open lake stations and WTPs since 1980; the rate of increase, however, has not always been consistent (Fig. 34). At all of the stations and seasonally (data not shown), there was a rapid increase in silica after 1995, and a dramatic drop from 2005–2008. These increases and decreases in silica were similar in timing to abrupt lake-wide changes in diatom biovolume (see Aquatic Life section). Nutrient load reductions have been accompanied by silica increases in other studies, as a reduction in diatom biovolume would lead to a lower demand for silica (Stoermer, 1993). Additionally, the timing of the changes suggests an effect by zebra mussels, whether direct or indirect.

Silica	Trend
All lake stations	↑
All WTPs	↑

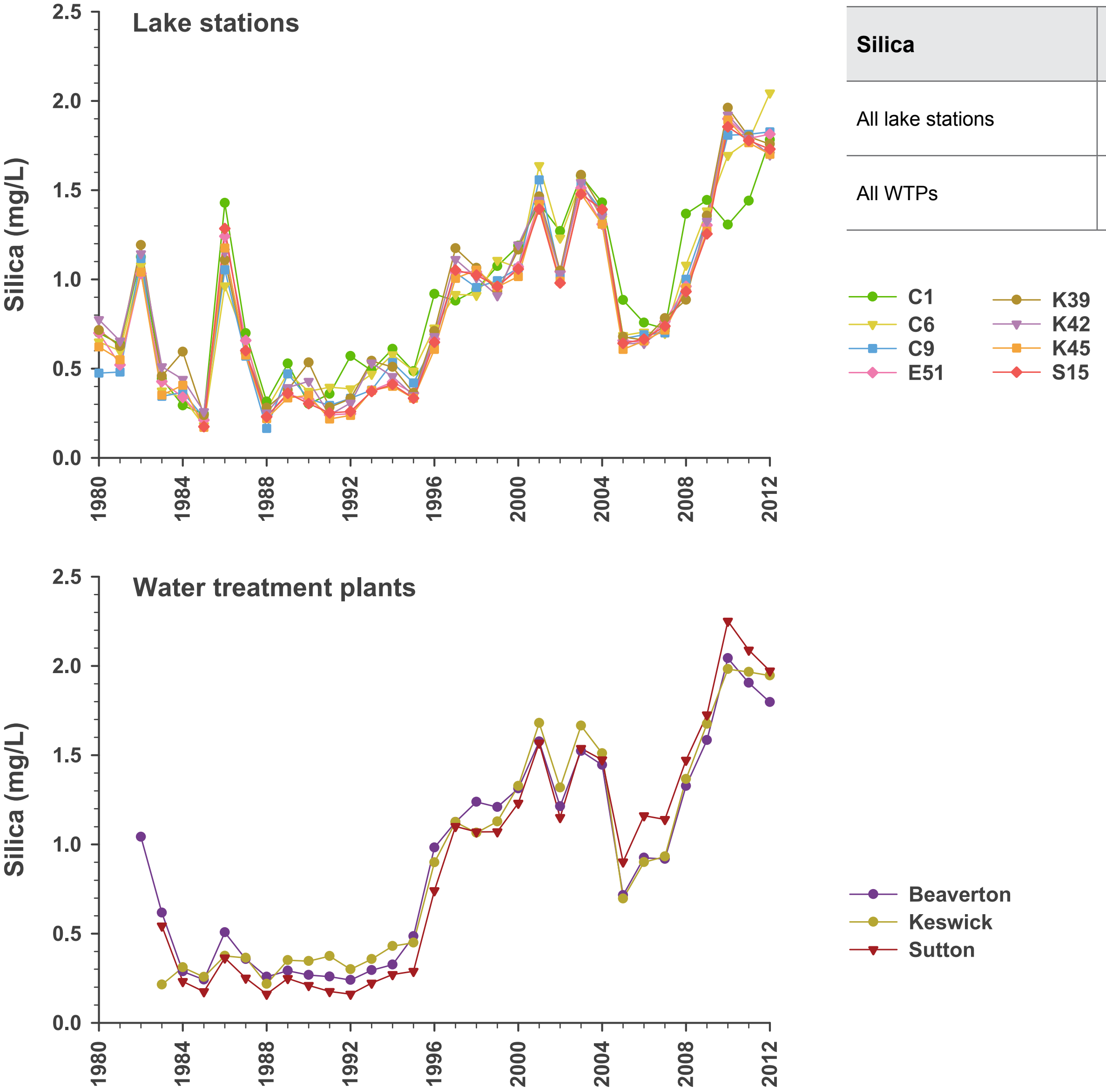


Figure 34: Silica in the lake and at water treatment plant (WTP) intakes

Whites Creek. *Credit: Jim Eddie*

Base cations (calcium, sodium, magnesium and potassium) are another component of freshwater that enter the lake in run-off from the watershed. At all lake stations but C1, all cations except calcium have significantly increased (Fig. 35). While the cations have not changed significantly at C1, concentrations were the greatest at this station in most years. A major source of these cations is likely associated with road salt use; in the following section, we will see that chloride has increased substantially in the lake. The most common road salt compound is NaCl, and Na (sodium) is increasing at a much faster rate than the other cations (0.68 mg/L/year compared to 0.02 and 0.04 mg/L/year for potassium and magnesium, respectively). It is possible that potassium and magnesium were also sometimes present in road salt as impurities, which might explain why they are increasing. Potassium is also present in fertilizers, and therefore changes in land use, as well as climatic conditions, could be affecting these ions.

Credit: Jim Eddie

Base cations	Sodium	Magnesium	Potassium
C1	↑	↔	↔
C6	↑	↓	↑
C9	↑	↑	↑
E51	↑	↑	↑
K39	↑	↑	↑
K42	↑	↑	↑
K45	↑	↑	↑
S15	↑	↑	↑

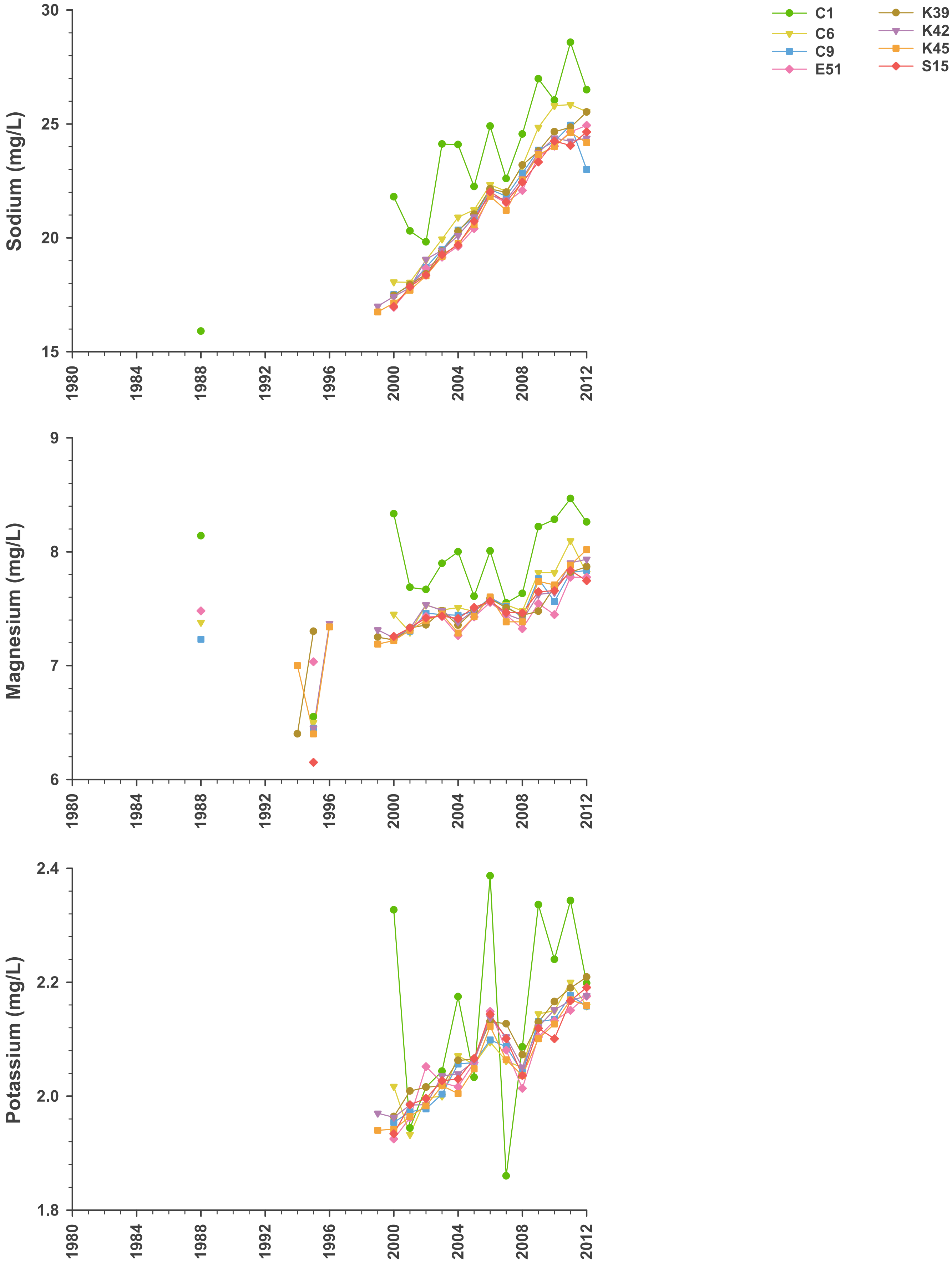


Figure 35: Base cations at the lake stations: Magnesium, sodium and potassium

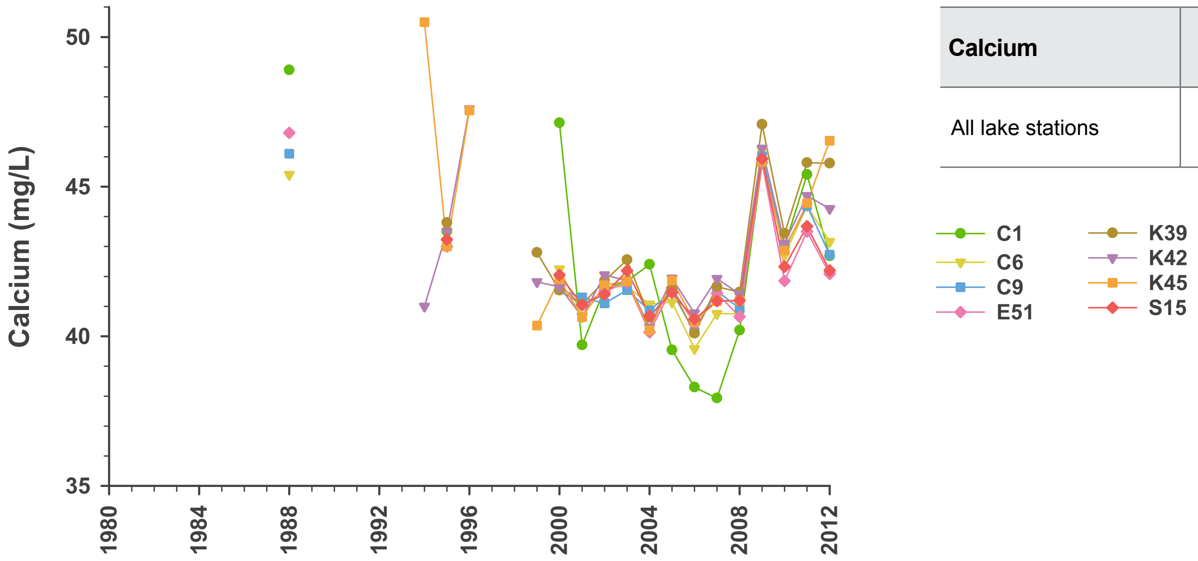
Zebra mussels on lake bottom.
Credit: Ted Ozersky

Unlike the other cations, the trend for calcium had no significant change at any lake stations (Fig. 36). Although the watershed is the primary source of calcium, it is likely that it is internal processes that are driving calcium concentrations in Lake Simcoe. Calcium is a major requirement of the zebra mussel, primarily for production of its shell; therefore, calcium concentration usually declines after the zebra mussel invasion and rapid increase in abundance. Unfortunately, insufficient data on calcium concentrations were collected prior to zebra mussel establishment and thus we are unable to determine whether a decrease in calcium occurred at this time. In 2009, however, calcium increased, which may be associated with an apparent decline of zebra mussels in the lake (see Aquatic Life section). Further studies could be performed that might elucidate the link between calcium and zebra mussels in Lake Simcoe, such as comparing the carbon to calcium ratio of zebra mussel shells.

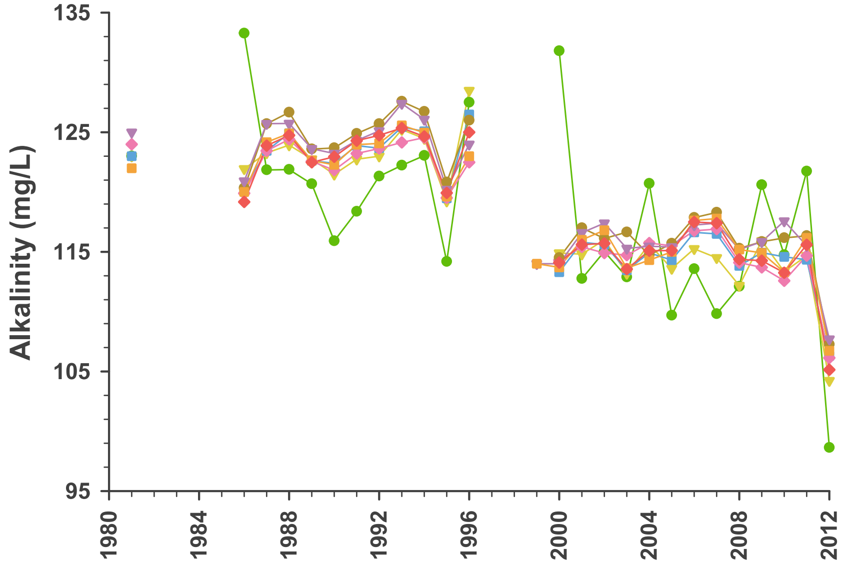
Alkalinity is a measure of the buffering capacity of water, and generally tends to follow a similar trend to calcium in lakes. Although there was a 3-year gap in the lake alkalinity data from 1997–1999, there was sufficient data to identify a significant decline in alkalinity in Lake Simcoe, which appears to be a step down that coincided with zebra mussel establishment (Fig. 36). Unlike calcium, however, alkalinity has not shown a recent increase following apparent declines in the zebra mussel.

Another measurement associated with calcium and alkalinity is dissolved inorganic carbon (DIC), which is composed of CO_2, H_2CO_3, HCO_3^- and CO_3^{2-}. DIC in the lake has decreased significantly, with an apparent decline beginning after 1994 and extreme increases occurring in 2009 and 2010 (Fig. 36). The DIC pattern showed a similar decline in the mid-1990s as did alkalinity, and followed the calcium increase peak around 2009, thus there might also be links between DIC and zebra mussels.

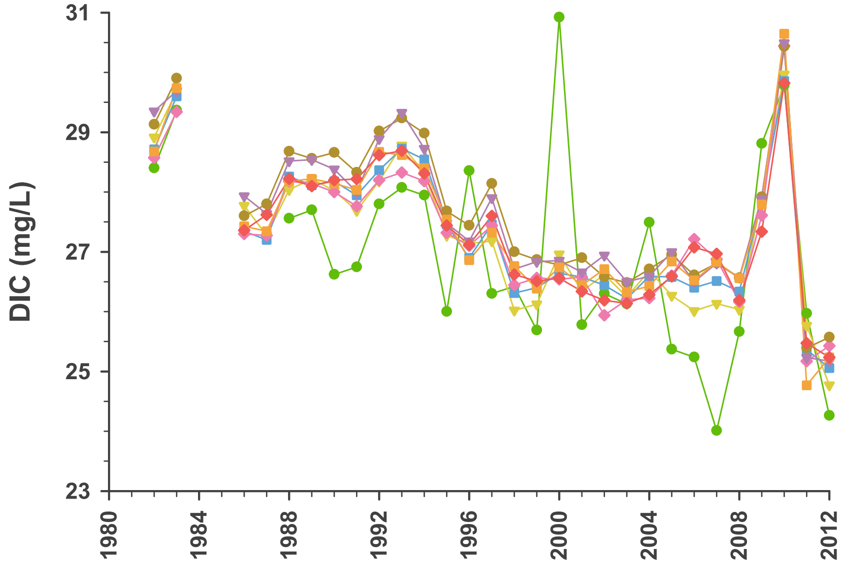
Ice forming between Snake Island and mainland



Calcium	Trend
All lake stations	↔



Alkalinity	Trend
All lake stations	↓



DIC	Trend
All lake stations	↓

Figure 36: Calcium, alkalinity and dissolved inorganic carbon (DIC) at the lake stations

North Schomberg River. *Credit: Jim Eddie*

Dissolved organic carbon (DOC) is generally composed of organic carbon compounds less than ~ 0.4 µm that can come from decomposed organic matter from the watershed (allochthonous) or within the lake (autochthonous). In Lake Simcoe, DOC has significantly increased, apparently starting in 1999, with the rate increasing in recent years (Fig. 37). DOC has also increased in lakes near Dorset, Ontario, likely from allochthonous sources caused by an increase in air temperature that has increased decomposition of organic matter and mineralization of DOC in soils (Keller et al., 2008). The source of DOC in Lake Simcoe could be similar, although there also could be a large autochthonous component. Macrophyte abundance has increased in the lake, especially in Cook's Bay (Depew et al., 2011; Ginn, 2011; see Aquatic Life section) where DOC is the highest; thus the decomposition of these macrophytes could be the source of increasing DOC. Future research on this topic could use stable isotope analysis to help identify the source of DOC.

Shoreline of Cook's Bay

DOC	Trend
All lake stations	↑

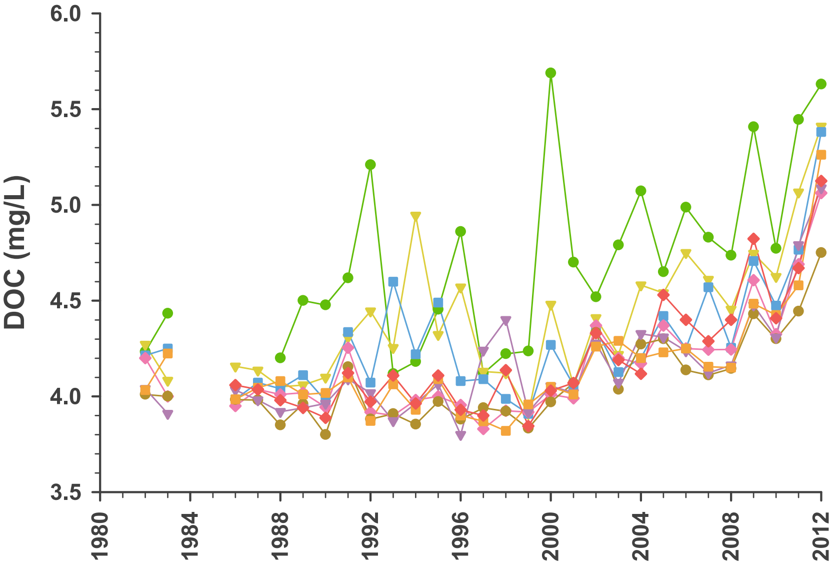


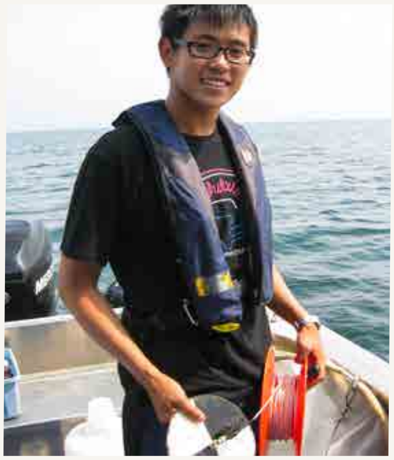
Figure 37: Dissolved organic carbon (DOC) at the lake stations

Water clarity is essentially a measure of the depth to which one can see down in the lake, which is reduced by algae, DOC and suspended sediments.

Water clarity at the open lake stations has significantly increased (Fig. 38). Early increases during the 1980s coincided with the decreases in nutrients and phytoplankton following sewage diversion into the Holland River. The greatest increases occurred after zebra mussel establishment (1996); however, the rate has appeared to stabilize or decline over the past decade or more. Interestingly, recent decreases in phytoplankton and chlorophyll *a* have not resulted in an increase in water clarity. It is possible that the observed increase in DOC, which can darken the water, has counter-acted an expected increase in water clarity due to less phytoplankton.

Water clarity monitoring

METHODS



Water clarity was measured at all open lake stations using a Secchi disk, which is a round black and white disk. The Secchi disk is lowered into the lake until it is no longer visible; this depth is called the Secchi disk depth. If the water is clear to the lake bottom, the bottom depth is the Secchi disk depth. For station C1, the maximum water depth is 3 m, and in recent years, Secchi depth was often recorded as the depth of the bottom.

Secchi disk depth	Trend
All lake stations	↑

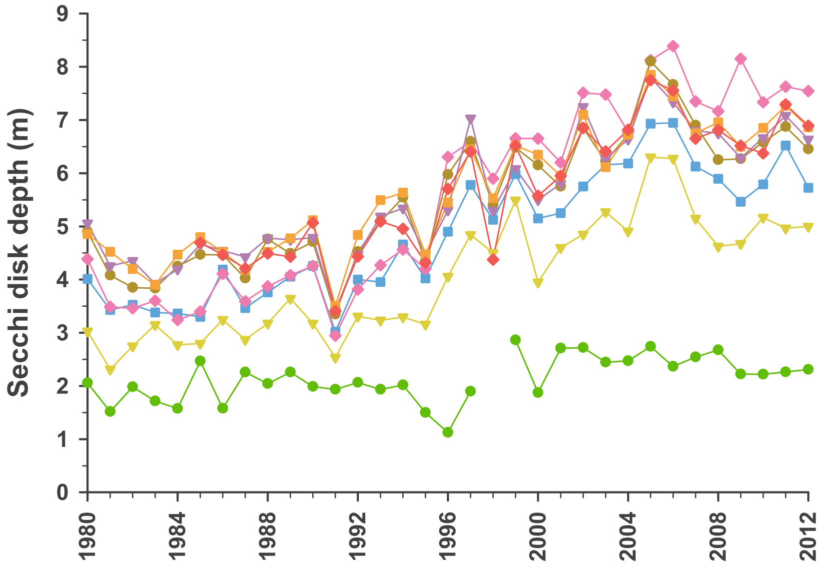


Figure 38: Water clarity (Secchi disk depth) at the lake stations. *NOTE: The maximum water depth at station C1 is 3 m*

RESEARCH

Heavy metals and organic chemicals are often very low in lake water because they readily settle into the lake sediments. Sediment surveys are a good way to measure these contaminants, as concentrations are higher, and information from multiple years can be obtained in a single sediment core. A sediment survey performed in 2008 showed that Kempenfelt Bay sediments had the highest concentrations of metals due to urban and industrial sources. Metal concentrations of historical concern (e.g., chromium) have decreased from peak levels due to improved wastewater treatment and changes in industrial activity, while metals typically found in uncontrolled urban stormwater run-off (e.g., zinc) remain at elevated concentrations. A sediment survey will be repeated and the results will be presented in a future monitoring report on Lake Simcoe. For more results of the 2008 survey, please see the Lake Simcoe Water Quality Update (Young et al., 2010) and Landre et al. (2011).

Total suspended solids (TSS) are a physical contaminant rather than a chemical one. Their presence can cloud water, decreasing water clarity and impairing spawning habitat for some fish species. TSS have been measured in tributaries but not consistently enough for long-term trend analysis, and they have not been measured in the lake. The LSRCA and the MOECC are currently monitoring TSS regularly in tributaries, and trends will be presented in the next monitoring report.

Aquatic Pollutants

In addition to nutrients, there are many other pollutants that can make their way into lakes and rivers and can have negative effects on the health of aquatic biota and sometimes humans. Some examples are total suspended solids (TSS), chloride, metals, organic chemicals, pharmaceuticals and other contaminants of emerging concern, and pathogens; however, not all of these are measured annually in Lake Simcoe.

Chloride

One contaminant with long-term data in the tributaries and the lake is chloride. Although present naturally in the environment, chloride can cause harm at high concentrations. The Canadian Water Quality Guidelines were recently revised for chloride in freshwater; chronic (constant) exposure is now 120 mg/L and acute (short term) exposure is 640 mg/L.

Recent chloride concentrations around the watershed varied considerably, ranging from 10 mg/L in the Talbot River to 207 mg/L in the East Holland River (Fig. 39). Of the tributaries reported here, three had chloride concentrations above the chronic objective: the East Holland River and Lovers Creek, both of which drain from urban areas, and the North Schomberg River, which is very close to a major highway (Hwy 400). Sensitive biota in these tributaries could be affected by high chloride concentrations. Concentrations across the lake were much more uniform, ranging from 42 mg/L at the Beaverton WTP to 50 mg/L at the bottom of Cook's Bay (C1) (Fig. 39). Annual averages in the lake had less variation because the lake is continuously mixed; however, unlike with nutrients such as total P and N, chloride levels at sites in the lake were higher than some sites in the watershed.

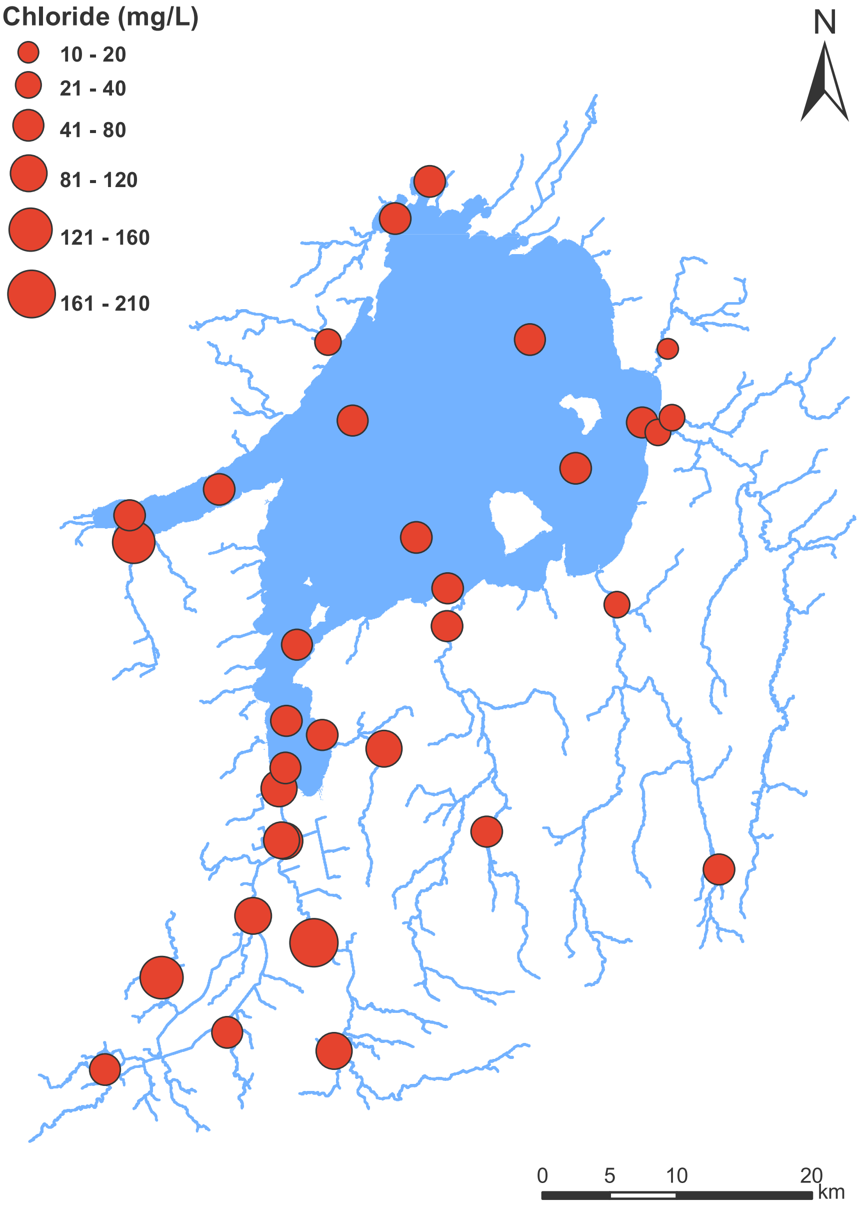


Figure 39: Recent chloride concentrations (average of 2009–2012). *See Fig. 3 for station names.*

➔ RESEARCH

Dr. Chris Metcalfe at Trent University worked with the MOECC to characterize contaminants of emerging concern (CECs) at water pollution control plants (WPCPs) in the Lake Simcoe watershed. Indicator compounds for personal care products, pharmaceuticals, steroids, hormones and artificial sweeteners were measured in the influent and effluent of six WPCPs. Dr. Metcalfe's work showed that the treatment technologies of WPCPs did not entirely remove CECs, but discharge concentrations of CECs in treated wastewater were relatively low, and therefore loading from WPCPs are not a significant source of organic chemicals and emerging compounds.

Chloride	Trend
All tributaries	↑
All lake stations	↑
All WTPs	↑

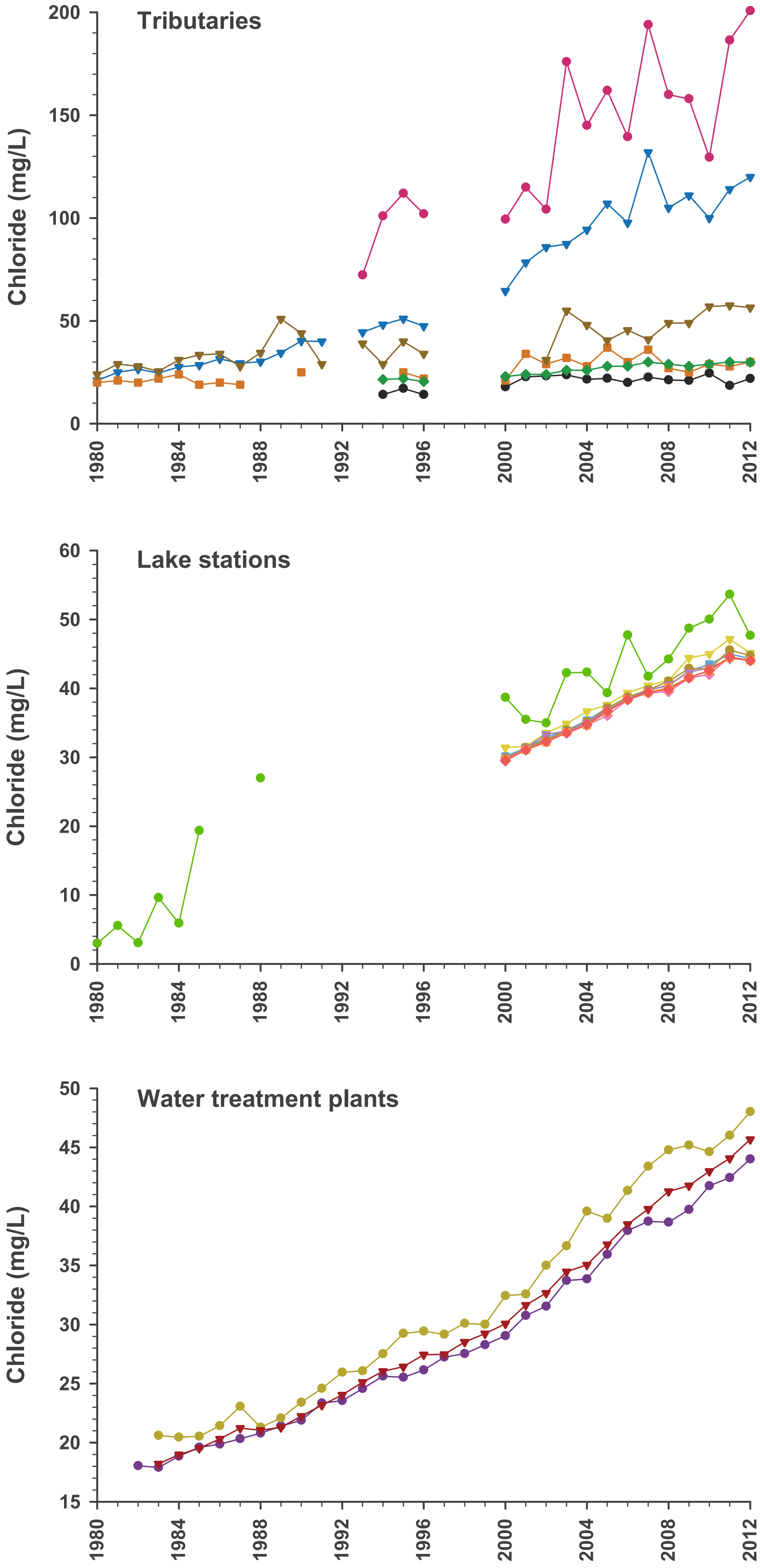
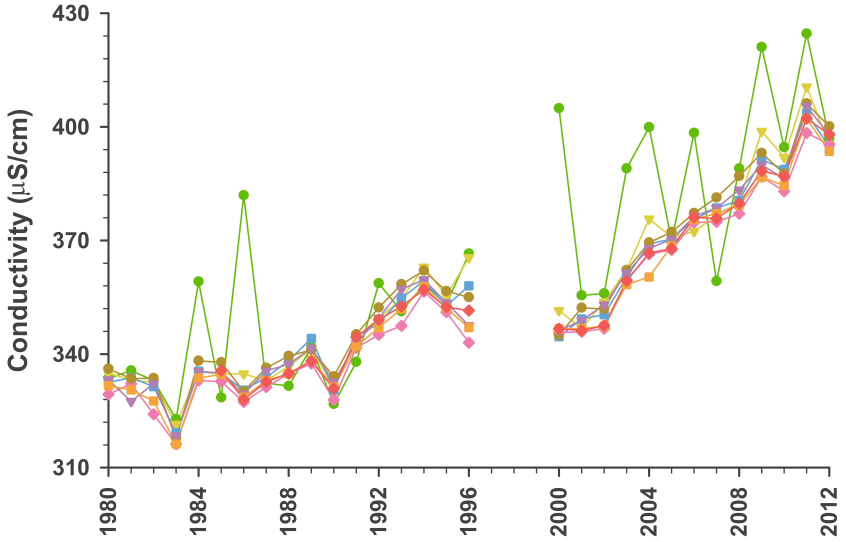


Figure 40: Chloride concentration in tributaries, the lake and at water treatment plant (WTP) intakes



Conductivity	Trend
All lake stations	↑

Figure 41: Conductivity at the lake stations

MOECC is partnering with the LSRCA and local municipalities to reduce road salt use in priority subwatersheds such as the Holland River. It is critical to raise awareness of the vulnerability of Lake Simcoe and its tributaries to chloride impacts. A key focus will be promoting the use of best practices to control snow and ice to commercial parking lot operators and road managers, balancing the need to reduce hazards, such as slipping on ice, with the need to protect the watershed ecosystem from impairment from de-icing chemicals like road salt. The project includes:

- making maps of salt vulnerable areas in the Lake Simcoe watershed available,
- training and evaluating the tendencies of trained contractors to adopt snow and ice control practices that reduce the risk of road salt contamination, and;
- monitoring chloride concentrations in surface water and stormwater for the purpose of understanding the effectiveness of snow and ice control best practices.

Credit: Jim Eddie

Chloride has increased significantly at all sites across the watershed (Fig. 40). Conductivity, which is measured at the lake sites, has also increased significantly (Fig. 41). Conductivity measures the ability of water to pass an electrical current, thus is heavily influenced by ions that carry a negative charge such as chloride. The rate of chloride increase in the lake since 2000 was 1.3 mg/L/year, which was more than double the previously reported rate of 0.6 mg/L/year from 1971 to 1996 in Atherley Narrows (MOE, 1998). If chloride continues to increase at the same rate of the last decade, the lake will reach the chronic objective of 120 mg/L in 57 years, which could affect lake biota.

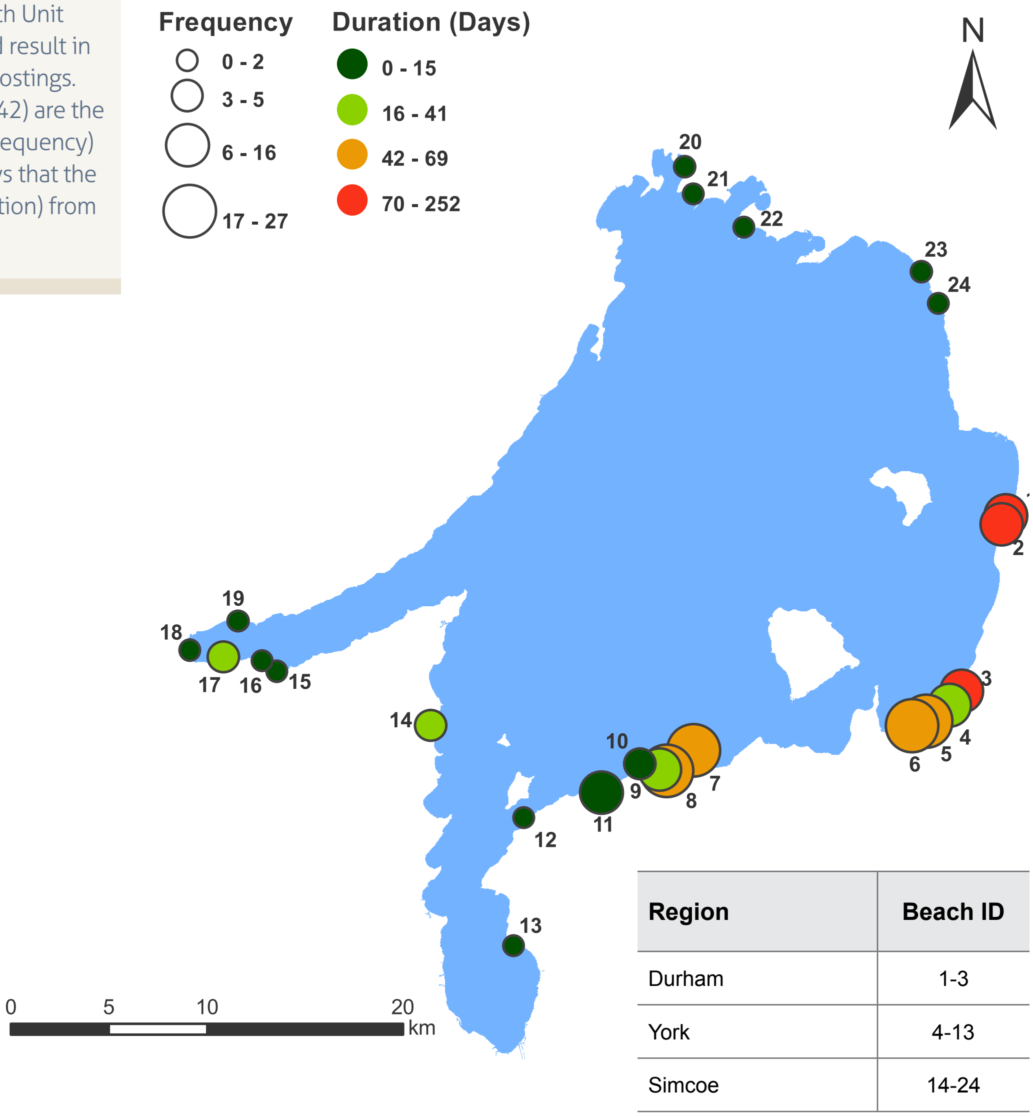
The source of chloride to the lake and tributaries is most likely from the application of road salt (Nicholls, 1998; Winter et al., 2011a), which is increasing as the population grows, and new roads and subdivisions are built. The highest concentrations of chloride were recorded in those tributaries draining urban areas or located near highways.

METHODS

In the LSPP, beach postings are used as an indicator for pathogens, and Health Units use *Escherichia coli* as the primary indicator for when to post beaches. During summer months, the Health Units test beaches weekly, and will post a swimming advisory when the geometric mean concentration of *E. coli* from five samples exceeds 100 cfu/mL, or other unfavourable conditions occur. Once a beach has been posted with an advisory, subsequent samples are collected to determine when bacterium levels are safe to remove the posting. York Health Unit retests daily, Simcoe Muskoka District Health Unit retests beaches daily–weekly, while Durham Health Unit retests weekly, which would result in longer durations of beach postings. Presented on the map (Fig. 42) are the total number of postings (Frequency) and the total number of days that the beaches were posted (Duration) from 2009–2012.

Pathogens

The Lake Simcoe watershed has an abundance of public beaches within 10 km of most settled areas, and these beaches are a destination for many people visiting the watershed. A target in the LSPP is to reduce the number of beach postings. Public beaches are posted with swimming advisories when it is suspected that gastrointestinal pathogens might be present, which are a concern for human health. The primary source of pathogens that cause gastrointestinal illness (e.g., *Camplyobacter)* to recreational waters is from fecal contamination. Recreational waters can be contaminated by waste from animals (e.g., agricultural run-off, pets, wildlife) or humans (e.g., sewage spills, leaky septic systems, boat discharge). *Escherichia coli* is a common bacterium found in fecal matter that, although often harmless to humans, is easily measured and thus is commonly used to detect whether water has been contaminated.



Region	Beach ID
Durham	1-3
York	4-13
Simcoe	14-24

Figure 42: Summer beach postings across the lake: Total number of postings (Frequency) and the total number of days that the beaches were posted (Duration) from 2009–2012

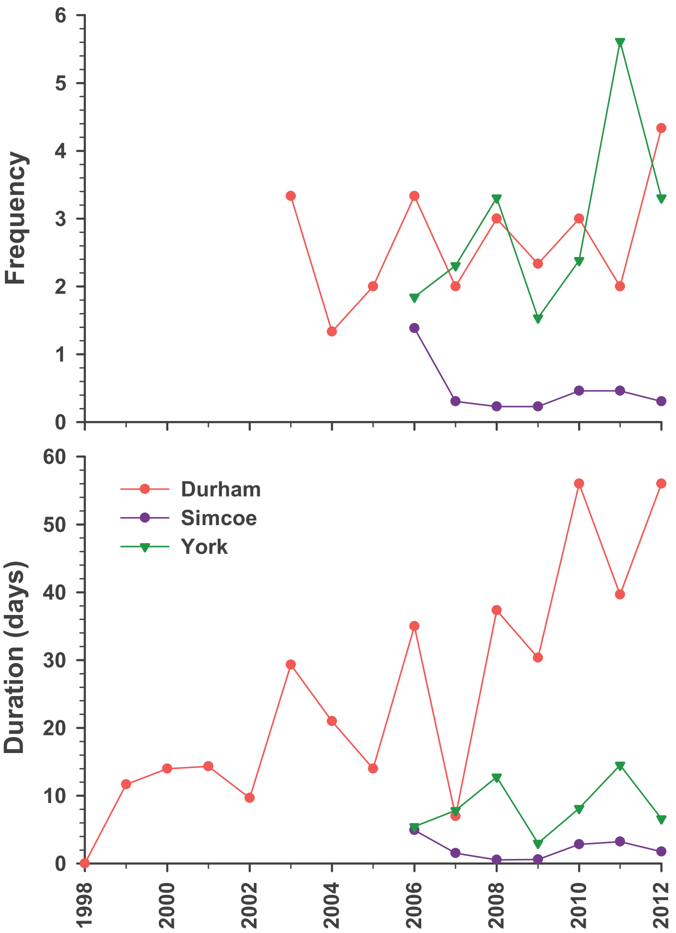
RESEARCH

The sources of bacteria in Lake Simcoe were investigated further using two types of gastrointestinal bacteria: one a pathogen, *Campylobacter*, and the other not, *Bacteroidales*. The research was performed by EC, MOECC and the University of Guelph at five beaches along the southeastern shore in 2010 and 2011. The results suggested that potential sources of *Campylobacter* included run-off and bird feces (Khan et al., 2013), while *Bacteroidales* was thought to come from fecal contamination, such as cattle, most specifically in the fall.

Canada Geese on Beaverton Beach North

Beach postings were uncommon along most shores of the lake. From 2009–2012 along the north shore of the lake and in Kempenfelt Bay, there were fewer than 10 advisory postings, all but one lasting fewer than 16 days. Along the southern and eastern shores of the Main Basin beaches were posted more often and for longer durations (Fig. 42). Beaches along these shores are primarily in the York and Durham Regions, and these regions also showed the greatest average number of postings over time. The duration of postings at Durham beaches was the longest, which would at least partly be due to weekly rather than daily retesting. However, although the frequency of retesting has remained the same, the duration of postings at Durham region beaches has increased significantly since 1998 (Fig. 43).

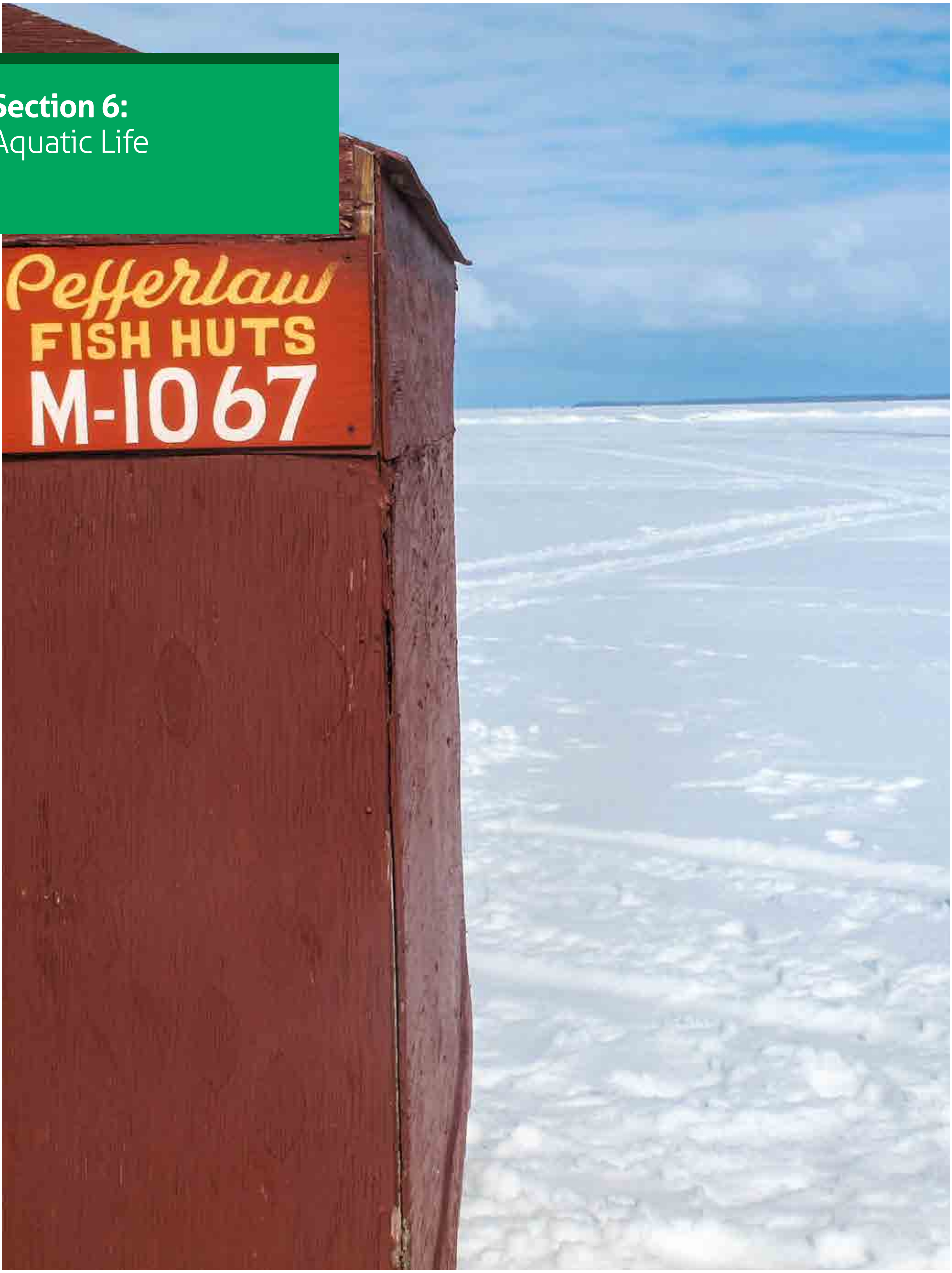
Data were not available before 2006 for other regions, but there does not appear to have been any significant change in duration or number of postings at these beaches. Key factors contributing to more beach postings are storm events and increased sources of bacteria. The southern and eastern beaches of Lake Simcoe have greater exposure to onshore winds, and thus would be more susceptible to changes in weather, such as storm events. This might explain the annual variability in number and duration of postings, which were more evident in the exposed Durham and York regions.



Region	Average number of postings	Average duration of postings
Durham	↔	↑
Simcoe	↔	↔
York	↔	↔

Figure 43: Summer beach postings within regions: Annual averages of duration and frequency

Section 6: Aquatic Life



Aquatic Life

The health of aquatic communities is an important indicator of the health of the ecosystem, providing insight that cannot be obtained from water quality measurements alone. As tributary and lake communities are sensitive to their environment, changes to these communities can integrate changes over time or from the effects of more than one stressor. In addition, particular species are more sensitive and thus can be used as individual indicators of aquatic health, such as lake trout. For these reasons, the key aquatic life indicators in the LSPP focus on aquatic communities and/or sensitive species:

- natural reproduction and survival of native aquatic communities
- presence and abundance of key sensitive species, and;
- shifts in cold, warm and tributary fish community composition

Tributary Communities

Benthic invertebrates and fish

Uxbridge Brook tributary. *Credit: LSRCA*

Two types of aquatic communities have been monitored in tributaries: benthic invertebrate communities and fish communities. Benthic invertebrates are small animals without backbones that live on, under or around the rocks, macrophytes and sediment at the bottom of tributaries and lakes. In tributaries, benthic communities are made up of worms, crustaceans, insects, arachnids and bivalves. Because benthic invertebrate species each have different environmental tolerances, the make-up of a tributary benthic community can tell us a lot about the water quality of the tributary at the sample site, which may be influenced by surrounding land use. Communities with more sensitive species (e.g., insects from the families Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) — the EPT group) usually represent better water quality, while those composed mostly of non-sensitive taxa, e.g., Crustacea (crayfish, amphipods and/or isopods), Chironomidae and Oligochaeta, represent poor water quality.

Compared to benthic invertebrates, fish are more mobile, so are not as sensitive to immediate changes in local water quality. Over the long term, however, tributary fish communities are sensitive to changes in water temperature, dissolved oxygen, flow, water quality and habitat. In particular, temperature is a major regulator of species presence, as certain species such as brook trout (*Salvelinus fontinalis*) and mottled sculpin (*Cottus bairdi*) require coldwater.

Brook trout. *Credit: LSRCA*

METHODS

Tributary fish monitoring. *Credit: LSRCA*

Benthic invertebrate monitoring. *Credit: LSRCA*

Since 2002, the LSRCA have monitored fish (with electrofishing) and benthic invertebrate (with kick and sweeps) communities at over 200 tributary sites across the watershed. For each community, they have calculated indices of biotic integrity that use the proportion of the different taxa to describe the ecological health of a site, using the Hilsenhoff Biotic Index (HBI) for benthic invertebrates and the Index of Biotic Integrity (IBI) for fish. For more information on methods and results of this program, please see LSRCA (2013). The percent of sites ranking Poor, Fair or Good HBI or IBI were estimated for recent years (2009–2012). A subset of the LSRCA sites have been monitored in most years since 2002 (Fig. 44). Trend analysis was performed on sites that were monitored for more than seven of the 11 years. For benthic invertebrates, trends of average relative abundance and HBI in riffles during the fall sampling from 12 of LSRCA's sites were analyzed. For fish, IBI trends for 21 long-term fish sites were analyzed. In addition, brook trout catch per unit effort (CPUE), which were calculated as the estimated number of fish captured divided by electrofishing effort, are presented for 11 sites.

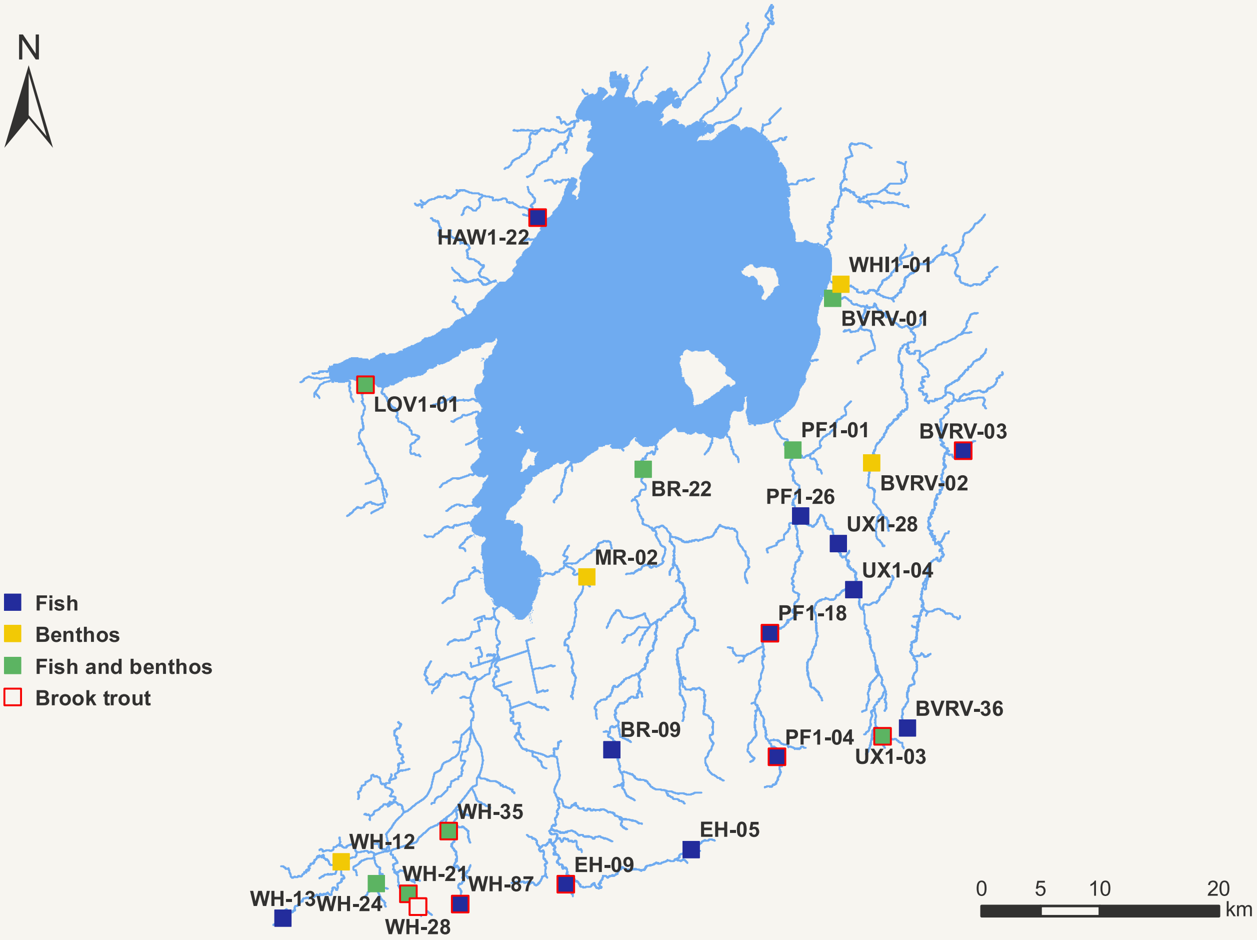


Figure 44: Tributary sites monitored since 2002 for fish, benthic invertebrates and brook trout

The IBI and HBI rankings in recent years (2009–2012) varied substantially across the watershed with only 24% of the fish sites and 38% of benthic invertebrate sites having IBI and HBI rankings, respectively, of Good. Two out of five sites in Ramara Creeks, and four out of four of Barrie Creeks had no fish. For benthic invertebrate sites, Hawkestone, Hewitts and Oro South Creeks had the highest rankings, and Barrie Creeks had the lowest (LSRCA, 2013).

There were no significant long-term changes in the IBI or HBI scores of the tributary communities; however, with only 11 or fewer years of data, there may be changes occurring that are not yet significant. For example, there were four benthic invertebrate sites that had close but not significant changes in HBI scores (Fig. 45). Two sites on the West Holland River had average HBI rankings of Fair (WH-12) and Good (WH-35) with apparent increases over the monitoring period due to higher proportions of EPT and fewer crustaceans and/or worms. Although WH-35 is primarily surrounded by agriculture, it has a wide buffer area, which could lead

Tributary biotic integrity	**Fish IBI**	**Benthos HBI**
All stations	↔	↔

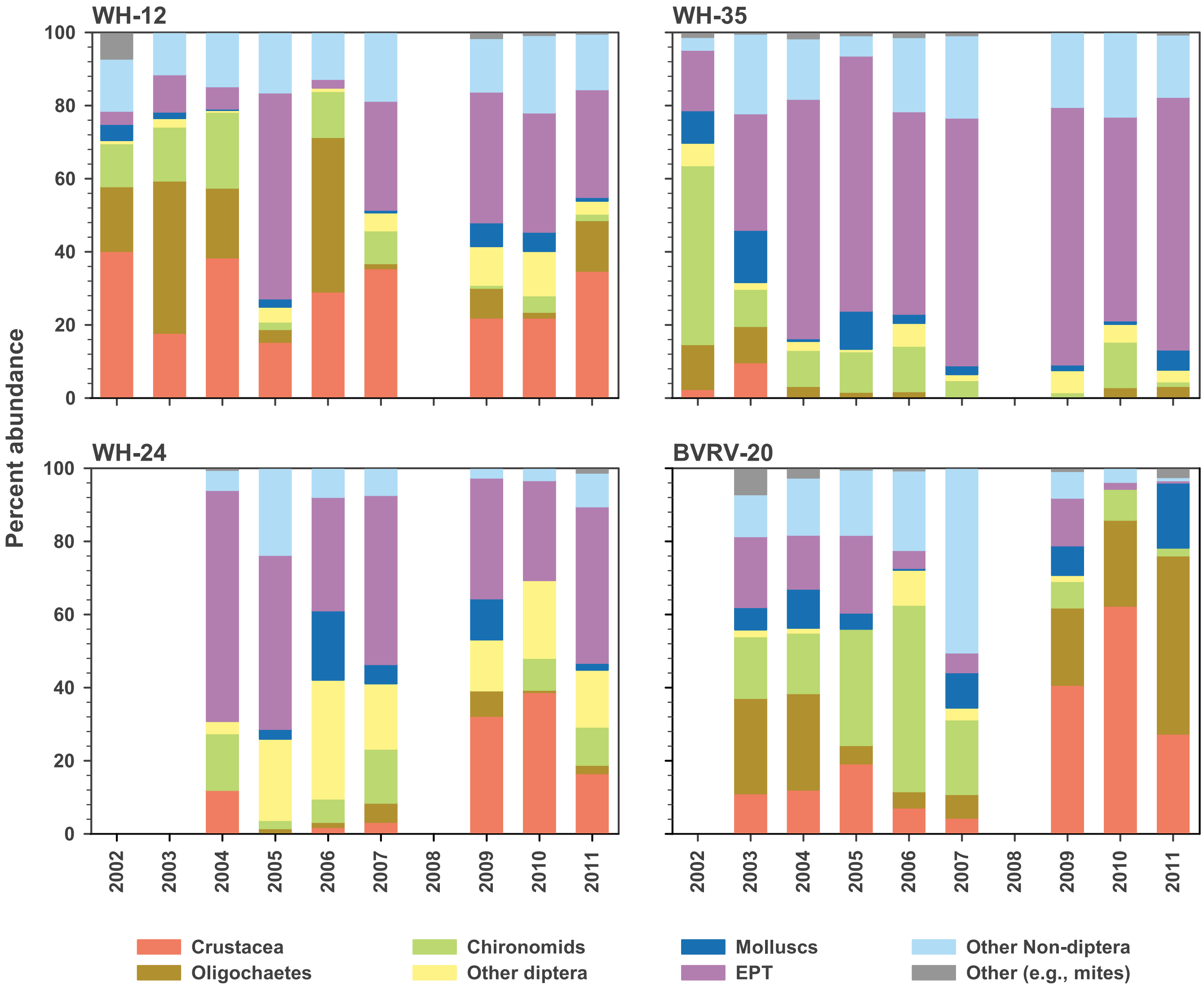


Figure 45: Tributary benthic invertebrates: Relative abundance of major taxa at four sites. *See Fig. 44 for site locations*

to improved stream quality (LSRCA, 2013). Meanwhile, another site on the West Holland River with an HBI ranking of Very Good (WH-24), and a site on the Beaver River that ranked Fair (BVRV-02) appear to have declined in ecological health due to increasing crustaceans and/or oligochaetes and fewer EPTs (Fig. 45). About half of the sites in the West Holland subwatershed ranked Fair or better. The range of results in the West Holland River illustrates how site-specific benthic communities can be.

Of the fish communities, there were two with close to significant decreasing IBI trends, both in the lower reach of the Pefferlaw River (PF1-26 average IBI rank was Fair, and PF1-01 was Good) (LSRCA, 2013). A decline at PF1-26 would likely be due to the loss of the coldwater mottled sculpin, which has not been captured there since 2003. PF1-01 is at the mouth of the Pefferlaw River, where the round goby was first detected in 2004, and has increased in dominance and replaced native fish species.

Brook trout is a key sensitive species in tributary fish communities, and its presence is specifically mentioned as an indicator in the LSPP. It prefers coldwater streams with a temperature range of 14–19 °C (Jobling, 1981); therefore, it could be vulnerable to increased stream temperatures due to climate warming or increases in land use such as impervious surfaces or online ponds. Eleven of the LSRCA's long-term tributary sites have historically contained brook trout (Fig. 44). While brook trout CPUE varied among sites and over time, there were no significant temporal trends at any of the sites (Fig. 46), including WH-87 where summer average daily maximum temperature significantly increased from 2005–2011 with a peak temperature of 18.8 °C in 2009 (LSRCA, 2013). It will be important to continue to monitor tributary fish, especially brook trout, and benthic invertebrate communities to determine whether further changes occur.

RESEARCH

Dr. Noreen Kelly, a postdoctoral visitor at York University, has analyzed the LSRCA's Hilsenhoff Biotic Index (HBI) rankings for benthic invertebrates based on characteristics of the local environment and 2008/2009 natural heritage categories. Sites with better water quality (e.g., low levels of metals, phosphorus and/or chloride) had HBI rankings above Fair. HBI rankings were below Fair at sites within the more developed watersheds, indicating that loss of natural areas in the watershed can decrease the ecological integrity of benthic communities.

Les Stanfield of MNRF's Science and Research Branch analyzed fish assemblages in the streams sampled by the LSRCA and found that both land use and fragmentation were significant predictors of fish assemblages, and the patterns varied with geology (Stanfield, 2012).

Brook trout abundance	Trend
All stations	↔

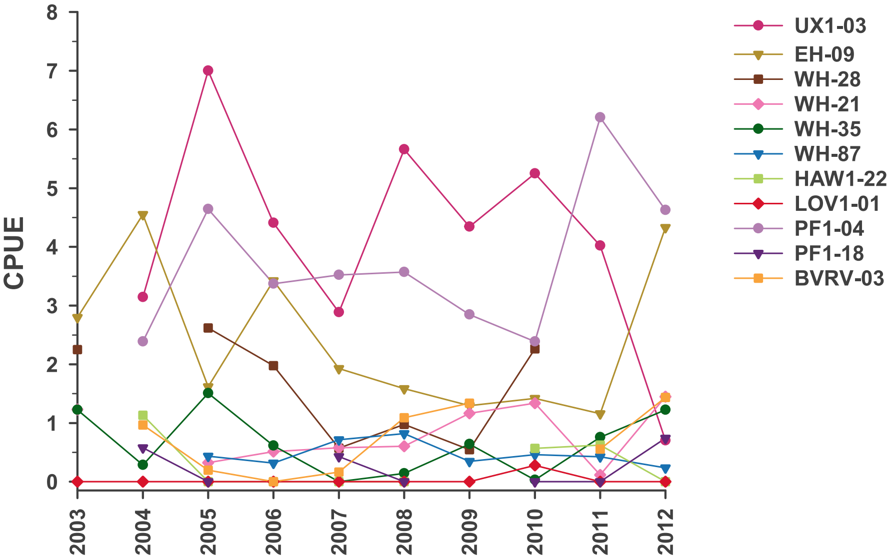


Figure 46: Brook trout abundance (catch per unit effort; CPUE) trends. *See Fig. 44 for site locations*

Lake Communities

Aquatic plants and algae

In shallow areas along the shoreline where sufficient sunlight reaches the lake bottom, different types of attached aquatic plants grow (e.g., benthic algae, periphyton and macrophytes). In Lake Simcoe, there is no historical routine monitoring program for attached aquatic plants at consistent lake stations, but many observations and studies since 1971 suggest that the attached plant communities of the lake have changed substantially.

Coontail on south Kempenfelt shore

Three benthic green algal genera have been studied in Lake Simcoe: *Cladophora*, *Dichotomosiphon* and *Chara*. *Cladophora* attaches to hard substrates along the shoreline, and can be abundant in eutrophic lakes and/or lakes invaded with zebra mussels (Depew et al., 2011). Abundant *Cladophora* was observed near the WPCP outflows of Barrie and especially Orillia in 1970 (Veal and Clark, 1970), and 1976 and 1980 (Dobson et al., 1982). Although it has been detected in the lake since 1980, there have been no reports of problematic *Cladophora*, not even following the invasion of dreissenids (Depew et al., 2011). *Dichotomosiphon tuberosus*, which prefers softer substrates, made a brief appearance in Lake Simcoe from 1978–1990 as the dominant benthic alga but has not been reported since (Neil et al., 1992). *Chara*, the largest attached alga, has been continuously reported among the macrophyte studies. It was the most common species in 1971 (Millard and Veal, 1971) but, based on a 2008 survey by the LSRCA, it was mostly replaced in shallower water by eurasian watermilfoil (*Myriophyllum spicatum*) as this invasive species is an excellent competitor that shades other species with a thick canopy (LSRCA, 2013). In 2008, coontail (*Ceratophyllum demersum*) was the dominant macrophyte species in the lake, especially at deeper (>3 m) depths as this species is tolerant of lower light levels.

The most information on changes in macrophytes over time is available for Cook's Bay. Studies were replicated in 1984 and 1987 in Cook's Bay to observe the effects of the redirection of sewage from Newmarket and Aurora to Lake Ontario. Between these years, substantial changes were observed; there were increases in plant coverage, and a 55% increase in total macrophyte biomass. This was the expected response to the sewage diversion, which reduced P and phytoplankton, and increased water clarity allowing macrophytes more light for establishment at deeper depths (Neil et al., 1988). Between the surveys in 1987 and 2006, very little change was observed in Cook's Bay, even though this is the period of zebra mussel invasion and water clarity increases. In 2006, macrophytes were growing slightly deeper, with a small increase in overall biomass from 1.2 kg/m^2 in 1987 to 1.4 kg/m^2 in 2006 (Stantec, 2007). Much larger changes were observed in the 2008 survey by LSRCA, with macrophytes growing up to 2 m deeper with a biomass of 3.1 kg/m^2. From 2006 to 2008, water clarity was stable or decreased (see Fig. 38), so would not explain increased macrophyte growth. A more likely explanation may be related to changes in Cook's Bay due to climate change, such as reduced ice cover, allowing a longer growing period, along with warmer water temperatures. Another macrophyte survey at the same Cook's Bay sites was performed in 2011 by the LSRCA, which will be compared with older studies and may provide further insights. Additionally, in 2008, the LSRCA began sampling macrophytes at 215 sites across the lake with a five-year cycle (see LSRCA (2013) for results).

Benthic invertebrates

Benthic invertebrates found in the lake can be classified into similar groups as tributary benthic invertebrates (worms, crustaceans, insects, arachnids and bivalves) but some of the taxa within the groups can be quite different; crustaceans in a lake usually consist of ostracods, isopods and amphipods, and bivalves include dreissenid mussels.

Beach near Black River

When Rawson (1930) reported on the benthic invertebrate community of Lake Simcoe, he suggested that it represented a eutrophic lake with some oligotrophic species (e.g., *Mysis relicta*) present. By the 1970s, the benthic community clearly represented eutrophic conditions (Ralston et al., 1975); oligochaetes, which were termed "sludge worms" and are commonly found in polluted lakes, constituted 93% of the benthic community at a deep site in the Main Basin (Veal and Clark, 1970). Since the 1980s, the benthic community has improved substantially. For example, in 2012, oligochaetes only made up 7.5% of the deepwater benthic community of the main basin (Fig. 47). Studies comparing data in the 1980s to the 2000s have shown that total benthic invertebrate abundance in Lake Simcoe has decreased overall (Jiminez et al., 2011; Rennie and Evans, 2012); taxa that were primarily responsible for the decrease were worms (oligochaetes, polychaetes and nematodes) and ostracods. Decreasing abundance, especially worms, suggests an improvement in the benthic environment associated with nutrient declines since the 1980s.

METHODS

Petite Ponar Grab. *Credit: MNRF*

There has been no consistent annual lake benthic monitoring program on Lake Simcoe, but many studies over the past century can provide information on changes in their status. Data presented here are from the most recent benthic invertebrate collections by the LSRCA on soft substrates using a Petite Ponar Grab, which began in 2008 across the lake at varying stations. Benthic invertebrate composition can differ across lake basins and by depth; therefore, only the Main Basin is presented and was separated into three depth zones: shoreline (0–1 m), nearshore (4–14 m) and deepwater (>20 m). Total (black line; only for nearshore and deepwater) and relative abundance are presented in Fig. 47 as averages based on 2–41 sites sampled.

Other signs of improvement in the benthic environment have been the recovery of species that are sensitive to low oxygen conditions. Rennie and Evans (2012) reported that three sensitive chironomid genera (*Heterotrissocladius*, *Dicrotendipes* and *Sergentia* spp.) have reappeared in recent years, and the relative abundance of a sensitive chironomid group (*Micropsectra* gr.) has increased. The planktivorous fish data shown in the Invasive Species section suggests the recovery of the opossum shrimp (*Mysis relicta*), a small shrimp-like species that can be sensitive to low dissolved oxygen levels. Because the opossum shrimp spends the day on the lake bottom, it is difficult to collect in daytime samples but is a common prey item for planktivorous fish. Previously in Lake Simcoe, it was detected infrequently in fish diets in the 1920s (Rawson, 1930) and in 1983 (see Fig. 15); in the summer of 2009, the opossum shrimp was much more commonly consumed by planktivores, and nighttime netting data showed densities as high as 402/m^2 at station K42 (MNRF, unpublished data).

A major change in the benthic community in recent years has been the introduction of dreissenid mussels, as mentioned in the Invasive Species section. Dreissenids have affected the benthic community directly, by increasing total biomass (Rennie and Evans, 2012), and possibly indirectly; Ozersky et al. (2011b) showed that the abundance of non-dreissenid invertebrates in nearshore rocky habitats increased comparing 1993 with 2008, which could have been due to increased resource depositions or substrates from dreissenids. Across the lake and at all depths, Jiminez et al. (2011) showed that some benthic taxa (gastropods, amphipods, isopods and native bivalves) increased between 1983 and 2008, which were likely associated with dreissenid establishment.

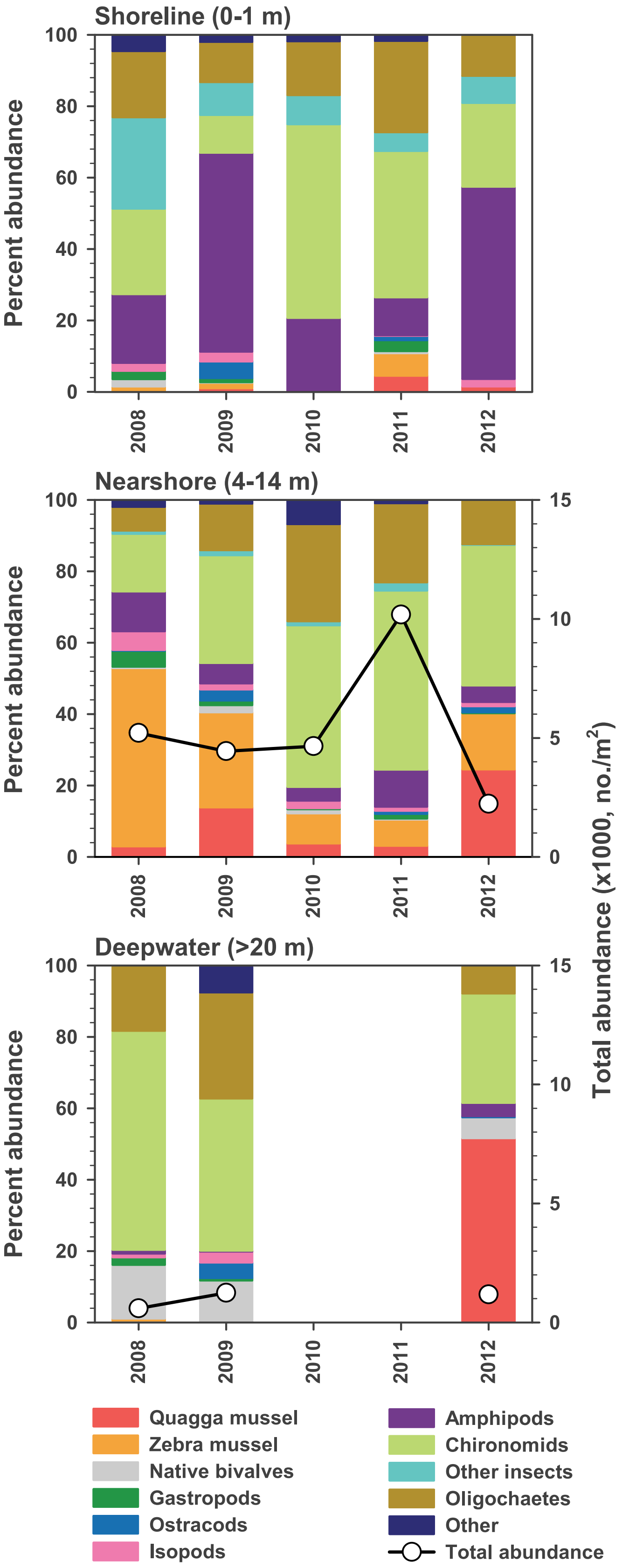
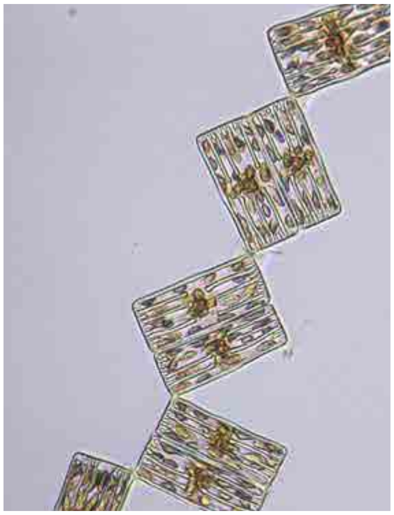


Figure 47: Relative and total abundance of benthic invertebrates in the soft substrate of three depth zones of Lake Simcoe's main basin. *NOTE: total abundance was not measured at shoreline sites , and the distinction between dreissenid species in 2011 was preliminary.*

Phytoplankton

In the open water of a lake, the small, free-floating algae are called phytoplankton. Phytoplankton are the primary producers in a food web, getting energy from the sun and nutrients in the water, which is then moved up the food chain to herbivores and fish. The abundance of phytoplankton can be controlled from the bottom-up (e.g., light and nutrients such as P and silica) or the top-down (i.e., herbivores such as zooplankton or benthic invertebrates).



Tabellaria, a colonial diatom

Total phytoplankton abundance was generally greatest at the Cook's Bay stations, where total P was also the highest, with diatoms making up the largest phytoplankton component (Fig. 48). At the Cook's Bay stations (except the very shallow C1), phytoplankton abundance (total biovolume and chlorophyll *a*) and diatom biovolume decreased significantly, and chlorophyll *a* also decreased at stations E51 and K39 (Fig. 49). Chlorophytes and cyanobacteria, important but less common phytoplankton groups, decreased at most stations except C1. There have been anecdotal reports of cyanobacterial blooms in Lake Simcoe over the past decade; however, these were not captured in the routine phytoplankton monitoring nor were reports made to MOECC's algal monitoring group for analysis and confirmation through Ontario's algal bloom response protocol.

Phytoplankton biovolume	Total	Diatom	Chloro	Cyano	Chlorophyll *a*
C1	↔	↓	↔	↔	↔
C6	↓	↓	↓	↓	↓
C9	↓	↓	↓	↓	↓
E51	↔	↔	↓	↓	↓
K39	↔	↔	↓	↓	↓
K42	↔	↔	↓	↓	↔
K45	↔	↔	↔	↓	↔
S15	↔	↔	↓	↓	↔

METHODS

Dinobryon, a colonial chrysophyte

Phytoplankton were collected by the MOECC from the euphotic zone along with water quality samples at open lake stations during the ice-free season. The abundance of phytoplankton was measured as phytoplankton biovolume, which was based on individual algae counts from a composite sample of the ice-free season, or the average ice-free concentration of chlorophyll *a*, a common pigment found in most algae.

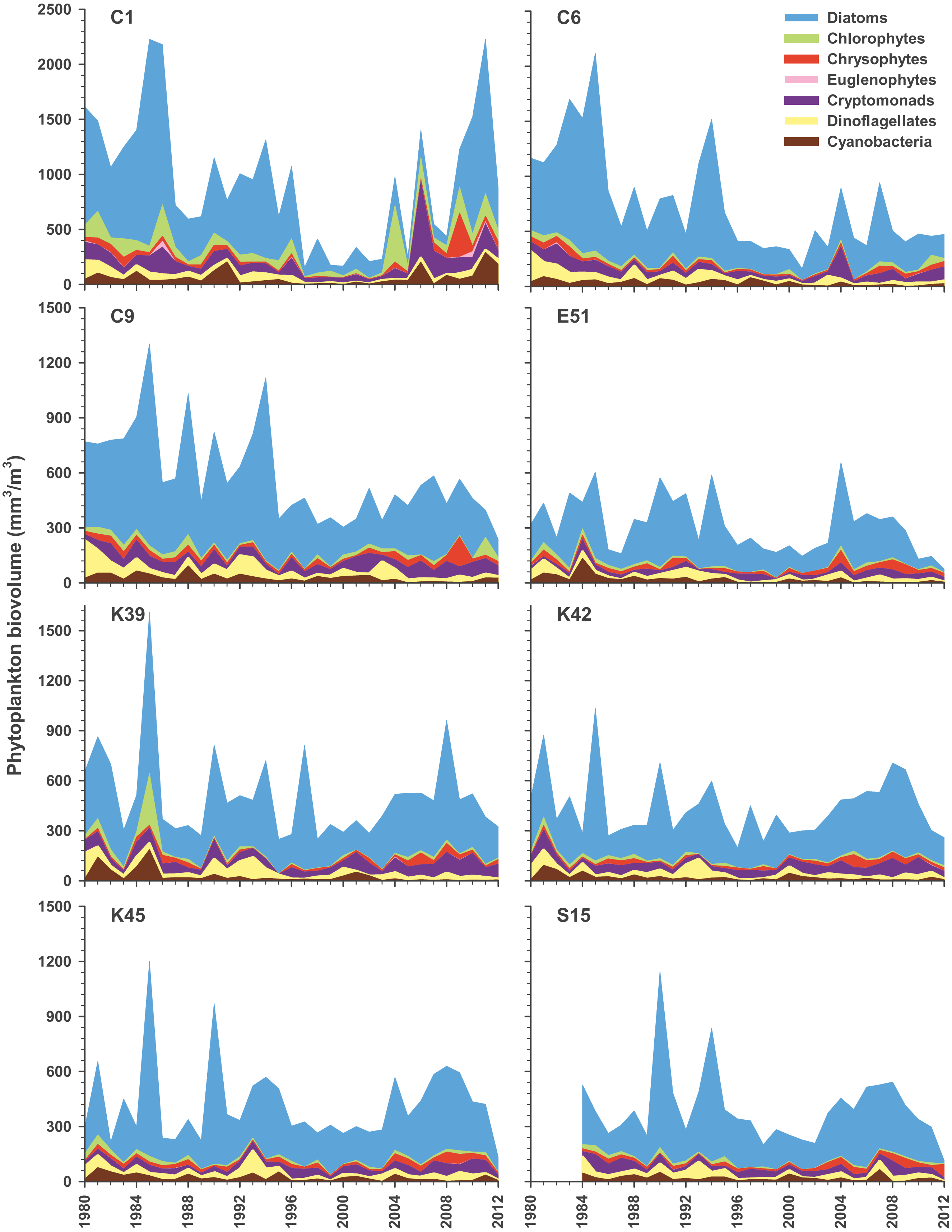


Figure 48: The biovolume of phytoplankton groups at the lake stations

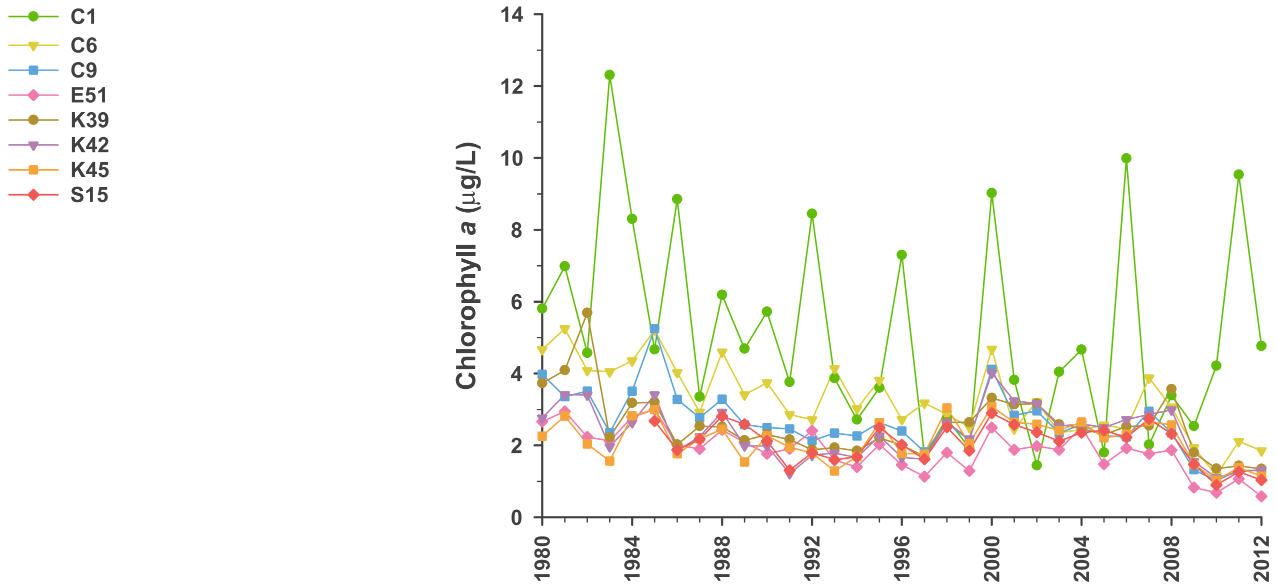


Figure 49: Chlorophyll *a* concentration at the lake stations

East Holland River. *Credit: Jim Eddie*

Nutrients appear to have been an important driver of changes in phytoplankton biovolume, especially during the greatest decreases in the 1980s and early 1990s, which coincided with the sewage diversion in 1984 and resultant decreases in P concentration. Herbivores (zooplankton and zebra mussels) have also played an important role in controlling phytoplankton abundance. There was an abrupt decrease in phytoplankton biovolume coinciding with zebra mussel establishment, and the species that made up the phytoplankton community also changed (Winter et al., 2011b). For a brief period (~ 2004–2010), phytoplankton biovolume increased; however, in 2011 and 2012, phytoplankton biovolume and chlorophyll *a* decreased at all stations but the shallowest stations in Cook's Bay (C1 and C6), coinciding with the recent decreases observed in total P. Although there have been improvements in the phytoplankton trends overall, there have not been any notable changes in the abundance of the oligotrophic taxa (*Cyclotella*, *Bicosoeca*, *Chrysolykos* and *Kephyrion*) recorded by Nicholls et al. (1985).

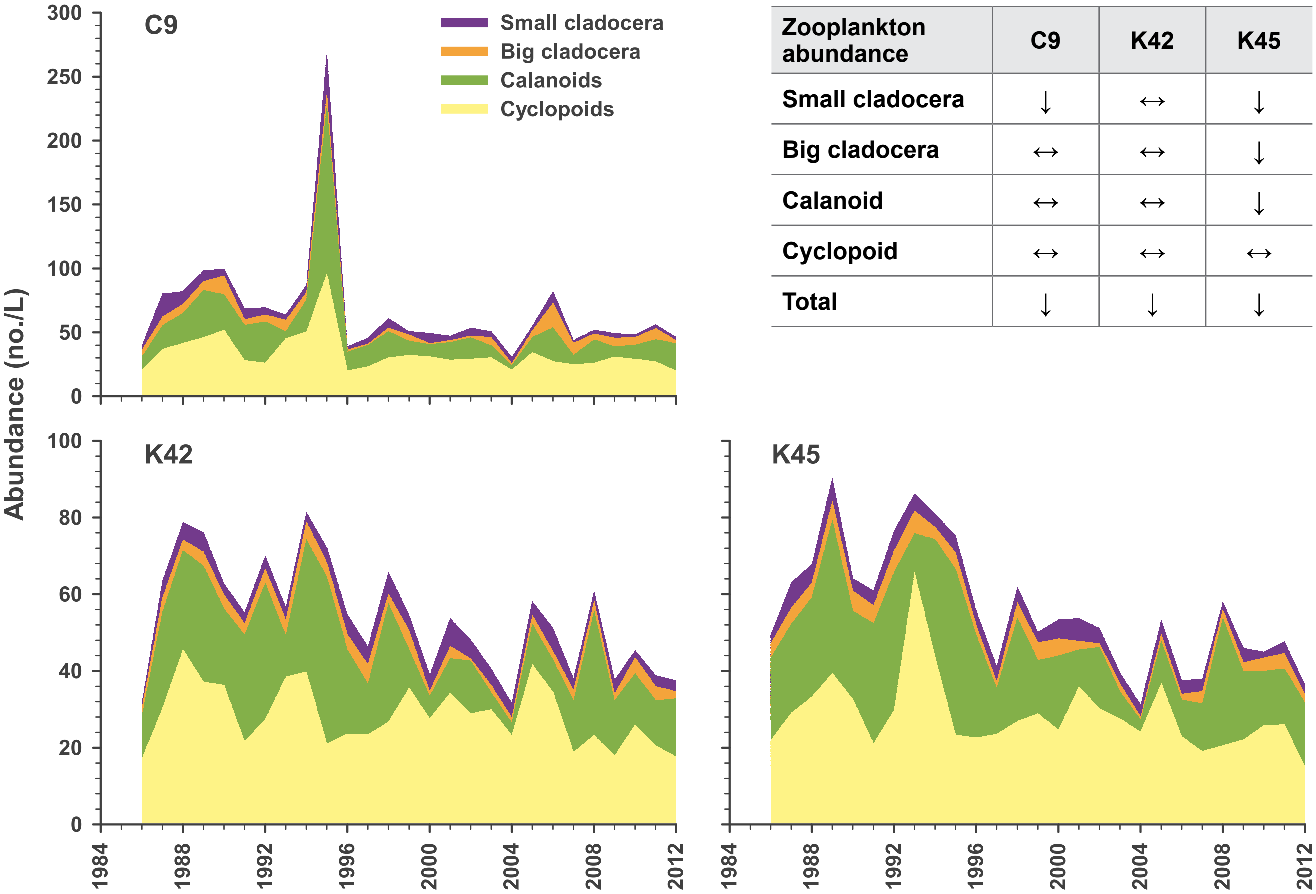
Zooplankton

Zooplankton are small crustaceans found in the lake, which are also an important part of the food web, as they transfer energy from phytoplankton to planktivorous fish.

Total zooplankton abundance was similar at all three stations with the exception of an extremely large peak in small cladocerans and immature cyclopoids at C9 in 1995 (Fig. 50). Copepods, primarily immature individuals, dominated the zooplankton communities at all stations. While total zooplankton abundance significantly decreased at the three stations, not all zooplankton groups declined significantly. The largest decrease in abundance occurred after 1994, following spiny water flea establishment. Beforehand, from 1986–1993, zooplankton (calanoid, cyclopoid and big cladocera) abundance appeared to increase, with possible increases occurring again starting around 2004. Changes in zooplankton abundance were synchronous with shifts in the zooplankton community, especially the cladocerans, which are the primary prey of the spiny water flea. From 1993 to 1994, the average number of cladoceran species was cut in half from 6 to 3 species, while starting in the early 2000s, cladoceran species richness started to increase (Fig. 51).

METHODS

Zooplankton were collected by the MOECC during the ice-free sampling at the open lake stations. Since 1986, three stations (K42, K45 and C9) have been consistently sampled from 1-m above the bottom to the lake surface. Zooplankton were identified to species but are presented here as densities of copepods (calanoids or cyclopoids), and cladocerans (small ≤ 0.6 mm < big).



Zooplankton abundance	C9	K42	K45
Small cladocera	↓	↔	↓
Big cladocera	↔	↔	↓
Calanoid	↔	↔	↓
Cyclopoid	↔	↔	↔
Total	↓	↓	↓

Figure 50: Zooplankton abundance at three lake stations

Cladoceran species richness	Trend
C9	↔
K42	↔
K45	↓

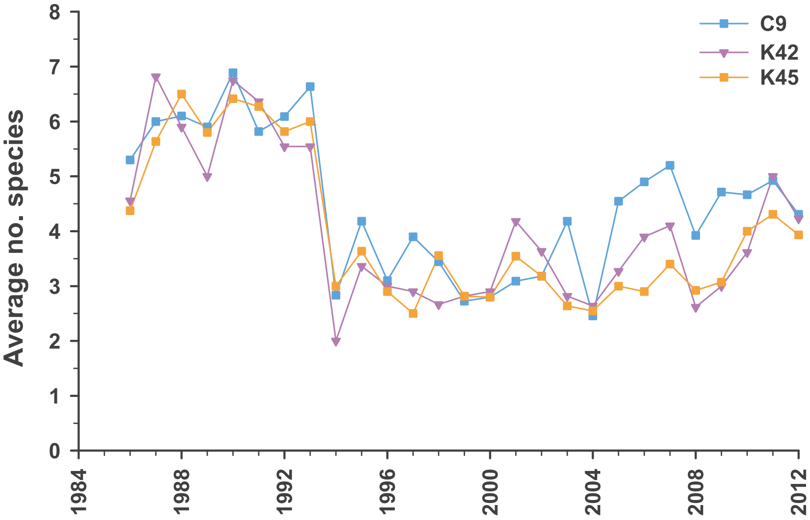


Figure 51: Cladoceran species richness at three lake stations

The factors affecting zooplankton total abundance and community composition were likely the same. At the start of the dataset, planktivorous fish, such as cisco and rainbow smelt, were decreasing in number, thus releasing zooplankton from predation. Then another predator invaded the lake, the spiny water flea, which drastically reduced zooplankton abundance and cladoceran species richness. In recent years, the effect of climate change has likely also been important on both abundance and community composition; warmer water temperatures and longer seasons would benefit some species by increasing growth rates and lengthening the growing season. However, these factors would be detrimental to coldwater species, such as *Daphnia longiremis* and *Leptodiaptomus sicilis*, which have been extremely rare since 2000. Current research by the MOECC is examining the zooplankton community and what is affecting it, as well as the effects it may be having on lower (phytoplankton) and higher (fish) trophic levels.

Top of Cook's Bay looking northwest

Fish

The most up-to-date species list identifies 52 fish species permanently inhabiting Lake Simcoe (from 1951–2007 LSFAU programs; Moles, 2010). These species are commonly categorized into separate fish communities based on their habitat preferences (e.g., warmwater, benthic, pelagic, coldwater). Many of the stressors already discussed in this report have an effect on fish communities. These include shoreline development, land use patterns, climate change (increasing water temperature for longer durations), increasing water clarity and dissolved oxygen, increasing macrophyte abundance and distribution, invasive species and pollutants. These factors can affect fish populations directly or indirectly by changing their habitat, food availability or predator abundance, as well as metabolic costs, growth performance and reproductive success.

The harvest of fish species, if not properly managed, can be another contributing key stress to the fish community. Lake Simcoe is the most intensely fished inland lake in Ontario (MNRF, 2014), with a thriving recreational fishery that targets a variety of species. MNRF's LSFAU (originally the Lake Simcoe Fisheries Management Unit) was created in 1964 at Sibbald Point to better understand the fish communities, and the fishery and its potential effects (MacCrimmon and Skobe, 1970).

The Lake Simcoe Fish Community Objectives (FCOs), implemented in 2011, provide a common goal and a comprehensive set of objectives that guide MNRF fisheries' decisions, and the collective efforts of agencies and organizations to manage the aquatic resources of the lake and its watershed. The objectives for the coldwater, warmwater and tributary fish communities encompass a responsibility to maintain populations of native fish species and promote natural reproduction, provide sustainable harvest opportunities, and identify opportunities for enhancement and restoration of habitats. A guiding principle for all fish communities is to base management decisions upon the best scientific knowledge, including Aboriginal traditional knowledge, incorporated into an adaptive management approach.

METHODS

Summer creel survey. *Credit: MNRF*

Winter creel survey. *Credit: MNRF*

The habits of winter anglers have been monitored since 1961 and summer anglers since 1981 using standardized roving creel surveys (Liddle and Moles, 2012). Travelling by boat in the summer (mid-May to early September) and by snowmobile in the winter (end of January to mid-March), MNRF's LSFAU staff surveyed anglers on the lake to measure total angling effort (the total number of days spent fishing on the lake by all anglers) and total catch by species. Creel surveys have been performed every 2–5 years.

The total amount of time spent angling during the winter has increased over the past five decades, estimated at 244,000 hours in 1961 and increasing to 702,000 hours in 2005 with an apparent decrease in 2009 and 2010. The total amount of fish caught was also much higher during the past 20 years than in previous decades. Recent creel surveys suggest that winter anglers primarily fish for and catch lake whitefish (*Coregonus clupeaformis*), lake trout and yellow perch (Fig. 52). In 2001, the cisco fishery was closed but incidental catch has been observed since then.

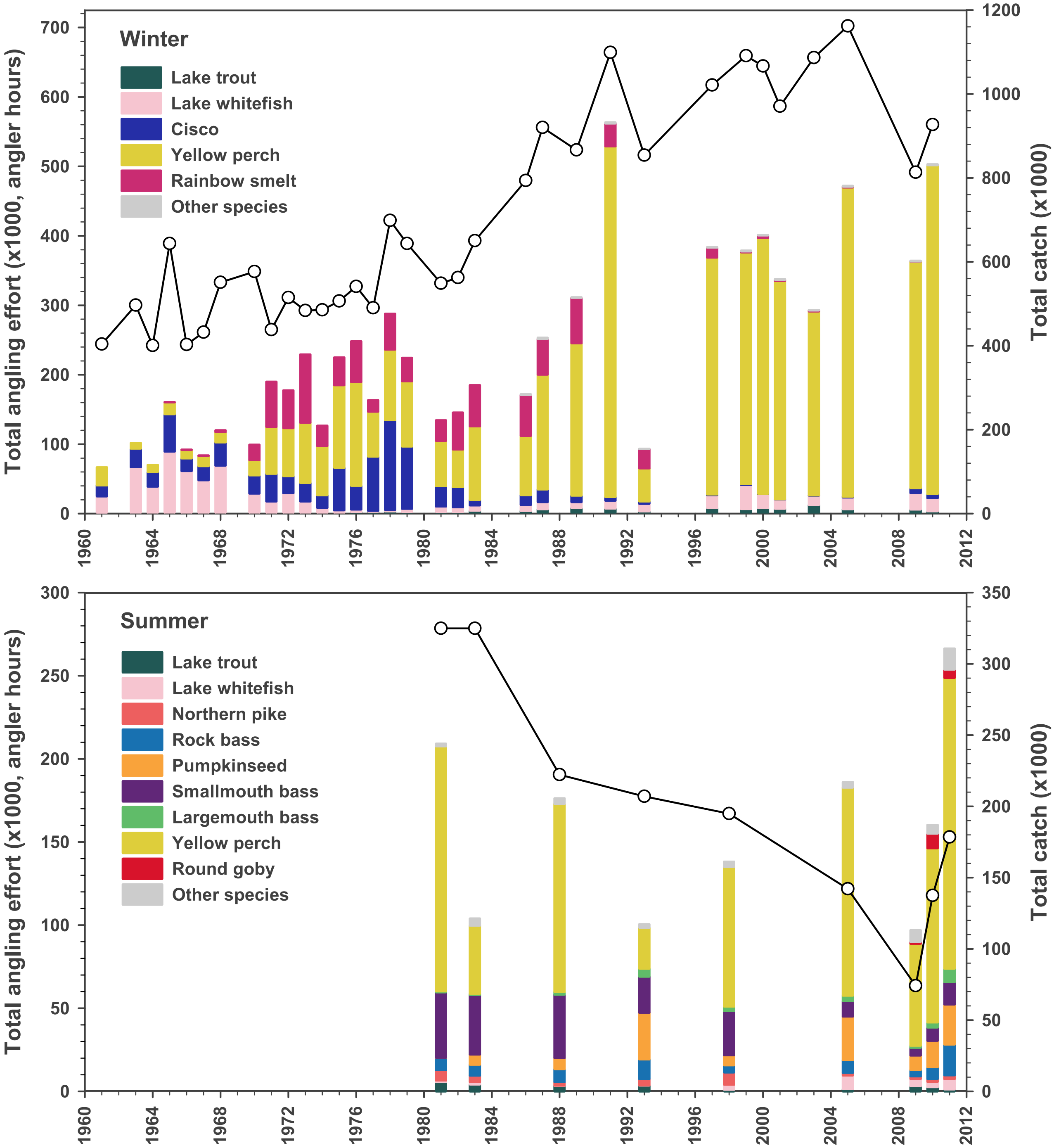


Figure 52: Winter and summer creel trends showing total angling effort (black lines) and total catch by species (coloured bars)

Summer angling effort has decreased since the 1980s; although, unlike winter, summer angling effort has increased in the two most recent survey years. Summer anglers target a wide range of species, including yellow perch, lake trout, lake whitefish, northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*). The most often caught species in recent summer surveys were yellow perch, pumpkinseed, rock bass and smallmouth bass (Fig. 52). Round goby was also incidentally caught by anglers. The information provided by creel surveys on the status of the recreational fishery can be used, along with other information, to support fisheries' management decisions and to provide information on fish population trends that inform the ecological health of the lake (Liddle and Moles, 2012).

The nearshore small fish community is diverse, making up over 75% (>40 of 52 species) of fish species in Lake Simcoe. This diverse community has shown substantial changes both across the lake and over time.

Mimic shiners. *Credit: MNRF*

A considerable proportion of the contemporary small fish community is made up of mimic and emerald shiners, but not always in the same proportions across the lake. Mimic shiner (*Notropis volucellus*) dominated the southeast shore of the Main Basin, Cook's Bay, and the north shore of Kempenfelt Bay, while emerald shiner (*Notropis atherinoides*) dominated the north shore of the Main Basin. Along the south shore of Kempenfelt Bay, shiners made up only a small portion of the community, which was instead dominated by rock bass, along with bluntnose minnow (*Pimephales notatus*) and yellow perch (Fig. 53). The dominance of mimic shiners is a recent phenomenon, and is one of the most significant changes in the small fish community. Prior to 2007 when the small fish biodiversity program began, this species was rarely observed, did not appear on Lake Simcoe fish species lists (Amtstaetter, 2003), and wasn't recorded during historical small fish sampling in Cook's Bay, Main Basin and Kempenfelt Bay. Trumpickas et al. (2012) examined whether there had been changes in small fish biodiversity by comparing historical vs. contemporary communities at the same sampling sites. The authors showed that, even with the addition of mimic shiner to the small fish community, the average number of species declined over time in Cook's Bay and the Main Basin. This decline in species richness was not clearly linked to increases in water clarity or macrophyte density, or with densities of nearshore benthic invertebrates.

METHODS

Fyke net. *Credit: MNRF*

The MNRF's LSFAU small fish biodiversity program has been monitoring the small bodied, nearshore dwelling fish community along the Lake Simcoe shoreline every June since 2007. Each section of shoreline was sampled in a different year, within which sites represented all shoreline habitats, such as rocky, sandy and muddy substrates, and overlapped with some historical (1982–1995) sampling sites for comparisons. Small fish were targeted using daytime hauls of seine nets and overnight sets of fyke nets. Small mesh gillnets have also been used, but not in all years or at all sites; therefore, gillnet data are not displayed here.

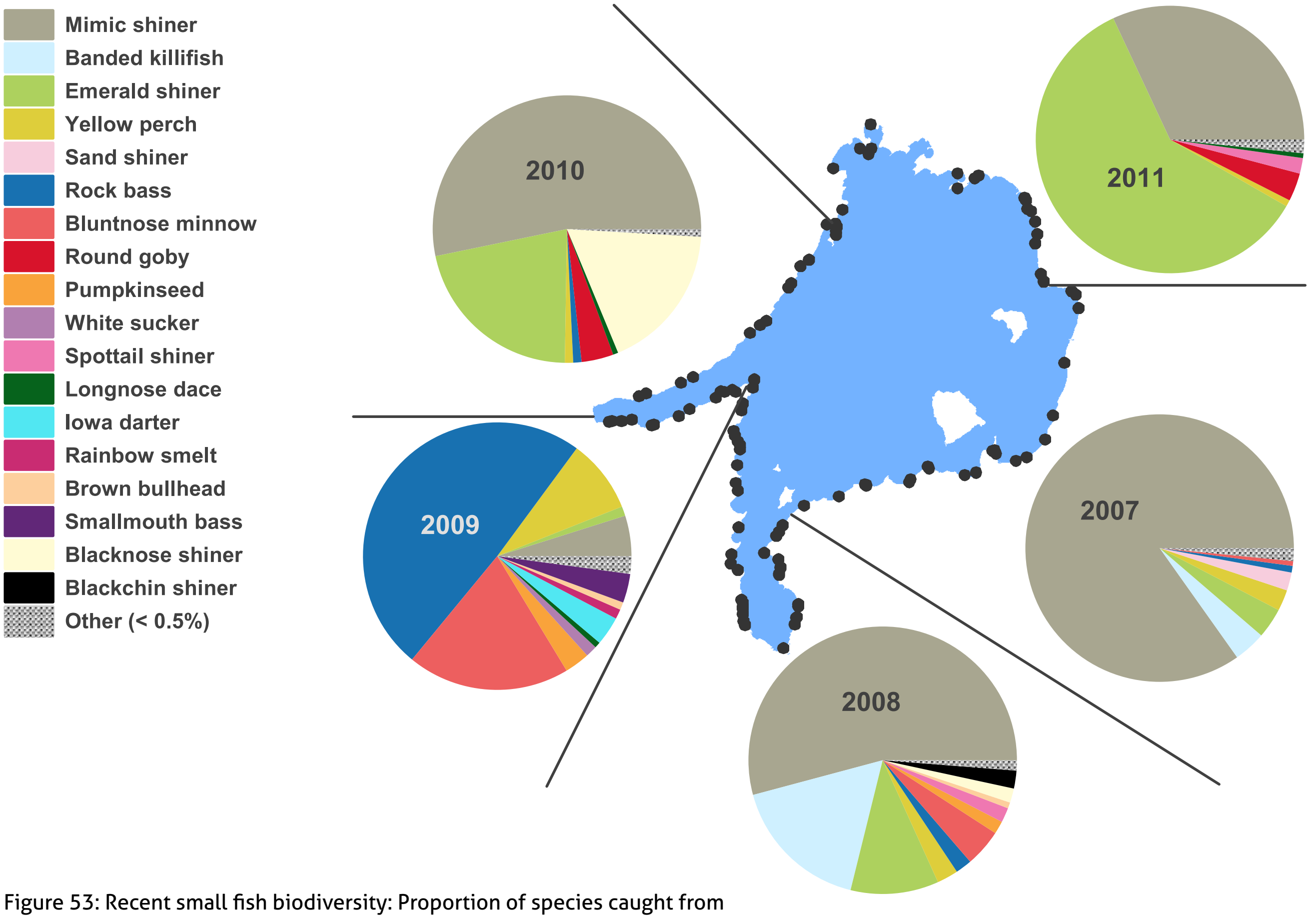


Figure 53: Recent small fish biodiversity: Proportion of species caught from five sections of the Lake Simcoe shoreline

➔ RESEARCH

Side-scan sonar. *Credit: MNRF*

Research by Dr. Erin Dunlop of MNRF's Aquatic Research and Monitoring Section is currently being conducted to better understand the link between habitat and nearshore fish biodiversity. This research will help explain the observed spatial and temporal variability in small fish biodiversity, by combining small fish community sampling with nearshore fish habitat mapping. The researchers have been sampling the nearshore small fish community in southeastern Lake Simcoe since 2011. Sampling occurs in the summer at randomly selected sites along the southeastern shoreline. The nearshore habitat is also mapped using a side-scan sonar. Side-scan sonar emits sound waves that bounce off of the lake bottom, and records the returning signal. Different bottom substrates (such as mud, sand or rocks) reflect sound differently and this allows substrates to be characterized and mapped. Bottom substrate is an important component of fish habitat. So far, from 2011–2013, 8.25 km^2 of the nearshore (<7 m depth) of southeastern Lake Simcoe has been surveyed using side-scan sonar. Ground-truthing of different substrate types identified with side-scan sonar was conducted using an underwater video camera and sediment grabs in select locations.

METHODS

NSCIN monitoring. *Credit: MNRF*

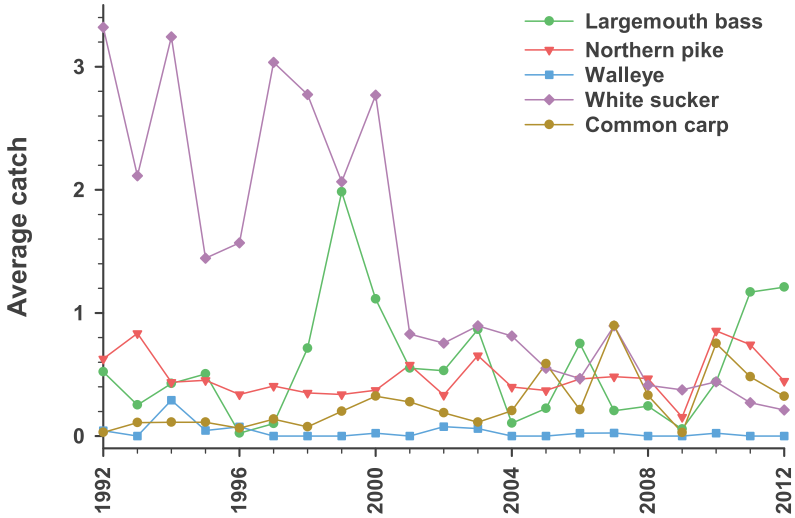
Warm water fish community data were collected from 1992–2012 by the LSFAU using Nearshore Community Index Netting (NSCIN), a provincial standard monitoring method (Stirling, 1999). NSCIN monitors the warmwater fish community including species such as bluegill, black crappie, brown bullhead, largemouth bass, northern pike, pumpkinseed, rock bass, smallmouth bass, white sucker, walleye and yellow perch. NSCIN sampling is conducted from August 1 until surface water temperature falls to 13 °C, using a 1.8 m trapnet set for approximately 22 hours. Sites are randomly selected along the shoreline from Island Grove to Mara Point, including nearby islands.

The warmwater fish community is particularly susceptible to changes in water clarity, invasive species (e.g., round goby and dreissenid mussels), climate change and the recreational fishery.

NSCIN catch. *Credit: MNRF*

Although there have been many environmental changes over the past two decades that might affect warmwater fish abundances, the average catch of most species did not significantly change (Fig. 54). There was a decline in white sucker (*Catostomus commersoni*) abundance and an increase in the common carp but, because these species are at low abundance, the overall changes in average catch were less than two fish. Of the warmwater fish with higher abundances, only bluegill (*Lepomis macrochirus*) and smallmouth bass exhibited significant changes over the past two decades. Bluegill, which is native to Ontario lakes, was first detected in Lake Simcoe with the NSCIN program in 2000, remaining at low abundances until increasing in 2010–2012. While smallmouth bass catch has significantly decreased, there is evidence that age 4 and 5 smallmouth bass are getting larger, possibly because of warmer water temperatures, increased availability of food, or the reduction in its population abundance (i.e., density-dependent growth) (Fig. 55).

Warmwater species with low abundance	Trend
Largemouth bass	↔
Northern pike	↔
Walleye	↔
White sucker	↓
Common carp	↑



Warmwater species with high abundance	Trend
Black crappie	↔
Bluegill	↑
Pumpkinseed	↔
Rock bass	↔
Smallmouth bass	↓
Yellow perch	↔

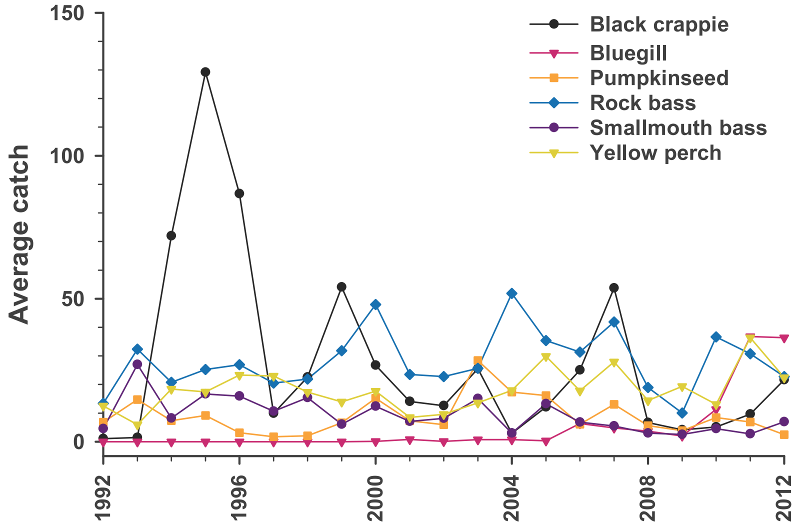


Figure 54: Warmwater fish species abundance separated into low (top figure) and high (bottom) average catch

Smallmouth bass	Trend
Abundance (catch)	↓
Length (age 4)	↑
Length (age 5)	↑

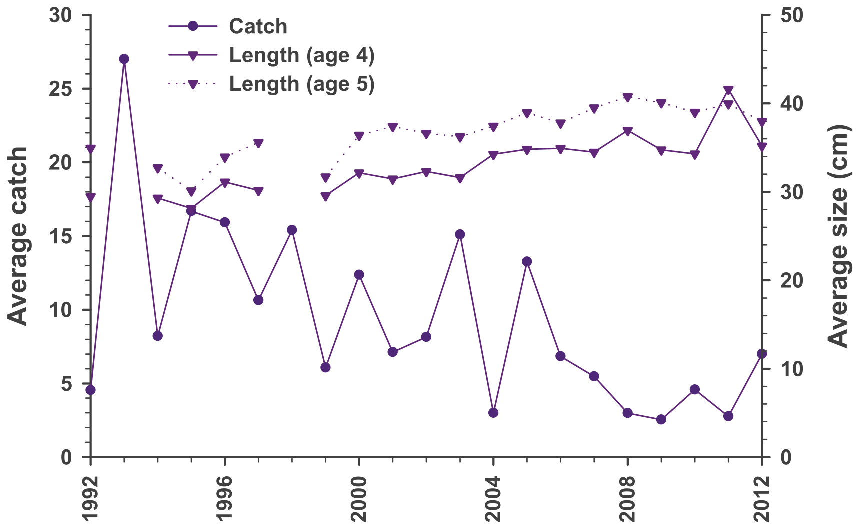


Figure 55: Smallmouth bass abundance and size

As mentioned above in the recreational fishery section, yellow perch is a very popular winter and summer sportfish. NSCIN catch of yellow perch has shown a gradual but not significant increase. In 1993, there was concern about the perch population when its numbers declined after a cool summer in 1992, but the population recovered quickly and, with increasingly warm summers, has been doing well. Interestingly, preliminary results suggest that catch of yellow perch in the offshore netting program (OSBIN; next section) has significantly increased since 2003 (Fig. 56). This could be the result of a change in fish habitat or the food web, or a combination of factors.

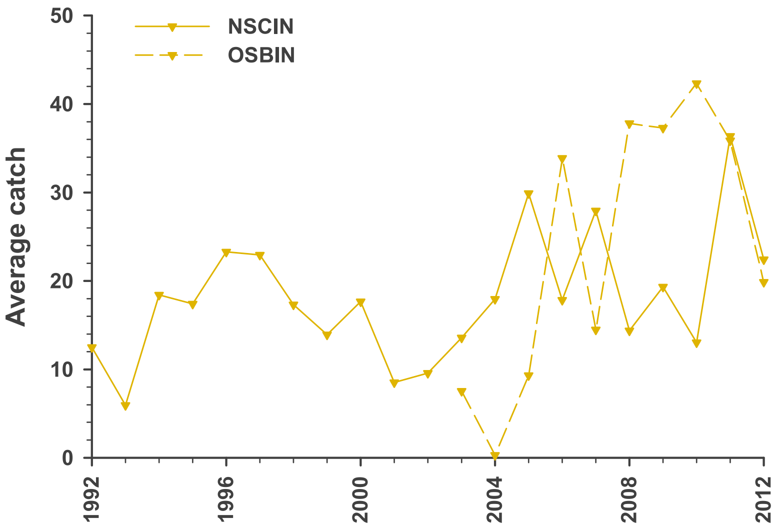


Figure 56: Yellow perch abundance: Nearshore (NSCIN) and offshore (OSBIN) netting

Yellow perch abundance	Trend
Nearshore (NSCIN)	↔
Offshore (OSBIN)	↑

Coldwater fish species are key indicators of the LSPP as they are important to the recreational fishery and are very sensitive to water quality. The coldwater fish community is affected by deepwater dissolved oxygen as well as changes in the climate (e.g., duration of ice cover and spring water temperature can affect spawning success), invasive species (e.g., round goby, spiny water flea, rainbow smelt) and the recreational fishery. The coldwater fish community experienced a collapse in Lake Simcoe, beginning with lake trout in the 1960s, followed by lake whitefish in the 1970s, cisco in the 1980s and rainbow smelt in the 1990s. The collapse was primarily due to low dissolved oxygen caused by eutrophication; however, other factors were likely important, such as the loss of spawning habitat. As a result of the collapse, some of these fish species have required special regulations or other management actions for rehabilitation in the lake. Lake trout and lake whitefish have been maintained by a stocking program, and changes were made to the cisco fishery, starting with a reduced limit (reduction to 6 per day) in 1995 and closure of the fishery in 2001 (Johanson, 2004).

A combination of monitoring programs and Lake Simcoe research can be used to support management decisions. For example, the signs of natural recruitment of lake trout led to the reduction in the annual number of stocked lake trout, and routine monitoring backed by research has contributed to the recent re-opening of the cisco fishery. These illustrate how monitoring is important to the people that use the lake for recreation.

METHODS

Credit: MNRF

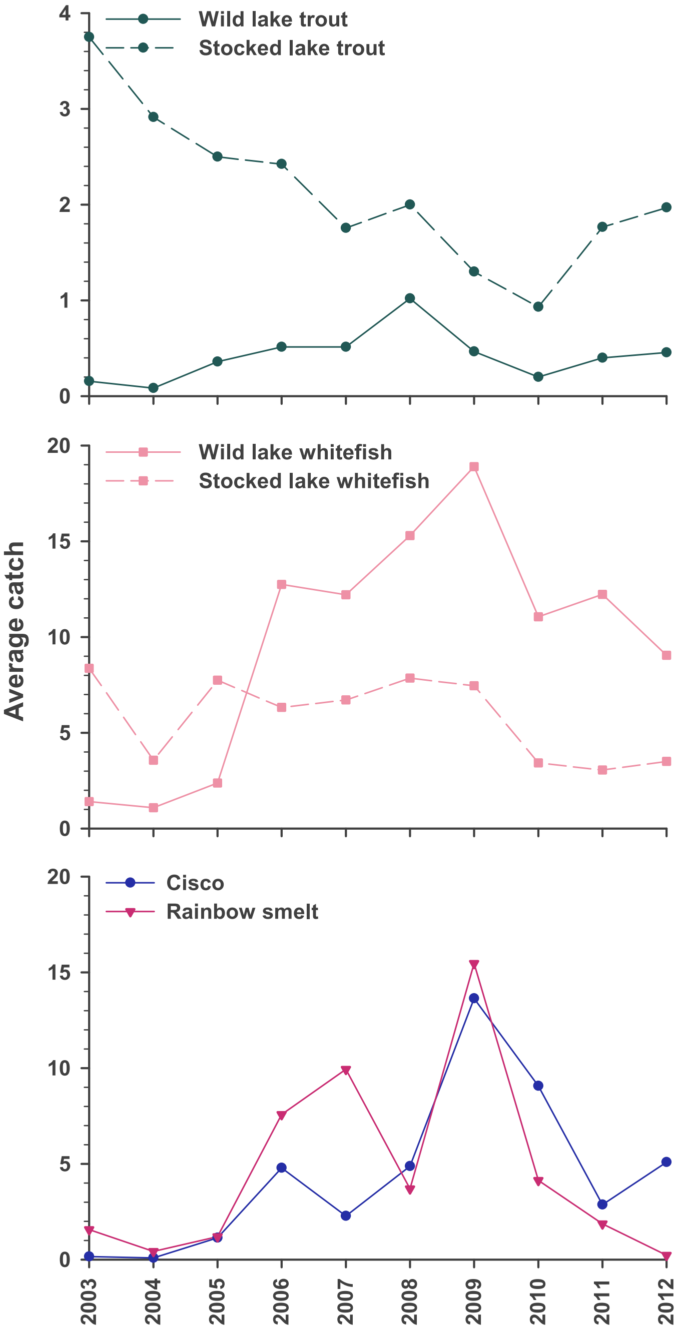
Offshore Benthic Index Netting (OSBIN) is MNRF's LSFAU deepwater gill netting program undertaken in the mid-summer season on Lake Simcoe. This program monitors the offshore, coldwater fish community, including lake trout, cisco, rainbow smelt and lake whitefish in their summer habitat using gill nets set along the lake bottom at depths ≥ 20 m. Information gathered by the OSBIN program is used to report on the health of the coldwater fish community including the extent of natural reproduction in species such as lake trout and lake whitefish.

Through improvements to the coldwater habitat, there have been encouraging signs of recovery to the naturally-produced (i.e., wild), native, coldwater fish community. After almost 20 years with virtually no evidence of natural lake trout reproduction, two young-of-the-year wild lake trout were caught in 2001 during the LSFAU's benthic trawling program (Willox, 2001). Following this initial observation, natural recruitment has persisted, as shown with the OSBIN program in which wild lake trout have been consistently caught every year since 2003 (Fig. 57). Further evidence comes from the recreational fishery surveys, where winter anglers have reported high catches of wild lake trout (e.g., > 40% of total lake trout catch in 2009 and 2010; Dolson, 2012). To encourage natural recruitment, the annual stocking rate of lake trout was reduced by half in 2010 (Borwick et al., 2009). The size of lake trout have not changed overall; there was a decline in stocked lake trout size at age 6 reported by Dolson (2012); however, there appeared to be recent increases in size in 2011 and 2012 (Fig. 58).

OSBIN monitoring. *Credit: MNRF*

After the wild lake whitefish population collapsed in 1970s, some long lived wild whitefish continued to persist while young wild whitefish were rarely caught (Amtstaetter, 2002). Encouragingly, since 2006, there has been a substantial increase in the catch of wild lake whitefish compared to previous years (Fig. 57), suggesting natural recruitment is recovering. Cisco abundance has also been significantly increasing (Fig. 57), and there are several other lines of evidence suggesting the status of the cisco population has improved. For example, the cisco population appears to have recently produced three strong year classes in 2004, 2008 and 2012 (Fig. 59). A variety of factors likely contributed to the recent signs of recovery of the cisco population, including improved dissolved oxygen in the hypolimnion. Cisco was the historically preferred prey of lake trout (Rawson, 1930; MacCrimmon and Skobe, 1970) but was rarely observed in lake trout stomachs prior to 2012 (Adkinson, 2013). Rainbow smelt, on the other hand, is the most common lake trout prey item (Adkinson, 2013) despite its low abundance in the lake in recent years (Fig. 57).

Lake trout stocking. *Credit: MNRF*



Offshore fish abundance	Trend
Stocked lake trout	↓
Wild lake trout	↔
Stocked lake whitefish	↔
Wild lake whitefish	↔
Cisco	↑
Rainbow smelt	↔

Figure 57: Offshore fish species abundance

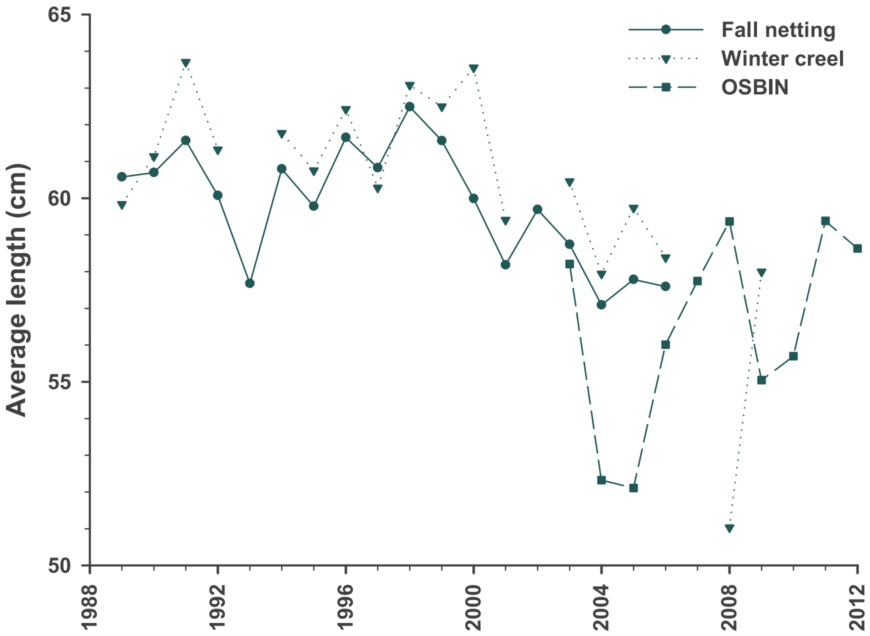


Figure 58: Lake trout growth trends: Size at age 6 from three monitoring programs

Cisco. *Credit: MNRF*

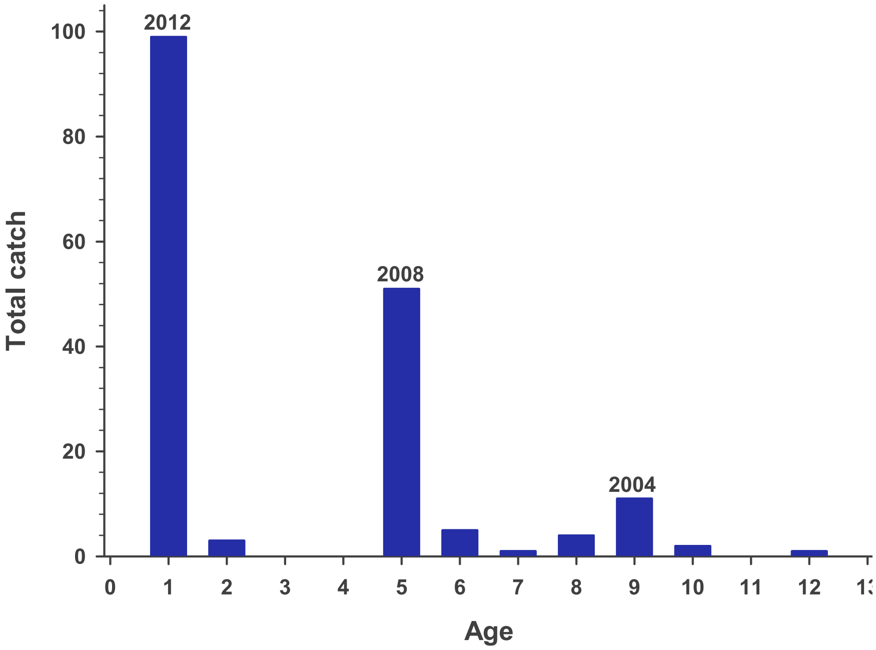


Figure 59: Total cisco catch by age in 2013 showing three strong year classes

RESEARCH

Dr. Erin Dunlop of MNRF's Aquatic Research and Monitoring Section is using hydroacoustics to better understand the dynamics of the offshore pelagic fish community. Pelagic fish (e.g., cisco, rainbow smelt and emerald shiner) live out in the open water of the lake and are important links in the food web because they eat zooplankton and are fed on by predators such as lake trout. Hydroacoustics use sound waves to collect information on pelagic fish and invertebrate abundance, spatial distribution and behaviour. Beginning in 2011, day and night hydroacoustic surveys have been conducted each year in late summer (Fig. 60). Suspended gillnets and pelagic trawling were conducted along acoustic transects to identify fish species observed on the echograms. In 2013, multi-frequency transducers were added to the surveys, which allow a holistic view of the aquatic community in the offshore pelagic zone, from zooplankton up to large predatory fish. Traditional benthic gill netting (i.e., the LSFAU's OSBIN program) is being combined with acoustics to better understand and confirm trends in fish populations and to monitor the health of the offshore ecosystem. For example, acoustic research detected high abundances of cisco and confirmed that 2012 was an excellent year class.

Split-beam transducer. *Credit: MNRF*

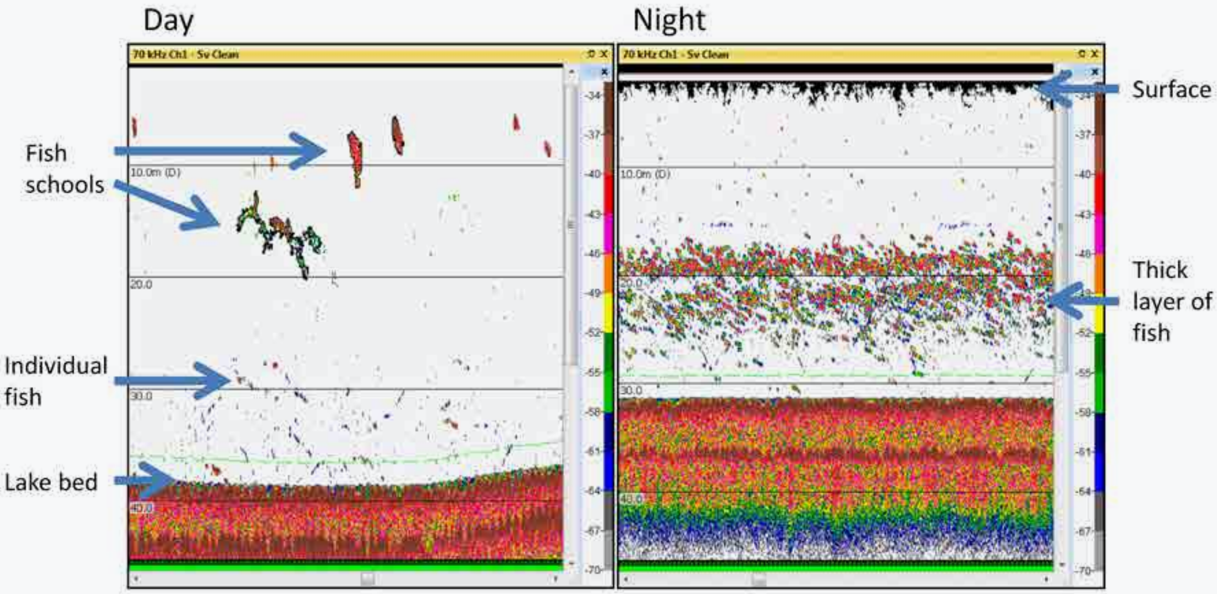
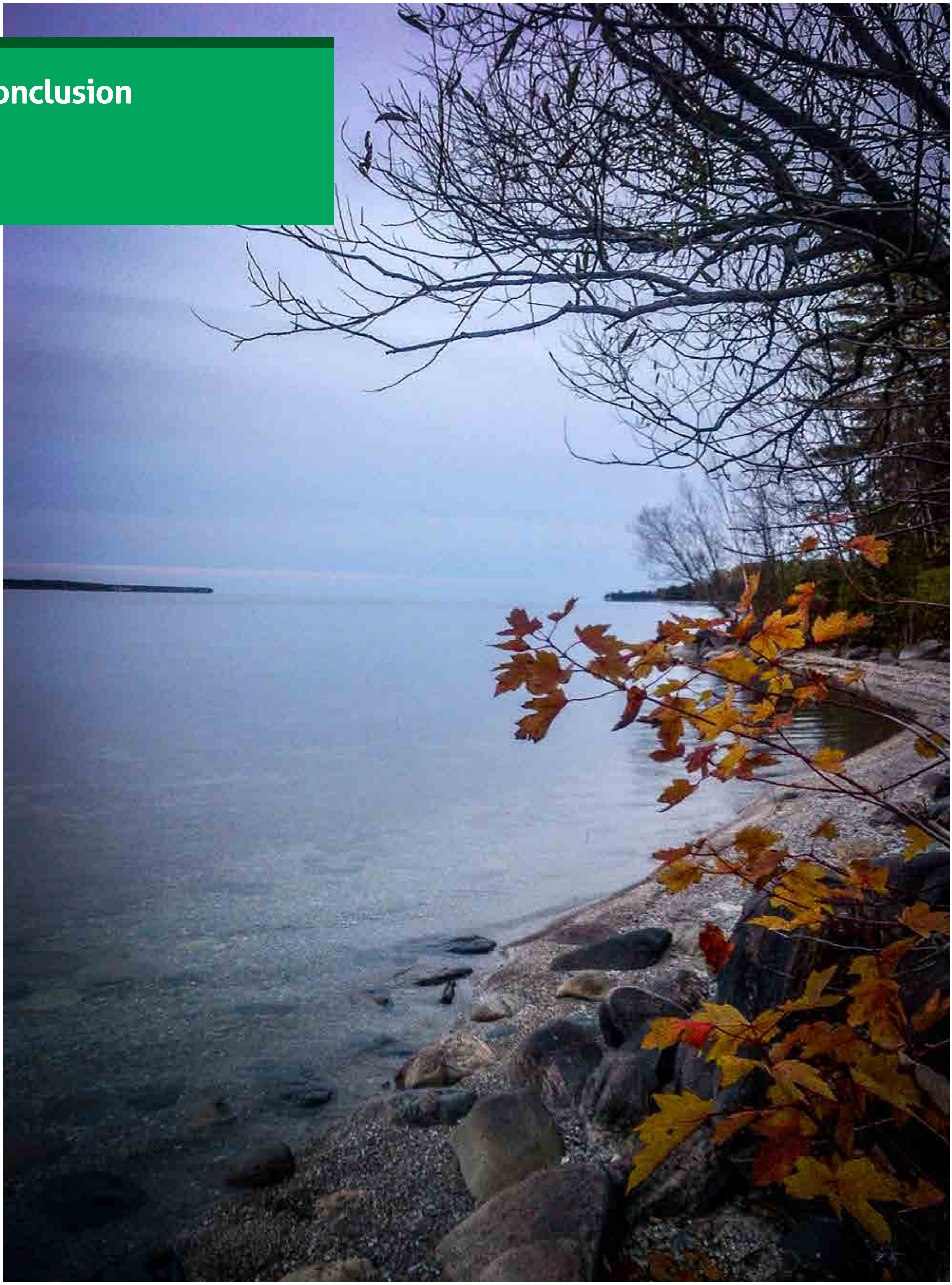


Figure 60: Hydroacoustic echogram showing day and night distributions of fish

Conclusion



Conclusion

The analyses of the monitoring data indicate that there are a number of stressors affecting the ecological health of Lake Simcoe and its watershed. In particular, there have been significant increases in human population growth and urbanization, and almost half of the watershed is being used for agriculture. As a result, the amount of natural and woodland cover mapped in 2008/2009 was below guideline levels for wildlife species in some watersheds, and indices of fragmentation were high. The amount of natural cover within riparian zones was below guidelines in all subwatersheds, and more than half of the lake's shoreline was altered. While the amount of wetland cover met the guideline level in almost all subwatersheds, there is a need to improve and protect wetland coverage because they are excellent P filterers. Forty-eight plant and animal species in the lake and watershed were considered to be invasive, some of which have had (e.g., zebra mussel and spiny water flea) or are expected to have (e.g., emerald ash borer) a significant effect. The effects of climate change have also become apparent. With significant increases in annual air temperature, the duration of ice cover on the lake during winter was significantly shorter while the amount of time the lake is thermally stratified during the summer was significantly longer. There was evidence that these changes are leading to alterations in the timing of seasonal processes like lake trout spawning.

In spite of these stressors, several improvements in the water quality and aquatic life of Lake Simcoe were detected. Total P significantly decreased in most of the tributaries that flow into the lake, at some nearshore lake stations, and in the open waters of the lake during springtime. These decreases were particularly notable during the 1980s and early 1990s when P reductions were initiated. With these decreases in P, the end of summer deepwater dissolved oxygen has significantly improved as a result of a reduction in the summer dissolved oxygen depletion rate since the mid-1980s, and higher dissolved oxygen concentrations in the water before the lake stratified in the spring. In response to improved oxygen in the deep, coldwater habitat, sensitive aquatic biota have shown signs of recovery. There has been evidence of the recovery of several sensitive benthic invertebrate taxa, and in the native coldwater fish community; wild lake trout have been consistently captured since 2003, and wild lake whitefish and cisco increased in abundance in recent years.

There are, however, still indicators showing the cumulative effects of stressors, and where further improvement is required. Although P concentrations have decreased in many tributaries, concentrations in some tributaries and at the open-water lake stations during the summer were still above objectives. Additionally, although increased deepwater dissolved oxygen was likely responsible for the improvement in sensitive aquatic biota, we are not yet at the MVWHDO target for the lake of 7 mg/L. There have also been significant increases observed in chloride concentrations attributed to the use of road salt. The aquatic life of Lake Simcoe and its tributaries has been affected by water quality, climate change, invasive species and other stressors. In tributary aquatic communities, less than one-quarter of fish communities and just over one-third of benthic invertebrate communities indicated "Good" or better ecological integrity. Aquatic plant species abundance has changed, especially in Cook's Bay where an invasive species, eurasian watermilfoil, is prevalent and overall macrophyte coverage has increased. In the zooplankton community there was a decline in some coolwater zooplankton species following increases in water temperature that could be a result of climate change.

Whites Creek. *Credit: Jim Eddie*

What's Next

The results presented here provide many encouraging signs of recovery in the Lake Simcoe ecosystem, suggesting that remedial efforts have been effective in improving the ecological health of Lake Simcoe. These improvements have occurred despite the additional challenges that have faced the lake, such as human population growth, invasive species and climate change. It is especially encouraging that aquatic biota have responded to improvements in their habitat such as increases in deepwater dissolved oxygen. However, as illustrated by these results, our efforts must continue in order to protect and restore the health of the Lake Simcoe ecosystem. We must also continue to monitor and study the effects of existing and emerging stressors.

Further research will be required to understand the cumulative effects our remediation efforts and multiple stressors will have on key indicators. Some of the many research projects on Lake Simcoe that were highlighted through this report have provided insight on other gaps in our knowledge and will also guide future research priorities.

Ongoing monitoring of the stressors and indicators will allow us to assess the overall ecological health of the Lake Simcoe ecosystem, which is an essential component of the adaptive management approach. Several monitoring programs have been proposed to fill gaps in our ability to assess ecological health; for example, a site-level monitoring program to quantify the quality of terrestrial habitats. The next Lake Simcoe monitoring report will have five additional years of data with which to examine changes since the implementation of the LSPP and will help inform its 10-year review.

Holland Marsh

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Notes

Protecting Lake Simcoe is a partnership among all of us.

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