The Smoke, Canoe, and Tea lakes fish movement project in Algonquin Provincial Park

Information Report IR-22

Science and Research Branch

Ministry of Natural Resources and Forestry

Ontario

Science and Research Information Report IR-22

The Smoke, Canoe, and Tea lakes fish movement project in Algonquin Provincial Park

Mark Ridgway[1], Bailey McMeans[2] and Mathew Wells[3]

[1] Harkness Laboratory of Fisheries Research, Aquatic Research and Monitoring Section, Ontario Ministry of Natural Resources and Forestry

[2] Department of Biology, University of Toronto, Mississauga, Ontario

[3] Department of Physical and Environmental Science, University of Toronto, Scarborough, Ontario

2021

Science and Research Branch

Ministry of Natural Resources and Forestry

Copies of this publication are available from info.mnrfscience@ontario.ca.

Cette publication hautement spécialisée, The Smoke, Canoe, and Tea Lakes Fish Movement Project in Algonquin Provincial Park, n'est disponible qu'en anglais conformément au Règlement 671/92, selon lequel il n'est pas obligatoire de la traduire en vertu de la Loi sur les services en français. Pour obtenir des renseignements en français, veuillez communiquer avec le ministère des Richesses naturelles et des Forêts au info.mnrfscience@ontario.ca.

Cover photo: Harkness Lab crew placing acoustic receivers in Smoke Lake, March 2021. Photo by Nick Lacombe.

Cite this report as:

Ridgway, M., B. McMeans and M. Wells. 2021. The Smoke, Canoe, and Tea lakes fish movement project in Algonquin Provincial Park. Ontario Ministry of Natural Resources and Forestry, Science and Research Branch, Peterborough, ON. Science and Research Information Report IR-22. 10 p. + appendix.

Abstract

Climate change is occurring in Algonquin Provincial Park, Ontario, and across Canada, with the increase expected to continue in the coming decades. The annual cycle of warm- and coldwater temperatures in lakes and associated movements of fish will be changing in step with how lakes respond in a warming world. Changes in lake thermal structure and their annual timing is being observed or predicted to occur based on how lake size affects seasonal heating, cooling, and ice formation. How will coldwater fish species such as lake trout and their food webs respond to these changing conditions? How will warmwater species such as smallmouth bass respond? Because fish rely on different food webs at different times of the year, changes in how they move and occupy habitat to feed and survive in response to seasonal changes in temperature will give new insight into how fish and their food webs can be expected to change in the coming decades.

Smoke, Canoe, and Tea lakes in Algonquin Park will be the focus of a collaborative five-year research project. The three lakes represent a size gradient that will ensure a range of timing in heating, cooling, and ice formation. These lakes are connected and share the same fish species. This study will deepen our understanding of how fish movement and habitat occupancy changes with lake heating and cooling and what can be expected with further climate change. This work supports our understanding of how lake food webs will change in the coming decades to inform fisheries and aquatic management.

Résumé

Projet de suivi des mouvements des poissons des lacs Smoke, Canoe et Tea dans le parc provincial Algonquin

Le changement climatique est manifeste dans le parc provincial Algonquin en Ontario, ainsi que partout au Canada, et l’on s’attend à ce que ses répercussions continuent d’augmenter au cours des prochaines décennies. Le cycle annuel des températures des eaux se réchauffant et se refroidissant et les mouvements de poissons qui y sont associés évolueront au rythme des réactions des lacs dans un monde de plus en plus chaud. Nous observons actuellement, ou anticipons, des modifications à la structure thermique des lacs et au calendrier annuel s’y rapportant. Ces modifications mettent en lumière l’incidence de la taille des lacs sur le réchauffement, le refroidissement et la formation de la glace d’une saison à l’autre. Comment les espèces de poissons d’eau froide comme le touladi et leurs réseaux alimentaires s’adapteront-ils à ces conditions changeantes? Comment les espèces d’eau chaude comme l’achigan à petite bouche vont-elles réagir? Comme les poissons dépendent de divers réseaux alimentaires à différents moments de l’année, le suivi de leurs mouvements et de leur occupation des habitats pour se nourrir et survivre en réponse aux variations saisonnières de température procurera un nouvel éclairage : nous en saurons davantage sur la façon dont les poissons et leurs réseaux alimentaires s’adapteront au cours des décennies à venir.

Les lacs Smoke, Canoe et Tea du parc Algonquin feront l’objet d’un projet de recherche coopératif d’une durée de cinq ans. Ces trois lacs représentent un gradient de taille qui garantira l’intégration de différentes périodes pour évaluer le réchauffement, le refroidissement et la formation de la glace. Ces lacs sont reliés et partagent les mêmes espèces de poissons. Cette étude nous permettra de mieux comprendre comment les mouvements des poissons et l’occupation de l’habitat varient sous l’effet du réchauffement et du refroidissement des lacs, ainsi que ce qui peut être attendu du changement climatique qui se poursuit. Elle nous aidera à mieux saisir comment les réseaux alimentaires des lacs vont évoluer au cours des prochaines décennies afin d’éclairer la gestion des pêches et des milieux aquatiques.

Acknowledgements

The authors thank the research team for review of this report, as well as Ontario Parks and Harkness Lab staff for comments. Trevor Middel supplied the map in Figure 3.

Contents

Introduction

Lakes are ecosystems in motion. Wind forces water movement and mixing in complex ways while heating from the sun results in summer stratification of warm over cold water. During winter this stratification is absent and cold water defines the whole lake environment, with ice cover serving as a lid on the lake until it melts in spring. In Canada, and around the world, lake size determines the seasonal timing of heating, cooling, and ice cover in predictable ways. Forecasting effects of climate change on lakes is difficult, but possible because mixing and heating of lakes stem from physical processes. Determining effects of climate change on fish and food webs in lakes is less clear, given the complexity of their movements and their seasonal responses to heating and cooling that vary among species.

Introduced in this report is a study designed to address questions related to how fish and their food webs respond to seasonal heating and cooling patterns and how climate may affect these patterns. Because fish live in ecosystems in motion, observing them and their food web responses in real time — while in motion themselves — is ideal to understand their patterns and needs. To capture the effect of lake size on seasonal patterns of heating and cooling, three lakes of different sizes were chosen to track detailed movements of fish in three dimensions over several seasons and years. The lakes selected for this study are Smoke, Canoe, and Tea lakes in Algonquin Provincial Park in central Ontario, Canada.

Smoke, Canoe, and Tea lakes are well suited to address our uncertainty about how fish will respond to climate change. Tea Lake is the smallest, followed by Canoe Lake, and Smoke Lake, with each double the size of the previous. This gradient in lake size provides a gradient in heating and cooling patterns. The lakes are interconnected within the same watershed and share the same fish assemblage comprising warm- and coldwater species. The lakes' proximity to Highway 60 make it logistically feasible to conduct this multi-year project across seasons and years.

The Smoke, Canoe, and Tea lakes project (abbreviated to the SCT project) is based on networks of acoustic receivers in each lake in sufficient numbers to capture fish movement in three dimensions (3D). Fish are surgically implanted with acoustic tags that transmit individual identifications as well as their depth. As individual fish move among receivers in each network, their identity and depth are recorded by the closest receivers, and groups of receivers detecting an individual fish are used to triangulate position relative to the lake surface. In this way, fish position is determined in 3D every four to six minutes through all seasons of a year, for several years. The SCT project begins in 2021 with installation of the Smoke Lake network, followed by installation of the Canoe and Tea lake networks in 2022. The study will continue until 2026.

The purpose of this report is to document the study background, the questions being addressed, and the team of collaborators involved.

Lakes and climate change

Lakes are sentinels of climate change. The basic elements of warming, mixing, and cooling on an annual cycle and how these change with lake size have long determined how lake ecosystems function around the world. In future decades, the timing of the annual cycle will change. Climate change alters the timing and extent of these basic elements in such a way as to raise concern about the sustainability of fish populations in lakes where climate warming effects are likely to be most severe. Of all groups of fish, coldwater species are projected to be most affected by warming.

Freshwater species are the most endangered fauna in the world (Dudgeon et al. 2006, Strayer and Dudgeon 2010). Invasive species, loss of habitat, water pollution, and climate change all having a role in negatively affecting freshwater fauna. Climate change in lakes can affect spawning times of fish, productivity of food webs, and interactions between predators and prey. The effects of climate change on freshwater ecosystems and species was included in supporting material, with a high degree of confidence, for the United Nations Intergovernmental Panel on Climate Change (IPCC; Settele et al. 2014).

Algonquin Provincial Park itself is a climate island because of its higher elevation relative to the surrounding landscape in southcentral Ontario (Ridgway et al. 2018). Lakes in the park retain coldwater fish species such as lake trout, cisco, and lake whitefish that colonized the landscape following retreat of glacial ice across the park over 12,000 years ago. The distribution of fish species in the park is a story of glacial retreat generally, large glacial great lakes draining through the park, and access different fish species had at different times to colonize the newly released landscape (Ridgway et al. 2017).

Climate change will alter many aspects of the annual cycle of lake warming, mixing, and cooling as well as the duration of ice cover (Woolway et al. 2020). It is uncertain whether warming will increase fish production in lakes and lead to greater sustainability. We lack understanding of how changes in the physical properties of lakes result in changes in fish movement and food webs in real time — the basis for fish production and sustainability. Changes in thermal conditions of lakes are projected to impose environmental constraints on coldwater fish but may or may not affect warmwater fish. Declines in walleye production in some jurisdictions are attributable to climate change so it is not clear whether both cold- and warmwater species will respond to warming in similar ways.

By comparing the timing of heating and cooling of lakes around the world, general patterns are emerging in how lakes will respond to warming in coming decades. This information is summarized in Table 1. Lake size emerges as a major driver affecting lake response to a warming world.

Table 1. Summary of climate change effects on lakes, including expected or observed outcomes, and the effect of lake size on the outcome. (Sources: Sharma et al. 2016, 2019; Woolway et al. 2020)

Lake feature	Change	Outcome	Lake size effect
Lake heating	Increasing	Warmer summer surface waters for all lakes	Small lakes will gain summer heat faster and have higher temperatures than large lakes
Winter ice cover	Reduced	Reduced number of weeks of ice cover; later ice formation and earlier ice-out	Small lakes have fewer weeks of ice cover than large lakes
Winds	Calming	Mixing of surface waters reduced in spring and summer	Small lakes with more calmer conditions than large lakes
Summer thermocline	Longer duration	Sharper boundary between warm and cold layers lasting longer into fall	Small lakes warm faster than large lakes; small lakes with longer duration of thermocline than large lakes
Dissolved oxygen	Lower in deeper cold water zone during summer	Longer periods of low oxygen in summer reduces coldwater habitat	Primarily occurring in smaller lakes

Lakes, fish habitat, and food webs

Fish habitat in lakes is based on the temperature preference, or thermal envelope, of different fish species as well as physical habitat such as spawning sites or rearing areas for young fish. The thermal envelope is broad and defined at whole lake scale. Physical habitat is local and defined at the scale of bays, shoals, wetlands, lake bottoms, and open water. The link between thermal habitat and physical habitat is movement. Fish move to feed or spawn in physical habitat and do so within or beyond their thermal envelope. Since lakes are ecosystems in motion, interactions between lakes in motion and fish movement are complex and can only be investigated with acoustic telemetry. Acoustic telemetry is a means of tracking fish location with great precision in both space and time using surgically implanted tags that transmit at regular intervals and receiver networks in lakes that record the tag transmissions.

Figure 1 summarizes the annual cycle of seasonal effects on lake temperature and corresponding responses by fishes. In summer, the full extent of separation between warm- and coldwater fish occurs because of the strong temperature differences between warm

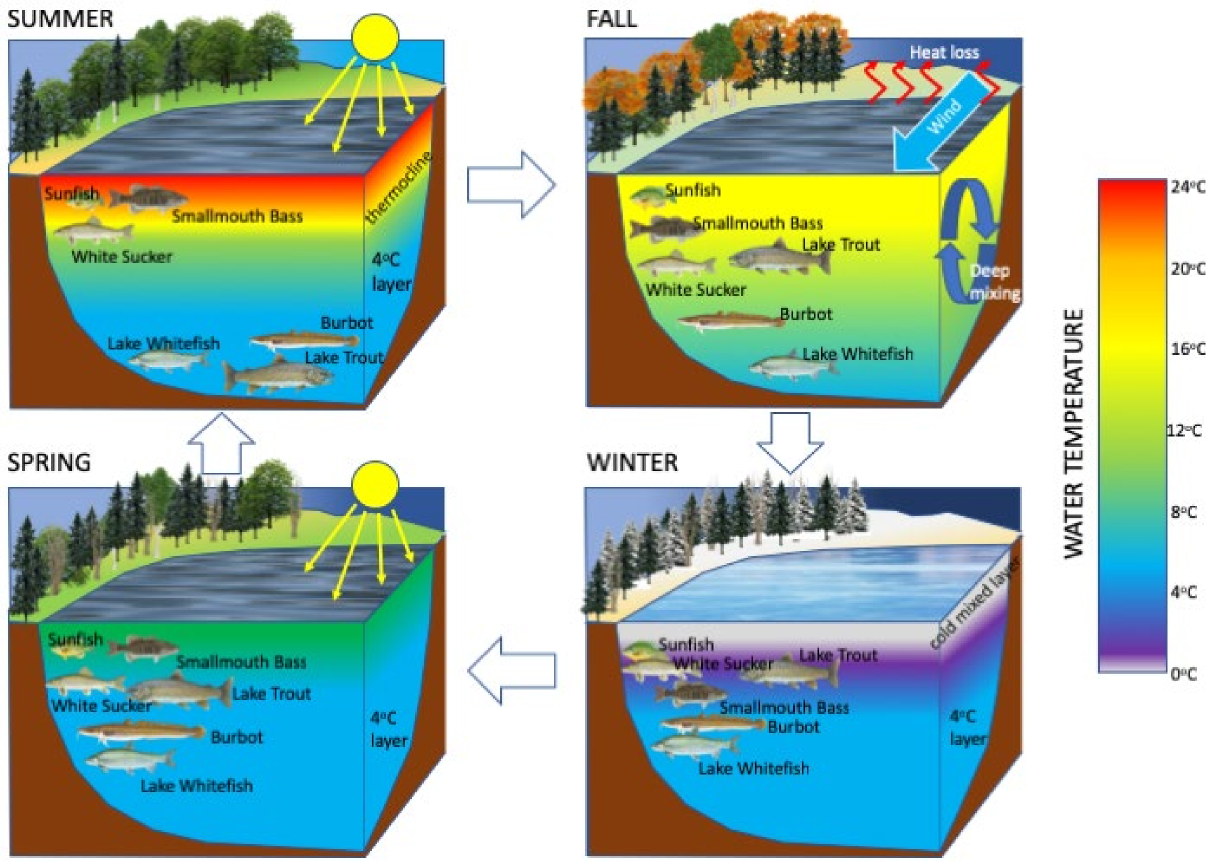

Figure 1. The seasonal cycle of lake temperature and how it changes with depth. Fish species respond in different ways in each season based on their temperature preferences. This response ranges from separation of warm- and coldwater fish in different habitats in summer to use of different habitats and more overlap in other seasons. Image produced by Mathew Wells.

surface waters and deeper cold water. With heat loss in fall of each year, the separation among species detected in summer breaks down and fish species begin to utilize different lake habitats under cooling conditions. In winter, under ice cover, coldwater fish species may be active and occupy different habitats while species suited to warm water are relatively inactive to conserve energy. With spring warming comes a realignment of fish habitat by different species. Warmwater fish like smallmouth bass become active inshore while lake trout or lake whitefish shift from shallow habitats to deeper habitats in step with warming conditions.

For lake trout, a coldwater species, the annual cycle of seasons is generally a story of tracking the coldwater environment whether it is deep in summer or throughout the lake in winter. For other species, such as smallmouth bass, warm water defines their preferred habitat, so warm temperatures in summer are a match for their preferred temperatures while winter temperatures are not. As a result, smallmouth bass are active in summer and much less so in winter. For most fish species in lakes, the distinction between cold- and warmwater preferences defines how they occupy different lake habitats depending on the season.

Coldwater species also include lake whitefish and burbot (or ling) along with lake trout. Warmwater species include pumpkinseed sunfish and smallmouth bass. Some species, such as brook trout and common sucker, prefer water temperatures between strictly cold and warm environments so their temperature preferences have a wider range than other species.

Through all seasons, fish are part of food webs in lakes. Depending on their temperature preferences and season, finding food in lakes will locate fish in different habitats pursuing prey and being part of food webs in areas such as lake bottoms, open water, or inshore. What part of lakes are exploited by fish of different thermal envelopes will depend on season. Coldwater species like lake trout may be inshore in winter and spring, but offshore or foraging in cold water on the lake bottom in summer.

Elements like carbon and nitrogen accumulate in fish based on their foraging location and whether they are top predators or feed lower in the food web. Carbon and nitrogen can be thought of as tracers of food web structure in aquatic food webs like those of Smoke, Canoe, and Tea lakes. As part of the SCT project, carbon and nitrogen will be tracked using non-lethal biopsies of fish over seasons. At times, fish may be using food webs in multiple habitats as *dual fuels*, for example, when transitioning from nearshore to deeper areas of lakes, during the transition from one season to another. Or does this occur on a shorter time scale? Multiple use of habitats and the idea of dual fuels would point to vulnerability of fish to warming effects if feeding habitats are particularly vulnerable to climate change.

Warming global temperatures that affect fish habitat, defined as their thermal envelope, also remain a looming uncertainty for fish production and sustainable harvest into the future. Emerging evidence suggests that shorter, warmer winters may be detrimental to fish production. Since lake size is a driver controlling many lake processes, such as heating, mixing, and ice cover, to name a few, these effects may differ among lakes of different size. A better understanding is needed of how fish use habitat and how production changes through time in lakes of different size. Accomplishing this requires a closer look into how fish move among habitats within their thermal envelope, and how fish habitat changes with warming.

A key prey species for lake trout is the small fish, cisco. Cisco live in open water areas of lakes and as adults prefer cold water. They are too small for an acoustic tag so their distribution in each lake will be monitored using sonar, or sound pulses, which involves recording echo signals from the fish to reveal their depth and location in the lake. Cisco sonar surveys provide a full lake story of cisco distribution and abundance in one evening. Results will be matched with lake trout movements to determine if cisco drive lake trout distribution and movement at the scale of whole lakes.

Lakes and fish assessment

Fish monitoring and assessment programs can only detect fish based on where nets are placed in lakes. Many agencies use bottom set nets to acquire an index of relative fish abundance in lakes. When set for differing durations of *soak time*, nets can provide a wide range in catch of fish species. In Ontario, the inland lakes Broad-scale Monitoring Program applies a standard netting protocol that includes a consistent depth range of net sites, a common net configuration and mesh series, and 18-hour overnight net sets. In the park, lake surveys use the same stratified depth sampling and net configuration. Nets are set for only 1 hour (i.e., not overnight) and as a result catches are lower. As in all fish surveys, regardless of soak time, information gained from a survey can only come from where nets are placed. In Ontario, including Algonquin Park, that information is based on lake bottom net sets. Fish do not always live near the bottom, as shown in Figure 2. The SCT project will provide detailed movement data for estimating the probability of fish being on bottom, given they also live in open water areas of lakes above monitoring nets. This information will greatly improve catch data by providing a basis for adjusting it based on availability of fish (i.e., probability of being on bottom) to the sampling net. This adjustment will improve accuracy of fish population estimates.

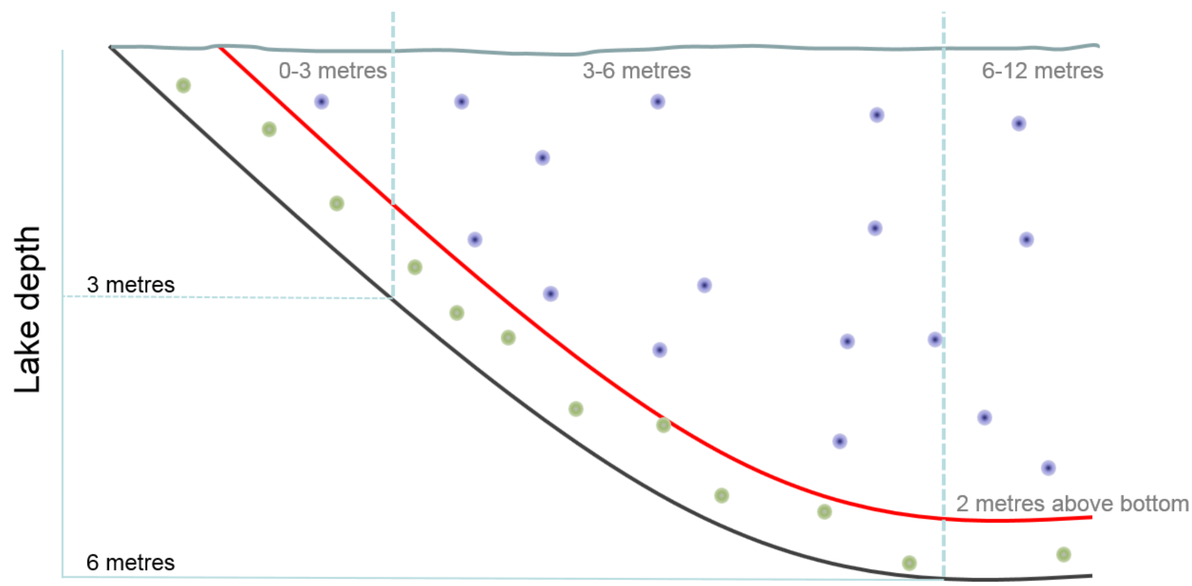

Figure 2. A profile of a lake basin with bottom (black line) and lake surface (blue line) as shown. Fish are distributed in the lake as being close to bottom (green points) or in the open water (blue points). The height of bottom set gill nets used in monitoring is shown by red line. The sample zone is between lake bottom and height of net.

Guiding questions for the Smoke, Canoe, and Tea lakes project

Several guiding questions are being pursued by the SCT project research team based on the background information and need to understand many aspects of lake fish ecology.

- Given climate warming in the coming decades, how is fish habitat use and production changing seasonally and over years from small to large lakes?
- How predictable is fish habitat use? To what extent are fish relying on *dual fuels* in food webs?
- Does the value of *sub-optimal* habitat that seems less important today change to become more vital for production as conditions change in future?
- How do patterns in heating and cooling of water temperature over days, months, and seasons affect fish movement? How do these patterns change during periods of open water vs. ice cover?
- Given that fish occupy both lake bottom and open water, what is the availability of fish to monitoring gear set on the lake bottom?

How the receiver network works in Smoke, Canoe, and Tea lakes

The receiver network in the SCT project consists of 149 receivers distributed among the three lakes, including some in connecting channels. Characteristics of each lake and the number of receivers currently allocated to each lake are summarized in Table 2. Figure 3 shows the planned distribution of receivers in each lake. Full deployment of all receivers may vary somewhat from what is shown in Figure 3 and several receivers, not shown, are planned for Bonita Lake to capture travel among lakes via Bonita.

Table 2. Characteristics of Smoke, Canoe, and Tea lakes in Algonquin Provincial Park, Ontario, and numbers of acoustic receivers planned for each lake.

Lake	Surface area, hectares	Volume, million cubic metres	Mean depth, metres	Maximum depth, metres	Number of receivers
Smoke	661	106.3	16.2	55	86
Canoe	367	44.8	12. 6	42.7	41
Tea	150	8.7	5.9	15.6	22

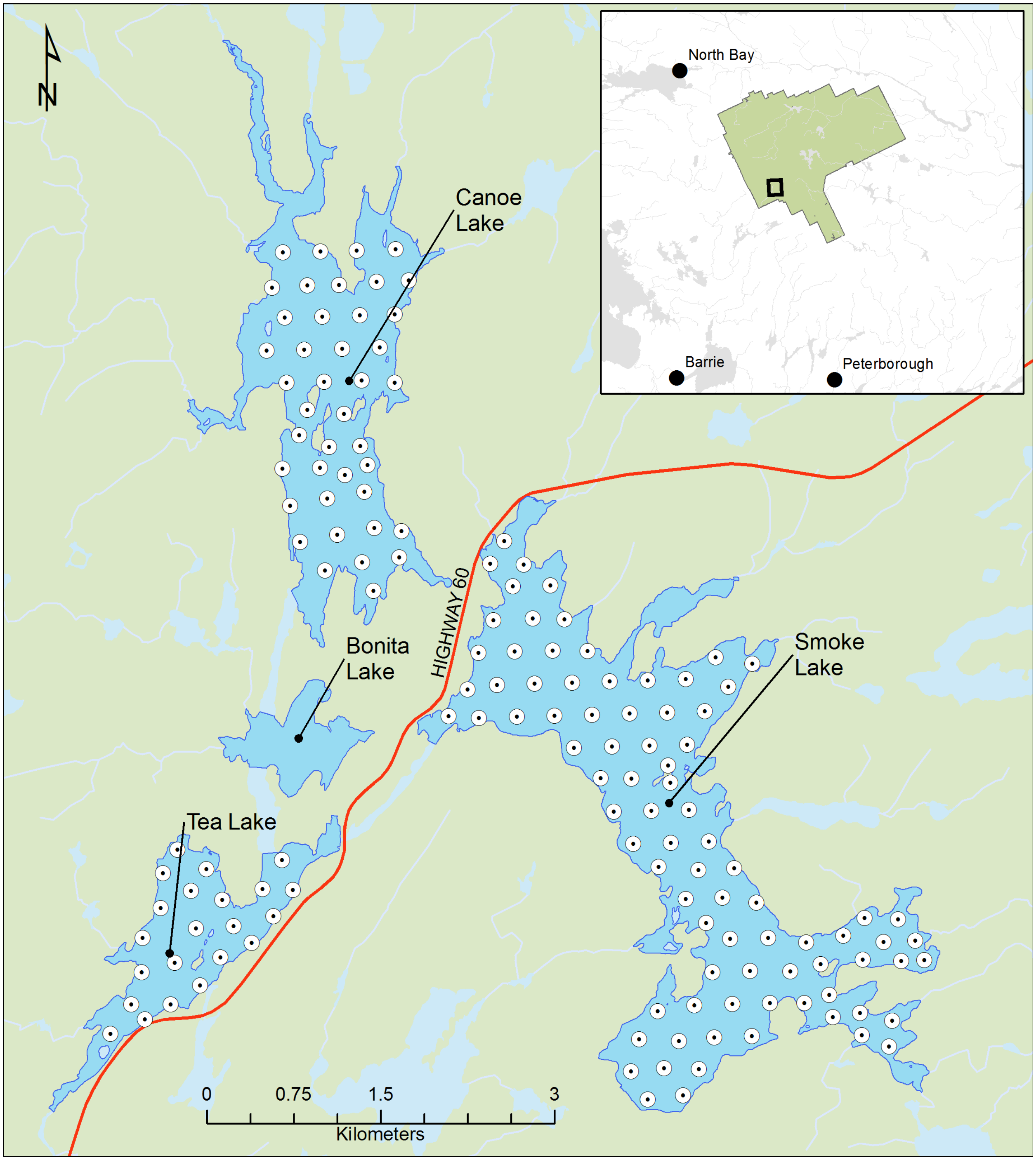

Figure 3. Acoustic receiver network planned for Smoke, Canoe, and Tea lakes in Algonquin Provincial Park, Ontario. Locations of submerged receivers and floats are indicated as points (enlarged here) in each lake. Receivers are spaced about 275 metres apart, on average. As well, several receivers will be deployed in Bonita Lake, not shown, to capture travel among lakes. Inset map shows the location of the study lakes in the park**.**

Conventional Global Positioning System (GPS) signals are unable to penetrate water so sound transmission in water is the technological basis for the SCT project. The speed of sound in water varies with water temperature and density of particles in the water. For the receiver network, each receiver has its own tag beeping at a slow and steady rate such that neighbouring receivers can detect it. Since all receivers in a network are broadcasting in this manner, the whole receiver network in a lake 'knows where it is', so to speak. Receivers also have a highly accurate internal clock that is synchronized among receivers. These two features turn the network into something similar to a GPS network, but within the lake.

Fish with surgically implanted acoustic tags move among the receiver sites with their tags transmitting acoustic signals every four to six minutes. The tags are pressure sensitive, so depth data is broadcast as well. Receivers near a tagged fish record its presence, its depth, and when the transmission was detected. The difference in the time of arrival of a transmission between receivers is calculated and this value, combined with the speed of sound in water, is used to determine how far away the fish was from the receivers that detected it. Repeated over hours, days, weeks, months, and years, the receiver network in each lake records hundreds of thousands to millions of acoustic tag detections giving detailed insight into fish movement patterns. Tag detections are saved in each receiver and downloaded in spring and fall of each year. Computer analysis converts the detection data to fish positions for further analysis. This method is how the movement trail of an individual fish can be assembled after each download.

Many of the acoustic receiver stations also have companion temperature recorders so that the thermal conditions of each lake can be estimated at time scales that are matched to fish movements. Water temperature data collected across the surface of the lakes will be used to generate computer models of water movement that in turn may help explain fish movement and seasonal habitat use. Linking fish movement to water movement is important in our understanding of lakes as ecosystems in motion.

Over the course of the SCT project, field crews will also be conducting limnological surveys (to track biological, chemical, and physical features) in each lake in each season. This work, combined with that involved in other surveys, will make the SCT project investigators regular visitors to the three lakes comprising this study. The SCT project collaborators are committed to providing annual updates on progress and recent findings.

References

Dudgeon, D. and 10 co-authors. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews 81: 163–182.

Ridgway, M., T. Middel and A. Bell. 2017. Aquatic ecology, history and diversity of Algonquin Provincial Park. Ontario Ministry of Natural Resources and Forestry, Science and Research Branch, Peterborough, ON. Science and Research Information Report IR-10. 203 p.

Ridgway, M., D. Smith and T. Middel. 2018. Climate warming projections for Algonquin Provincial Park. Ontario Ministry of Natural Resources and Forestry, Peterborough, ON. Science and Information Report IR-14. 24 p.

Settele, J., R. Scholes, R. Betts, S. Bunn, P. Leadley, D. Nepstad, J.T. Overpeck and M.A. Taboada. 2014. Terrestrial and inland water systems. Pp. 271–359 *in* Field, C.B. and 15 co-editors (eds.). Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Sharma, S., J.J. Magnuson, R.D. Batt, L.A. Winslow, J. Korhonen and Y. Aono. 2016. Direct observation of ice seasonality reveal changes in climate over the past 320–570 years. Nature Scientific Reports 6: 25061.

Sharma, S., K. Blagrave, J.J. Magnuson, C.M. O'Reilly, S. Olivre, R.D. Batt, M.R. Magee, D. Straile, G.A. Weyhenmeyer, L. Winslow and R.I. Wolway. 2019. Widespread loss of lake ice around the Northern Hemisphere in a warming world. Nature Climate Change 9: 227–231.

Strayer, D.L. and D. Dudgeon. 2010. Freshwater biodiversity conservation: Recent progress and future challenges. Journal of the North American Benthological Society 29: 344–358.

Woolway, R.I., B.M. Kraemer, J.D. Lenters, C.J. Merchant, C.M. O'Reilly and S. Sharma. 2020. Global lake responses to climate change. Nature Reviews Earth and Environment 1: 388–403.

Appendix 1. Collaborators

Several university labs in Ontario have joined to participate in the SCT project. This research effort includes the development and training of M.Sc. and Ph.D. students. Below is a list of faculty researchers and government scientists involved in the SCT project, funding sources, and partners:

- Baily McMeans, Department of Biology, University of Toronto Mississauga
- Mark Ridgway, Harkness Laboratory of Fisheries Research, Ontario Ministry of Natural Resources and Forestry
- Mathew Wells, Department of Physical and Environmental Sciences, University of Toronto Scarborough
- Kevin McCann, Department of Integrative Biology, University of Guelph
- Aaron Fisk, Great Lakes Institute for Environmental Research, University of Windsor
- Paul Blanchfield, Department of Fisheries and Oceans
- Tyler Tunney, Department of Fisheries and Oceans
- Funding: Alliance grant; Natural Science and Research Council of Canada
- Partner agencies: Ontario Ministry of Natural Resources and Forestry; Department of Fisheries and Oceans
- Acoustic technology: InnovaSea Inc. Bedford, Nova Scotia

For more information, contact bailey.mcmeans@utoronto.ca or mark.ridgway@ontario.ca.

(0k P.R. 21 05 14)
ISBN 978-1-4868-5266-6 (pdf)