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Aquatic ecology, history, and diversity of Algonquin Provincial Park

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Aquatic ecology, history, and diversity of Algonquin Provincial Park

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Cover photo by Krystal Mitchell. Kioshkokwi Lake, Algonquin Provincial Park. Kioshkokwi Lake was one of the main access points to the Algonquin landscape for water and aquatic species during the draining of Glacial Lake Algonquin, 11,000–13,000 years ago.

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Summary

Algonquin Park covers 7,630 km² of south-central Ontario and includes nearly 1,300 lakes (>5ha) and over 3,700 km of rivers and streams, second order and larger (Figure 1). Today, Algonquin Park appears as a source for watersheds beginning on the highlands, sweeping down through lake and river systems to areas outside the park, and finally continuing on through the larger Laurentian Great Lakes system (Figure 2). The watershed distribution in the park and the system of drainage we observe today was not always present in its current pattern. For most of its history, the Algonquin Park landscape was different from what exists today. Drainage and species colonization routes that once dictated watershed ecosystems long ago are no longer in existence. There is a history of water on this landscape that defines what we see today. There is also a more recent history of water and aquatic ecosystems on the landscape stemming from human activity over the past century. This report on the Aquatic Ecology, History and Diversity of Algonquin Provincial Park summarizes changes occurring on these 2 time scales. One is measured in centuries and millennia, beginning with retreat of the Laurentide Ice Sheet, while the other is measured in decades over the last century.

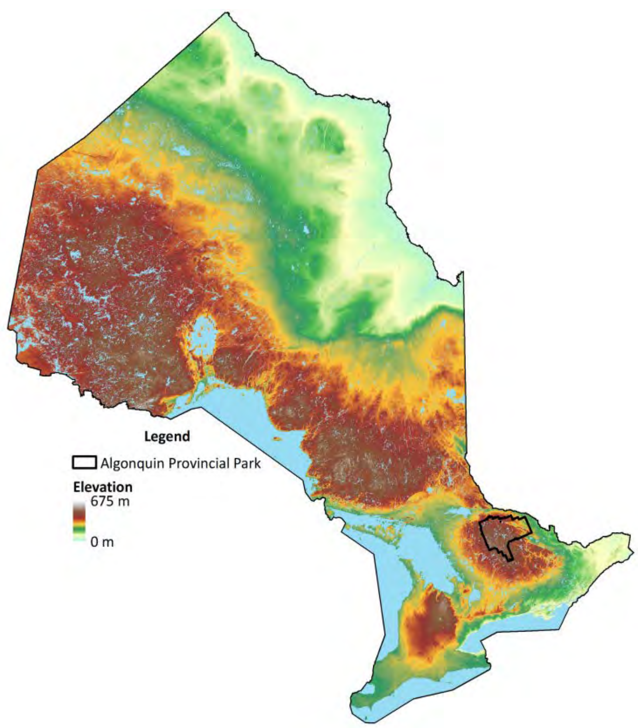


Figure 1. Location of Algonquin Provincial Park within Ontario. Shading indicates elevation.

The aquatic ecosystems that developed over thousands of years were influenced directly by the retreat of the Laurentide Ice Sheet and the glacial Great Lakes of the

day, particularly Lake Algonquin and its extensive watershed. The lake food webs located in the northern areas of Algonquin Park retain the signature of inundation from Lake Algonquin and several of its last stages as it drained and changed from a pro-glacial Great Lake to the Great Lakes we recognize today. At the time, the western watershed limits for Algonquin Park and the Ottawa valley extended to Saskatchewan. The drainage patterns at the end of the glacial era represent fish re-colonization in 2 phases. One is the tracking of the retreating glacial front by species now widespread in the park and the other is entry to the park landscape by species arriving only near the end of glacial Lake Algonquin's existence.

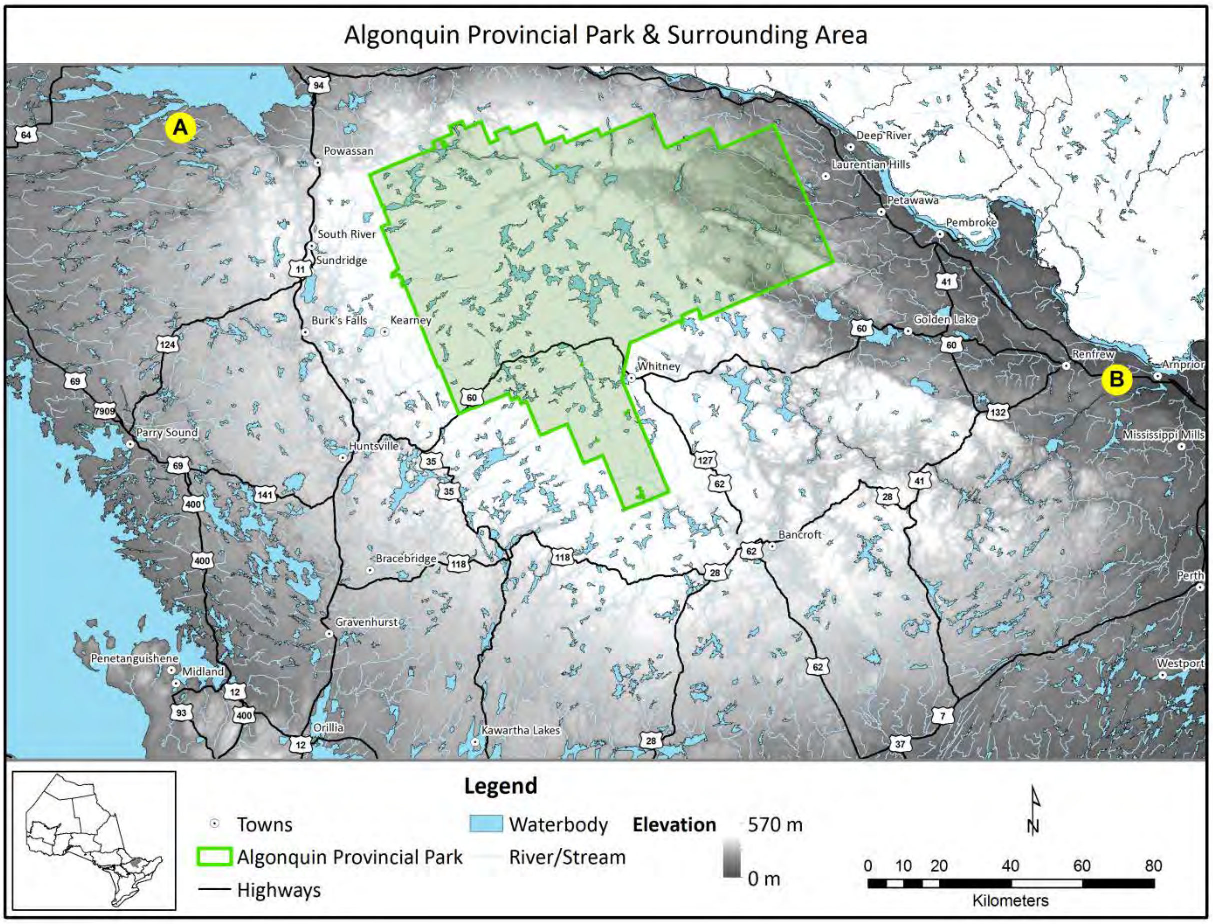
Beginning in the 20th century and ongoing, a more recent history of lakes and rivers in Algonquin Park has been defined by human influence directly within the park boundary and from global trends outside its boundary. Authorized and unauthorized fish species introductions in Algonquin Park have altered lake food webs and threaten native fish assemblages. Spread of these species will erode the native food webs in lakes and put at risk fish species that cannot compete or avoid predation.

There is clear evidence of climate warming in Algonquin Park as the global trend in rising temperatures from beyond the park boundaries arrives and alters aquatic ecosystems. Changes detected on the Algonquin Park landscape in average annual air temperature and the timing of winter ice on lakes is consistent with observations from other landscapes or model projections to this point. Over the 21st century climate change will affect native fish species in Algonquin Park, favour species such as smallmouth bass, or result in relatively small risk for other species.

Despite recent changes, Algonquin Park retains much of its native aquatic ecosystems and species assemblage. Sixty native or introduced fish species have been detected in the park including stream observations. Brook trout occupy all fourth order watersheds in Algonquin Park and occur in 444 lakes indicating that the park serves as a stronghold for this species in Ontario. Brook trout occupies numerous streams and rivers in the park. Climate warming and species introductions are projected to reduce brook trout across many areas of south central Ontario and may do so in Algonquin Park. The park will also serve as a refuge for this species given the extent of projected loss outside the park's boundaries.

There are 188 lake trout populations in Algonquin Park with 162 of this lake set also a brook trout lake. One unique feature of Algonquin Park is the presence of all lake trout food web classes from small bodied fish in lakes with only small prey to lakes with extended food webs producing large bodied lake trout. The glacial history of the park accounts for this diversity.

Algonquin Park is an important area for the conservation of fish species diversity with unique food webs stemming directly from glacial history. Few protected areas in Ontario have such an important aquatic legacy.



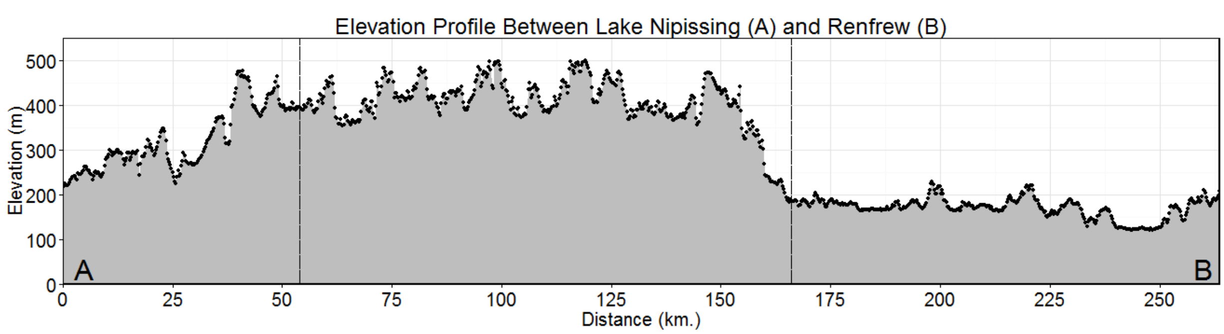


Figure 2. Map showing location of Algonquin Park (green boundary) and the provincial road system access in south-central Ontario (top panel). An elevation profile (metres; lower panel) through Algonquin Park on a transect from point A (west) to point B (east) as shown in top panel map. Vertical dashed lines on elevation profile indicate the boundaries of Algonquin Provincial Park.

Résumé

Écologie aquatique, historique et diversité du parc provincial Algonquin

Le parc Algonquin couvre une superficie de 7 630 km² dans le Centre-Sud de l'Ontario. On y trouve près de 1 300 lacs de plus de 5 ha et plus de 3 700 km de rivières et de ruisseaux de deuxième ordre ou plus vastes. Aujourd'hui, le parc Algonquin est la source de bassins hydrographiques qui prennent naissance sur les hautes terres, et traversent le parc par ses lacs et rivières jusqu'au réseau plus vaste des Grands Lacs et du Saint-Laurent. La répartition des bassins hydrographiques, le réseau hydrographique et les paysages du parc Algonquin ont évolué au fil des ans. Le réseau hydrographique et les voies de colonisation des espèces qui, jadis, dictaient la nature des écosystèmes des bassins hydrographiques n'existent plus. L'eau a toujours été présente dans le parc et a défini les paysages d'aujourd'hui. Plus récemment, l'activité humaine au cours du siècle dernier a transformé les ressources en eau et les écosystèmes aquatiques des paysages. Ce rapport sur l'écologie aquatique, l'historique et la diversité du parc provincial Algonquin résume les changements survenus entre ces deux échelles de temps. Une se mesure en siècles et millénaires et commence avec le retrait de la nappe glaciaire Laurentide, tandis que l'autre se mesure en décennies au cours du siècle dernier.

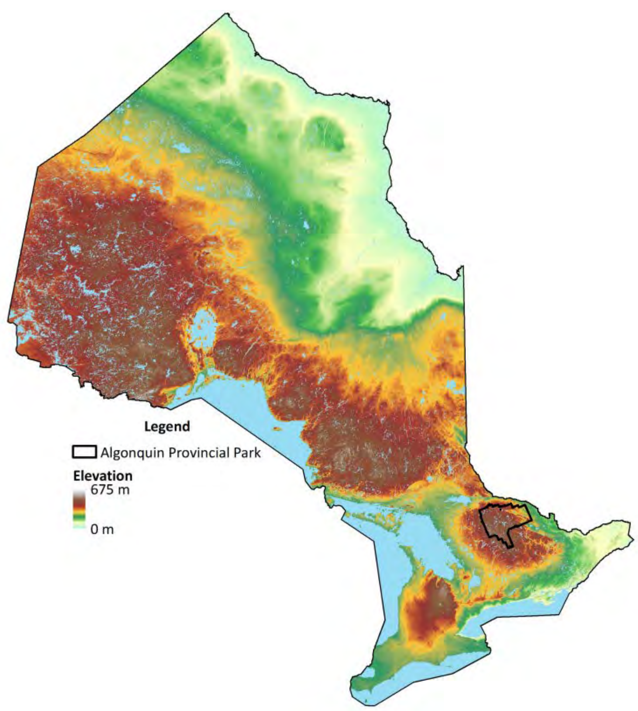


Figure 1. Emplacement du parc provincial Algonquin en Ontario. Les parties ombrées indiquent l'élévation.

Les écosystèmes aquatiques qui se sont formés pendant des millénaires ont été influencés directement par le retrait de la nappe glaciaire Laurentide et les Grands Lacs glaciaires de l’époque, particulièrement le lac Algonquin et son vaste bassin hydrographique. On peut voir dans le réseau alimentaire des lacs se trouvant dans la partie nord du parc Algonquin les vestiges de l’inondation causée par le lac Algonquin et plusieurs de ses derniers stades de drainage, lorsque ce Grand Lac proglaciaire est devenu les Grands Lacs d’aujourd’hui. À l’époque, le bassin hydrographique du parc Algonquin et de la vallée de l’Outaouais s’étendait à l’ouest jusqu’en Saskatchewan. Le rétablissement des colonies de poissons, en deux phases, s’explique par les régimes d’écoulement des eaux à la fin de l’ère glaciaire. Les espèces aujourd’hui répandues proviennent du retrait du front glaciaire et de l’arrivée d’espèces vers la fin de l’existence du lac glaciaire Algonquin.

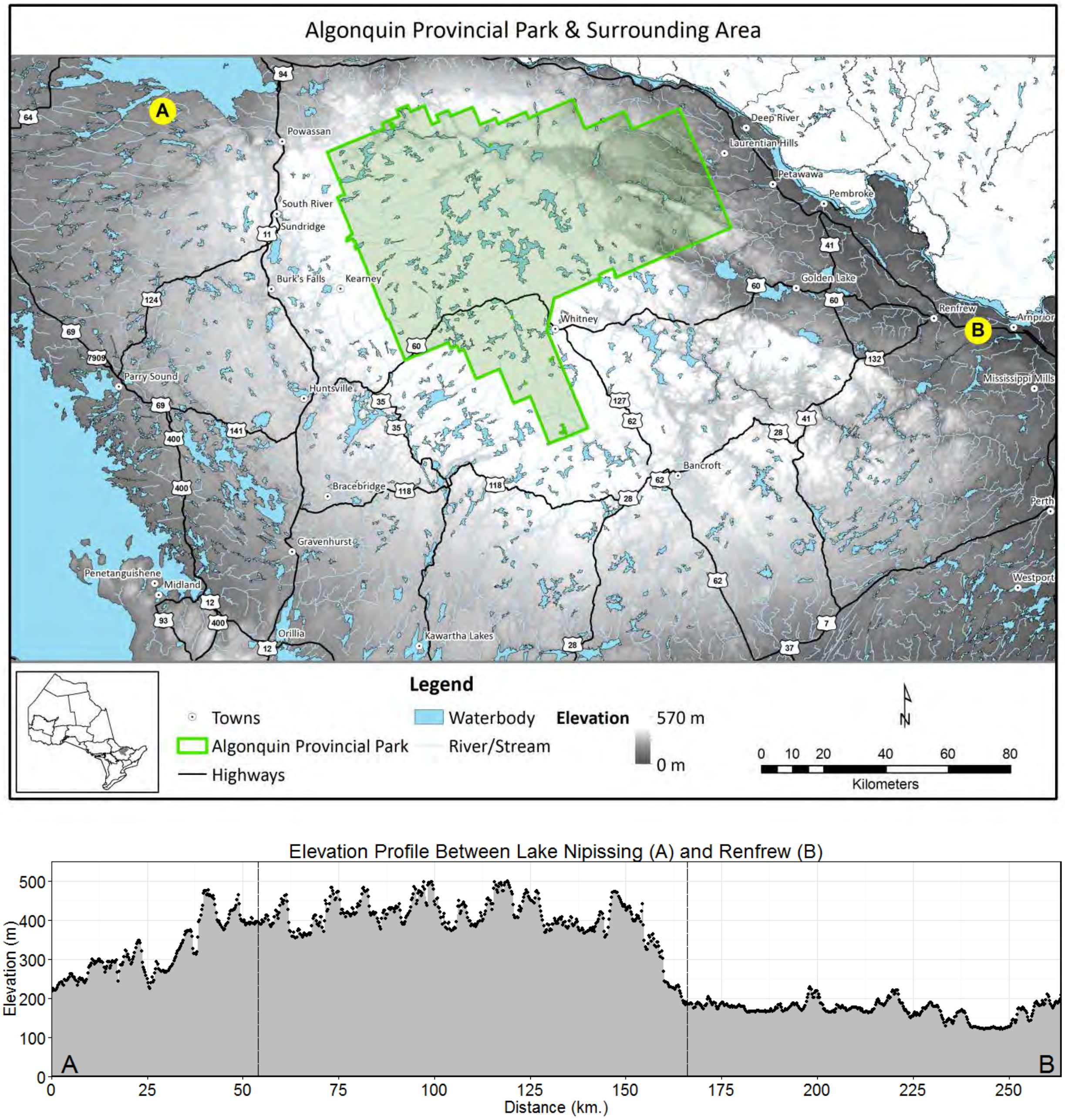
Depuis le début du XXe siècle, l’activité humaine dans les limites du parc Algonquin et les tendances à l’échelle mondiale ont eu des répercussions sur les lacs et les rivières du parc. L’introduction autorisée et non autorisée d’espèces de poissons a altéré le réseau alimentaire des lacs et mis en péril les communautés de poissons autochtones. La propagation de ces espèces minera le réseau alimentaire autochtone des lacs et mettra en péril les espèces de poissons qui ne peuvent s’adapter ou éviter la prédation.

Le réchauffement climatique de la planète se fait sentir dans le parc Algonquin et altère les écosystèmes aquatiques. Parmi les changements relevés dans le parc, citons l’augmentation de la température annuelle moyenne de l’air et la modification de la formation des glaces sur les lacs en hiver, ce qui est conforme aux faits observés à d’autres endroits ou aux modèles de projections. Pendant le XXIe siècle, le changement climatique aura une incidence sur les espèces de poissons autochtones présentes dans le parc Algonquin. Il favorisera des espèces comme l’achigan à petite bouche ou posera un risque relativement faible pour d’autres espèces.

Malgré les changements récents, le parc Algonquin a conservé la majeure partie de ses écosystèmes aquatiques et communautés d’espèces autochtones. Soixante espèces de poissons autochtones ou introduites ont été détectées dans le parc, notamment en observant les ruisseaux. Il y a de l’omble de fontaine dans tous les bassins hydrographiques de quatrième ordre du parc Algonquin et dans 443 lacs, ce qui signifie que le parc est un lieu important pour cette espèce en Ontario. On retrouve également l’omble de fontaine dans un grand nombre de ruisseaux et de rivières du parc. On prévoit que le changement climatique et l’introduction d’espèces réduiront le nombre d’ombles de fontaine dans plusieurs secteurs du Centre-Sud de l’Ontario et que cela pourrait se produire dans le parc Algonquin, qui servira également de refuge pour cette espèce compte tenu de la perte prévue de cette espèce en dehors des limites du parc.

Il y a 188 populations de touladis dans le parc Algonquin. Dans 162 des lacs du parc où il y a du touladi, il y a également de l'omble de fontaine. Une des caractéristiques uniques du parc Algonquin est la présence de toutes les catégories de réseaux alimentaires du touladi, qu'il s'agisse de poissons de petite taille dans les lacs où il n'y a que de petites proies ou de réseaux alimentaires élargis dans les lacs produisant des touladis de grande taille. Cette diversité s'explique par les origines glaciaires du parc.

Le parc Algonquin est une zone importante pour la protection de la diversité des espèces de poissons, car on y trouve des réseaux alimentaires uniques dont les origines remontent à l'histoire glaciaire du parc. Peu de zones protégées ont laissé un héritage aquatique aussi important en Ontario.



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Introduction

Water has always defined the Algonquin Park landscape. What we see today as the system of lakes and rivers only partly reflects the history of water on this landscape. Over the past million years, there have been several ice age periods in North America occurring at approximately 100,000 year cycles of ice advance and retreat. Interactions between the Earth's long-term patterns of orbit, corresponding changes in summer heating at high northern latitudes and warming stemming from the suppression of bedrock elevation due to the mass of ice all lead to a general pattern of slow ice advance and rapid ice retreat in North America[(1)]. There were 3 previous ice ages in the past 400,000 years [(1,2)], prior to the last glacial period that influenced the Algonquin Park landscape. Each glacial cycle resulted in its own system of lakes and rivers after rapid retreat of the ice sheet. For Algonquin Park, recent evidence points to the last 2 periods of ice advance and retreat as covering the park's landscape while the first 2 produced ice advance close to but not covering Algonquin Park[(1)]. Regardless of the extent of ice coverage over Algonquin Park, drainage from each period of glacial ice retreat would have influenced drainage patterns at the time in the Algonquin and Ottawa Valley landscape. This report can only address the occurrence and outcomes stemming from the last glacial period as it affected the park landscape. Landscape patterns established before this last period were wiped clean by each successive glacial period. The glacial period last affecting the Algonquin Park landscape is labelled the Wisconsin Glacial Period in central North America and the movement of the glacial front from south to north is referred to as the retreat of the *Laurentide Ice Sheet*.

Beginning first as a place locked in nearly 2,000 metres of ice[(3)], through to a period when torrents of water moved over the land and through cut valleys, the ice sheet melted, retreated northward, and finally disappeared. Released from the tremendous weight of glacial ice, the Algonquin landscape has rebounded in elevation over thousands of years to form the watersheds we recognize today. This process, slow and still ongoing, determined the distribution of fish in watersheds as each species moved onto the Algonquin landscape to occupy lakes and rivers following drainage patterns that formed after ice retreat. Some fish species arrived early to the newly released landscape and have wide distributions among the aquatic ecosystems of Algonquin Park[(4,5)]. Other fish species arrived later and have a more limited distribution because the landscape rebounded, changed watershed connections and prevented them from reaching different areas of the park. The distribution of native fish today reflects this process including historical connections to the early stages of the Laurentian Great Lakes. Changes in aquatic ecosystems during this period occurred over thousands of years.

The next phase in the history of lakes and rivers in Algonquin Park occurred over the last century. During this period, authorized and unauthorized fish species introductions occurred to meet the demand for recreational fishing. Water management began as a means of transporting logs to mills and was followed by control structures for hydropower generation. Watersheds and aquatic ecosystems in Algonquin Park have also been affected by changes in the environment especially climate change in recent years. Changes in aquatic ecosystems during this period occurred over decades.

The purpose of this report is to summarize information on the watersheds of Algonquin Park including lakes, rivers, and their aquatic ecosystems. In doing so, all tertiary and fourth order watersheds have been mapped based on current elevation data, lake, and river characteristics summarized for each watershed and all water course connections located among watersheds. Multiple data sources have been used to locate fish species in each of the watersheds based on best available information.

The report also summarizes 2 important stressors stemming from human activity that have occurred over the past several decades: 1) climate change, and 2) fish species introductions, invasions, and at-risk status. Climate change in recent years has clearly shown a warming trend across the Algonquin Park landscape that in turn changes seasonal features such as ice-out dates on lakes. Fish species have been introduced in the park intentionally or un-intentionally and this has effects on native species. Concerns over species conservation can arise from these introductions.

The report is organized as follows:

1. **Retreat of the Laurentide Ice Sheet.** This section summarizes the general timing of glacial retreat from the Algonquin Park region including likely routes and the importance of the Ottawa Valley area as a glacial river system. The importance of glacial relict species is used to help outline the influence of Pleistocene Lake Algonquin.
2. **Algonquin Park landforms from glacial history.** This section summarizes landforms and structures generated by the retreating ice and associated water flow at the time. These elements help define the aquatic ecosystems of the park and provide an important setting for current information about the park.
3. **Watersheds of the Algonquin Park landscape.** The lakes and rivers of Algonquin Park today belong to a corresponding system of watersheds and their connections. This section summarizes the distribution and connections among these watersheds based on current detailed elevation data for the region.
4. **Barriers to fish passage in Algonquin Park.** Known artificial and natural barriers to fish movement in Algonquin Park are mapped (based on 2014 information).
5. **Wetlands of Algonquin Park.** The wetland distribution in Algonquin Park is mapped showing the park-wide distribution of this important habitat type.
6. **Climate environment of the Algonquin Park landscape.** This section summarizes recent temperature trends for this landscape and shows that climate change has arrived in Algonquin Park. Climate change has reduced the ice cover

season on Algonquin Park lakes through later ice-on and earlier ice-free dates as indicated by long-term monitoring at Lake Opeongo.

7. **Fish distribution in Algonquin Park.** The distribution of fish species and invertebrates reflects the glacial history of the region and serve as fingerprints for the period of glacial retreat linking Algonquin Park with the early development of the Laurentian Great Lakes.
8. **Fish in Algonquin Park and climate change.** Climate change affects fish physiology and fish population ecology by several processes all related to lake physics. One is the change in ice cover and general warming of lakes and streams beyond tolerances of several species. Another is the possible loss of oxygen in lakes due to longer periods of temperature stratification. Finally, all factors combined could lead to reduced habitat depending on species and lake size.
9. **Fish introductions in Algonquin Park.** Over the past century different fish species have been introduced to the Algonquin Park landscape — authorized and unauthorized — that are potential threats to the integrity of Algonquin's aquatic ecosystems. This section summarizes the known distribution of all fish species are mapped within Algonquin Park watersheds including changes that have occurred from species introductions over the past century.
10. **Aquatics species-at-risk in Algonquin Park**. This section highlights the lakes with fish species designated under an at-risk status along with lakes where status has not be assigned but where other occurrences are designated.
11. **Fish species distributions.** A series of maps are presented summarizing the stream and lake distribution of each fish species found in Algonquin Park. This mapped database is based on best available information through August 2016.

Descriptions of glacial processes, landforms, species interactions, etc., employ technical terms to communicate content. This report strives to minimize this aspect but eliminating technical terms can lead to a very inefficient way of describing the history of aquatic ecosystems in Algonquin Park. Since experts in the topics covered by this report use technical terms then some familiarity with their use is helpful for the reader. A glossary of technical terms is provided to aid in this process.

Retreat of the Laurentide Ice Sheet

The distribution of lakes and river systems within Algonquin Park cannot be fully appreciated unless the history of water flow at a regional scale is understood, including the importance of Algonquin Park's connection to the Glacial Great Lakes of the retreating Laurentide Ice Sheet. The Algonquin Park landscape was closely tied to large *glacial lakes*[6,7,8], their formation from melt water, and their drainage to the east. For a period of time watersheds further west than modern-day Lake Superior were connected to the drainage system of northern Algonquin Park. All together Algonquin Park was directly associated with glacial retreat and its drainage for a span of approximately 2 millennia.

A glacial lake has the edge of a glacier as one of its shorelines. Melt water collected at the glacial edge and extended away from the glacier in the form of a lake as it pooled in newly released basins near the retreating ice front. Without adjacent basins, melt water flowed from glacial fronts in the form of rivers and streams. Many glacial lakes of all sizes formed as the ice retreated northward with melting on the southern edge. The largest and most influential in terms of water volume and flow connections are labelled here as the Glacial Great Lakes. They rivalled and often exceeded the surface area and volume of the current Laurentian Great Lakes so familiar to us. Several of the Glacial Great Lakes drained through Algonquin Park and the adjacent Ottawa River valley before the drainage patterns we recognize today were set in place.

The Glacial Great Lakes of thousands of years ago were the set of lakes forming at the front of the receding Laurentide Ice Sheet on one side (normally north and northeast shores) and height of land largely to the south and south west on the other. The height of land increased as isostatic rebound started once the landscape was released from the weight of glacial ice. These large lakes filled basins near the glacial front and drained in many directions depending on what outlets became open during ice retreat. Lakes connected one to the other depending on these shifting flow connections. At times flow connections were governed by periods of re-advance of the Laurentide Ice Sheet in certain areas during which glacial lake levels rose. The Glacial Great Lakes would appear to move across the landscape as melt water sought any lower level available through newly opened and lower elevation outlets. Once outlets opened, lakes would drain until a new lower elevation water plane would establish leading to the appearance of movement or drift across the landscape[9].

The maximum extent of the Laurentide Ice Sheet occurred over 21,000 *calibrated years before present* (cal yrs BP)[3,6,7] south of the current Laurentian Great Lake watershed (all ages in this report are calibrated thousands of years before present (cal yrs BP); a conversion of radiocarbon dating to calendar years[10] (Table 1). Algonquin Park was covered in 2 kilometres of ice at the time[3]. In Ontario, lakes formed once the glaciers receded beyond the drainage divide separating flow to the Gulf of Mexico and flow to the Laurentian Great Lakes. North of this divide the southern shores of glacial lakes would cover the landscapes free of ice while northern shores were the edge of the receding ice sheet. Lake areas next to the glacial front were often deepest because this area was more depressed than southern areas due to the weight of ice.

The importance of Alqonquin Park during retreat of the Laurentide Ice Sheet is summarized in this report in 2 steps. First, the era of the Glacial Great Lakes is outlined including how this period ended. Much of the glacial and flow history of this time points to the region of northern Algonquin Park and the Ottawa River valley as important drainage routes. Second, Pleistocene Lake Algonquin is highlighted along with its role in south-central Ontario, specifically how Algonquin Park played a role in the end of this Glacial Great Lake. An understanding of this period is important for interpreting the current distribution of native fish in Algonquin Park.

The era of the Glacial Great Lakes

For over 8,000 years (16,500–8,500 cal yrs BP[1,2,6]; Table 1), the era of the Glacial Great Lakes produced a series of large lakes across North America that shifted in location and drainage as they traced the front of the retreating Laurentide Ice Sheet. This era played a significant role in establishing the lakes and watersheds we see today beginning with the opening of early Lake Erie (16,500 cal yrs BP)[7] and ending with the final sudden outburst of Lake Agassiz-Ojibway at the edge of the Hudson Bay lowlands at 8,450 cal yrs BP(7,9)(Table 1; Figure 1). Along the line of the northward retreating ice, melt water gained access to outlets in a series of steps as lower drainage points were released from the ice sheet making new connections among the lake and river systems of the time. Today it would be a challenge to recognize the Glacial Great Lakes and their river systems given how much change occurred in patterns of melt water flow in this 8,000 year period. But we do recognize the major lake and river systems left behind following glacial retreat. It includes all the large lakes along the southern edge of the Canadian Shield — Lakes Ontario and Champlain in the east through to Great Bear Lake in Northwest Territories, and the 2 largest river systems in North America, the Mississippi and Mackenzie Rivers, among others. It highlights the special role of the Ottawa River valley in routing melt water generally and how this affected the Algonquin Park landscape specifically.

The arc of large lakes along the southern edge of Canadian Shield bedrock is an important feature. It extends from the Laurentian Great Lakes in the east to Great Bear Lake in the Northwest Territories. The arc traces the approximate southern edge of the retreating Laurentide Ice Sheet at the same time as the Algonquin Park landscape was being released from ice(6,7)(Figure 1). Several Glacial Great Lakes were aligned with this arc of which 2 were directly relevant for the Algonquin Park landscape — Lakes Algonquin and Agassiz.

Glacial Lake Algonquin formed initially from melt water in what is now the Lake Huron and Lake Michigan basins approximately 14,000 cal yrs BP and lasted until 11,400 cal yrs BP[7]. Its lifespan of approximately 3,000 cal yrs had several defining features. There was a high-water phase with a relic fingerprint of its influence still detectable today, an expansive western drainage boundary into what is now Saskatchewan, and a relatively rapid end when it drained through a series of lower elevation drainage sites in the northern areas of Algonquin Park itself. Throughout its history Lake Algonquin was connected, isolated and re-connected with Lake Agassiz to the west (Figure 3).

Lake Algonquin drained through 4 major outlets in its lifespan[7]. First, in the early stages of development, Lake Algonquin drained through what is now the Port Huron/Sarnia outlet in the south which continued to function through most of the lake's history. Second, and coincident with the Port Huron/Sarnia outlet, was the outlet from what is now Saginaw Bay of southwest Lake Huron. Third, after sufficient ice retreat north of Severn Sound in Georgian Bay, Lake Algonquin drained through current day Lake Simcoe continuing through the Kawartha Lake system and finally into the Bay of Quinte region via the Trent River system. This period is referred to as the Kirkfield Phase of Lake Algonquin in recognition of its route through the Kirkfield/Fenelon Falls outlet at the time. Fourth, at peak levels, Lake Algonquin drained through Port Huron/Sarnia, Fenelon Falls and the north region of Algonquin Park. This period represented the Main Phase of Lake Algonquin.

Glacial Lake Agassiz formed west of what is now Lake Superior in central Canada and had a lifespan of nearly 6,000 cal yrs [9,12,13](Figure 3). It began existence as the source water for the early Mississippi River system newly released from ice and ended with a location in northern Ontario and Manitoba eventually emptying into Hudson Bay[11]. Lake Agassiz best exemplified the migratory nature of Glacial Great Lakes as they shifted drainage outlets with retreat of the Laurentide Ice Sheet[9].

The Mississippi River drained from the ice sheet and Glacial Lake Agassiz towards the Gulf of Mexico, losing the connection and regaining it through periods of glacial re-advance and retreat in the Laurentian Great Lakes basin. When connections to the Mississippi River were broken, Lake Agassiz drained west or east depending on what drainage connections were functioning at the time. Easterly drainage of Lake Agassiz occurred for thousands of years from what is now the Lake Superior and Lake Nipigon basins to early stages of Lakes Huron and Michigan and on through the Ottawa valley via Lake Nipissing[6,7].

Both Lakes Algonquin and Agassiz, and their drainage connections when operating, were critically important as dispersal corridors for many species of North American freshwater fish re-colonizing new glacier-free landscapes via drainage systems at that time[14,15]. Beginning from watershed systems at the perimeter of the Laurentide Ice Sheet at its maximum (Figure 3a), fish followed the retreat of the ice sheet with species tolerant of cold melt water likely occupying areas closer to the edge of the ice than species preferring warmer water — areas that would be found further from the ice edge. The Mississippian and Atlantic refuges for freshwater fish were important sources of fish species for colonizing Algonquin Park[15] (Figure 3a).

At 13,800 cal yrs BP, the Laurentide Ice sheet had retreated northward enough for several glacial Great Lakes to form at the ice edge (Figure 3b). Lakes Agassiz and Algonquin were among the lake set but were not directly connected at this time. Two features of the ice sheet stand out at this point: the retreat of the ice sheet beginning in the area of the Mackenzie River system of northwest Canada while at the same time the ice sheet had just reached the southern panhandle of Algonquin Park. The striking feature of this period is the apparent early opening of melt water to the Arctic Ocean in the west at a time when melt water in the east was draining south of Algonquin Park with the main outflow of Lake Algonquin being Kirkfield/Fenelon Falls drainage point.

Algonquin Park was recolonized during this period with cold-water fish likely moving from south to north by tracing the retreating Laurentide Ice Sheet through drainage systems operating at the time[4,5,14]. Most of Algonquin Park would be free of glacial ice over a period of approximately 800 cal yrs (Figure 3b–c). The timing of ice retreat in Algonquin Park and the first stages of re-colonization by fish coincided with a significant event in the glacial era with direct global implications.

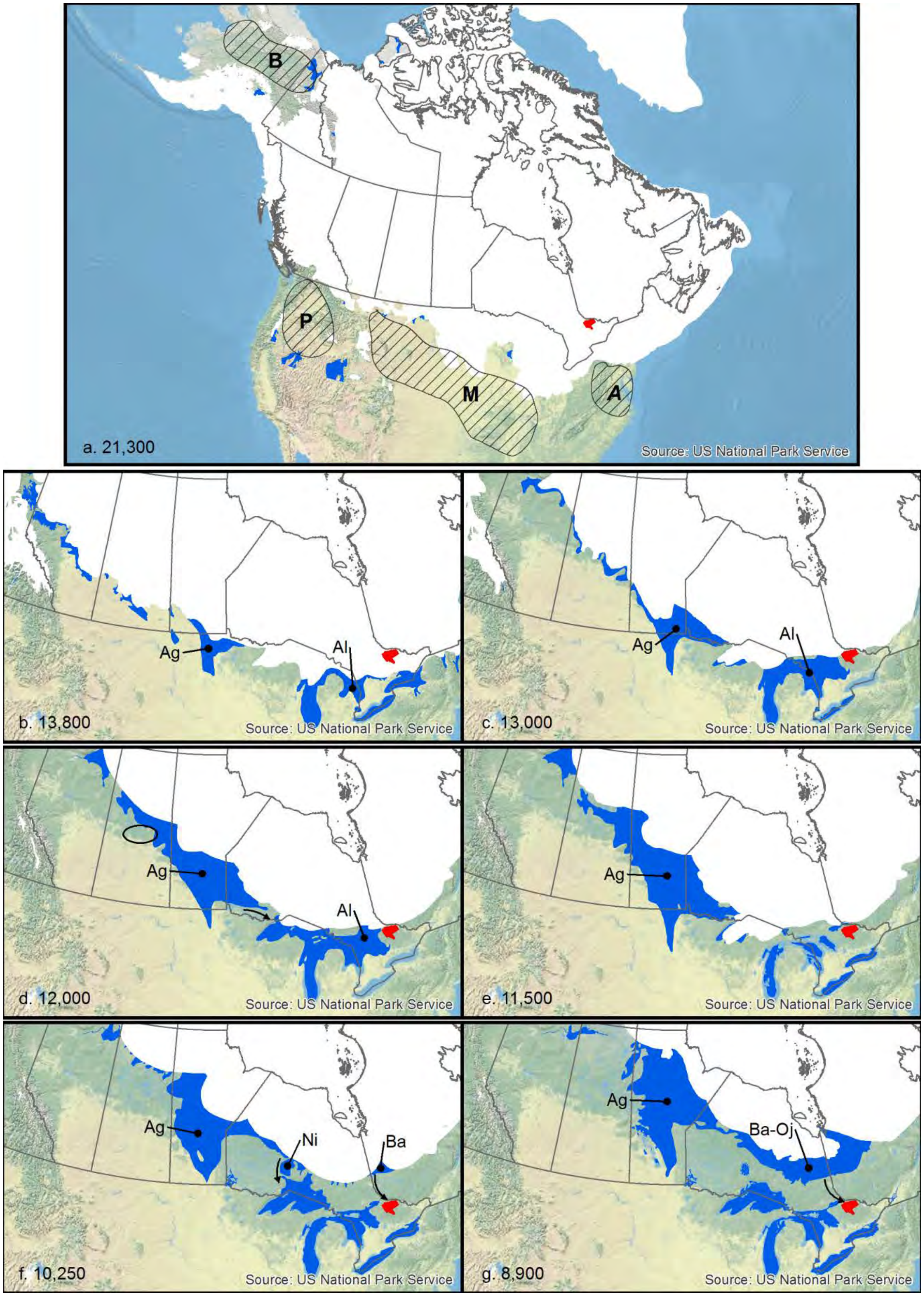


Figure 3. (a) The maximum extent of the Laurentide Ice Sheet in North America and the glacial refuges for freshwater fish at that time[15]. The red symbol is the location of Algonquin Park. M = Mississippian refuge; A = Atlantic refuge; P = Pacific refuge, and B = Beringian refuge. (b) The glacial front at 13,800 cal yrs BP with Algonquin Park shown

in red. For this and all other maps (b–g), Ag = Lake Agassiz; Al = Lake Algonquin; Ni = Lake Nipigon. Lakes Agassiz and Algonquin are in their early stages of development and not connected via drainage at this stage of ice retreat. The Kirkfield phase of Lake Algonquin will begin and provides drainage through southern Ontario. (c) The glacial front at 13,000 cal yrs BP showing large areas of Algonquin Park as ice free. Lake Algonquin is now in its Main Phase and draining through Port Huron, Kirkfield/Fenelon Falls and soon in the northern areas of Algonquin Park. (d) The glacial front at 12,000 cal yrs BP showing the opening of the Lake Superior basin and a drainage connection between Lake Agassiz and the Main Phase of Lake Algonquin. Drainage of Lake Algonquin continues through the 3 drain points as before with greater flow now through Algonquin Park. The western boundary of the drainage system travelling through Algonquin Park after this period was the Saskatchewan River indicated by the black oval. (e) The glacial front at 11,500 cal yrs BP showing a glacial re-advance in the Lake Superior basin effectively separating Lakes Agassiz and Algonquin. This is the post-Lake Algonquin period with drainage occurring through a series sills of lower elevation in the northern regions of Algonquin Park. Lake Algonquin ceases to exist and is partitioned into several lakes as the next stage in the formation of the modern Laurentian Great Lakes. (f) The glacial front at 10,200 cal yrs BP showing a reconnection between Lakes Agassiz and the early Laurentian Great Lakes via several drainage points along the western shore of Lake Nipigon. Drainage through Algonquin Park has ceased but drainage from Agassiz and the early Laurentian Great Lakes is flowing through the Ottawa Valley via Lake Nipissing. Lake Barlow begins to develop north of Algonquin Park. (g) The glacial front at 8,900 cal yrs BP showing the combined Lakes Agassiz and Barlow-Ojibway in northern Ontario. This large lake system drains south to the Ottawa Valley. The early Laurentian Great Lakes also continue to drain through the Ottawa Valley via Lake Nipissing. In 4 centuries (8,450 cal yrs BP) the Agassiz/Barlow-Ojibway lake system will drain into Hudson Bay. This map series is based on Dyke's (2004)[6] maps of glacial retreat in North America.

The Mackenzie River in northwest Canada drained a series of Glacial Great Lakes in central and western North America, including areas of Lake Agassiz, to the Arctic Ocean at a time when glacial retreat had just uncovered the Algonquin Park landscape (Figure 3b–d). At this point, an outburst of glacial melt water through the MacKenzie River system 12,500 cal yrs BP had global effects. The scale of water loss through the Mackenzie River delta was large enough to raise the Arctic Ocean by 6 m, alter ocean currents in the North Atlantic to a degree that changed global climate, resulting in lower temperatures worldwide[15b,16,17]. This episode is known as the Younger-Dryas event and it effectively ended the Pleistocene era and initiated the Holocene era. This event slowed retreat of the Laurentide Ice Sheet just north Algonquin Park in the Ottawa River valley.

Prior to and during the Younger-Dryas event, glacial retreat had opened a drainage point (water level = 385 m) in the South River area of northwest Algonquin Park during the Main Phase of Lake Algonquin[18,19]. Water flow drained through the northern regions of the park. The extent of the drainage area during the Main Phase of Lake Algonquin was large. During this time (12,700 cal yrs BP)[7], Lake Algonquin covered the basins of Lakes Huron and Michigan and what was ice-free of the Lake Superior basin (Figure 3d). To the west, glacial Lake Agassiz was large and occupied much of what was ice-free in northwest Ontario and Manitoba (ie., Moorehead Phase for Lake Agassiz; Figure 3d)[7], extending west to what is now the Saskatchewan River (Figure 3d). Drainage eastward from this point was sustained by rivers connecting the glacial lake system along the front of the retreating Laurentide Ice Sheet[7]. The northern regions of Algonquin Park therefore had a watershed extending to the current prairie region of Saskatchewan (Figure 3d). It was periods such as this that effectively served as east-west corridors for fish movement during re-colonization[14].

The Younger-Dryas event had important consequences for Algonquin Park. First, because of lower global temperatures, the pace of ice retreat slowed and in some areas there was glacial re-advance. One location was the Lake Superior basin where glacial re-advances isolated drainages between Lakes Agassiz and Algonquin[7] (Figure 3e). Without a contribution of glacial melt water from Lake Agassiz in the west and with the Laurentide Ice Sheet now north of the Lake Huron/Michigan basin (Figure 3e), Lake Algonquin became isolated from direct melt water generally, while co-occurring with a period of a drying climate[20]. As a result, the water level of Lake Algonquin began to fall through a series of outlets at lower elevations[7]. The outlets leading to the demise of Lake Algonquin were located in, or in close proximity to, the northern regions of Algonquin Park at elevations below the water level for Main Phase Lake Algonquin[18]. This drainage system ended Lake Algonquin as single lake ecosystem resulting in the formation of separate lakes in the basins of Lake Michigan, main basin of Lake Huron and Georgian Bay (Figure 3e).

A closer examination of the approximate location of the Laurentide Ice Sheet in Algonquin Park during this period reveals the Younger-Dryas event likely resulted in 2 phases of ice retreat[6] (Figure 4). In a span of 600–800 cal yrs glacial ice retreated over most of the park's highlands with the glacial front located in the northern region of Algonquin Park at 13,000 cal yrs BP. The rate of retreat declined sharply over the next 1,000 cal yrs as the ice slowly moved north of Algonquin Park. The Laurentide Ice Sheet was north of the park's boundary at 12,000 cal yrs BP (Figure 4). The timing of this lower rate of retreat coincided with the Younger-Dryas event. At the start of the glacial retreat on the Algonquin Park landscape, Lake Algonquin was draining through the Kirkfield/Fenelon Falls outlet, on through the Kawartha lake region and into the Bay of Quinte[7]. When glacial retreat was complete for Algonquin Park (12,000 cal yrs BP; Figure 4), Lake Algonquin drainage had ceased in the Kirkfield/Fenelon Falls outlet and switched to the north regions of the park, drained through different valleys and reached the Champlain Sea (marine ecosystem) that was then situated immediately east of Algonquin Park[7,8]. The drainage of Lake Algonquin through the park was freshwater input for a large marine estuarine environment located just east of Algonquin Park, the Champlain Sea. The slow rate of glacial retreat allowed drainage points in and adjacent to the park to operate for centuries as input for an estuary.

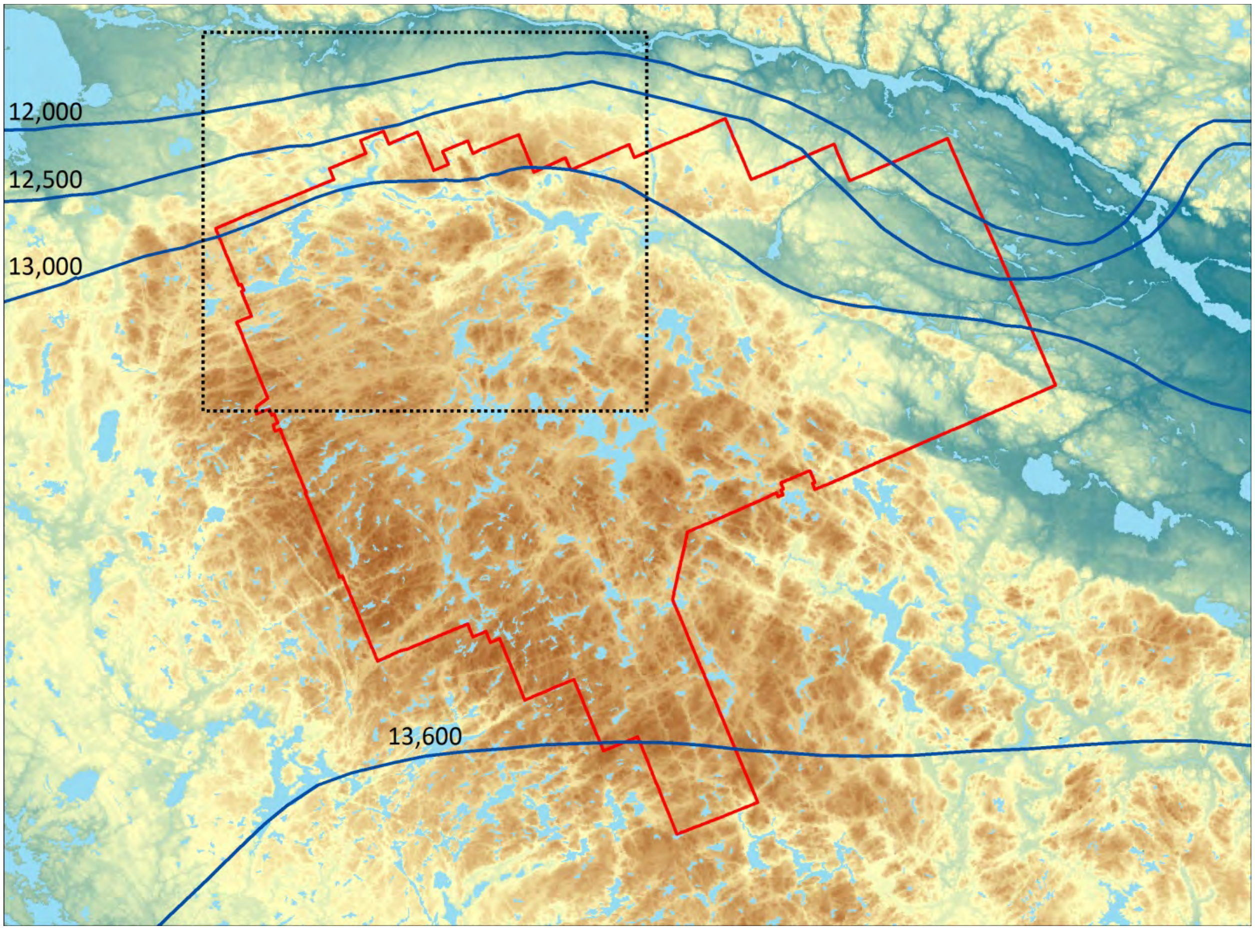


Figure 4. The approximate timing of retreat of the Laurentide Ice Sheet on the Algonquin Park landscape in cal. yrs BP (Dyke 2004)[6]. Each line represents the location of the glacial front over a span of 1,600 cal yrs. The dashed box is the region of northwest Algonquin Park where several drainage routes were functioning during the post-Lake Algonquin phase. Maps for this region are in Figure 5.

Further retreat of the Laurentide Ice Sheet reconnected Lake Agassiz drainage to the drainage systems of southern Ontario[7] (Figure 3f). At this stage, Lake Algonquin had ceased to exist and the ice sheet was no longer in contact with what was then the early stages of the Laurentian Great Lakes we recognize today. Lake Nipigon served as the drainage route for Lake Agassiz through a series of pour points on its western shore[12,13](Figure 3f). Water flowed into Lake Superior from Nipigon and on through Lake Nipissing and the Ottawa River valley. Algonquin Park was now isolated from direct Great Lake water flow as it went through isostatic rebound leaving the Ottawa River valley to carry drainage from as far away as northwest Ontario and Manitoba. To the north of Algonquin Park, glacial Great Lakes Barlow and Ojibway started to form and drainage from this system through the Lake Temiskaming watershed also contributed water flow to the Ottawa River valley[8](Figure 3g).

From approximately 13,000–12,000 cal yrs BP, drainage of Main Phase Lake Algonquin defined what we observe today in the aquatic ecosystems of northern Algonquin Park

(Figure 5). While the Laurentide Ice Sheet was situated in the northern regions of Algonquin Park, the Main Phase of Lake Algonquin was isolated from melt water originating from Lake Agassiz and elsewhere in the Lake Algonquin basin. Decreased inflow of melt water and slowly retreating ice sheet produced a series of new drainage outlets just north of Algonquin Park over several centuries. This process is revealed in northern watersheds of Algonquin Park[7,18,19,21] (Figure 5).

While the Laurentide Ice Sheet retreated northward, but still within the boundaries of modern day Algonquin Park, a drainage point in the South River watershed (385 m) was captured west of North Tea Lake. This allowed water to flow into the watersheds east of the drain point and fill areas below the water level of Main Phase Lake Algonquin (Figure 5a). Through continued slow retreat of the glacial front, additional drainage points were captured in a succession of lower elevation points[18,19,21] (Figure 5b–f). One is widely known as the Fossmill outlet[4,12] (Figure 5c) but it is one of several that functioned over the centuries[19]. As the glacial edge moved north, and for a period retreated eastward towards Mattawa, lowering phases of Lake Algonquin captured new drainage points in Algonquin Park. By the end, water levels during the Main Phase of Lake Algonquin had dropped by approximately 80 m[7].

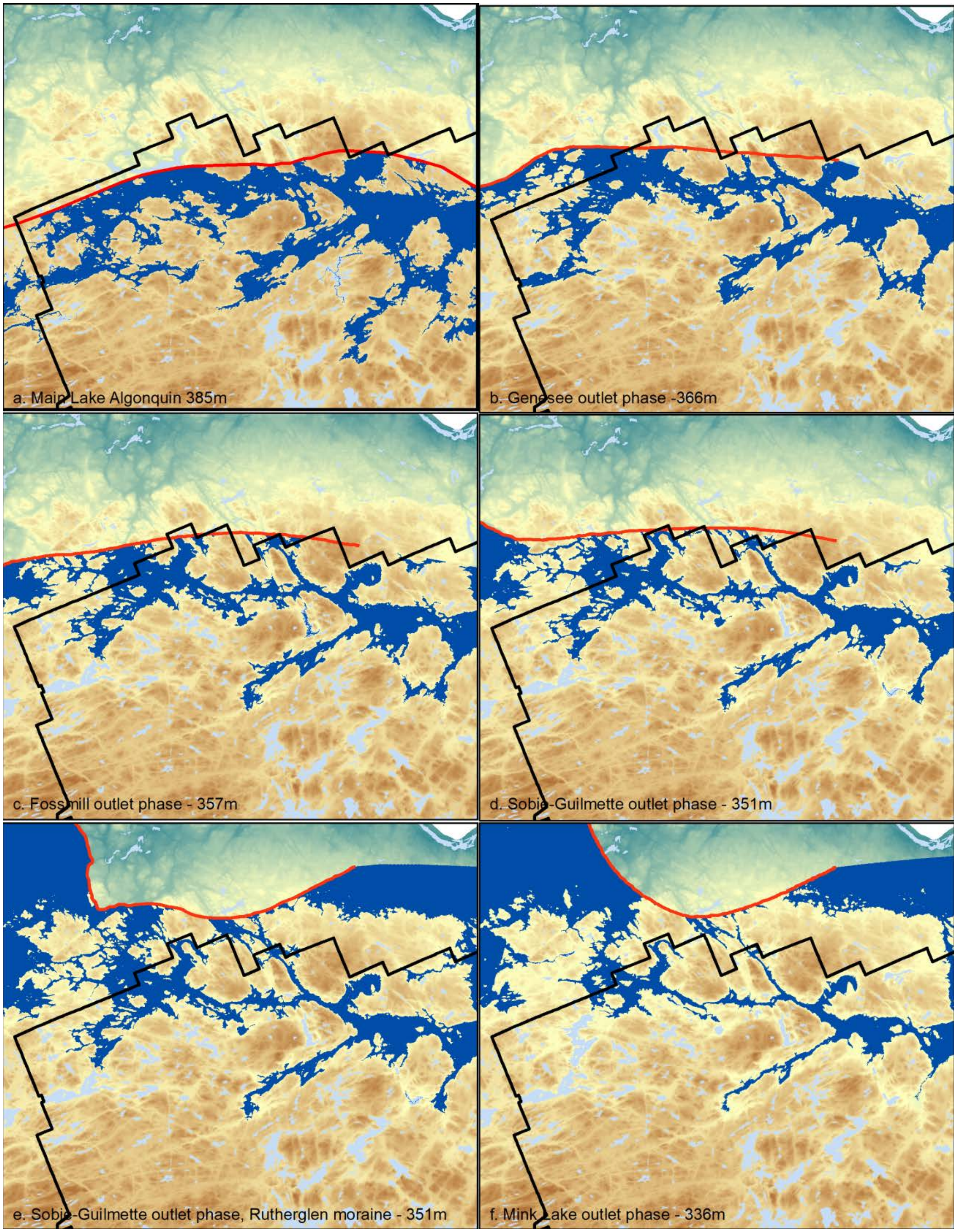


Figure 5. A digital elevation map series showing the inundation of northern Algonquin Park during the main phase of Lake Algonquin (a) to the last period of post Lake Algonquin when water drained over the Mink Lake Sill (f). Levels indicated in each figure represent the water level at the time. Drainage direction in each figure is from left to right. The red line in each figure is the approximate location of the southern edge of

the Laurentide Ice Sheet. The extent of the red line of each map is the position as derived from Harrison (1972)[18] and Dyke (2004)[6]. The glacial edge is not extended across a panel where there is current uncertainty regarding the ice limit in that area. The boundary of Algonquin Park is in black. (a) The drainage route of Main Lake Algonquin when the glacial ice edge was near the northern boundary of Algonquin Park with a water level at 385 m. (b) The first post Lake Algonquin outlet at the Genessee moraine (Harrison 1972)[18]. Several lakes in Algonquin Park are now isolated relative to the 385 water level. (c–d) The Fossmill and Sobie-Guillmette outlet period where both served as drainage points for a period of time. (e–f) The northward swing of the Laurentide Ice Sheet opens new northern drainage points. (f) The Mink Lake sill phase (water level = 336 m) was the last period of post Lake Algonquin flow in the park. When water levels over the Mink Lake sill declined to 327 m then flow stopped and Algonquin Park watersheds became isolated from post Lake Algonquin flow.

There is a clear set of biological indicators revealing where Lake Algonquin inundated the landscape. Several planktonic and *benthic* species of invertebrates are known to be indicative of the presence of Lake Algonquin waters and are found today as glacial relics in south central Ontario, including the Laurentian Great Lakes[22,23,24]. One species in particular is detected if lakes have adequate depth and oxygen, the crustacean *Mysis diluviana* (hereafter referred to as *Mysis*). This species persists in deep, cold waters that are oxygenated throughout the year. It is a predator of smaller zooplankton and undergoes a daily migration from deep waters where it hides during the day to surface waters at night where it feeds. *Mysis* cannot swim against currents so its presence in lakes means it was deposited by water levels higher than observed today[23]. The distribution of *Mysis* in south-central Ontario represents the limits of the Main Phase of Lake Alqonquin (Figure 6). The elevation contour of 385 m is indicated on the map and shows that *Mysis* is not detected in lakes above this elevation. Figure 7 illustrates the distribution of *Mysis* in lakes in and around the northern half of Algonquin Park. Since many lakes in Algonquin Park meet the environmental requirements of *Mysis*, yet do not contain this species, then the conclusion is that the drainage of the Main Phase of Lake Algonquin through the park landscape was restricted to areas below the 385 m contour[22,23]. Some studies refer to the 381 m elevation contour as the boundary for *Mysis*[22,23] but other quaternary geologists identified the 385 m used here[19]. Some lakes, such as Lake Lavieille, do not contain *Mysis* but are identified as below the 385 m elevation. This outcome could stem from vertical drops or other forms of blockage such as steep flow gradients draining those systems during this period that prevented the inward movement of *Mysis*.

The presence of *Mysis* therefore points to a major division in the history of water drainage patterns in Algonquin Park. Above the 385 m elevation contour, *Mysis* is absent and inundation by Lake Algonquin on the landscape did not occur. In these lake ecosystems, the functional role of *Mysis* as a large zooplankton predator is filled by another species, the larval stages of a midge fly, *Chaoborus punctipennis*. *Chaoborus* also undergoes daily vertical migration and preys on smaller zooplankton similar to *Mysis*. It is rare to find *Mysis diluviana* and *Chaoborus punctipennis* co-existing in lakes.

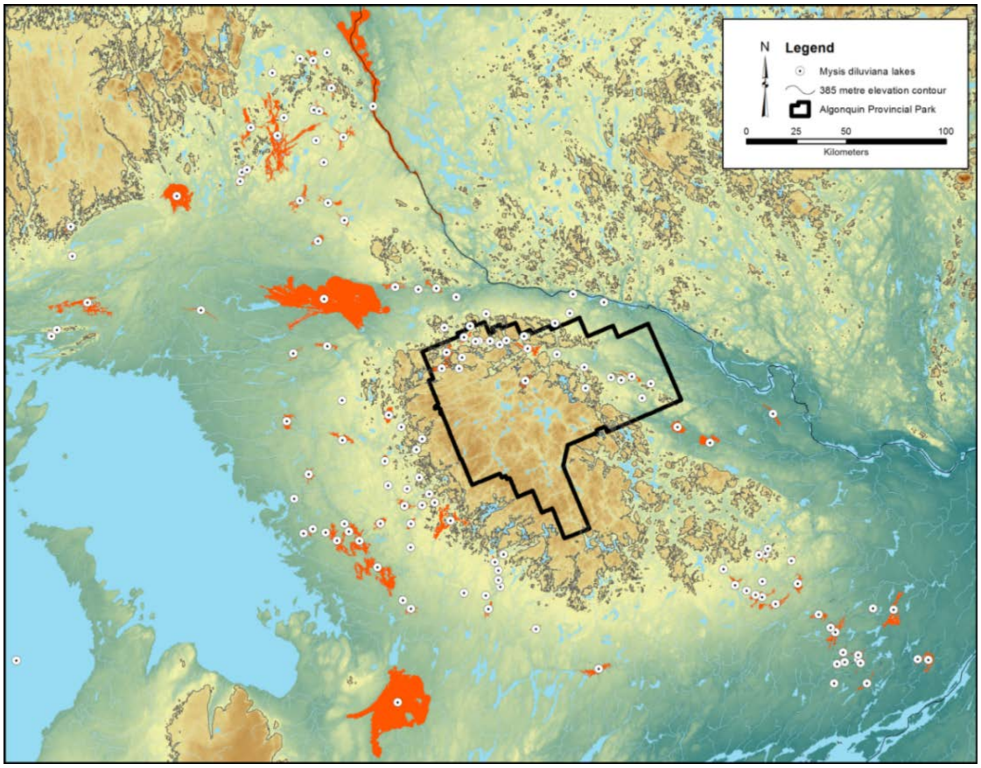


Figure 6. The distribution of *Mysis diluviana* in south central Ontario with the 385 m elevation contour shown. The boundary of Algonquin Park is in black.

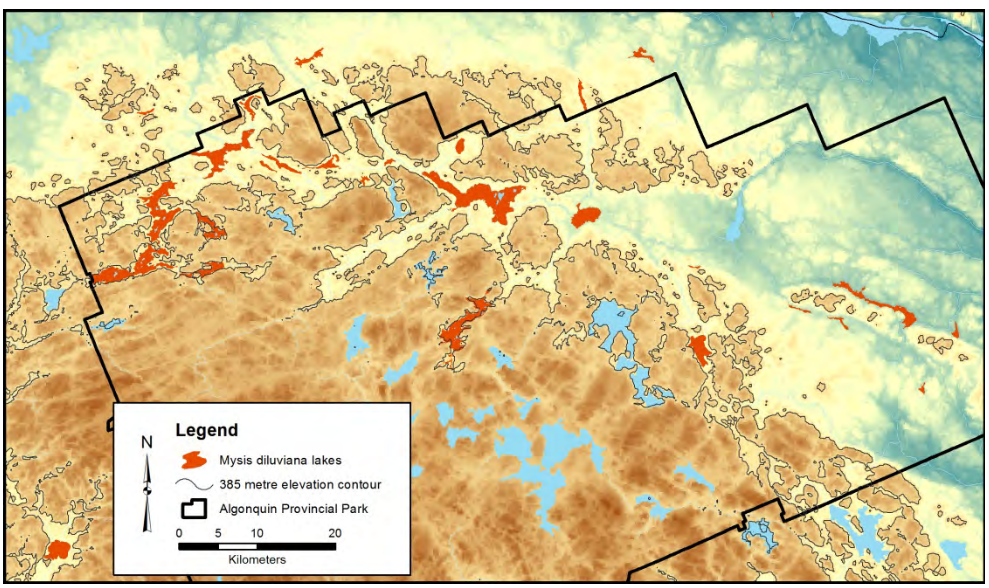


Figure 7. The distribution of *Mysis diluviana* in Algonquin Park with the 385 m elevation contour. The lower elevation areas of the park are indicated with lighter shading. *Mysis* occurs in lakes once inundated by Main Phase Lake Algonquin.

Along with *Mysis* and other invertebrates are fish assemblages unique to watersheds covered by Main Phase Lake Algonquin[(22)]. Early Great Lakes fauna from bottom invertebrates to zooplankton to fish species are located in the northern regions of the park and are not found in other locations within the park boundary. The fish species richness of Algonquin Park increases northward in contrast to the general phenomenon of declining fish species richness in northern regions of Canada. This is due entirely to the influence of Main Phase Lake Algonquin within the park landscape.

This drainage history of the park landscape is also informative regarding origins of fish species with respect to glacial refugia using molecular patterns in DNA[(14)]. Few fish species have been surveyed but 2 species point to the complexity of re-colonization patterns. For lake whitefish, genetic evidence points to dispersal from a Mississippian refuge during glacial retreat and subsequent spread across central and western Canada along the retreating glacial front[(25)](Figure 3a). Lake whitefish in other refuge locations in North American did not disperse widely. Thus, the Main Phase of Lake Algonquin and its western connection to the Lake Agassiz watershed facilitated a wide dispersal of lake whitefish that tracked the retreat of the Laurentide Ice Sheet. All lake whitefish in Algonquin Park originate from the Mississippian refuge[(14,25)].

This is not the case for lake trout dispersal along the retreating front of the Laurentide Ice Sheet. Lake trout also resided in the Mississippian refuge and dispersal from this region led to a similar pattern of occupancy in central and western regions of Canada[(26)]. However, lake trout occupying refuges in western Canada/Alaska (Beringian refuge; Figure 3a) and eastern North America (Atlantic refuge; Figure 3a) also dispersed widely[(14,26)]. Lake trout from the Mississippian and 2 Beringian refuges dispersed throughout central Canada with some populations comprised of fish from 2 separate glacial refugia[(25)]. The Main Phase of Lake Algonquin and its connection to Lake Agassiz led to east and west dispersal routes for lake trout versus the pattern observed for lake whitefish. In Algonquin Park, genetic evidence points to lake trout originating from the Mississippian refuge and from the Atlantic refuge[(27)] (Figure 8). This dichotomy is largely described by the 385 m elevation contour with Atlantic refuge lake trout occupying lakes below 385 m and Mississippian lake trout occupying lakes at higher elevation (Figure 8). Not all lakes follow this partition with some lakes revealing colonization by both Mississippian and Atlantic lineages (eg., White Partridge Lake; Figure 8).

Both lake whitefish and lake trout are tolerant of cold water and likely lived in the frigid waters accompanying a glacial retreat. They are widely distributed in Algonquin Park (see fish distribution maps) indicating that both traced the retreating Laurentide Ice Sheet whether over the highlands between 13,000–13,800 cal yrs BP or via the late drainage of Main Phase Lake Algonquin between 12,000–13,000 cal yrs BP. However, differences in the representation of linages from glacial refuges points to differences in how these species came to occupy Algonquin Park despite similar preferences for cold water.

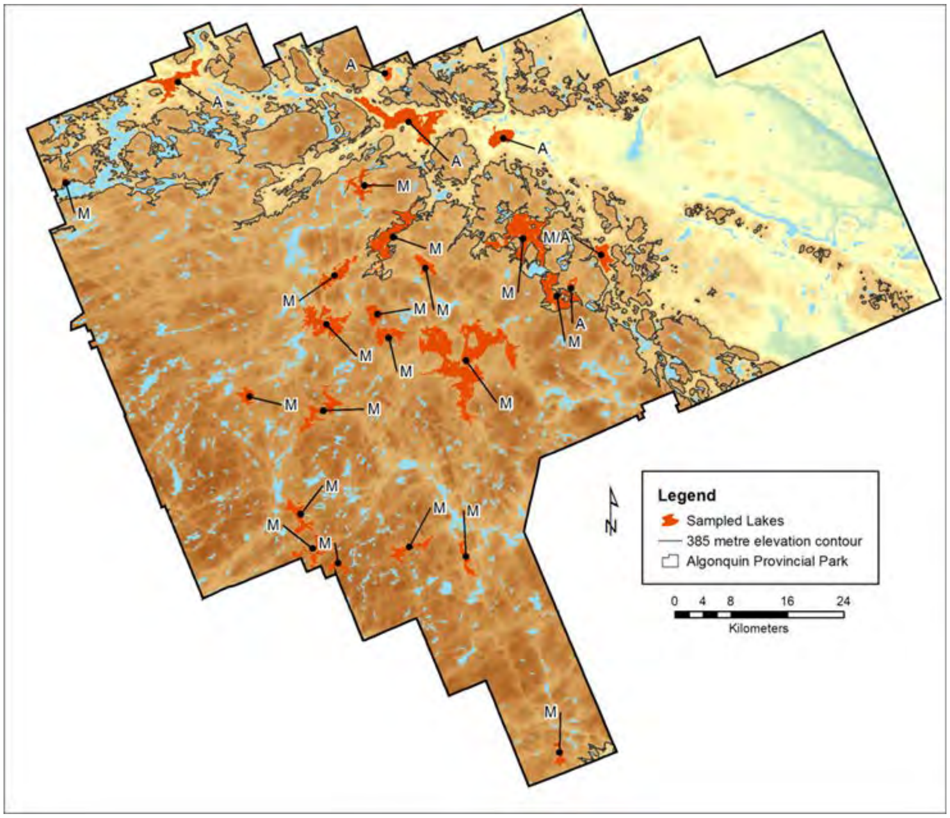


Figure 8. The representation of lake trout lineages from the Mississippian (M) and Atlantic (A) glacial refuges[27].

The end of the Glacial Great Lakes

The end of the Glacial Great Lake era came suddenly. Approximately 8,500 cal yrs BP a combined Glacial Lake Agassiz/Barlow-Ojibway represented the waters of what were 2 separate lakes (Figure 3g). Agassiz formed initially in northwestern Ontario for approximately 5,000 cal yrs[9,13] (13,000–8,450 cal yrs BP) and Barlow-Ojibway formed from below James Bay in the north and Lake Temiskaming to the south and remained separate from Agassiz for 3,000 cal yrs[8,9] (11,700–8,880 cal yrs BP). Through its time as a separate lake, Barlow-Ojibway drained south through the Ottawa River valley while Agassiz drained in its later stages through multiple outlets on the west side of Lake Nipigon and eastward through the early Laurentian Great Lakes. The lakes were combined for approximately 4 centuries before the end. Their combined waters covered 841,000 km² representing 3.5 times the total surface area of the current Laurentian Great Lakes (244,079 km²) [9]. It was the last significant glacial Great Lake and it drained through the Ottawa River valley to the south.

At the end, glacial Lake Agassiz-Ojibway was held back by the remains of the Laurentide Ice Sheet at a lake level approximately 200 m above sea level[28]. The ice sheet formed a horseshoe shape over what is now the coastal area of Hudson Bay with a large iceberg calving front in the middle area of the horseshoe. The remaining Laurentide Ice Sheet was in decline at this time with melting and loss of icebergs on the north side as well as melting and runoff on the south side. By 8,450 cal yr BP, the force of water held back by the ice front was sufficient to float the remaining ice sheet in an area along southern Hudson Bay causing escape of melt water beneath the ice sheet into Hudson Bay(28). This event raised sea levels, freshened the North Atlantic for a second time causing changes in ocean currents, changed atmospheric circulation and led to global cooling period approximately 8,200 cal yrs BP(13,15b,28). The depth contours of Hudson Bay and its substrate material retain the marks of this event. The final outburst of Lake Agassiz-Ojibway ended the Ottawa River valley as a drainage system for Glacial Great Lakes.

The volume of water in the final outburst of the last Glacial Great Lake was approximately 163,000 km³ and occurred over one year at a rate of 5,000,000 m³/sec(11). Two comparisons help put this into perspective. The Laurentian Great Lakes hold 23,000 km³ of water with an average rate of flow through the St. Lawrence River of 16,800 m³/sec. The rate of flow into Hudson Bay in the year of the outburst was over 10 times the combined annual outflow of the world's current top ten rivers (top ten rivers average annual flow = 447,048 m³/sec; Mississippi River watershed is 10th largest in the world).

The Ottawa River valley

The Ottawa River valley drained the Glacial Great Lakes for approximately 4,000 years(7)(12,500–8,500 cal yrs BP; Table 1). At one period or another, the Ottawa River Valley was receiving water flow draining 2 sets of Great Lakes — the early Laurentian Great Lakes via the Lake Nipissing outlet as well as the flow from the combined lake system of Agassiz-Ojibway(6,7,8,9). For an additional 3,000 years, after the demise of Lake Agassiz-Ojibway in its final outburst to Hudson Bay, the Ottawa River Valley continued to receive water flow from early Lake Huron(8). At approximately 5,500 cal yrs BP, isostatic rebound reduced eastward flow from Lake Huron to the Ottawa valley and Lake Nipissing began its now recognized feature of draining westward to Lake Huron via the French River.

From the time when the northern regions of Algonquin Park began to serve as drainage for Main Phase Lake Algonquin through to the formation of the Laurentian Great Lakes, the drainage networks of Algonquin Park and the Ottawa Valley carried a large proportion of melt water in eastern North America and subsequently the early drainage of the developing Laurentian Great Lakes — for a total duration of approximately 7,000 cal yrs.

Table 1. Events occurring during the retreat of the Laurentide Ice Sheet for the Great Lakes basin and Algonquin Park. Years are expressed as calibrated years before present (cal yr BP), representing calendar years. Source literature expressing timing of Laurentide Ice Sheet retreat in 14C years was converted to cal yrs BP using the Fairbanks et al (2005) calibration model[10].

Years ago (cal yr BP)	Ice age landmark description [6,7,9]
21,300	• Maximum extent of the Laurentide Ice Sheet (LIS) south of Great Lakes Basin. No pro-glacial lakes at the ice front because location was south of Great Lakes Basin divide.
16,500	• Southwest Lake Erie basin opens permanently to begin retreat of the LIS from Great Lakes Basin. The era of the Glacial Great Lakes begins.
15,600	• Southern Lake Huron basin ice-free with periods of LIS re-advances.
14,000	• Early glacial Lake Algonquin forms in southern Lake Huron basin. Northern Lake Huron basin remains locked in LIS.
13,800	• Kirkfield outlet opens at Fenelon Falls initiating the Kirkfield phase of Lake Algonquin. Lake Algonquin covers ice-free areas of current Lakes Huron and Michigan basins. Southern edge of the LIS located in the current North Channel of Lake Huron.
13,600	• Southern Algonquin Park released from LIS.
13,000	• LIS retreats beyond the northern edge of Algonquin Park and locates in the Ottawa Valley. LIS retreat from Algonquin Park lasts for ~600 cal yrs. This is the period of fish colonization on the Algonquin Park highlands. • Main Lake Algonquin extends over the current basins of Lakes Huron, Michigan and most of Superior; connects with glacial Lake Agassiz in the west resulting in a drainage area extending westward to what is now the Saskatchewan River. Drainage of this area runs along the LIS front in the Ottawa Valley. • End of the Kirkfield outlet phase (~800 cal yrs) of Lake Algonquin through isostatic rebound.
12,500	• Lake Agassiz drains northwest to the Arctic Ocean via the MacKenzie River valley, raises sea levels in the Arctic by 6 m, freshens the North Atlantic Ocean causing changes in currents and alters global weather for centuries. This event ends the Pleistocene era (the Younger-Dryas event). The Holocene era begins.

Years ago (cal yr BP)	Ice age landmark description [6,7,9]
	• High water phase of Lake Algonquin has lasted ~600 years. Ice receding from the highlands south of North Bay remove an ice dam (at Deux-Riviere) supporting main Lake Algonquin and drainage via a series of outlets in the Ottawa Valley begins. This ends the pro-glacial period in the Lake Huron basin and begins a period of phased descent in water levels as a series of drainage outlets lowers Lake Huron basin water. • Champlain Sea approaches Algonquin Park from the east as far as Round Lake/Golden Lake and Petawawa.
11,400	• Lake Algonquin has drained through a series of Ottawa Valley outlets. Over the past ~1000 cal yrs, outlets such as the Fossmill, Sobie-Guillemette, and Mattawa have drained water from the Huron basin. • The period of drainage from the main Lake Algonquin phase through to the period of descending outlets corresponds to the period of fish and invertebrate colonization by species via Fossmill, Sobie-Guillemette and Mattawa outlets. • The Ottawa Valley also continues to drain water from glacial Lakes Agassiz (via Lake Nipigon) and Ojibway from the northwest and north, respectively. Two major drainage systems therefore meet in the Ottawa Valley north of Algonquin Park.
8,450	• Glacial Lake Agassiz/Ojibway breaks through ice barrier in Hudson Bay, drains in one year, and ends the era of the Glacial Great Lakes. This era lasted in Ontario for ~8,000 cal yrs. • Ottawa River ceases to be drainage of these pro-glacial lakes but continues to drain Lake Huron via Lake Nipissing. The Ottawa valley watersheds drained pro-glacial lakes for ~4,000 cal yrs.
5,500	• Drainage from Lake Huron through Lake Nipissing to the Ottawa valley ceases through isostatic rebound and reverses direction. This begins flow of Lake Nipissing to Lake Huron, isolates the Ottawa River from the Great Lakes, and initiates the drainage pattern we recognize today. • Ottawa Valley and River drained pro-Glacial Lakes and Laurentian Great Lakes for ~7,000 cal yrs.

Algonquin Park landforms from glacial history

The retreat of the Laurentide Ice Sheet is often described at large scales focusing on the main glacial Great Lakes and their drainage patterns among regions of North America. There is less known about the drainage networks below this level of observation for smaller landscapes such as Algonquin Park, especially if these landscapes were not inundated by drainage from glacial Great Lakes. The lack of a fine-scale focus should not be interpreted as the absence of lakes and drainage patterns in Algonquin Park relative to landscapes at larger scales [7,8].

Landforms and surficial geology left behind from the retreat of the Laurentide Ice Sheet can be informative about the patterns of ice retreat at scales within the park boundaries (Table 2). Figures 9, 10, and 11 provide map coverage of surficial geology associated with glacial retreat (Figure 9), the source of the glacial material (glacial deposit vs. glacial rivers; Figure 10), and the landforms left behind from glacial retreat (eg., drumlins, *eskers*, etc.; Figure 11). In the aggregate, the maps show that glacial retreat in Algonquin Park was not a uniform retreat northward of the ice front but rather a complicated system of runoff and drainage connections, perhaps with pockets of glacial ice remaining for periods of time.

First, and most generally, there is a complex of glacial deposits in Algonquin Park leading to differences among regions in content and processes at a landscape level within the park. Second, these arise directly from patterns of glacial retreat below scales typically used to describe retreat of the Laurentide Ice Sheet. Locations with deposits that are unsorted are labelled as glacial deposits and are largely defined by tills. Locations with deposits that are sorted (based on particle size) through melt water flow are labelled as glaciofluvial deposits and are largely defined by sands and gravels. There are several regions showing different patterns of landforms among the complex surficial geology left by glacial retreat. These are highlighted by bounded areas in different regions within Algonquin Park.

The area marked as A in Figures 9–11, aligns with the Nipissing River basin. In this area, there is a large proportion of surficial material classified as sand and gravel (Figure 9) corresponding to runoff from a glacier (=glaciofluvial origin in Figure 10). The Precambrian bedrock is largely buried given the extent of coverage by glacial deposits. The landforms remaining from this runoff pattern is a complex pattern of *kame* moraines and eskers (Figure 11). Kames are mound-like deposits of sorted materials collected in depressions of glaciers and deposited on the landscape when glaciers fully melted. Kames can also be ice-contact deltas formed by streams flowing off of, and through and around, the front edge of receding glaciers. Areas with this drainage pattern are kames because sediments are sorted and stratified by the action of stream flow. Kame deltas are deposited when flow enters a lake at the edge of a glacier. The landscape of the Nipissing River in area A appears to be a large kame delta system formed from drainage of the upper Nipissing River and higher elevation regions north and south of this watershed. Gaps in the kame delta may represent sites of isolated glacial ice deposited by a retreating glacier with runoff streams flowing around remnants of glacial ice.

Eskers represent sub-glacial stream flow prior to full melting, that are now detected as a gravel ridge. The orientation of the major esker in area A (Figure 11) points in the direction of flow indicating drainage was from southwest to northeast. The delta-like pattern of the sand, gravel and the large esker indicate extensive drainage systems beneath and at the trailing edge of receding glaciers in what appears to be a large basin-like area in the upper Nipissing River watershed.

The area marked as B in Figures 9–11 aligns with the upper watershed area of the Muskoka River. In this area, in contrast to the Nipissing River watershed, very little surficial geology remains as sands or gravels, and with only a relatively sparse covering of tills. Precambrian bedrock is the dominant form of surficial geology (Figure 9) suggesting that runoff was rapid and/or on a relatively steep gradient. The accumulation of surficial material was not the outcome of glacial retreat for this upper watershed as it was for the Nipissing River watershed (Figure 10). Figure 11 indicates that some of this watershed was a *spillway* for glacial flow which may have led to some of the till deposits (Figure 9) but little of the surficial geology in the upper watershed of Muskoka River remains as glacial material.

The area marked as C in Figures 9–11 aligns with the lower Petawawa River watershed and is centred on Lake Traverse. As in the Nipissing River watershed (area A), there is extensive coverage by sands and gravels with relatively more coverage by *diamicton tills* (Figure 9). The surficial geology was a combination of glacial deposits and glaciofluvial runoff. In contrast to the Nipissing River watershed where kame moraines and a large esker reflect glacial melt processes, the landform left by glacial retreat in this watershed was largely formed by spillways (Figure 11). Glacial spillways represent water flow, often at high volume, that form cut valleys through surficial material until a resistant geological layer is reach effectively forming the bed of the drainage system.

The area marked D in Figures 9–10 aligns with the Lakes Opeongo–Lavieille area and includes the upper watershed of the Opeongo River (Lake Opeongo) and the Crow River (Lake Lavieille). This area is defined by a greater proportion of till with some sand and gravel substrates interspersed among the till landscape (Figure 9). Most of this area is defined by glacial deposition with some glaciofluvial areas (Figure 10). Area D is a mix of 2 predominant melt water processes; spillways from Lake Opeongo towards the east and kame delta systems from Lake Opeongo towards the west (Figure 11). Eskers in area D and in areas to the west of area D point to the northeast indicating the directional flow of water beneath the retreating glacier. Interestingly, east of area D, are eskers aligned in a northerly direction indicating that in this region of Algonquin Park melt water from glacial retreat was in a different direction than in the central uplands north of area D.

The general pattern of glacial processes on the uplands of Algonquin Park can be partitioned into an east and west pattern centred on the Lake Opeongo watershed (Figure 11). In the west, kame deltas and kame formations formed through the melt water of the surface of the glacier, and in and around the remnants of glaciers forming a delta like pattern. In the east, spillway patterns appear to be more prevalent than kame delta formations pointing to strong runoff patterns producing the sorted glaciofluvial deposits. Both regions have sands and gravels from relatively different glaciofluvial processes. Outside of these areas, unsorted glacial tills (ie., diamicton tills) were deposited by glacial melting.

Table 2. The percentage composition of glacial material as surficial geology in tertiary watersheds of Algonquin Park based on Figure 9.

Watershed name	Material type in Algonquin Provincial Park as percent composition by watershed						
	Diamicton till	Gravel	Organic deposits	Precambrian bedrock	Sand	Silt	Lake
French	8.6	14.3	5.4	56.3	7.4	0.0	8.0
Magnetawan	0.2	11.4	4.6	75.3	2.2	0.0	6.4
Muskoka	5.7	7.2	4.4	68.5	1.3	0.1	12.7
Gull	20.5	23.3	6.2	44.7	0.2	0.0	5.2
Kipawa	24.7	15.3	3.9	36.3	5.5	0.1	14.2
Dumoine	33.1	16.4	12.4	33.1	0.7	0.0	4.3
Petawawa	18.5	22.0	6.6	40.3	3.1	0.0	9.5
Bonnechere	24.9	20.5	5.9	42.3	1.0	0.0	5.4
Upper Madawaska	22.2	10.7	7.6	46.6	1.2	0.0	11.7
Algonquin total (km^2)	**1472**	**1308.8**	**492.7**	**3375.5**	**196.0**	**1.9**	**782.5**

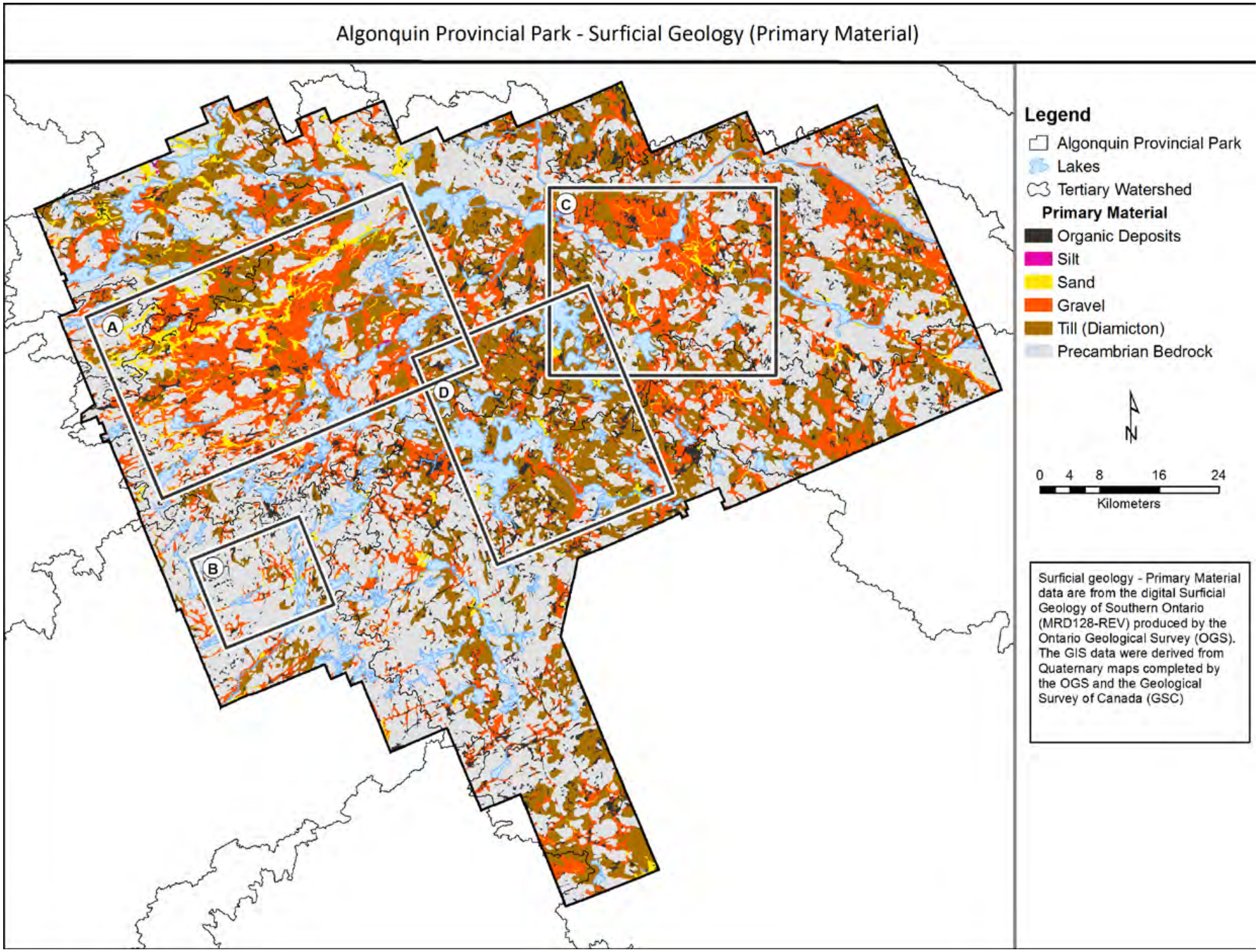


Figure 9. The distribution of primary surficial glacial material in Algonquin Park. Grey lines are tertiary watershed boundaries. Boxes A–D are specific regions of the park referred to in the text for Figures 9–11.

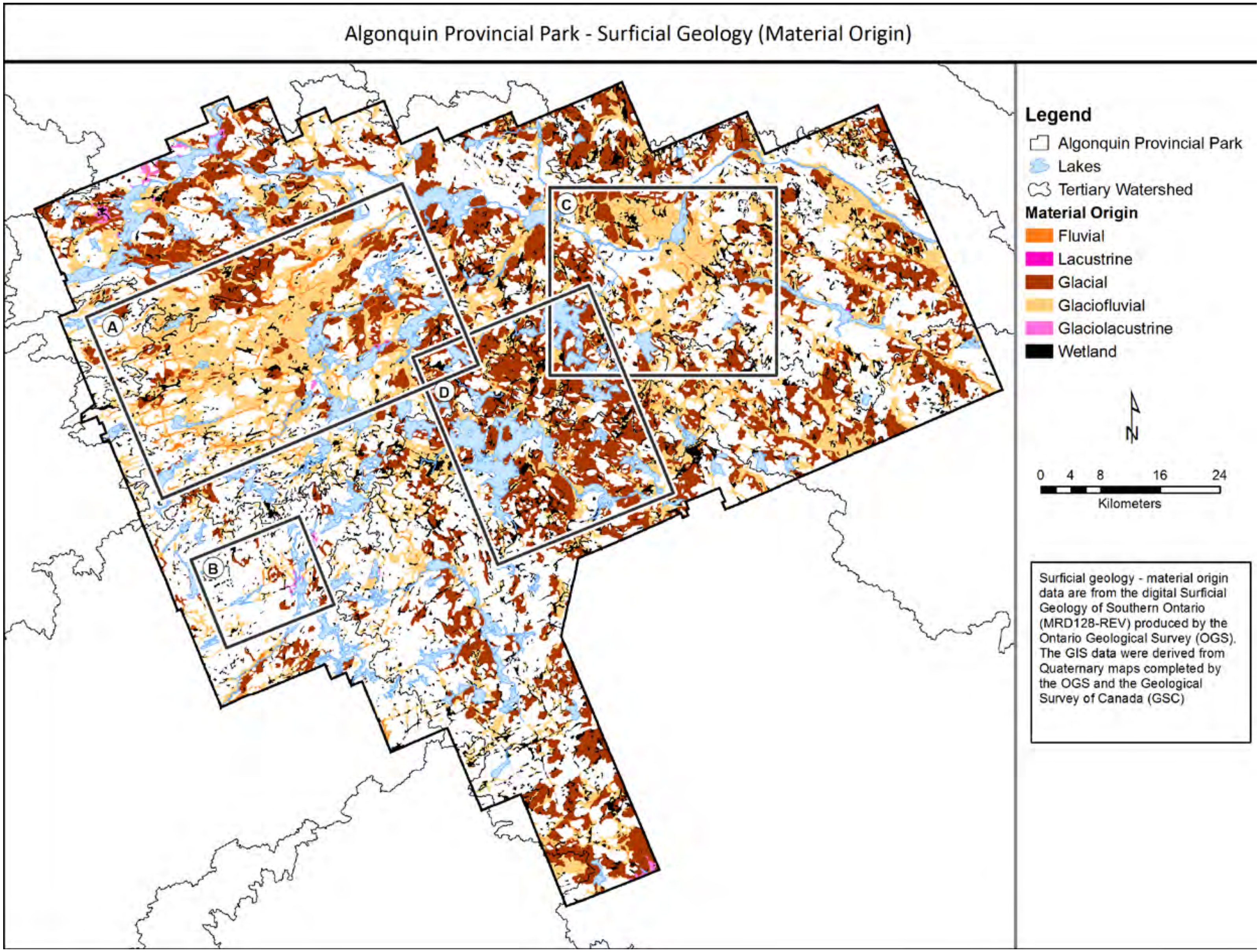


Figure 10. The distribution of material origin for surficial geology in Algonquin Park.

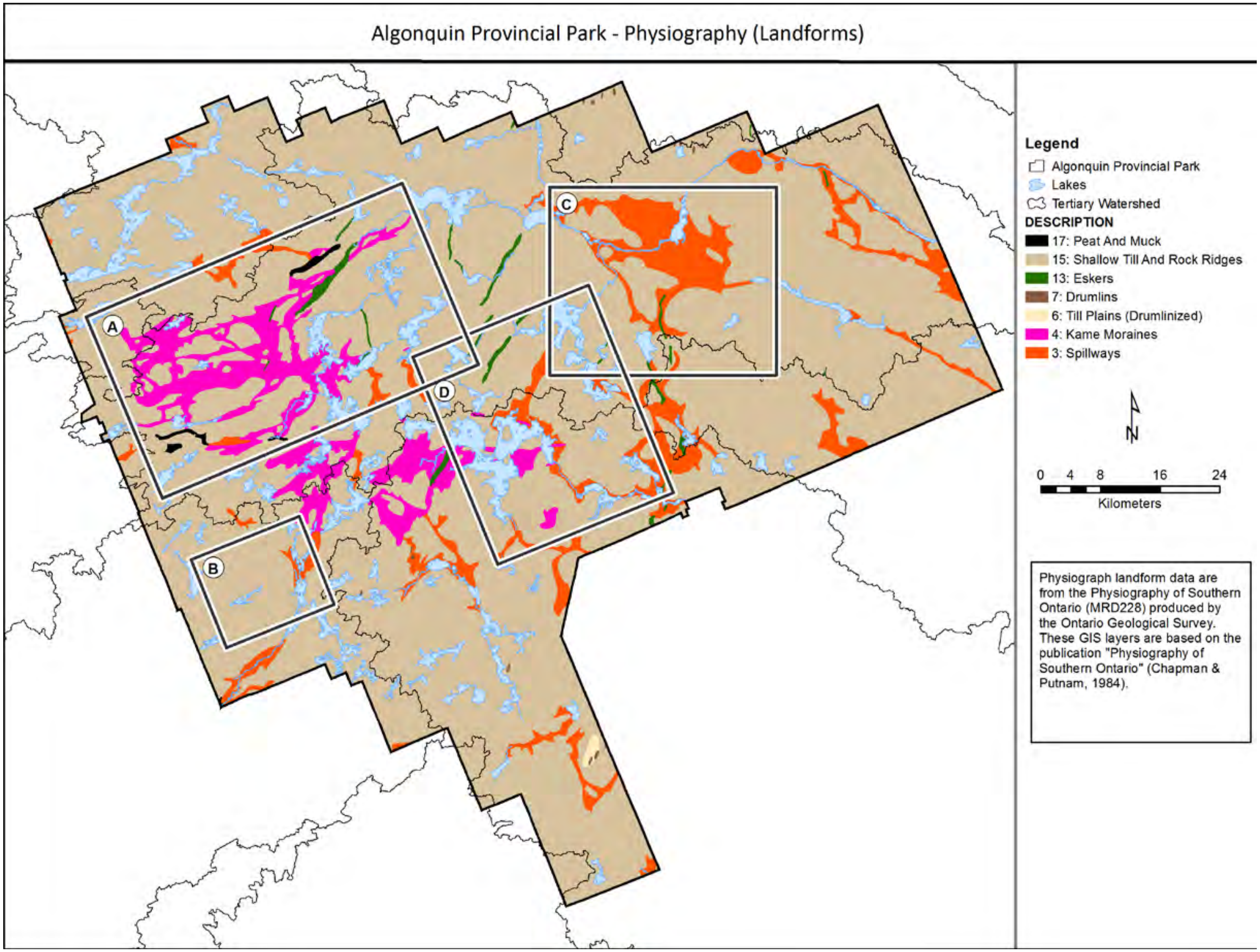


Figure 11. The glacial landforms distributed in Algonquin Park. The spillways now bisected by current tertiary watershed boundaries are likely the result of isostatic rebound since glacial retreat.

Watersheds of Algonquin Park

Water flowing in lakes and rivers can be organized into drainage basins. Drainage basins delineate the land area where all surface water flows from higher elevations to a single point at a lower elevation. Water flowing to this single point will generally join another waterbody such as a river, lake, wetland, sea, or ocean. In North America, a drainage basin is generally referred to as a watershed and is a reference to an area of land. In some countries, the term watershed refers specifically to the height of land which delineates drainage basins. In this document we use the term watershed in the North American sense.

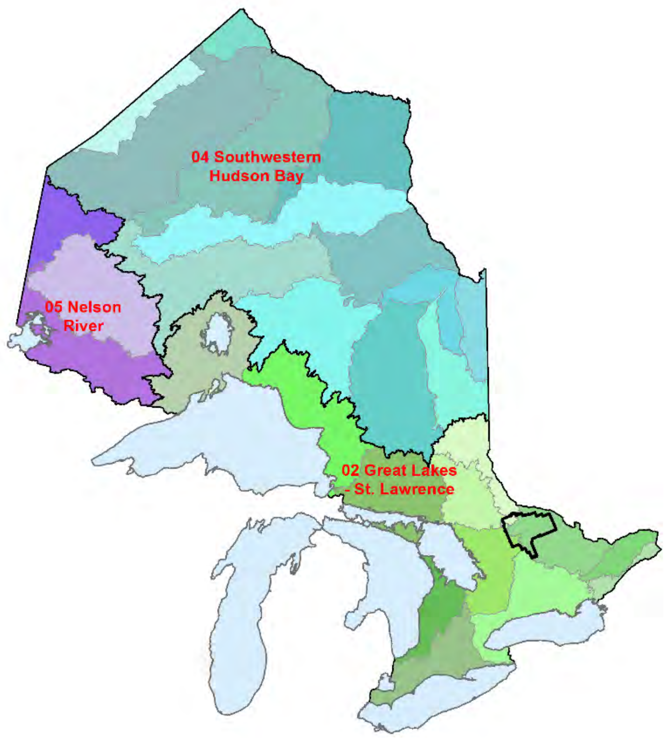


Figure 12. Primary and secondary watersheds of Ontario. The location of Algonquin Provincial Park is outlined in black.

Watersheds are hierarchically organized, with smaller watersheds nested inside larger ones. The terms primary (1st order), secondary (2nd order), tertiary (3rd order), and quaternary (4th order) are used to describe watersheds at increasing levels of nestedness. Primary watersheds are subdivided into secondary watersheds which are divided into tertiary watersheds which, in turn, are divided into quaternary watersheds.

Ontario is divided into 3 primary watersheds, Southwestern Hudson Bay, the Nelson River and the Great Lakes - St. Lawrence (Figure 12). All of Southern Ontario, including

Algonquin Provincial Park, drains through the Great Lakes - St. Lawrence Watershed eventually out into the Atlantic Ocean.

The Great Lakes - St. Lawrence watershed is subdivided into 12 secondary watersheds. Waters flowing from the height of land often referred to as the Algonquin Dome contribute to 5 secondary watersheds, Table 3. Headwater lakes for each of these watersheds are within the park boundaries and their protection is, in part, one of the reasons for the establishment of the park.

Headwater areas provide the source for many springs, seeps, and intermittent creeks which ultimately flow downslope resulting in a network of streams and lakes at lower elevations. Headwaters provide a supply of essential nutrients and clean, cool, well-oxygenated water to downstream reaches.

Table 3. List of secondary watersheds which intersect Algonquin Provincial Park, and their principal river systems.

Code	Secondary watershed name	Principal river/stream systems
2K	Central Ottawa	Petawawa R., Bonnechere R., Madawaska R., York R.
2H	Lake Ontario & Niagara Peninsula	Gull R.
2E	Eastern Georgian Bay	Muskoka R. , Magnetawan R.
2D	Wanipitei and French	South R.
2J	Upper Ottawa	Amable du Fond R.

Secondary to tertiary watersheds of Algonquin Park

Within Algonquin Provincial Park waters flow radially off the dome in 3 principal directions, west into Georgian Bay, east into the Ottawa River, and south into Lake Ontario (Figure 13) via 8 main river systems, 9 if you include the Gull River system which has its origins in the southwest side of the Park’s panhandle at Percy Lake. (Table 4).

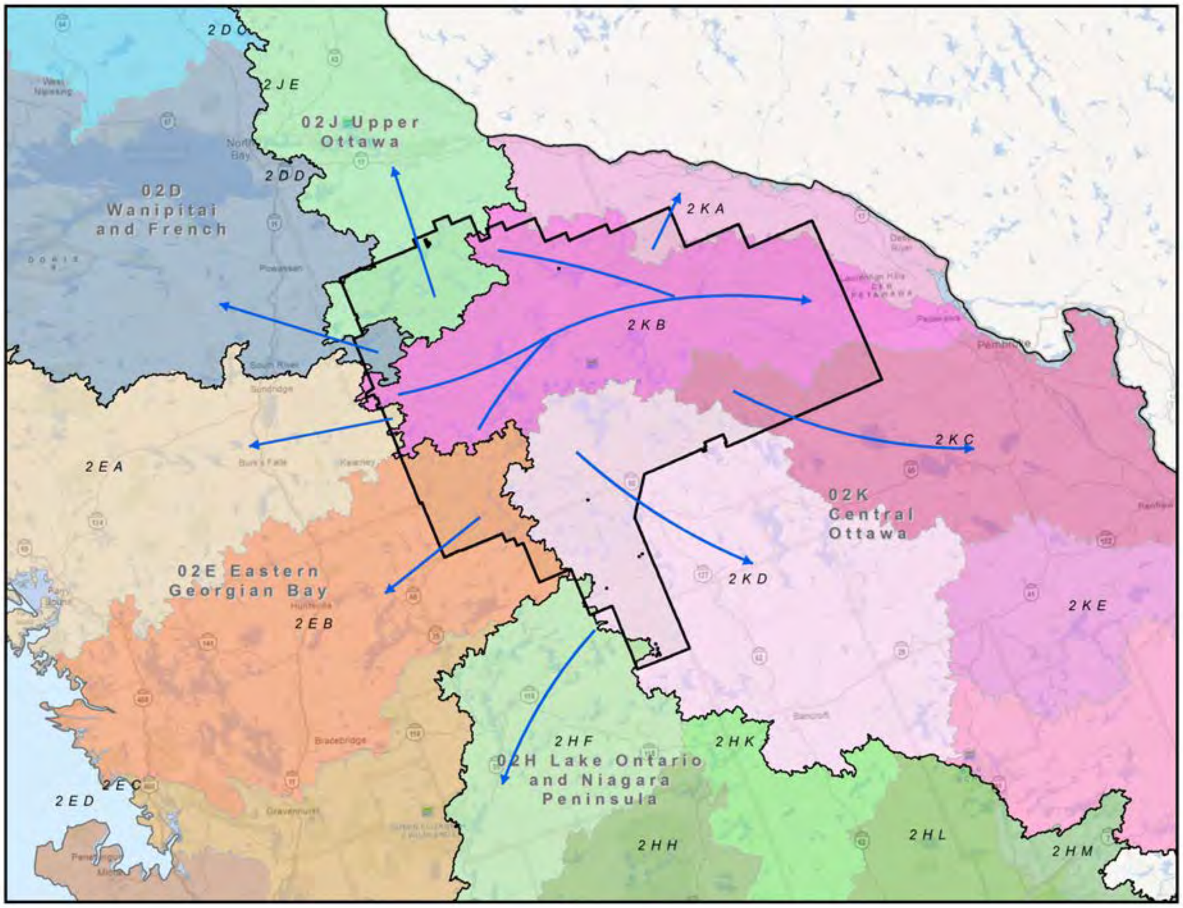


Figure 13. Secondary and tertiary watersheds of Algonquin Provincial Park. Blue arrows indicate general direction of waterflow. Bold lettering indicates the secondary watershed code and name.

Table 4. Summary of the large watersheds covering Algonquin Park. The total areas of each watershed are partitioned into the area and percent of total third order watershed within the boundaries of Algonquin Park.

2° Watershed name	3° Watershed name	3° Watershed code	Total area (km²)	Area within Algonquin Park (km²)	% in Algonquin Park	Headwaters primarily within Algonquin
Wanipitei and French	French	2DD	8875.4	127.3	1.4	No
Eastern Georgian Bay	Magnetawan	2EA	6039.6	30.4	0.1	No
	Muskoka	2EB	5634.6	655.7	11.6	Yes
Lake Ontario	Gull	2HF	3247.7	40.9	1.3	No
Upper Ottawa	Kipawa	2JE	6368.5	638.9	10.0	No
Central Ottawa	Dumoine	2KA	1692.7	163.5	9.7	No
	Petawawa	2KB	4191.2	3672.0	87.6	Yes
	Bonnechere	2KC	4225.0	524.8	12.4	Yes
	Upper Madawaska	2KD	6237.8	1780.0	28.5	Yes

Tertiary to quaternary watersheds of Algonquin Park

There are 9 tertiary (or third order) watersheds which encompass a portion of Algonquin Provincial Park. (Table 4). The extent of their area within and outside Algonquin Park can be seen in Figure 13. Together, the Petawawa and Upper Madawaska watersheds, cover over 70% of the surface area of the park and contain some of its most significant river systems such as the Nipissing, Petawawa, and Madawaska Rivers. Other watersheds, while only covering a small portion of the park's area, have their headwaters contained with the park boundaries and thus rely on park management practices for their protection. Maps for each tertiary watershed showing tertiary and quaternary watershed boundaries as well as lakes names for lakes larger than 10 ha are located at the end of this chapter (Figures 18–29)

Description of tertiary watersheds

2K — Central Ottawa — The Central Ottawa watershed contains 4 tertiary watersheds which intersect Algonquin Provincial Park. It includes the park's largest watershed, the Petawawa which covers nearly 50% of the total park area.

- 2KA — Dumoine
  The majority of this watershed lies in Quebec and is drained by the Dumoine River which empties into the Ottawa River near Rapides-des-Joachims in Quebec (Rolphton, Ontario). South of the Ottawa River a small portion of this watershed drains several small lakes within Algonquin Park including Bisset and Big Bisset Lakes through Bisset Creek into the Ottawa River. In the northeast corner of the park Kellys Lake and Hogsback Lake are included in this watershed (Figure 18).
- 2KB — Petawawa

  The Petawawa watershed by far covers the largest area of the park (3600 km²) and drains several major river systems including its namesake, the Petawawa. The total area drained by this watershed is 4200 km². The Petawawa River proper originates on the west side of Algonquin Park at Ralph Bice Lake which has its headwaters just outside the park boundary. Along the way to its outflow at the city of Petawawa the river takes in several major tributary rivers including, in downstream order, the Tim, Nipissing, Little Madawaska, North, Crow, and Barron Rivers.

  The Petawawa watershed extends clear from the west to the east side of Algonquin Park and encompasses many signature lakes and river systems within the park. Within the watershed there are several operational water control structures which may in the future represent biosecurity control options. Given the extent of this watershed within the park and that its headwaters at the westernmost end lie on the boundary of the park both the risk and impact of the introduction of non-native species has to be carefully considered (Figures 19–21).

  2KC — Bonnechere

  The Bonnechere watershed has its headwaters entirely within Algonquin Park and is drained by the Bonnechere River beginning at McKaskill Lake. The river continues through Round and Golden Lakes outside the park to eventually drain into the Ottawa River at Lacs des Chats south of the town of Castleford (Figure 22).

- 2KD — Upper Madawaska
  The Upper Madawaska watershed contains the Madawaska River and its main tributaries, the Opeongo, York, and Galipo Rivers. The lower limit of the Upper Madawaska river watershed is considered to be just west of where the Madawaska is joined by the York River. The Madawaska continues to flow through the Lower Madawaska River watershed eventually emptying into the Ottawa River at Arnprior. In this watershed there are several water control structures within or adjacent to Algonquin Provincial Park. (Figures 23–24).

2H — Lake Ontario and Niagara Peninsula

- 2HF — Gull
  Only a small portion of the Gull River watershed lies within Algonquin Park. The Gull River itself originates at Longboot Lake within the southern portion of the park. The Redstone River, a tributary of the Gull also has its origins inside the park at Upper Redstone Lake. The Gull River continues south through Haliburton eventually reaching Silver Lake. The Gull Rriver is an integral part of the Trent-Severn Waterway acting as water storage to maintain water levels in the canal system (Figure 25).

2E — Eastern Georgian Bay

- 2EB — Muskoka
  The Muskoka River has its origins in several sources within Algonquin Park. McCraney, Rain and West Harry Lakes drain into the Muskoka River via the Big East River, while the Oxtongue River drains Brown, Burnt Island, and Big Porcupine Lakes via Tea Lake. In the southern portion of the watershed Hinterland Creek drains several small lakes including Dividing, Whatnot, and McGarvey Lakes. Hinterland Creek eventually joins the Hollow River flowing into Kawagama Lake. While most of the watershed has its origins within the park boundaries, Crown Lake is in part of the watershed located outside the park and flows into Ragged Lake (Figure 26).

- 2EA — Magnetawan
  The Magnetawan River watershed barely intrudes into the park boundary. It lies adjacent to the Petawawa river watershed but flows west. The watershed only

contains several small lakes within the park, most notably Magnetawan Lake. The Magnetawan River flows through Parry Sound District and empties into Georgian Bay at the community of Britt (Figure 27).

2D — Wanipitei and French

- 2DD — French
  Directly north of the Magnetawan River watershed lies the French River watershed. Like the Magnetawan, the French barely enters the park but drains several lakes and creeks through the South River system. These include Winifred and Togo Lakes in the southern edges of the watershed and Pishnecka and Jeepi Lakes in the North. Eventually the South River flows into the southeastern end of Lake Nipissing forming the French River at the outflow of the lake (Figure 28).

2J — Upper Ottawa

- 2JE — Kipawa The majority of this third order watershed lies north of the Ottawa River and takes its name from the major river in it, the Kipawa. South of the Ottawa River, the Amable du Fond River drains north from the Algonquin Dome joining the Mattawa River at Samuel du Champlain Provincial Park. Much of the Amable du Fond river system originates outside the park boundaries. The Amable du Fond River itself originates at Pipe Lake then flows out of the park into Kawawaymog Lake. Shaw, Denis and Corkery Lakes flow into Kawawaymog flow as well. Also outside the park, Boon and Kuwasda Lakes flow through Kakasamic Lake and on into Lake Manitou. Stove, Tyne and Little Tyne Lakes join the outflow from Kawawaymog and enter the park through at North Tea Lake. The Amable du Fond river continues inside the park through Manitou and Kioshkokwi Lake, exiting the park at Kiosk. Lauder, Mink and several other lakes with interesting post glacial aquatic fauna also flow out of the park through the Amable du Fond River. (Figure 29).

Quaternary watersheds of Algonquin Provincial Park

In total there are 44 quaternary (fourth order) watersheds that are entirely contained within or which intersect Algonquin Provincial Park. The geographic extent of these watersheds is provided in Figure 14. A complete list of these watersheds and a summary of landcover characteristics obtained from the Provincial Land Cover (2000) Data Base are provided in Table 5.

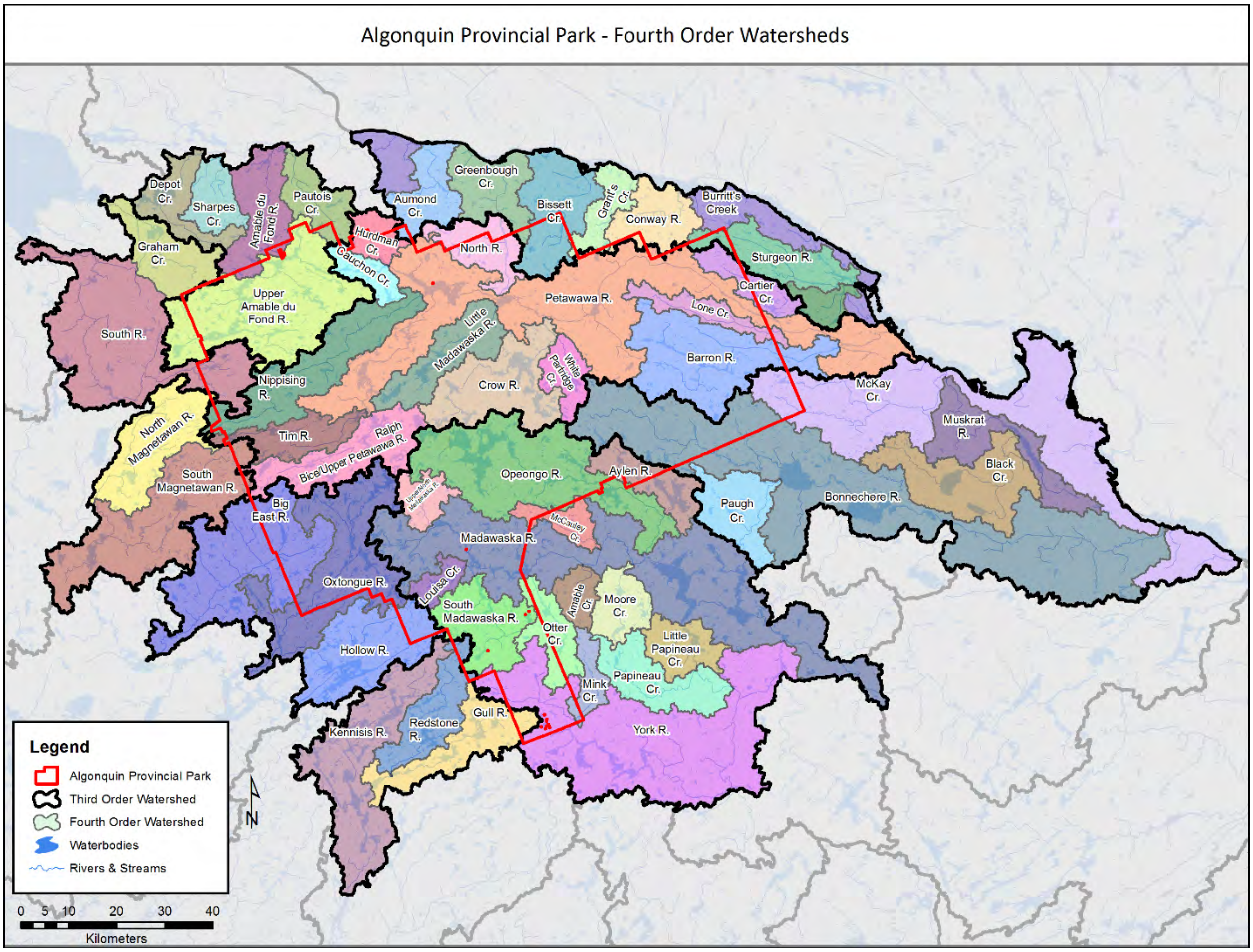


Figure 14. The fourth order watersheds of Algonquin Park and adjacent watersheds.

Table 5. A list of the fourth order watersheds within or partially within Algonquin Provincial Park, a summary of primary landcover classes for each watershed and counts with statistics for lakes with surface areas greater than 5 hectares within the watershed. Land cover is derived from the 27 class Provincial Land Cover (2000) Data Base. Lake count is derived from the Ontario Hydrographic Network Waterbody layer.

Watershed		Total area (km.²)	Landcover area of watershed and area within Algonquin Provincial Park (km.²)				For lakes > 5 ha.				
								Area statistics (ha.)			
Code	Name		Total	Water	Forested	Fen/bog	Count	Minimum	Maximum	Average	Total
02DD–22	Graham Cr.	235.7	3.7	0.3	3.5	0.0	2	5.4	27.5	16.4	32.9
02DD–23	South R.	828.6	123.7	9.7	107.5	6.6	22	5.1	364.8	37.8	831.4
02EA–21	North Magnetawan R.	345.2	1.7	0.0	1.6	0.1	0	0	0	0	0
02EA–22	South Magnetawan R.	644.0	28.9	2.2	26.2	0.5	13	5.1	57.2	12.5	162.5
02EB–11	Oxtongue R.	608.6	412.0	67.6	338.7	3.9	103	5.2	968.4	52.8	5435.2
02EB–12	Hollow R.	409.6	50.5	4.2	44.2	1.8	15	6.0	68.6	19.5	291.9
02EB–15	Big East R.	648.4	193.7	24.3	167.5	1.8	60	5.2	393.3	31.2	1869.0
02HF–08	Kennisis R.	568.9	0.0	0.0	0.1	0.0	0	0	0	0	0
02HF–10	Gull R.	275.9	22.7	1.2	21.2	0.3	4	6.9	28.3	16.1	64.3

Watershed		Total area (km.²)	Landcover area of watershed and area within Algonquin Provincial Park (km.²)				For lakes > 5 ha.				
								Area statistics (ha.)			
Code	Name		Total	Water	Forested	Fen/bog	Count	Minimum	Maximum	Average	Total
02HF–11	Redstone R.	235.4	18.3	1.6	16.2	0.5	5	7.7	43.3	21.8	109.2
02JE–03	Amable du Fond R.	258.5	20.7	0.9	18.9	0.2	4	6.2	43.2	16.9	67.4
02JE–04	Upper Amable du Fond R.	706.0	606.6	96.1	498.3	11.4	111	5.1	1479.9	76.4	8483.6
02JE–05	Pautois Cr.	175.8	12.6	1.3	10.7	0.6	5	5.0	125.6	35.1	175.6
02KA–03	Sturgeon R.	238.4	23.6	1.0	21.4	0.8	3	11.1	29.3	19.1	57.4
02KA–04	Conway R.	198.5	12.4	0.9	11.1	0.4	4	9.1	130.9	43.7	174.7
02KA–05	Grant's Cr.	127.2	6.3	0.5	5.8	0.0	0	0	0	0	0
02KA–06	Bissett Cr.	304.1	106.1	5.4	96.4	4.1	14	5.2	204.3	37.9	531.1
02KA–07	Greenbough Cr.	221.0	8.0	0.3	7.6	0.1	2	6.2	19.8	13.0	26.0
02KA–08	Aumond Cr.	186.2	7.2	0.0	6.8	0.0	2	0.0	8.5	4.3	8.5

Watershed		Total area (km.²)	Landcover area of watershed and area within Algonquin Provincial Park (km.²)				For lakes > 5 ha.				
								Area statistics (ha.)			
Code	Name		Total	Water	Forested	Fen/bog	Count	Minimum	Maximum	Average	Total
02KB–01	Petawawa R.	1383.3	1142.3	121.5	995.2	14.9	141	5.0	2548.6	65.3	9207.9
02KB–02	Barron R.	521.8	460.1	33.5	391.5	6.2	69	5.2	734.9	35.1	2419.8
02KB–03	Lone Cr.	123.4	114.1	2.8	109.2	1.0	6	5.7	34.2	15.8	94.7
02KB–04	White Partridge Cr.	117.5	117.5	11.2	100.4	3.2	17	6.4	586.9	54.8	932.4
02KB–05	Cartier Cr.	126.8	62.8	2.5	57.2	2.8	14	5.1	20.5	9.1	126.8
02KB–06	North R.	181.9	109.2	9.8	97.9	1.2	18	5.3	240.1	51.2	921.8
02KB–07	Hurdman Cr.	96.4	54.6	3.5	50.2	0.5	13	5.3	54.4	19.0	247.0
02KB–08	Cauchon Cr.	95.8	93.2	14.6	77.3	1.2	18	5.1	376.8	67.5	1214.4
02KB–09	Nippising R.	414.6	400.4	18.7	372.4	9.1	54	5.1	168.7	23.1	1245.1
02KB–10	Little Madawaska R.	245.1	245.1	30.5	208.3	6.3	24	5.2	1335.3	109.4	2625.2
02KB–11	Tim R.	178.5	170.4	16.8	151.0	2.6	30	5.0	196.6	42.5	1274.1

Watershed		Total area (km.²)	Landcover area of watershed and area within Algonquin Provincial Park (km.²)				For lakes > 5 ha.				
								Area statistics (ha.)			
Code	Name		Total	Water	Forested	Fen/bog	Count	Minimum	Maximum	Average	Total
02KB–12	Crow R.	387.5	387.5	60.8	320.2	6.6	39	6.1	2229.0	139.3	5432.5
02KB–13	Ralph Bice/ Upper Petawawa R.	319.6	316.8	64.1	246.4	6.3	59	5.1	1558.5	94.4	5566.9
02KC–01	McKay Cr.	1164.9	77.8	5.7	66.7	1.3	17	5.1	188.8	24.7	420.1
02KC–02	Bonnechere R.	1774.0	447.2	23.0	403.7	4.8	67	5.0	280.3	24.5	1644.6
02KD–01	Madawaska R.	1315.5	414.6	57.8	350.0	4.0	88	5.1	618.1	51.1	4501.1
02KD–02	York R.	1185.9	170.9	11.3	157.9	0.8	25	5.1	220.7	30.3	758.6
02KD–09	Aylen R.	180.3	80.0	5.3	68.9	4.1	12	6.1	207.7	35.9	430.4
02KD–10	Opeongo R.	716.1	587.6	109.9	467.8	8.1	87	5.0	5922.2	110.4	9600.5
02KD–15	Otter Cr.	162.1	63.9	2.9	59.9	0.8	6	10.6	551.5	117.6	705.6
02KD–16	Mink Cr.	90.5	9.6	0.5	9.1	0.0	1	16.2	16.2	16.2	16.2

Watershed		Total area (km.²)	Landcover area of watershed and area within Algonquin Provincial Park (km.²)				For lakes > 5 ha.				
								Area statistics (ha.)			
Code	Name		Total	Water	Forested	Fen/bog	Count	Minimum	Maximum	Average	Total
02KD–17	McCauley Cr.	92.1	21.4	1.5	19.8	0.0	10	5.3	42.7	15.9	158.6
02KD–18	South Madawaska R.	257.9	254.4	28.2	221.8	2.8	43	5.1	390.9	50.5	2172.1
02KD–19	Louisa Cr.	70.9	70.9	10.7	59.8	0.4	17	5.1	554.6	49.7	844.7
02KD–20	Upper/North Madawaska R.	101.7	101.7	0.0	0.0	0.0	23	5.5	44.1	17.4	399.1

Lake size distribution

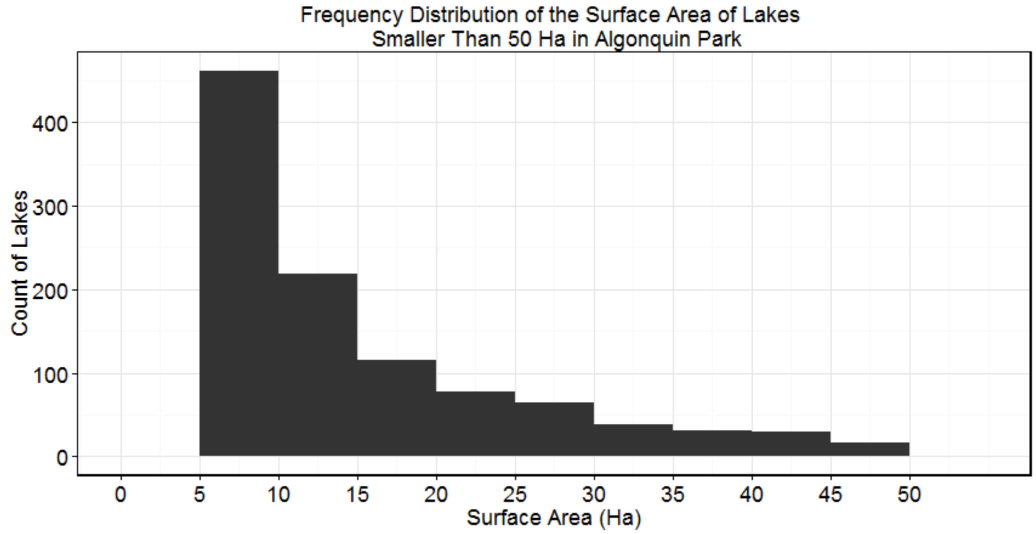
For the purposes of this report we used the Ontario Hydrographic Network Waterbody (OHN Waterbody) layer to characterize the size and distribution of lakes within the park. The OHN Waterbody layer is a compilation of surface water features across Ontario. The layer is considered a live dataset and as such is continually being updated as more accurate information becomes available. For our purposes we extracted water features larger than 5 ha from this layer to summarize. Unless otherwise noted this will define the size limit for a waterbody, or lake, in this report.

The surface area of lakes is referred to as lake size and at a landscape scale the distribution of lake sizes is often skewed to the right. This distibution results because there are many small lakes relative to larger lakes and the appearance of skew reflects landscape slope, history of lake formation, and underlying geology. Areas of Algonquin Park differ in slope and elevation rendering a wide range in lake sizes over the entire park area. Of the nearly 1300 lakes larger than 5 ha within the park, over 1000 are less than 50 ha in area but combined they comprise only 22% (~16,000 ha) of the parks total lake surface area. The distribution of lakes in other surface area categories is presented in Table 6.

Table 6. The number of lakes distributed among different surface area (hectares) categories.

Lake surface area in hectares (ha)	Count	Combined surface area (ha)
5–10	466	3,291
10–25	412	6,330
25–50	180	6,192
50–100	92	6,566
100–1000	109	30,535
1000+	9	18,575

Illustrating the size distribution of lakes within the park requires 2 figures for the distribution of large lakes to be discernable (Figure 15 a and b). At nearly 6000 ha, Lake Opeongo is by far the largest lake in the park followed by Cedar and Laviellle lakes at approximately 2600 and 2200 ha respectively. The 7 largest lakes in the park (Opeongo, Cedar, Lavieille, Big Trout, North Tea, Manitou, and Hogan) comprise a surface area greater than the smallest 1000 lakes combined.



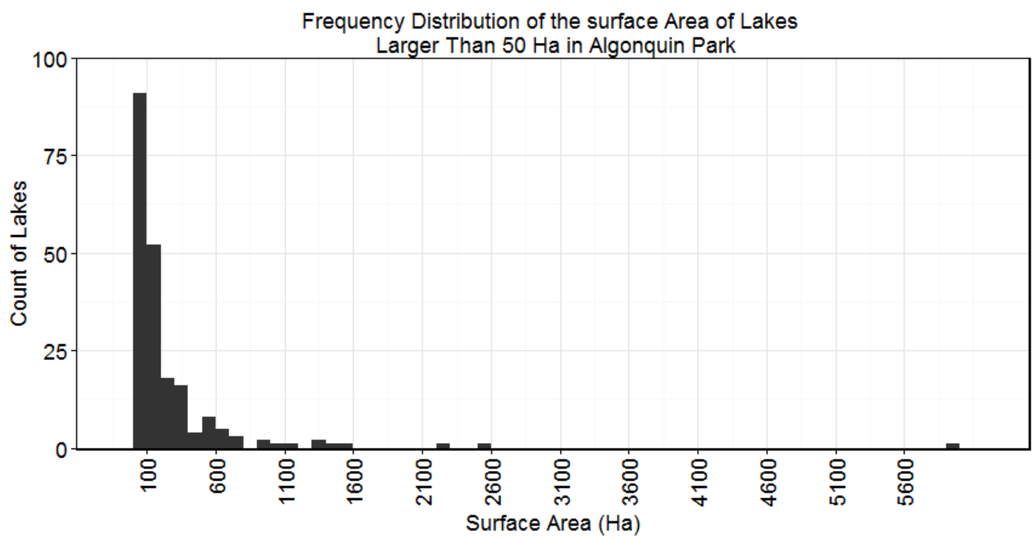


Figure 15. Frequency distribution of lake area 5–50 hectares and 50+ hectares within Algonquin Provincial Park.

Watershed connections in Algonquin Park

While the quaternary watershed boundaries represent the smallest scale available as a provincial dataset it is possible to map watershed boundaries at finer resolutions. Each of the quaternary watersheds mapped previously can be subdivided into progressively smaller watersheds or catchments. Geographic Information Systems tools can be used to analyze properly structured digital elevation models and flow networks to delineate landscape boundaries showing where water falling on the landscape will flow. Ministry of Natural Resources and Forestry (MNRF) has developed the Ontario Flow Assessment Tool Version III[29] (OFAT III), a web based application which allows users to, among other analyses, generate watersheds for any point placed upon a map and estimate various statistics for the resulting watershed.

As the nature of lakes and streams are influenced by the surrounding landscape from which water flows into them we were interested in pursuing finer scale catchments for lakes within Algonquin Provincial Park in order to add another layer to our understanding of their productivity. For each lake larger than 10 ha within the park, the lake outflow was identified and isolated as a pour point, a point where all waters falling upstream must flow through based on elevation. Each pour point was submitted to the OFAT III[29] tool and the resultant catchment boundaries and associated statistics were collated. In total 870 nested catchments were generated, with each downstream watershed containing the catchments upstream of it. For instance, the catchment generated for the pour point located at the McManus Lake outflow contains the catchments of 268 lake outflows which fall inside of it. The entire catchment for McManus Lake essentially encompasses the Petawawa watershed.

Figure 16 illustrates the spatial distribution of 10 hectare lakes across the landscape with each pour point representing one lake outflow, and their associated catchment areas. Various landscape features, including landcover, surficial geology, elevation, and slope have been summarized for each catchment area. Additional landscape features can be easily incorporated into this summary. The distribution of catchment sizes for each lake is represented in Figure 17. Given the wide range of catchment sizes, from 20 ha to 320,000 ha is was necessary to produce the figure using a log base 10 scale for the X axis. What can be seen is that the majority of catchments fall within 100 to 1000 ha.

The distribution of pour points, or outflows of 10+ ha lakes, is not even across the park landscape. Pour point density is highest in the Muskoka River watershed where the landscape is relatively steep and of higher elevation than other areas of the park (Figure 16). There is a higher density of 10 ha or greater lakes stemming from this topography.

In the northeast corner, pour point concentration appears lower because of lower slopes and more consistent elevation across this area of the park, this area has fewer lakes and larger river systems. The landform in this area of the park is largely outwash plains of glaciofluvial origin (Figure 10).

Interestingly, of the 873 catchments identified through this process, 528 contain only their outflow pour point and no others, meaning there are no lakes upstream of them. Water contribution to these lakes is solely through small streams and groundwater input.

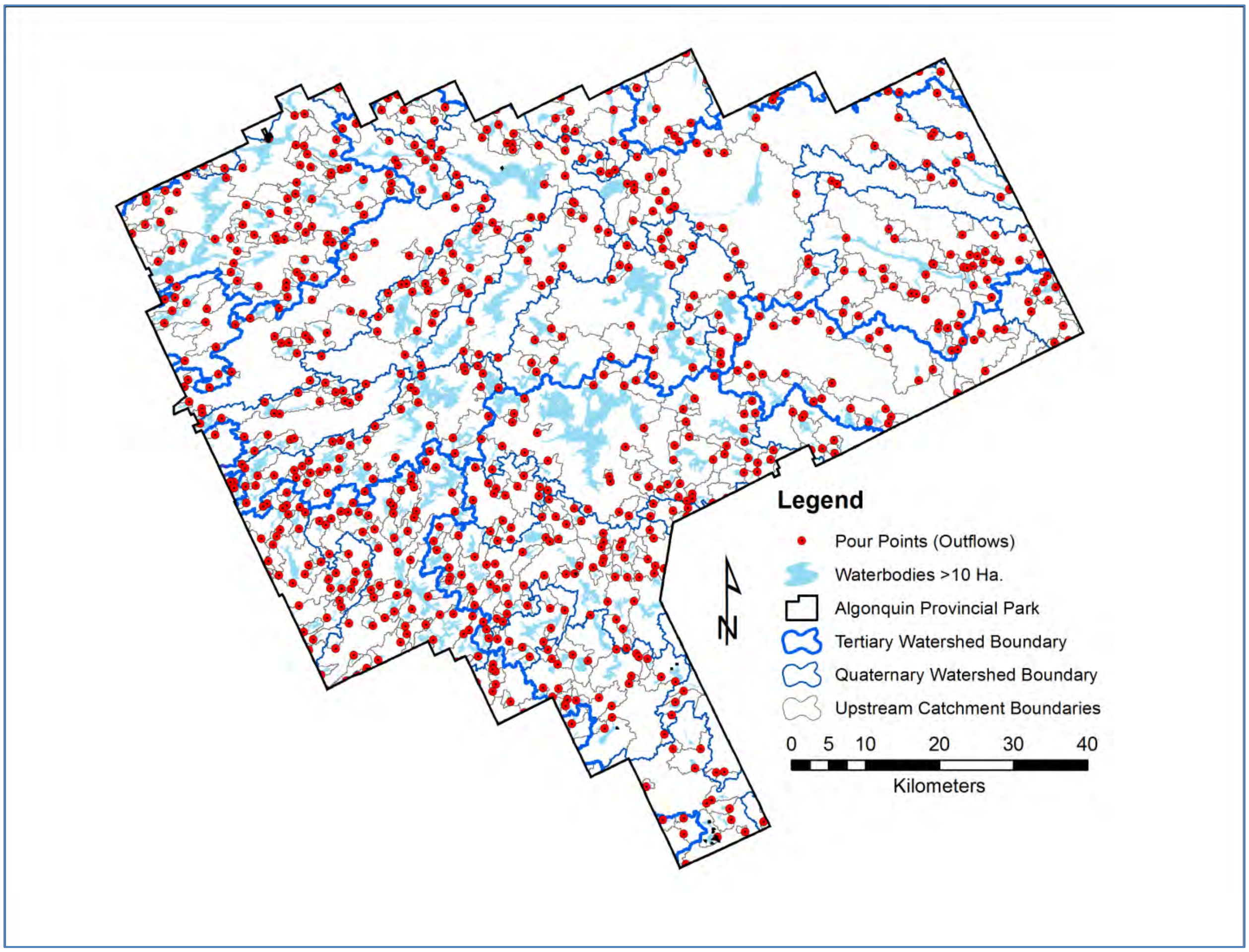


Figure 16. Map of pour points for lakes greater than 10 hectares in Algonquin Park and for adjacent watersheds whose origin is in the park with the pour point located outside of the park.

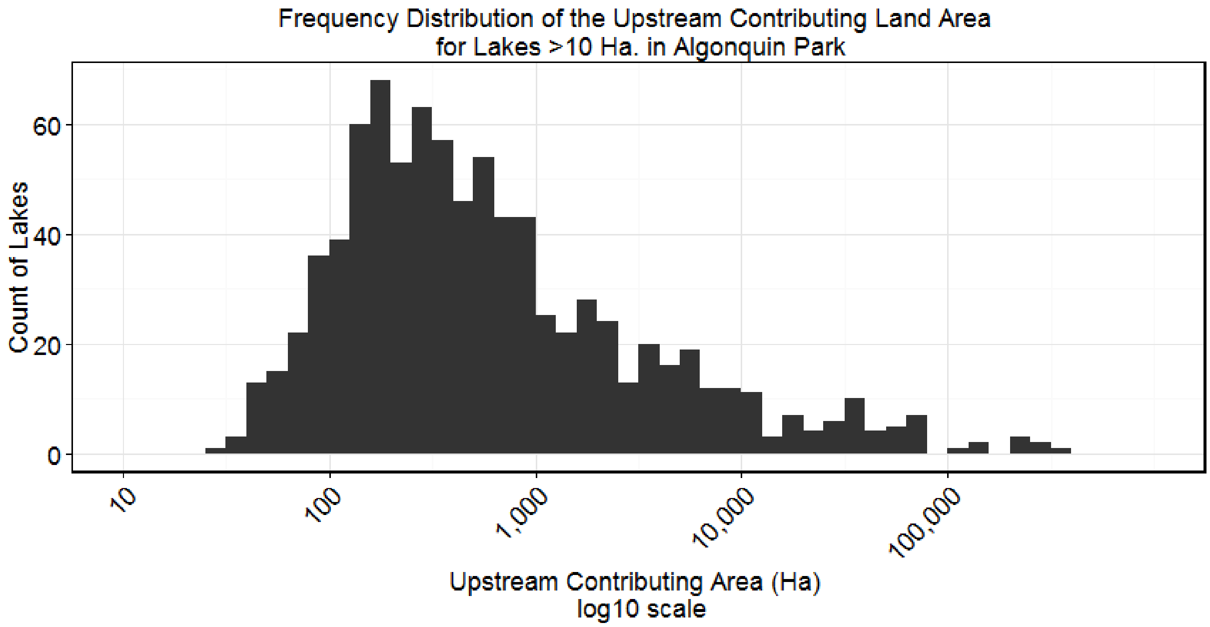


Figure 17. Frequency distribution of catchment surface area for lakes greater than 10 hectares in Algonquin Park.

Maps of tertiary watersheds of Algonquin Provincial Park

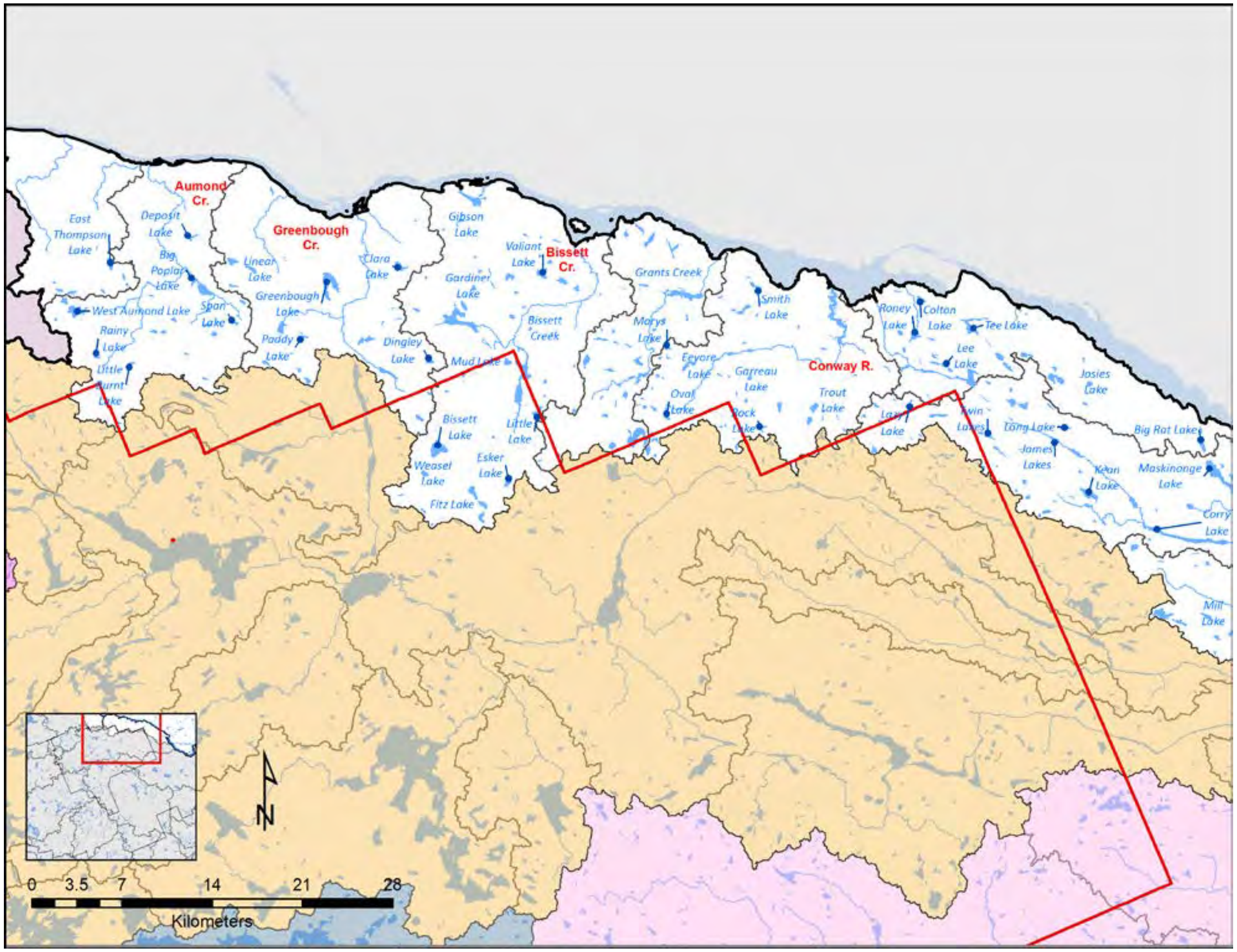


Figure 18. Lakes in the Central Ottawa — Dumoine River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

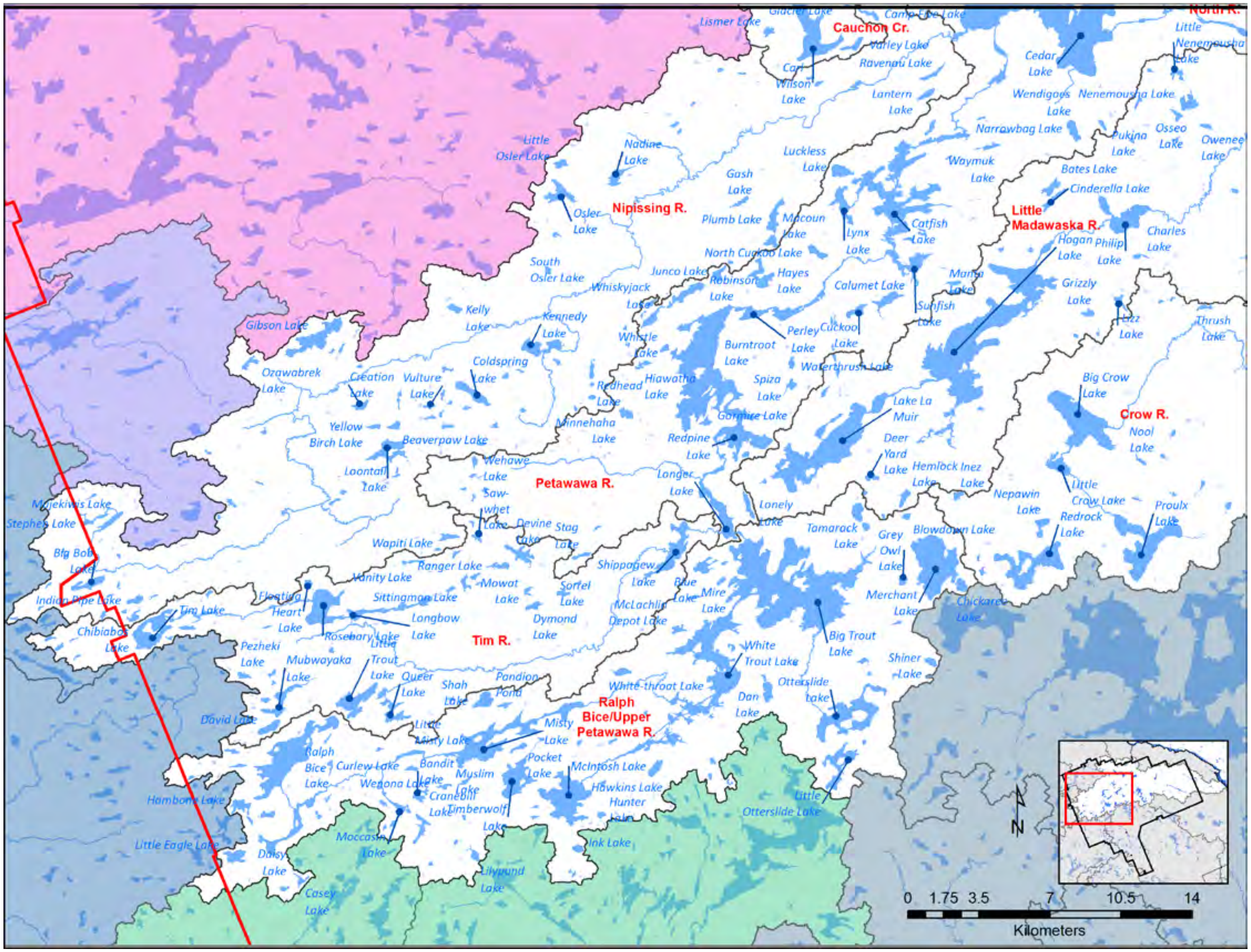


Figure 19. Lakes in the western side of the Petawawa River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

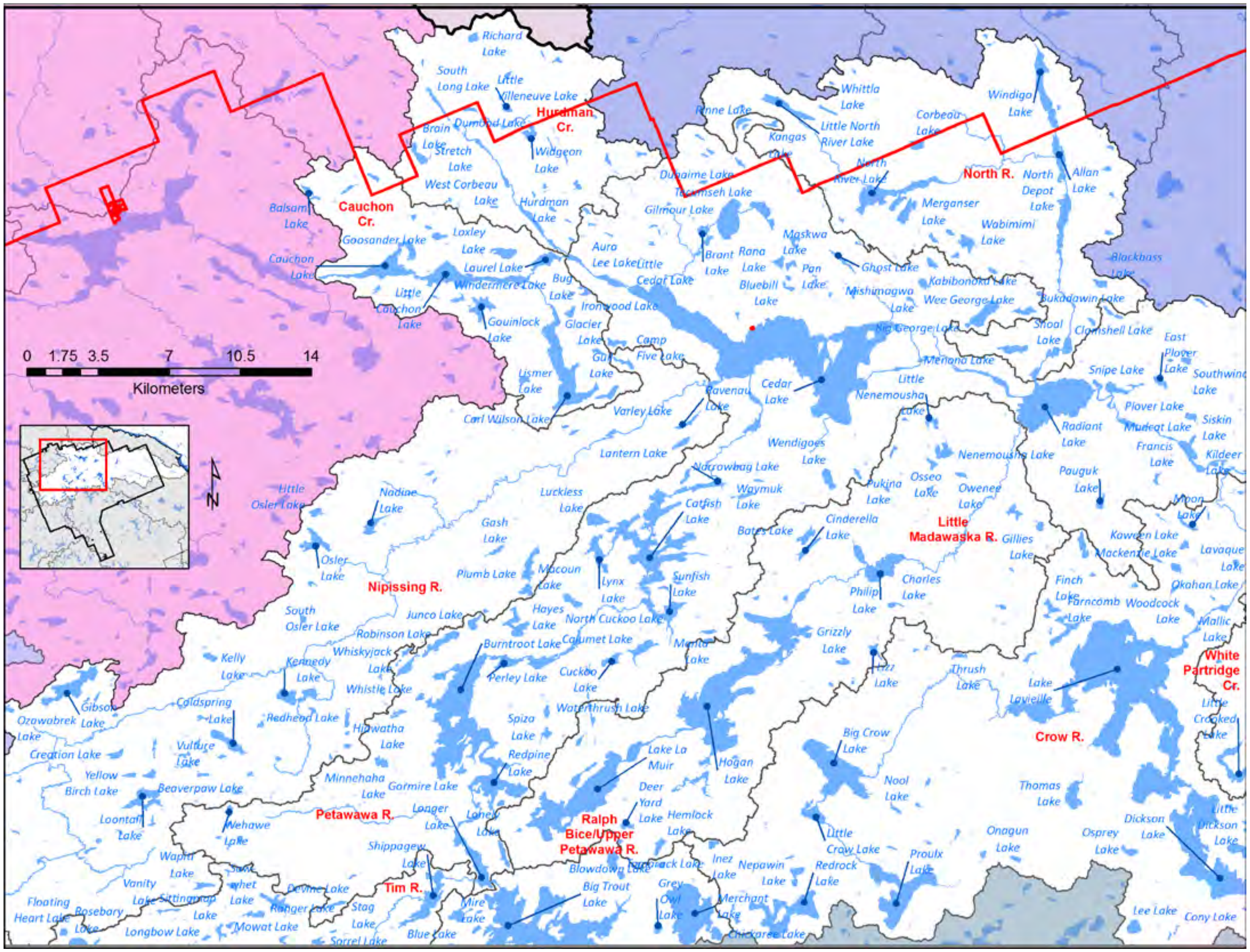


Figure 20. Lakes in the central portion of the Petawawa River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

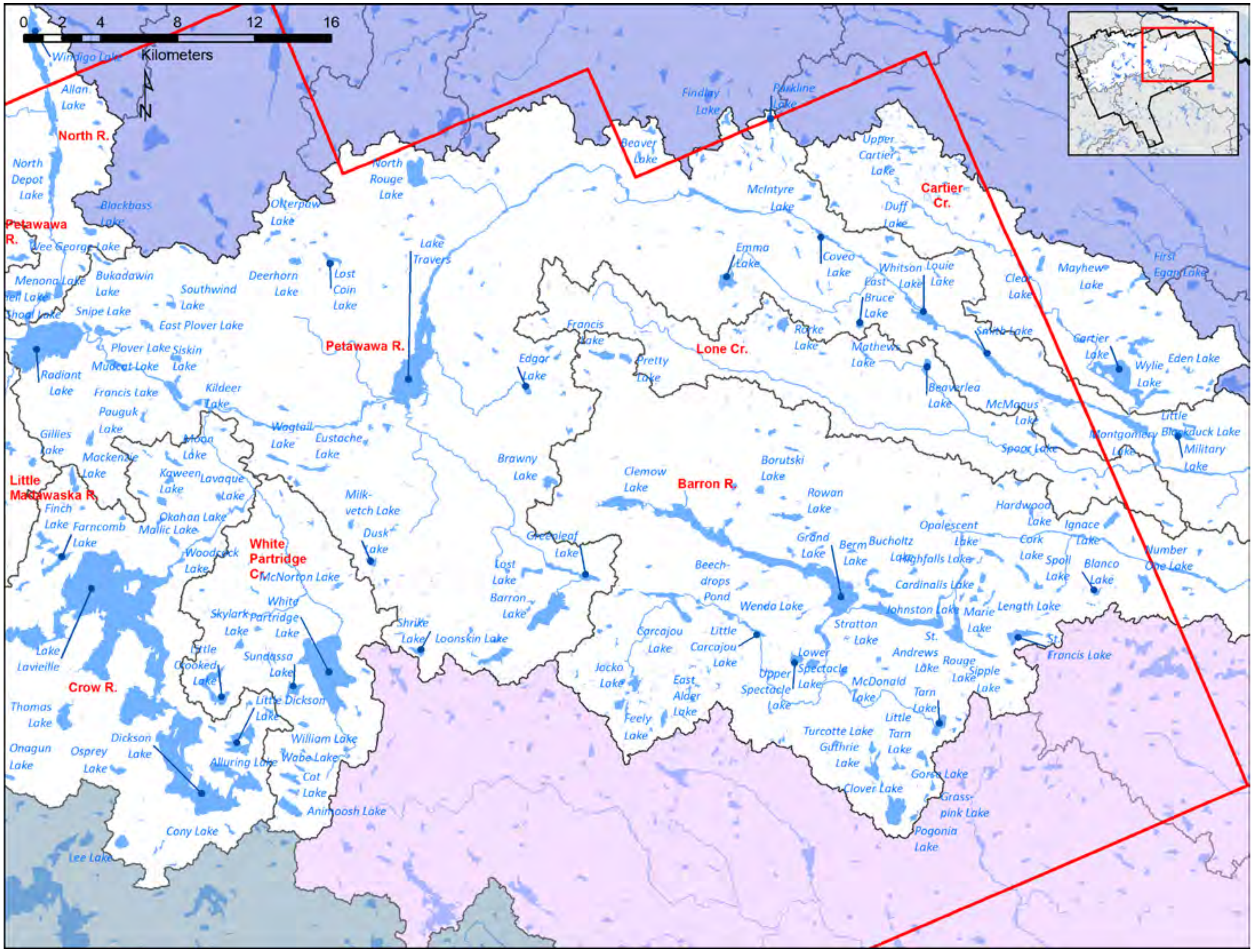


Figure 21. Lakes in the eastern side of the Petawawa River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

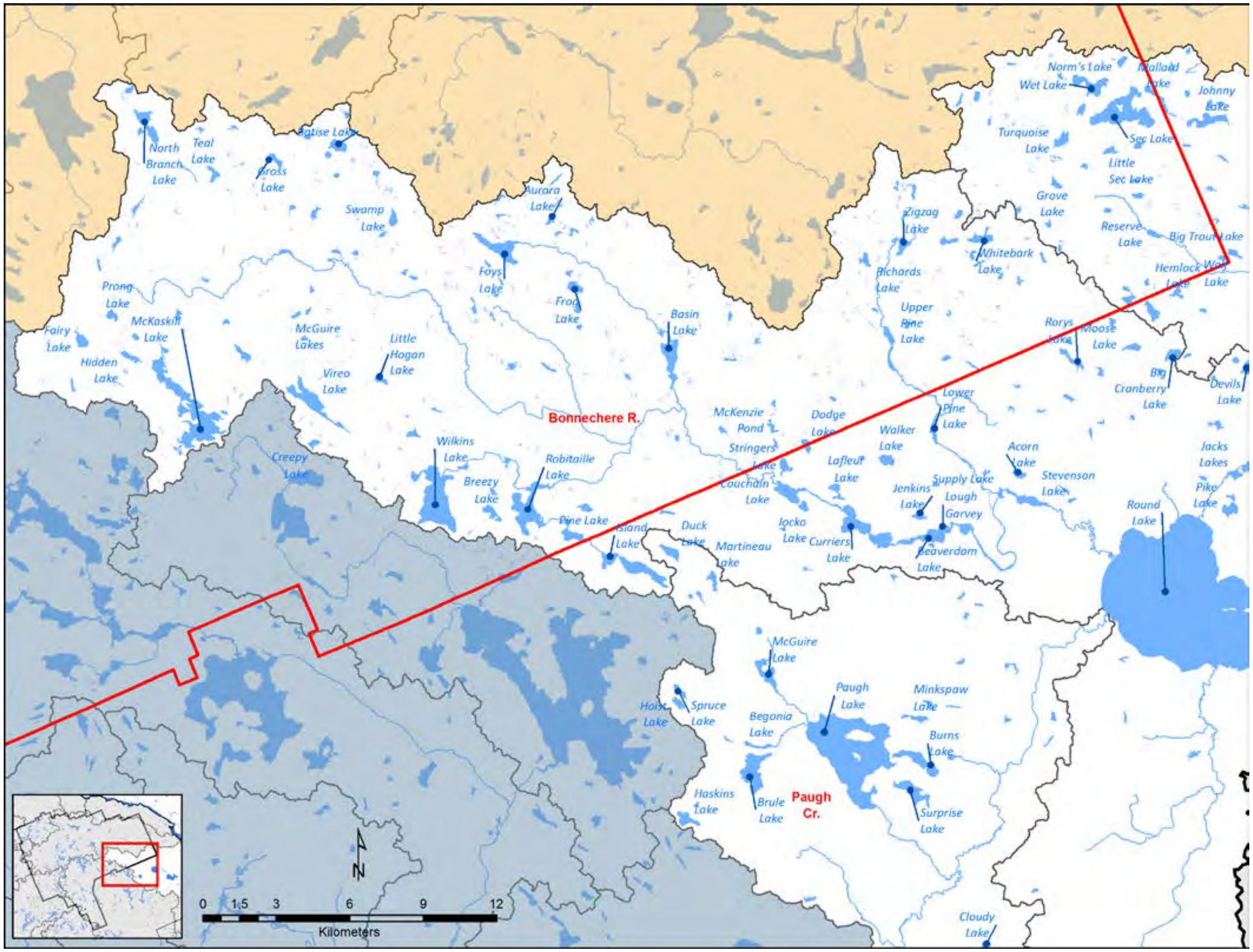


Figure 22. Lakes in the Central Ottawa — Bonnechere River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

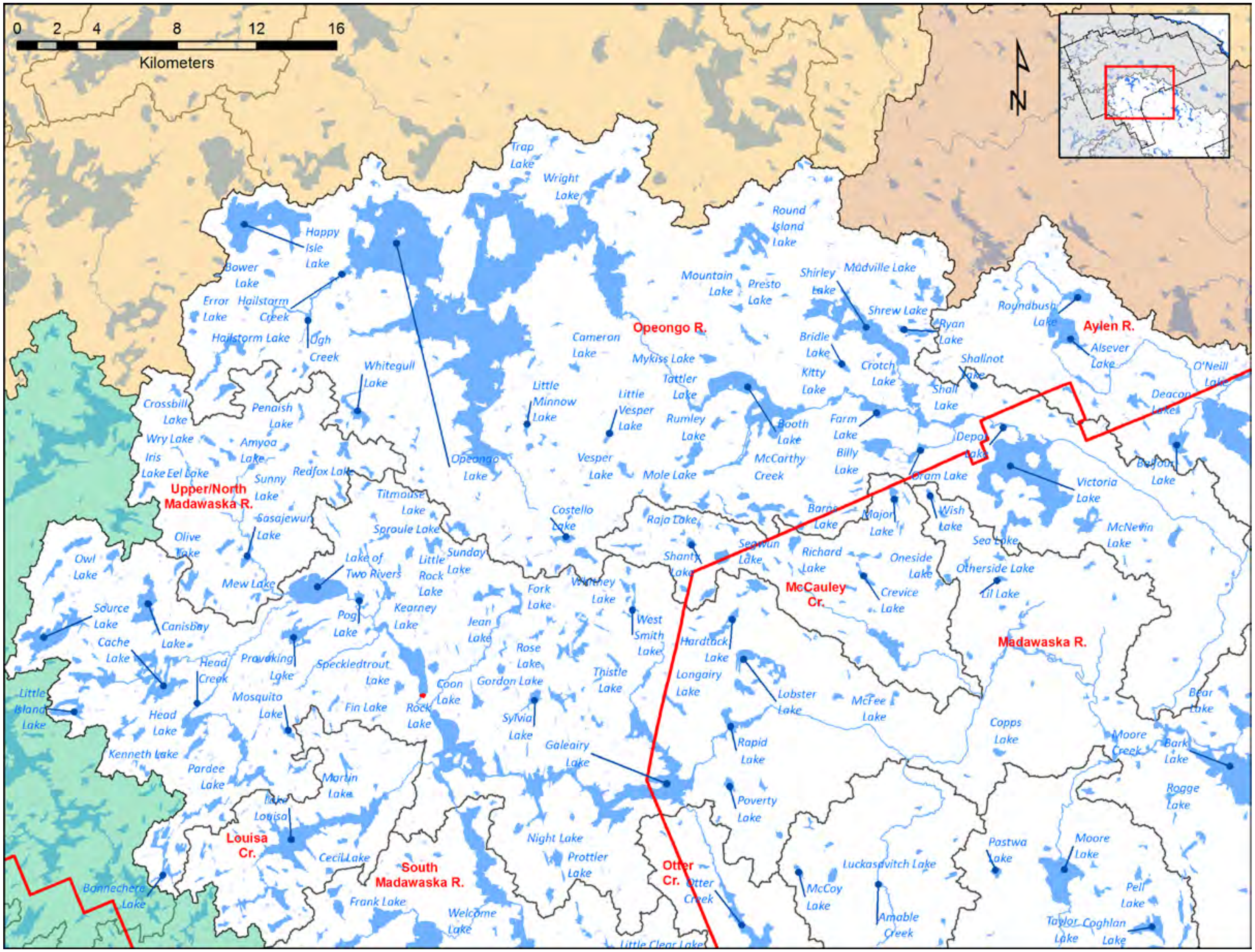


Figure 23. Lakes in the northern portion of the Upper Madawaska River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

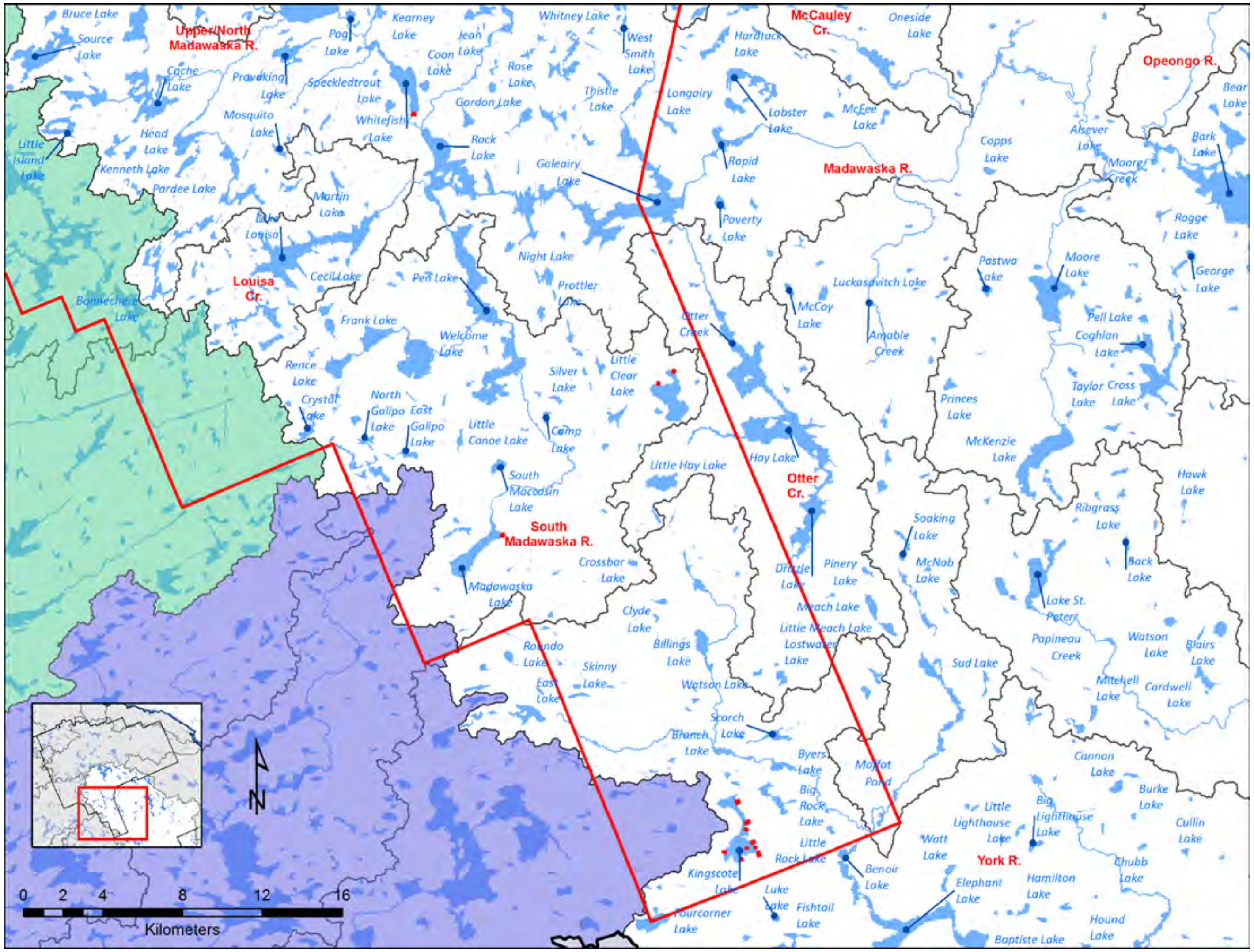


Figure 24. Lakes in the southern portion of the Upper Madawaska River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

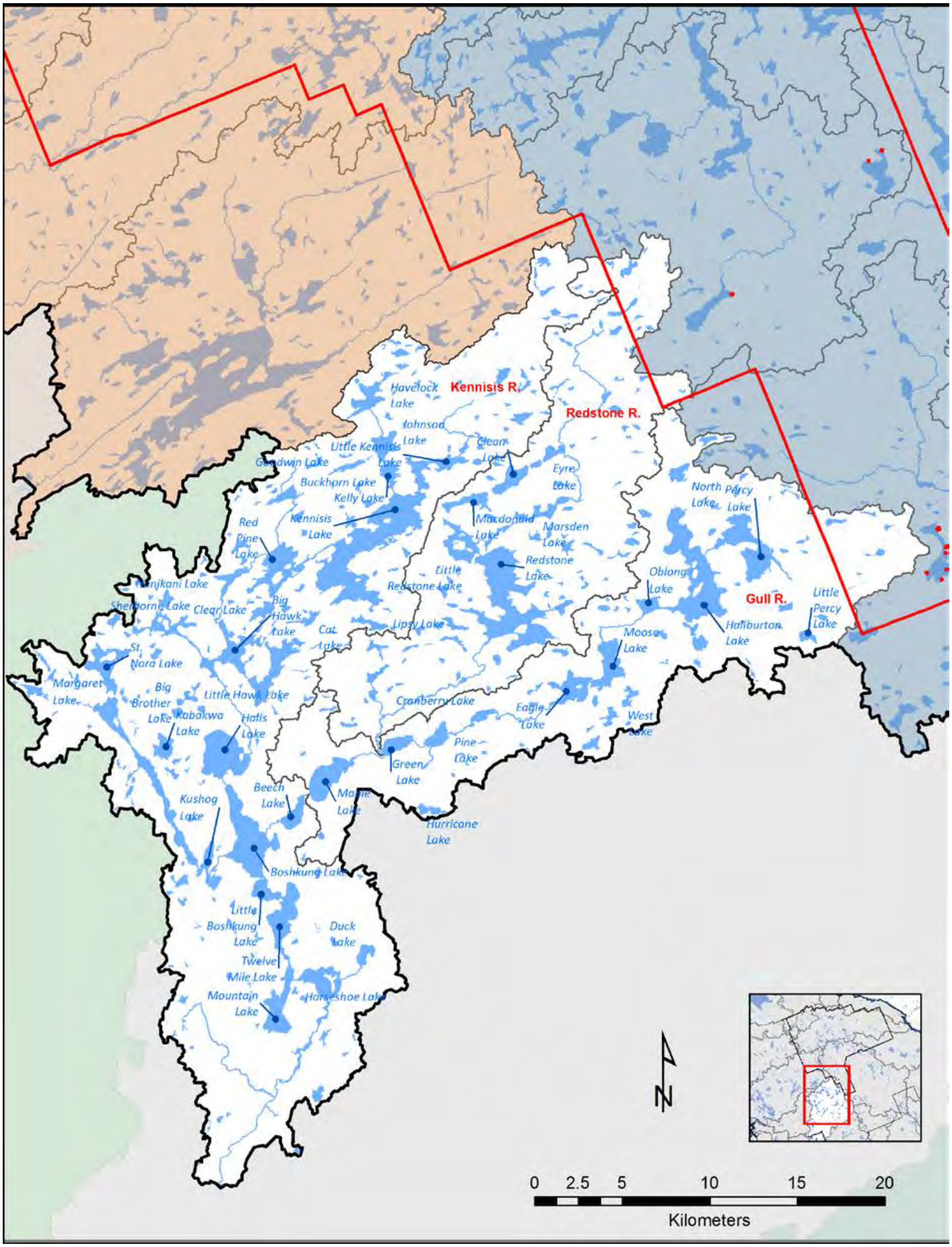


Figure 25. Lakes in the Gull River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

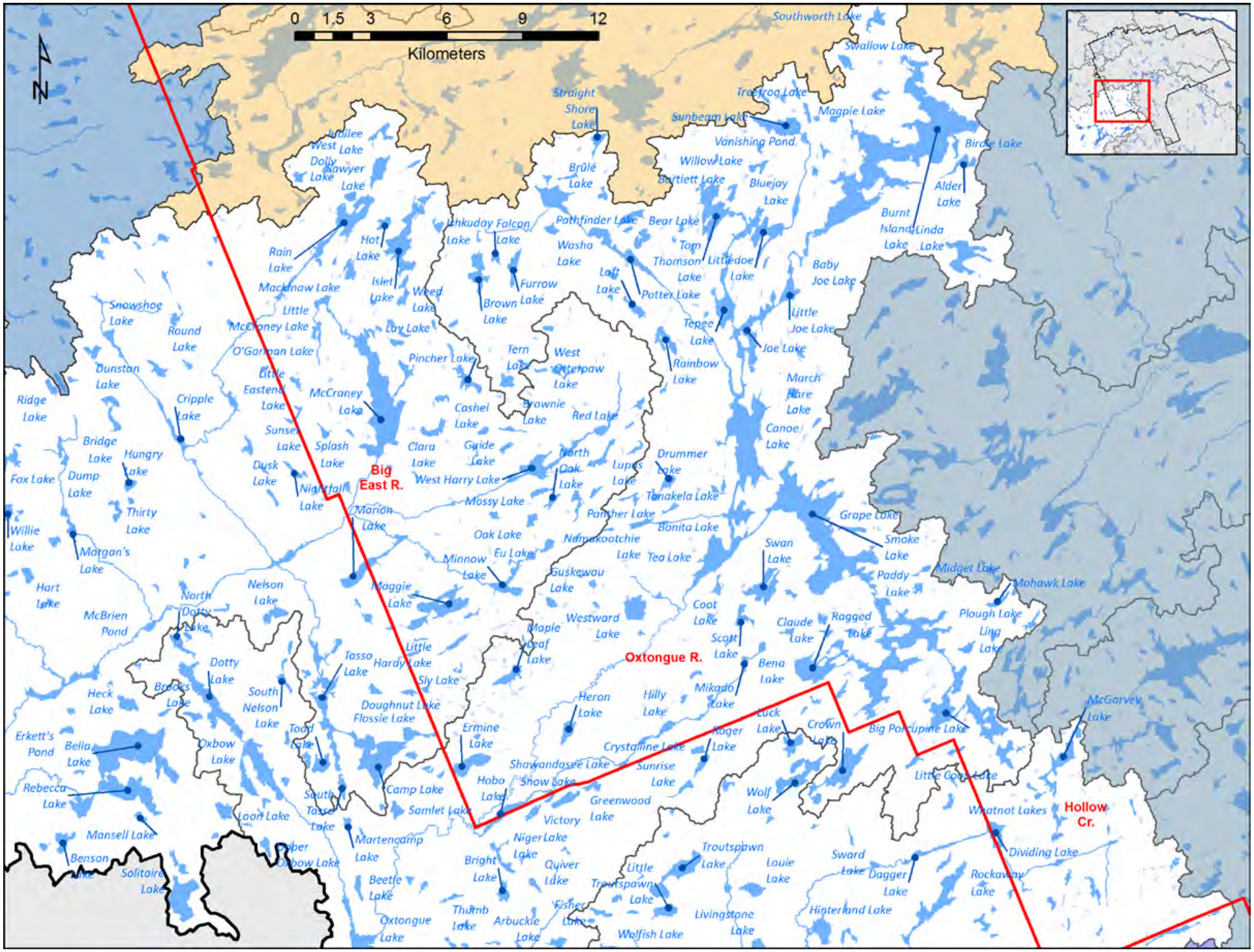


Figure 26. Lakes in the Muskoka River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

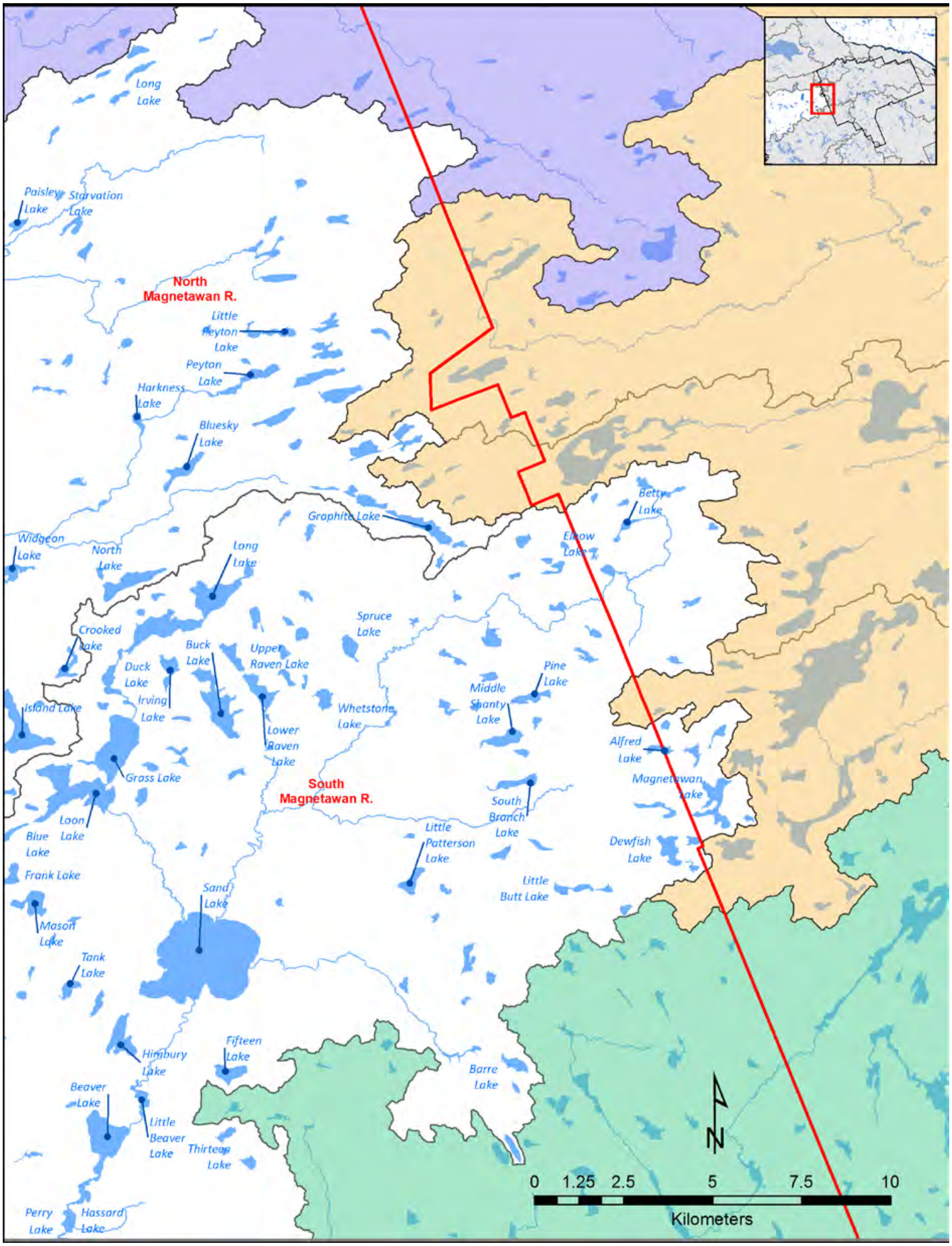


Figure 27. Lakes in the Magnetawan River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of the fourth order watersheds are in red.

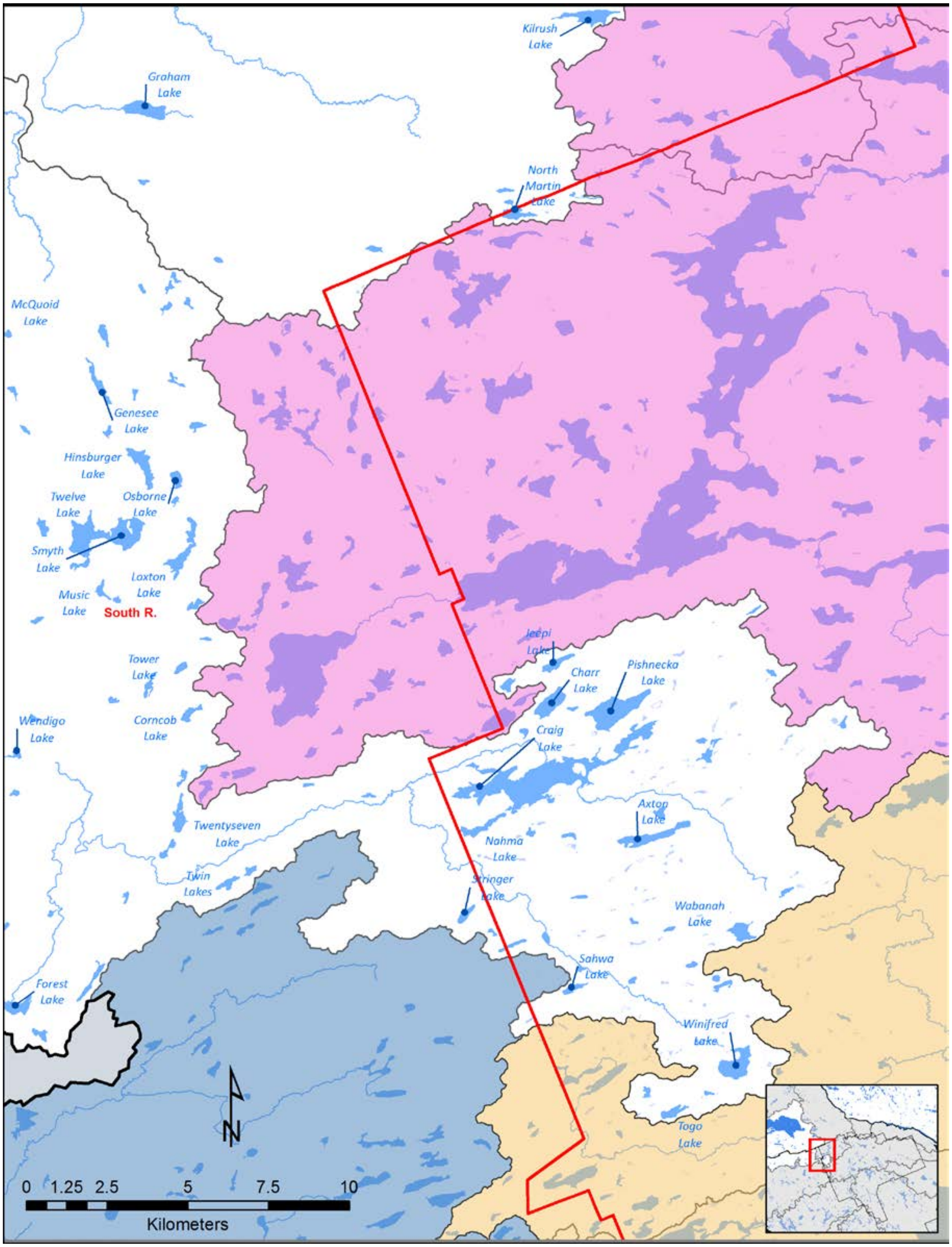


Figure 28. Lakes in the French River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the name of the fourth order watershed is in red.

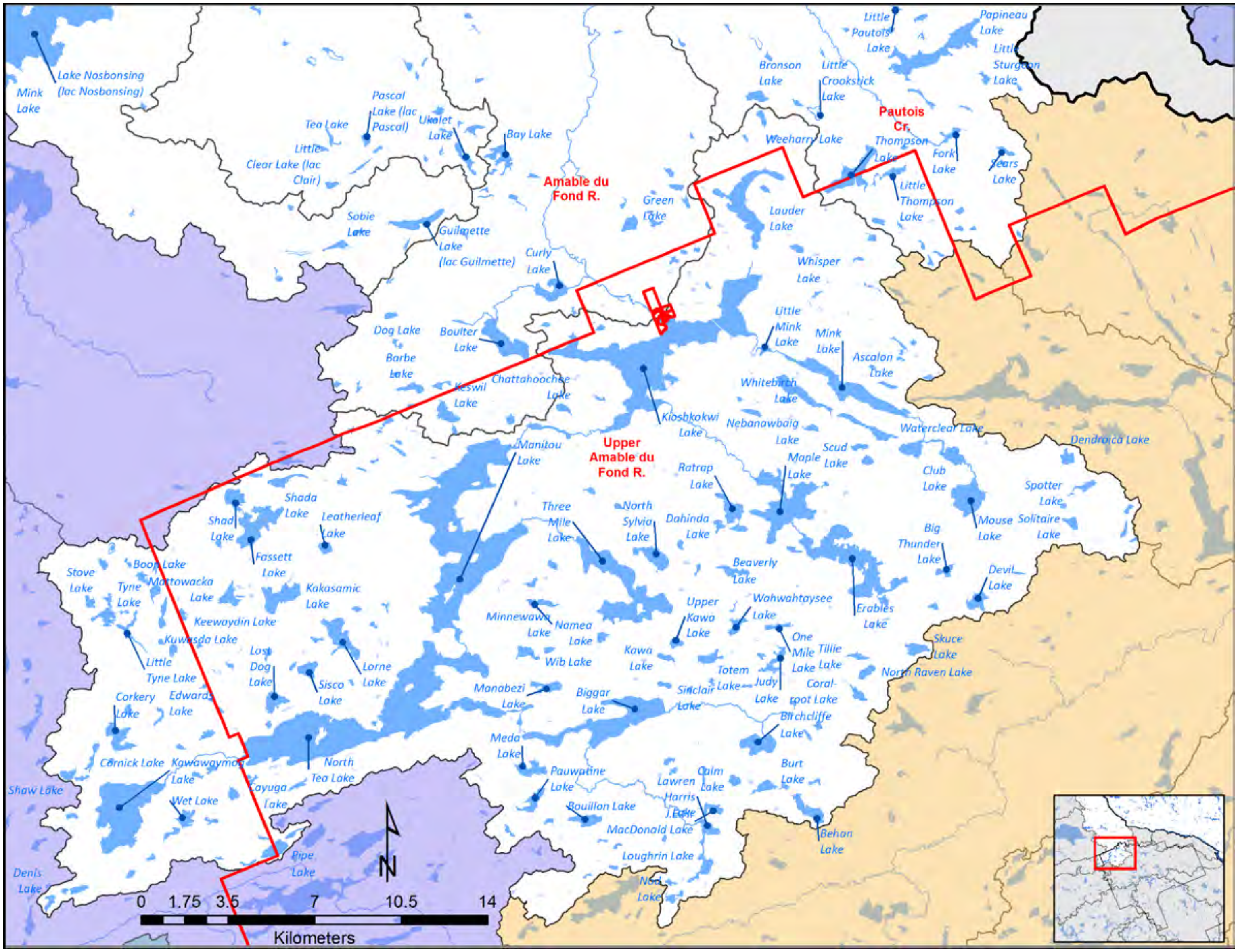


Figure 29. Lakes in the Kipawa River tertiary watershed. Grey lines indicate quaternary watershed boundaries, the names of fourth order watersheds are in red.

Barriers to fish passage

Natural and artificial barriers to fish passage are distributed throughout Algonquin Park. Natural barriers (Figure 30) include waterfalls, rapids, beaver dams, and intermittent streams and lakes. These barriers differ with respect to the timing of impassability and to the species of fish for which passage is blocked. Therefore the map of natural barriers is likely incomplete since barriers to fish passage can vary from one fish species to another.

There are 27 artificial barriers (Figure 30) in Algonquin Park of varying vintage and construction type (Table 7). Only 9 of these are currently in operation with 1 of the 9 operated by Ontario Power Generation.

Artificial barriers to fish passage have been considered a detriment to the natural flow patterns of watersheds. In locations where the function of the original dam has been lost the desire to restore natural flow to areas of watersheds has led to the removal of the dam structure. Fish species introductions or invasions have altered the natural fish community of watersheds in many cases so barriers to fish movements present an alternative view of dam function. When combined with natural barriers to fish passage, the suite of barriers in Algonquin Park may serve an important function in preventing the movement of introduced fish species. Barriers to fish passage can serve as biosecurity for native fauna of lakes and watersheds.

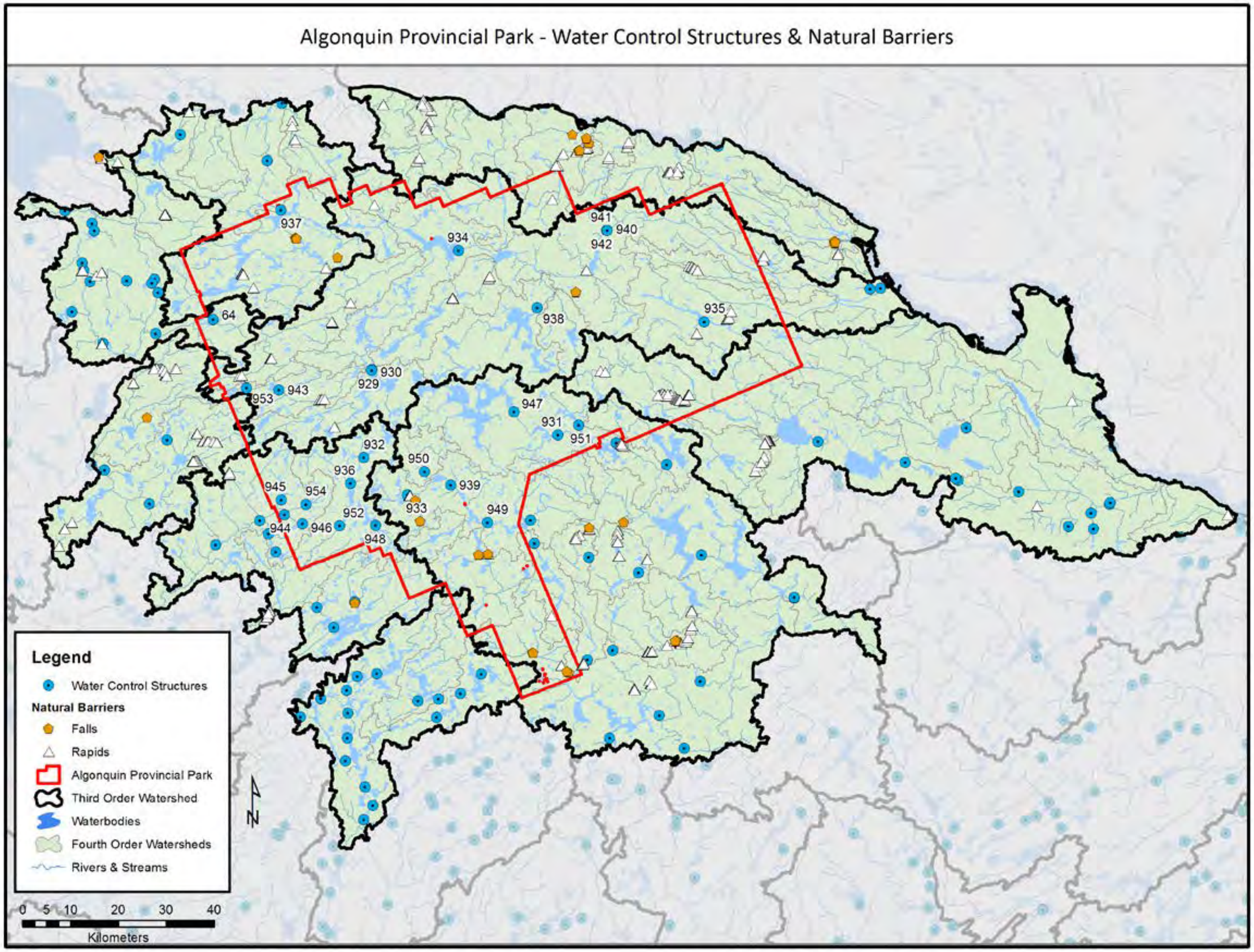


Figure 30. Water control structures and inventoried natural barriers in Algonquin Park watersheds.

Table 7. Dam structures listed for Algonquin Park. Dam ID in Figure 30 matches the ID here.

ID	Name	Owners	Date constructed (R indicates major rebuild)	Primary material	Structure type
64	Craig Lake	OPG	Unknown	Concrete	Stoplog Dam
929	Big Trout Lake (Main)	Provincial	1964	RFTC*	Weir
930	Big Trout Lake (Secondary)	Provincial	1964	RFTC*	Weir
931	Booth Lake	Provincial	1958	Concrete	Stoplog
932	Burnt Island Lake	Provincial	1924; R 1957	Concrete	Stoplog with Spillover Weir
933	Cache Lake	Provincial	1966	Concrete	Stoplog with Spillover Weir
934	Cedar Lake (Algonquin)	Provincial	1963	RFTC*	Weir
935	Grand Lake	Provincial	1971	Concrete	Weir
936	Joe Lake	Provincial	1938; R 1963	Concrete	Stoplog with Spillover Weir
937	Kiosk	Provincial	1962; R 1985; R 2013	Concrete	Weir (Vehicle Bridge)
938	Lake Lavieille	Provincial	1965	RFTC*	Weir

ID	Name	Owners	Date constructed (R indicates major rebuild)	Primary material	Structure type
939	Lake of Two Rivers	Provincial	Unknown; R 1965	Concrete	Stoplog (Vehicle Bridge)
940	Lake Travers (East)	Provincial	1961	Timber Crib	Weir
941	Lake Travers (Main)	Provincial	1961	Timber Crib	Weir
942	Lake Travers (West)	Provincial	1961	Timber Crib	Weir
943	Longbow Lake	Provincial	1974	RFTC*	Weir
944	Marion Lake	Provincial	1957	Rock	Weir
945	McCraney Lake	Provincial	1924; R 1956	Concrete	Stoplog with Spillover Weir
946	Minnow Lake	Provincial	Unknown	Rock	Weir
947	Opeongo Lake	Provincial	1955; R 2012	Concrete	Weir
948	Ragged Lake	Provincial	1930; R 1963	Concrete	Stoplog with Spillover Weir
949	Rock Lake	Provincial	1941 (or 1949)	Concrete	Weir
950	Sasajewun Lake	Provincial	1956; R: Unknown	Concrete	Stoplog (Vehicle Roadway as Weir)

ID	Name	Owners	Date constructed (R indicates major rebuild)	Primary material	Structure type
951	Shirley Lake	Provincial	1974	RFTC*	Weir
952	Tea Lake	Provincial	1900; R 1964	Concrete	Stoplog Dam with Spillover Weir
953	Tim Lake	Provincial	1973	RFTC*	Weir
954	West Harry Lake	Provincial	1973	RFTC*	Weir

*RFTC is rock fill and timber crib structure.

Wetlands of Algonquin Park

A wetland is an area seasonally or permanently covered by shallow water where the water table is close to or at the surface. Wetlands are an aquatic ecosystem because of the presence of water. They are also terrestrial ecosystem because of vegetation communities that are tolerant of wet and sometimes unproductive conditions. In either case, the presence of abundant water has caused the formation of soils favouring the dominance of either aquatic macrophytes or water-tolerant plants. The major types of wetlands are swamps, fens, marshes, bogs, and peatlands.

Classifications of wetlands are based on the extent of inundation, source of water (rain, drainage system, etc.) and vegetation community tolerant of different conditions. Wetlands of Algonquin Park are numerous, widely distributed, and of different origins. However, only the Percy Lake wetland complex in the southwest corner of the park panhandle has been evaluated using the Ontario Wetland Evaluation System (OWES). Other wetland locations are represented as polygons approximating the boundaries of the wetland based on aerial interpretation. Because of the lack of OWES wetland evaluation the precise boundaries, structure, and composition of each wetland is unknown. With this limitation in mind, there are approximately 16,000 wetland polygons in Algonquin Park covering a total area of 362 km² (Figure 31).

One category of wetland appears under-represented in the current inventory of wetland complexes. Wetlands along shores and bays within lake ecosystems develop from long-term patterns of fetch and wave disturbance. These physical processes sort and deposit substrate particles of different size that in turn form conditions where aquatic macrophytes can become established. Wetlands created by these physical processes are located in back bays with little fetch or in fringing areas of lakeshore protected from fetch. Some of these locations are mapped for Algonquin Park but many are not because they are driven by physical processes internal to each lake and not by processes linked to the water table. Two results stem from this observation. First, since fetch is a function of lake surface area then small lakes with little fetch will have a greater proportion of their shoreline vegetated than for larger lakes where fetch is greater. The wetland/vegetation criteria used for classification ought to lead to an inverse pattern of wetlands and lake surface area — small lakes have more wetland habitat per unit of surface area whereas large lakes have less wetland habitat per unit of surface area. Second, because lakes have different shapes then the location of lake-based wetlands will vary with the fetch patterns specific to different areas of a lake.

Similarly, the sorting of substrates in river and stream ecosystems often produces substrates favouring wetland areas. Deltaic areas often occur where rivers and streams reach lakes producing large complexes of wetlands that are also productive areas of fish habitat. Many of these areas are unmapped in Algonquin Park. The number of wetlands in the park likely exceeds the current polygon estimate.

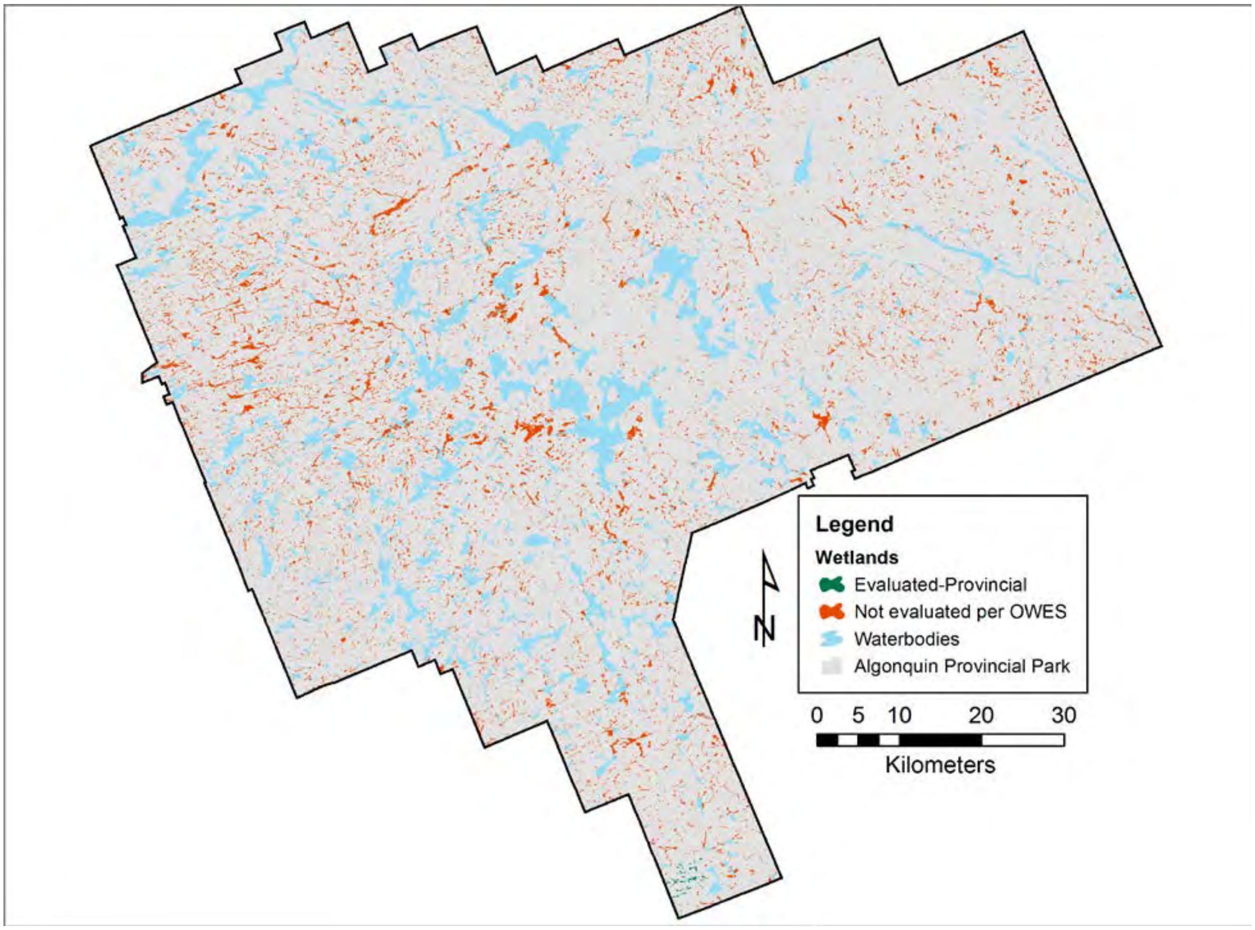


Figure 31. The wetland polygons of Algonquin Park. The Percy Lake wetland complex is the only wetland evaluated under the Ontario Wetland Evaluation System. It is located in the southwest corner of the park panhandle.

Climate environment of Algonquin Park

Air temperature and the climate environment are important factors governing aquatic ecosystems and fish populations. Air temperature directly affects seasonal warming patterns and this in turn affects lake thermal conditions [30], and seasonal events such as the *phenology* of ice cover [31]. Air temperature influences production of fish year-classes and species ranges [32,33], the distribution of fish in watersheds [34], and seasonal timing of fish activity [35,36].

The Algonquin Park landscape is predicted to warm under most climate projection scenarios from 0.7°C to 3.4°C in the decade of 2020 relative to an average temperature in the 1961–1990 period [37]. The change increases by mid-twenty-first century to 2.0–7.1°C in the same climate change models. Finally, in the decade of the 2080s, climate change will range from 3.3–10.6°C relative to the 1961–1990 average conditions for Algonquin Park [37].

Weather stations positioned in North Bay and Madawaska provide two of the longest time series of weather data available for the region near Algonquin Park. Based on average annual air temperature, there is a clear upward trend over the 20th century and continuing into the 21st century (Figure 32). The trend line points to an approximate increase of 1°C from the 2 sites. This represents a change consistent with model projections of climate change for Algonquin Park in the 2020s [37].

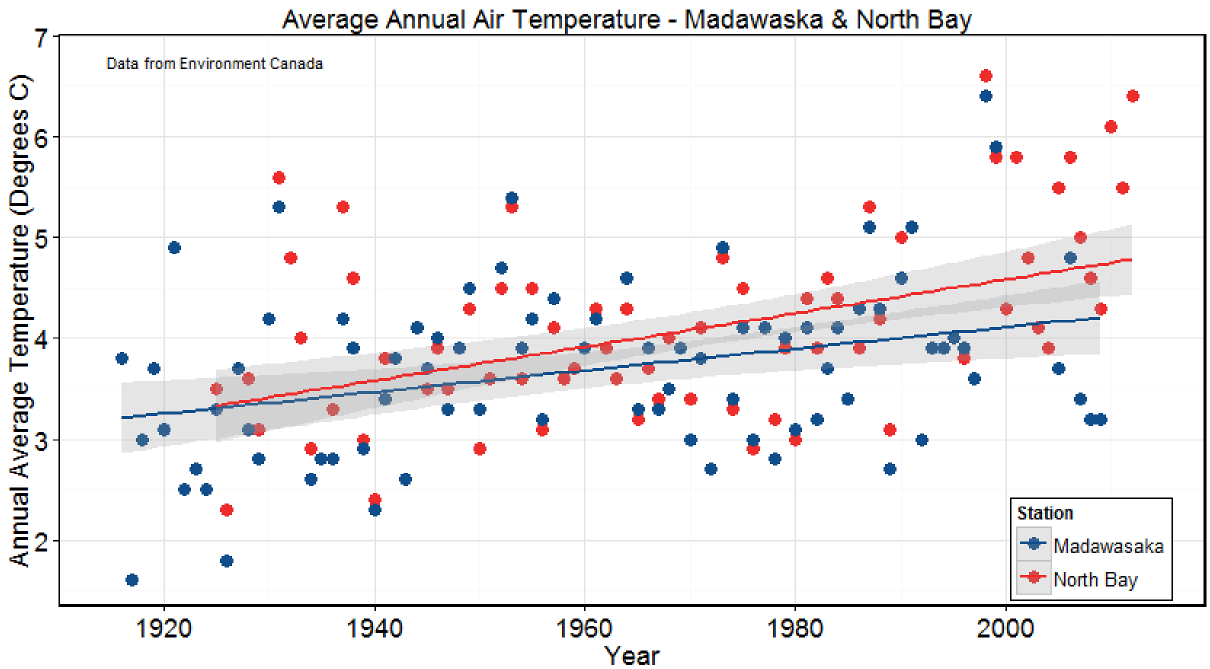


Figure 32. The observed average annual air temperature recorded at North Bay (blue points) with the North Bay trend line (blue line), and at Madawaska (red points) with the Madawaska trend line (red line). Observations began early in the 20th Century and show an increasing trend in average annual temperature for both sites. The grey areas for each trend line are the 95% confidence limits indicating the trend for increasing temperature falls within the grey area of each line 19 times out of 20.

The Algonquin climate thumb

Weather monitoring in Algonquin Park does not extend over the same time span as provided by the North Bay and Madawaska weather stations. In recent decades, weather stations in and around the park have been in operation and the combined time series of weather data, along with older time series (Figure 33), can be used to interpolate average air temperature over the park landscape. Based on the Historical Climate and Analysis Tool[38], an *interpolation* model of this combined data set for south central Ontario provides a 30 year average for the landscape.

For south central Ontario, the 30 year average annual temperature for the Algonquin Park landscape stands out as an extension of the landscape to the north of the park's position (Figure 33). It is labelled here as the Algonquin Climate Thumb and represents the climate location of the park with respect to the surrounding area. The average annual air temperature of Algonquin Park is largely below that of landscapes at similar latitudes outside of the park boundary (Figure 33).

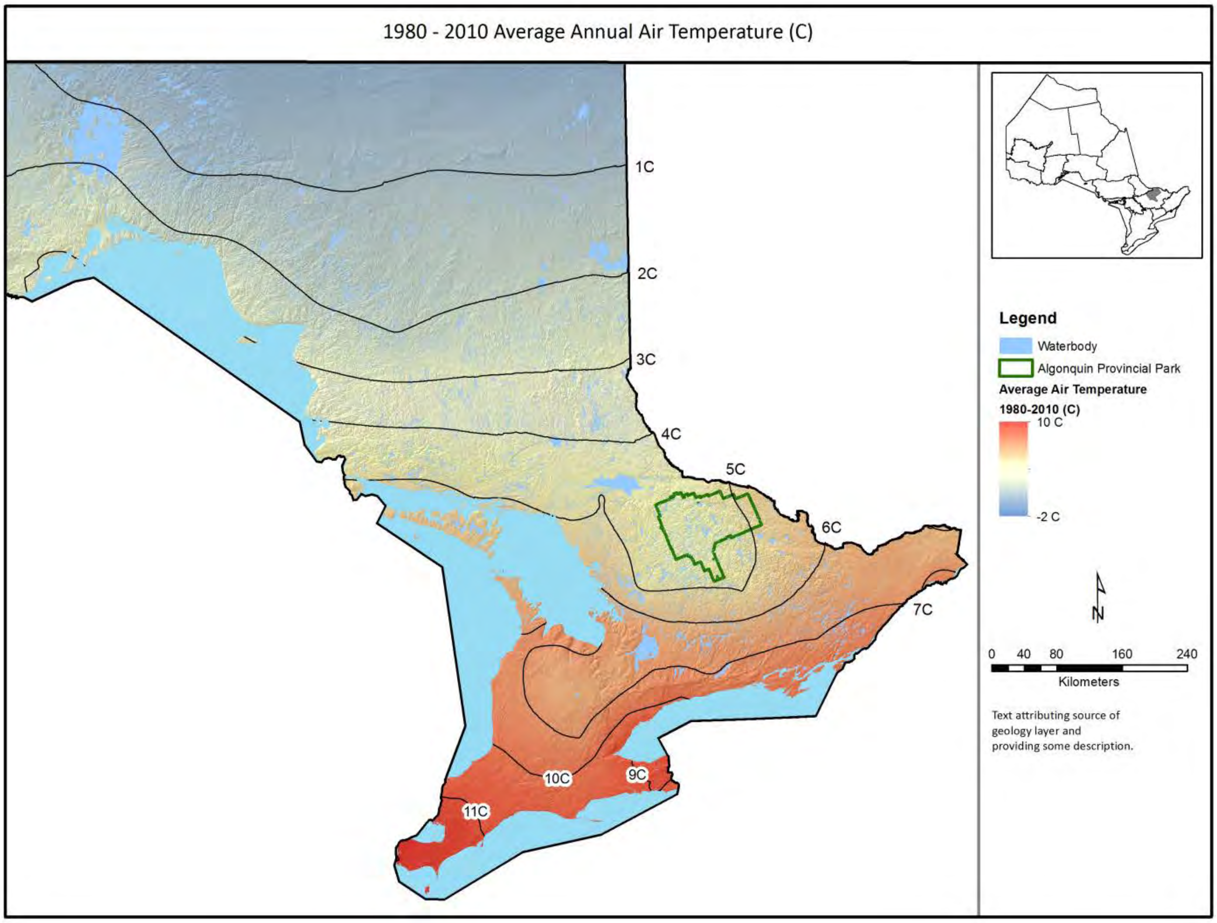


Figure 33. The average annual air temperature (1981–2010) of south-central Ontario illustrating the north-south gradient in temperature shown via colour scale and isotherms. Data interpolation is based on *kriging* analysis of regional air temperature records for each year (1981–2010) in Ontario [38].

A closer examination of Algonquin Park's Climate Thumb indicates where the coolest and warmest temperatures tend to be located within the park boundary (Figure 34). The southwest corner of the park in the Muskoka River watershed has the lowest average annual temperature (1981–2010) as it approaches 4°C while in the east average air temperature sits above 5°C.

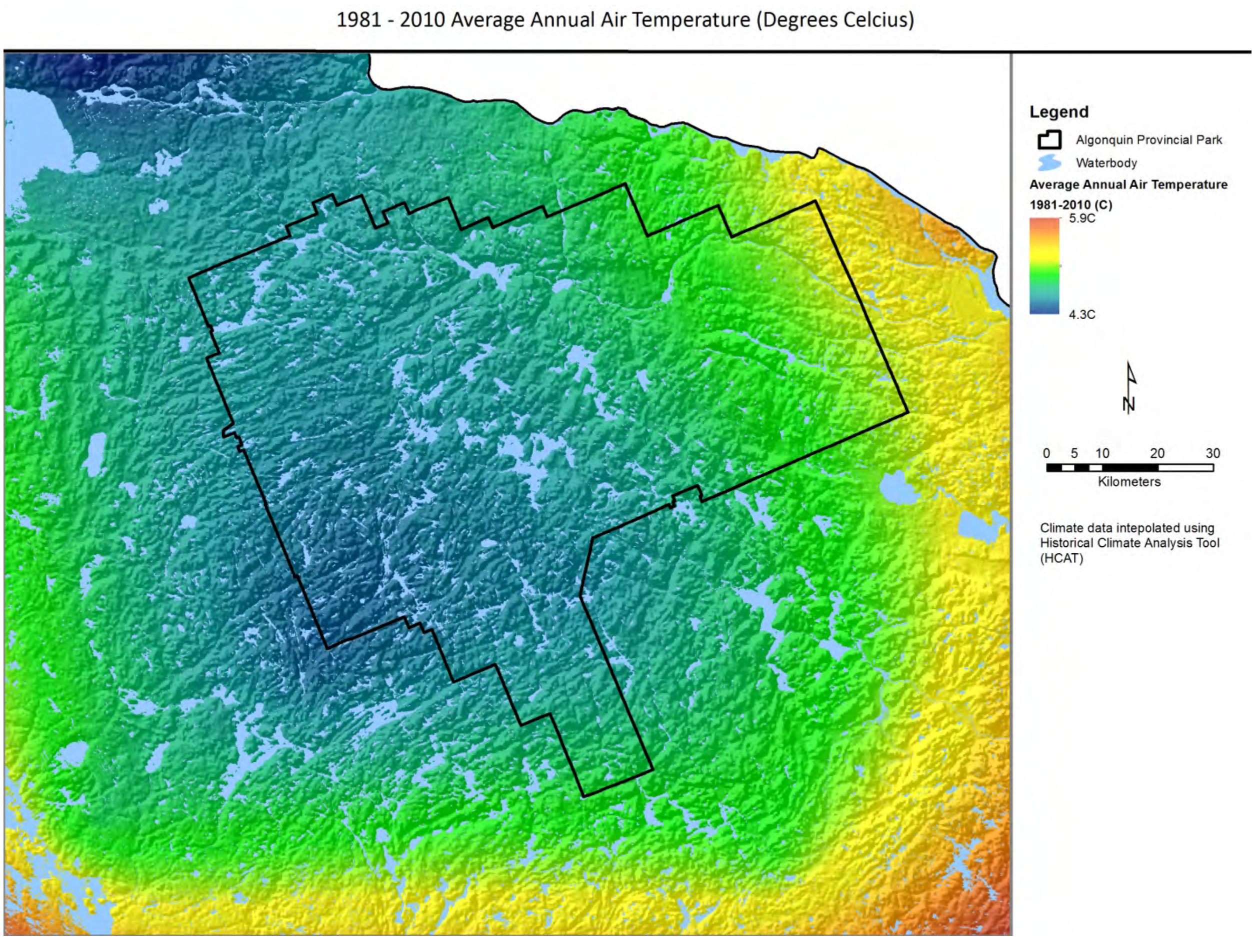


Figure 34. An outline of Algonquin Park showing a finer scale resolution of the interpolated average annual air temperature (1981–2010; the Algonquin Climate Thumb, note the change in scale and colours for this figure relative to Figure 33). Data interpolation is based on kriging analysis of regional air temperature records for each year (1981–2010) in Ontario [30].

The deviation of the interpolated map of average annual air temperature for each year relative to the mean will show if there is a shifting pattern over time. When plotted (Figure 35), there are years throughout the time series that are above or below the long term average annual air temperature for Algonquin Park. The trend line varies from the long-term average and shows a shifting pattern in deviation from the mean. The trend line indicates an increasing frequency of warm years relative to the start of the time series when most years were cooler than the long-term average. It is clear the Algonquin Park landscape is warming based on the temperature data from North Bay and Madawaska as indicators of change and the interpolated landscape average annual air temperature. It will continue to warm under climate projection models and this will have direct effects on lake conditions during winter and summer. How climate change affects Algonquin Park fish species is summarized in the section Fish in Algonquin Park and Climate Change.

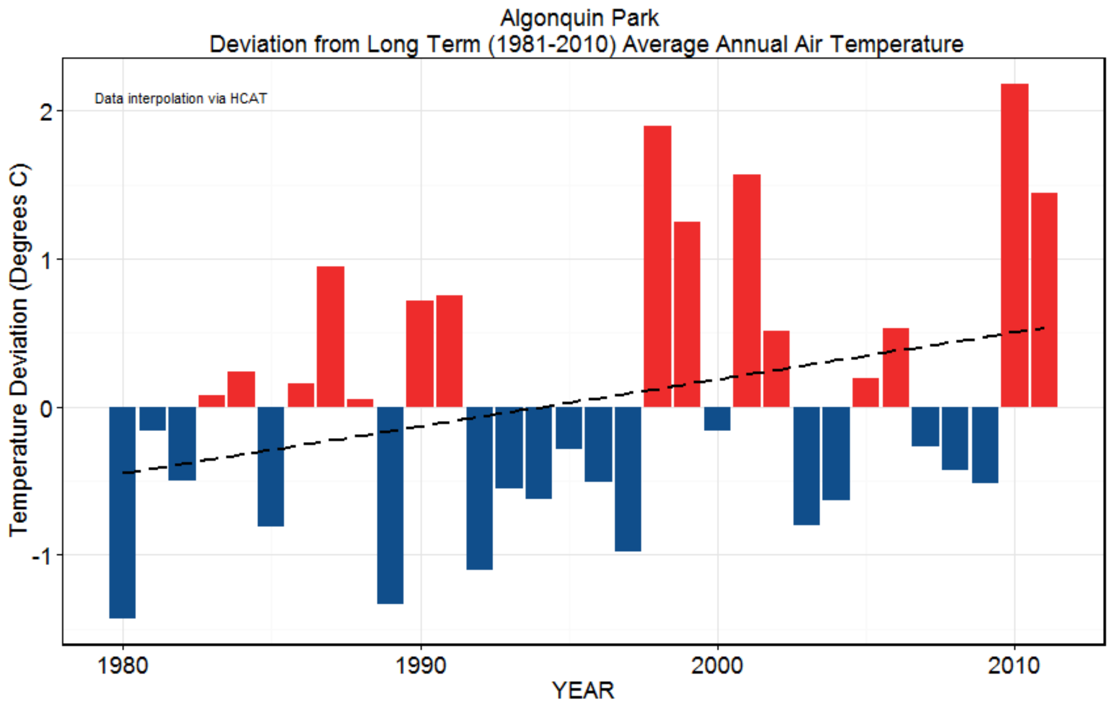


Figure 35. Average annual air temperature of Algonquin Provincial Park expressed as the deviation from the 30 year (1981–2010) average air temperature (from interpolated map for year x — average annual air temperature map in Figure 34). Negative values indicate the park landscape was cooler (blue) than the 30 year average and positive values indicate the park landscape was warmer (red) than the 30 year average. The dotted line is the trend line through the time series of temperature deviations from the long-term mean (Figure 34).

For Algonquin Park the long-term average of annual total precipitation (1981–2010) points to a clear west-to-east pattern (Figure 36). The highest levels to total annual precipitation fall in the west boundary area of the park with declining levels eastward. The long term average indicates that most of Algonquin Park is receiving approximately 1000 mm or less of total precipitation.

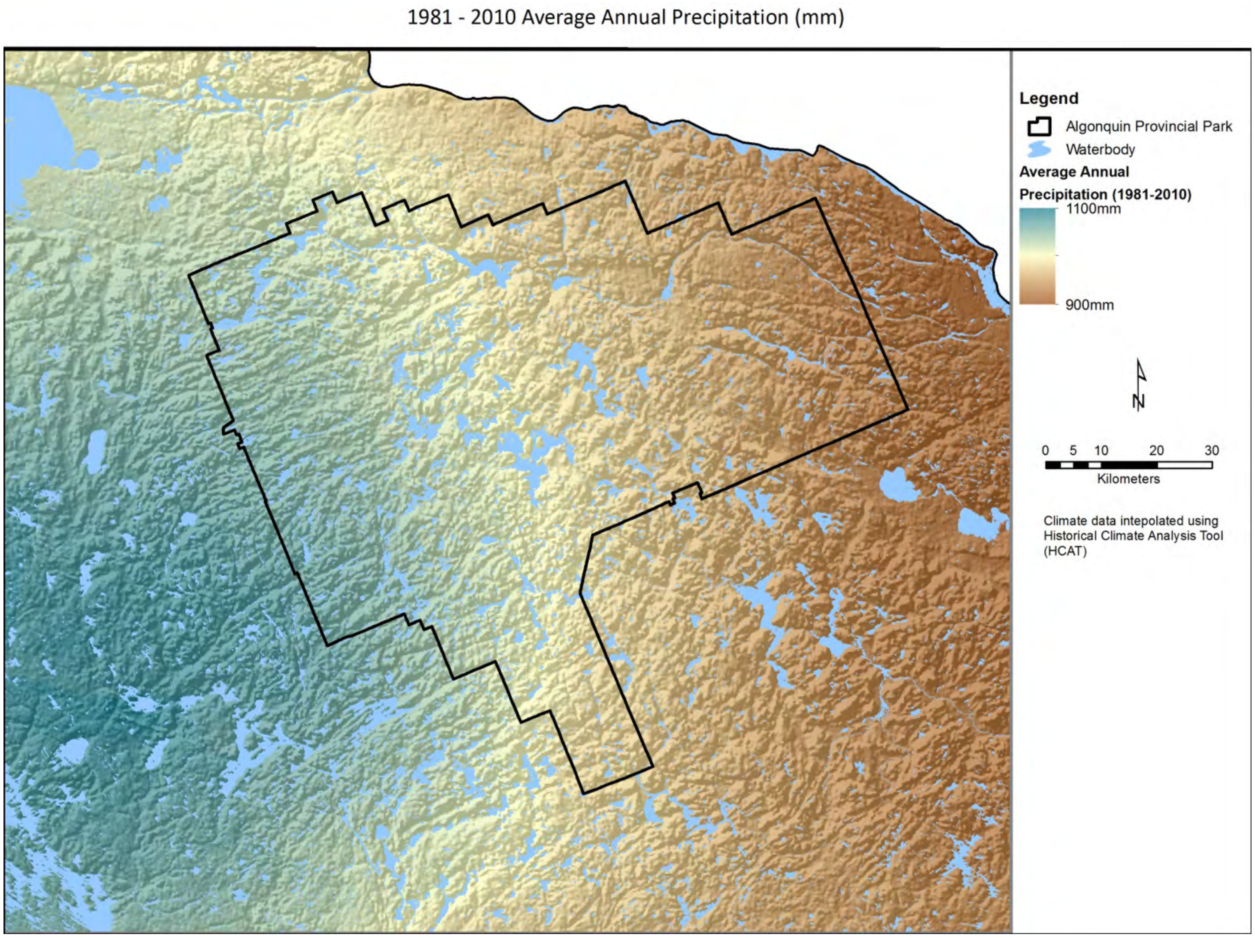


Figure 36. An outline of Algonquin Park showing a finer scale resolution of the interpolated average annual precipitation (1981–2010) of the Algonquin Climate Thumb. Data interpolation is based on kriging analysis of regional air temperature records for each year (1981–2010) in Ontario[38].

Lake ice phenology

Observations on the timing of ice-on, ice-off, or ice-free days on lakes are good proxies for climate change trends. The seasonal timing of ecological or ecosystem events is referred to as phenology and lake ice phenology refers to the timing of ice formation and loss. Multiple studies around the world summarize long-term observations of the timing of ice formation and loss on lakes. In Algonquin Park, the ice-free date for Sproule Bay, Lake Opeongo, is recorded each year by staff at the Harkness Laboratory of Fisheries Research. Dates for ice-on and corresponding ice duration on Sproule Bay are also recorded but less frequently as a function of staff available at that time of year.

Over a twenty-one year span, the ice-on date for Sproule Bay shows a clear rising trend indicating that ice-on is occurring at later dates (Figure 37). The rate of change in ice-on is 7.9 days per decade for this time series (trend line slope = +0.791 days per year).

Over a 51 year period (1964–2015), the ice-free date for Sproule Bay shows a negative trend pointing to an earlier ice-free date over this observation period (Figure 38). The rate of change in ice-free date is 2 days per decade for a total advance of approximately 10 days over this observation period (trend line slope = -0.201 days per year).

Over a twenty year span, the duration of ice cover on Sproule Bay showed a declining trend indicating that duration of winter ice cover is being reduced (Figure 39). The rate of reduction in ice cover duration was approximately 6 days per decade for this time series (trend line slope = -0.593 days per year). Longer ice-free seasons are now occurring on Sproule Bay than in the past.

The patterns detected at Sproule Bay are consistent with other studies summarizing ice phenology in North America. In south central Ontario, there is a general pattern showing significant trends towards earlier dates for ice-out and longer ice-free seasons on lakes [39]. The rate of change in the Sproule Bay ice-free date closely matches a set of lake observations in Maine over a similar 50 year time span [40]. In both locations, ice-free date is now at least 10 days earlier than 50 years ago.

Climate warming observed on the Algonquin Park landscape is registering as changes in lake ice phenology in the park. This pattern will continue into the 21st century under climate change projections.

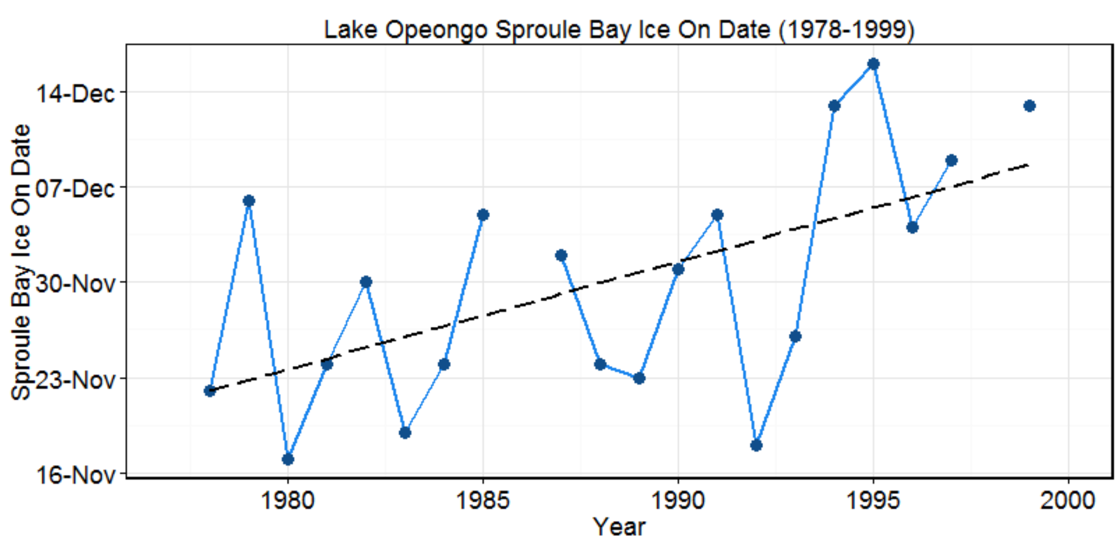


Figure 37. Ice-on dates for Sproule Bay, Lake Opeongo (1978–1999). Data are not available for each year because observers were not on site at the Harkness Laboratory

of Fisheries Research to record ice-on date. Ice-on occurs when the Sproule Bay surface is covered in ice.

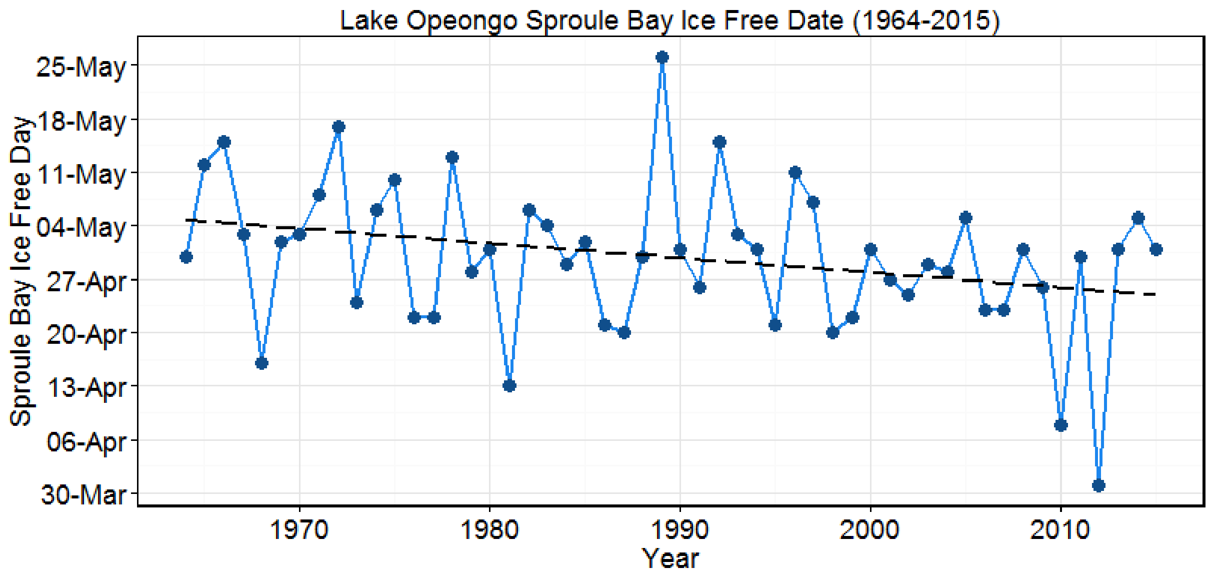


Figure 38. Ice-free day for Sproule Bay, Lake Opeongo (1964–2015) based on observed loss of ice from the surface of the bay as recorded from the boathouse dock at the Harkness Laboratory of Fisheries Research.

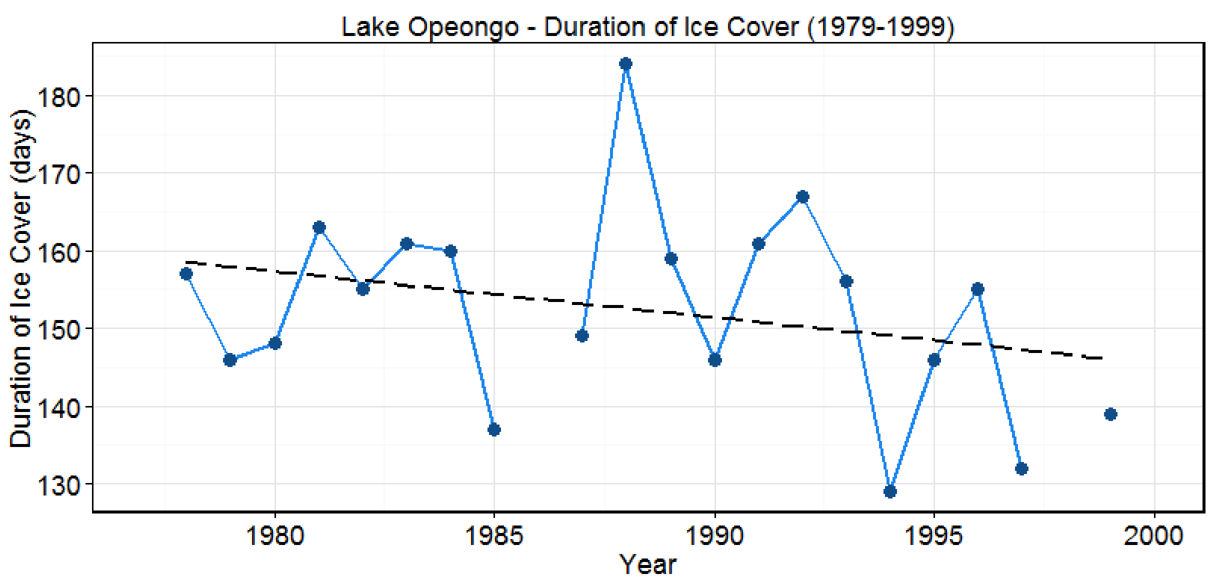


Figure 39. The duration (days) of ice cover on Sproule Bay, Lake Opeongo (1979–1999). Duration of ice cover is the difference between ice-on date in year *t* and ice=free date in year *t+1*.

Fish distribution in Algonquin Park

The distribution of fish species in Algonquin Park reflects 3 major phases in the aquatic history of the park. The first phase occurred as the landscape became free of glacial ice with fish species moving into watersheds following ice retreat. Recent analysis of paleohydrology estimated glacial lake water temperatures at approximately 5°C (Lake Agassiz [11,41,42]) so the set of species that followed the receding glacial front must have been cold water species. Movement likely occurred when the highlands of Algonquin Park were becoming ice-free in the period of 13,800 to 13,000 cal yrs BP Table 1, Figure 4). Since Main Lake Algonquin was expanding northward and situated west of Algonquin Park (Figure 5), watersheds draining to Lake Algonquin from the interior of Ontario at the time were the likely routes of entry during this phase.

The second phase occurred during the period when Lake Algonquin was dropping in elevation as the receding Laurentide Ice Sheet released different, lower elevation drainage points in the northwest areas of Algonquin Park (Figure 5). During this phase fish entered Algonquin Park through outlets such as Fossmill and Sobie-Guillemette, occupied the Amable du Fond watershed, travelled over the Mink Lake Sill, and occupied several other watersheds (Figure 5). Not all lakes connected to these watersheds received the same fish fauna. The presence of *Mysis diluviana* in Algonquin Park is indicative of influence from Lake Algonquin (Figure 7). There are several lakes that apparently were connected to Main Phase Lake Algonquin but do not have *Mysis* despite adequate habitat. This suggests that steep drainage gradients or barriers of some kind may have prevented occupancy by *Mysis*. Also, landscape changes in isostatic rebound may have rendered some watersheds inaccessible after release from ice.

The third phase in fish distribution occurred since the start of the twentieth century when authorized and unauthorized fish species introductions occurred in many watersheds. Smallmouth bass were introduced to provide fishing opportunities. Lake cisco were introduced as prey to increase lake trout production. In more recent years, other fish species such as northern pike, walleye, largemouth bass, and rock bass have been introduced to watersheds. Baitfish introductions have occurred through the release of live fish. Rainbow smelt and emerald shiner are 2 examples of this category of introduction.

This section summarizes the distribution of several native fish species in Algonquin Park including lake trout, brook trout, lake whitefish, cisco, and burbot. The distribution of smallmouth bass is also presented. The full set of all fish species distribution maps can be found in the section Fish Species Distribution Maps for Algonquin Park and associated Watersheds. For each species map, the grey lines represent the boundaries of fourth order watersheds in Algonquin Park and areas adjacent to Algonquin Park.

Lake trout and their food web classes

Lake trout occupy 188 lakes in Algonquin Park and are top predators in each lake ecosystem. The size of lake trout varies among lake ecosystems in the park and is governed by the size of the *prey field* in each lake. This diversity generally falls into 3 *food web* classes [43,44]. ***Class 1*** Lake trout lakes have no *pelagic* prey fish so lake trout rely on benthic invertebrates, zooplankton and perhaps small nearshore fish for food (Figure 40 and 41). A lake trout food web with 3 trophic levels (lake trout [3] consume zooplankton [2]; zooplankton consume phytoplankton [1]) resulting in lake trout with small body sizes. ***Class 2*** lake trout lakes have at least one species of pelagic prey fish (typically *Coregonus* spp.) as their principle prey item and contain 4 trophic levels (Figure 40 and 41; lake trout [4] consume pelagic prey fish [3]; pelagic prey fish consume zooplankton [2] ; zooplankton consume phytoplankton [1]). Lake trout in Class 2 lakes are larger as adults than lake trout in Class 1 lakes. ***Class 3*** lake trout lakes contain the pelagic prey fish and the predatory zooplankton *Mysis* and have 5 trophic levels (Figure 40 and 41; lake trout [5] consume prey fish [4]; prey fish consume *Mysis* [3]; *Mysis* consume zooplankton [2]; zooplankton consume phytoplankton [1]). Lake trout in Class 2 and Class 3 lakes reach large adult body sizes. In each of the food web classes, lake trout may forage on different prey items such as both invertebrates and prey fish in Class 1 and Class 2 at different times of the year depending on their size [45]. The classification presented here reflects the predominant food web pathways supporting lake trout in the different lake food webs [45].

Lake trout size differences between Class 1 and Class 2 or 3 lakes are based on the costs of foraging on prey of different sizes [46]. Lake trout pursuing small prey items (Class 1 lakes), with reduced caloric density (calories per weight of prey) such as zooplankton, forage more actively than lake trout pursuing larger prey items that return higher caloric densities. The pursuit of smaller prey with less nutritional reward leads to the size differences detected between Class 1 and other lake trout lake classes.

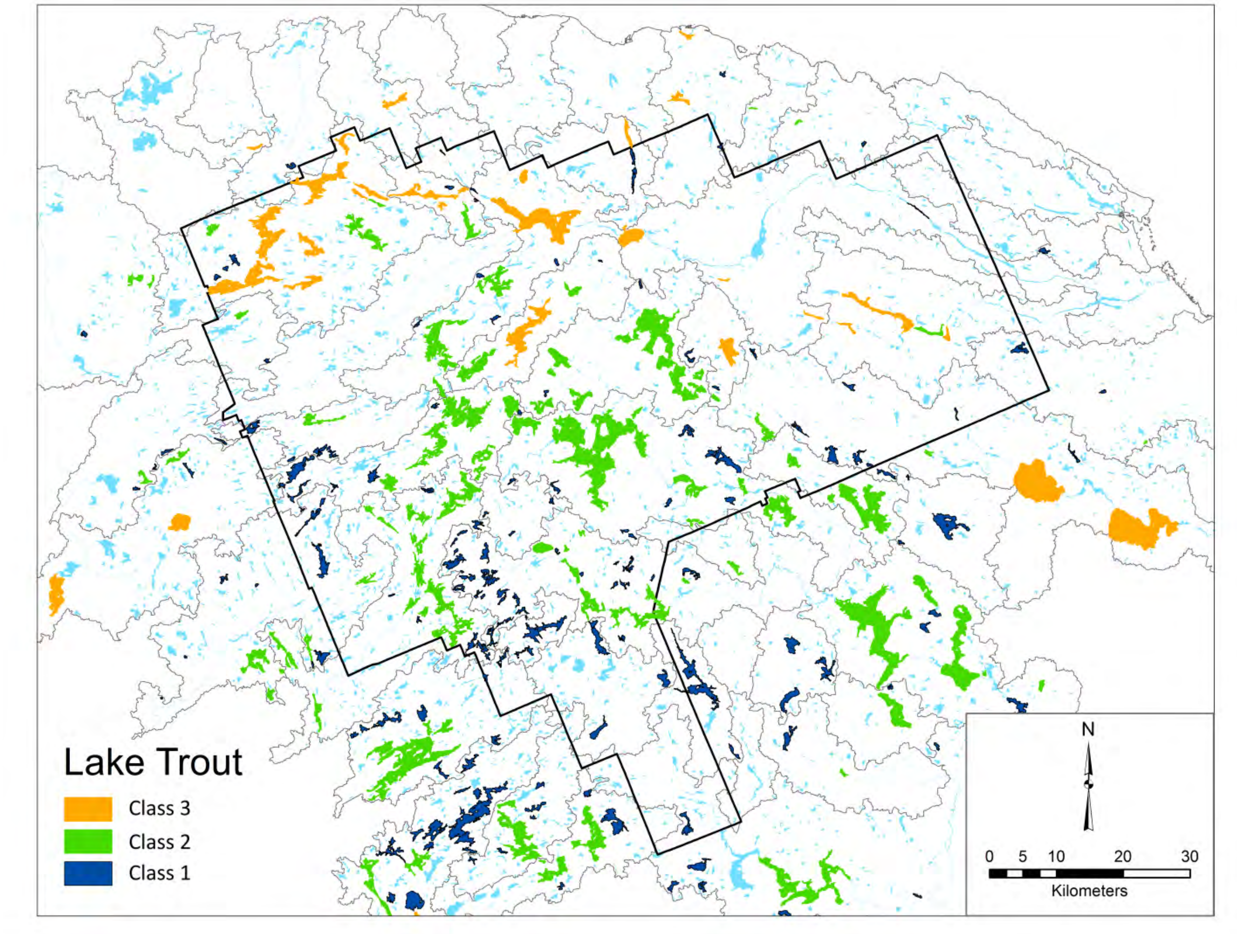


Figure 40. Lake trout distribution in Algonquin Park and adjacent watersheds indicating the 3 classes of lake trout food webs. Lakes without pelagic prey fish are labelled Class 1 (dark blue) and are comprised primarily of small-bodied lake trout. Lakes with access to prey fish in addition to a range of invertebrates are either Class 2 (green, *Mysis* absent) or Class 3 (orange, *Mysis* present) lakes and are comprised of large body lake trout.

Without larger prey, lake trout in Class 1 lakes are confined to a truncated prey field and are unable to achieve the sizes observed in lakes with a wider prey field including pelagic prey fish. As a result, lake trout in Class 1 lakes have a lower *trophic position* than lake trout in Class 2 lakes and in turn, Class 2 lakes have a lower trophic position than lake trout in Class 3 lakes.

The 3 classes of lake trout lakes can help explain differences in *biomagnification* of contaminants among lake trout lakes [44]. Contaminants increase in concentration due of the number of trophic positions. The addition of trophic positions in food webs adds steps in contaminant concentration. Class 3 lake trout lakes have longer food webs (ie., more trophic positions) and therefore can have higher concentrations of contaminants than lake trout in Class 1 lakes.

Lake trout food web classes are mapped based on whether pelagic prey fish are absent in lake trout lakes (Class 1), present but without *Mysis diluviana* (Class 2), or present but co-occurring with *Mysis diluviana* (Class 3) (Figure 40). Class 1 lake trout lakes can be found in different areas of Algonquin Park. Class 2 lakes are also distributed through the park and represented by lager lakes approximately in the central region of the park. Class 3 lakes are confined to those areas that were directly influenced by the drainage of glacial Lake Algonquin because of the presence of *Mysis diluviana* as both an indicator of Lake Algonquin and a glacial relict from that period. The glacial history of water movement and species distributions stemming from that movement are drivers of the mapped distribution of lake trout food web classes in Algonquin Park.

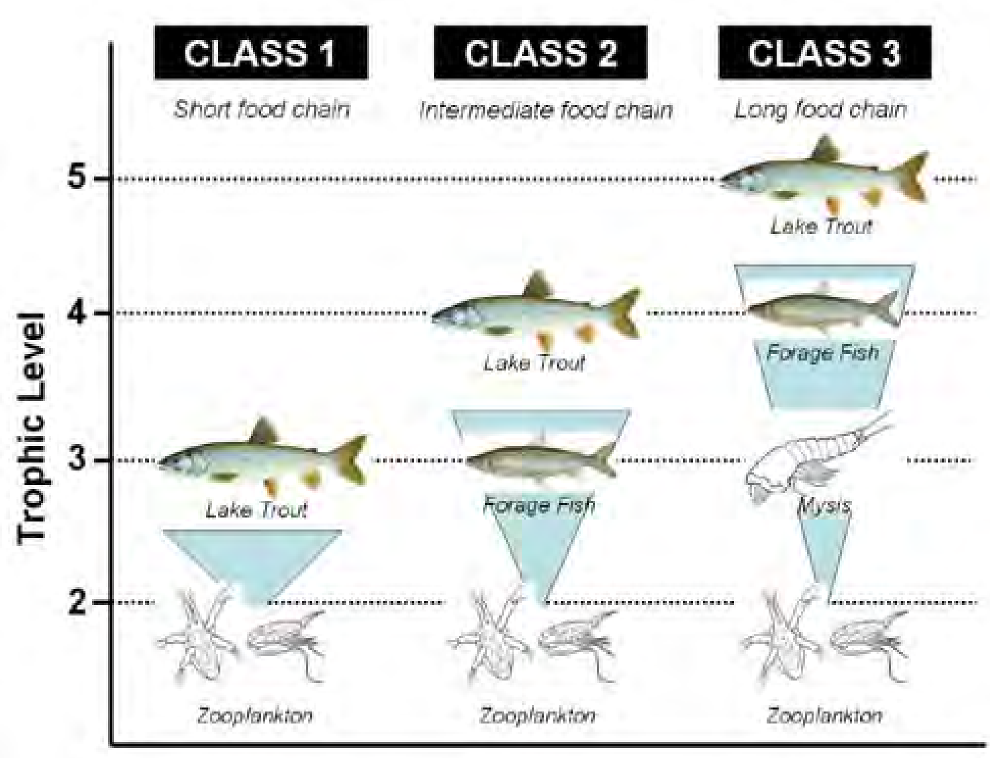


Figure 41. Lake trout food web classifications based on length of food chains supporting lake trout and their diet [43,44]. Diet of lake trout in Class 1 lakes is comprised of invertebrates (bottom and open-water) and small fish inshore. Diet of lake trout in Class 2 lakes is comprised of open water pelagic forage fish and similarly for Class 3 lakes with the exception that *Mysis* is part of the food chain. Lake trout in Class 1 lakes are small bodied with an occasional large fish while in Class 2 and 3 lakes, lake trout can achieve larger sizes. Modified from ([95, 96]).

Brook trout and their competitors/predators

Brook trout are widely distributed in lakes and streams of Algonquin Park (Figure 42), with 444 lakes listed as brook trout lakes in the park. Brook trout co-occur or have historically co-occurred with lake trout in 162 of the 188 lake trout lakes in the park (86%). The surface area distribution of brook trout lakes ranges from 1 ha to 5000 ha (Figure 43). There are also stream and river locations of brook trout where they may be resident throughout the year (Figure 42). The combined lake and stream distribution of brook trout shows this species is present in every fourth order watershed in Algonquin Park.

Brook trout seek out groundwater habitat in streams and inshore areas of lakes, prepare sites for spawning, cover the eggs with gravel, and leave the spawning site to groundwater flow over winter. Young brook trout swim-up from these sites and occupy inshore areas of lakes in spring [47,48]. Since the temperature of shallow groundwater is approximately the average annual air temperature, spawning sites for brook trout are slightly warmer than lake or stream water during winter [49,50]. The quality of each spawning site is determined by groundwater flow with high flow reflecting high quality sites relative to sites with little flow [51]. Groundwater flow at spawning sites is the most important factor in survival of young brook trout until they swim-up the following spring. The wide distribution of brook trout in Algonquin Park indicates a wide distribution of accessible sites with groundwater among all Algonquin watersheds.

Adult brook trout occupy areas of lakes in close proximity to the thermocline — the summer boundary between warm surface water and cold deeper water. They are typically found in water 13°C–17°C and can live in colder water [52,53]. Young brook trout occupy inshore areas of lakes and streams after swim-up from spawning areas and move around the perimetres of lakes through spring [54]. They live close to shore until water temperatures rise in spring at which point young brook trout seek refuge in coldwater seepage habitat. This habitat can be critical for population survival [47]. This proximity to shore or near the thermocline imposes competitive or predation risk on brook trout depending on other co-occurring fish species.

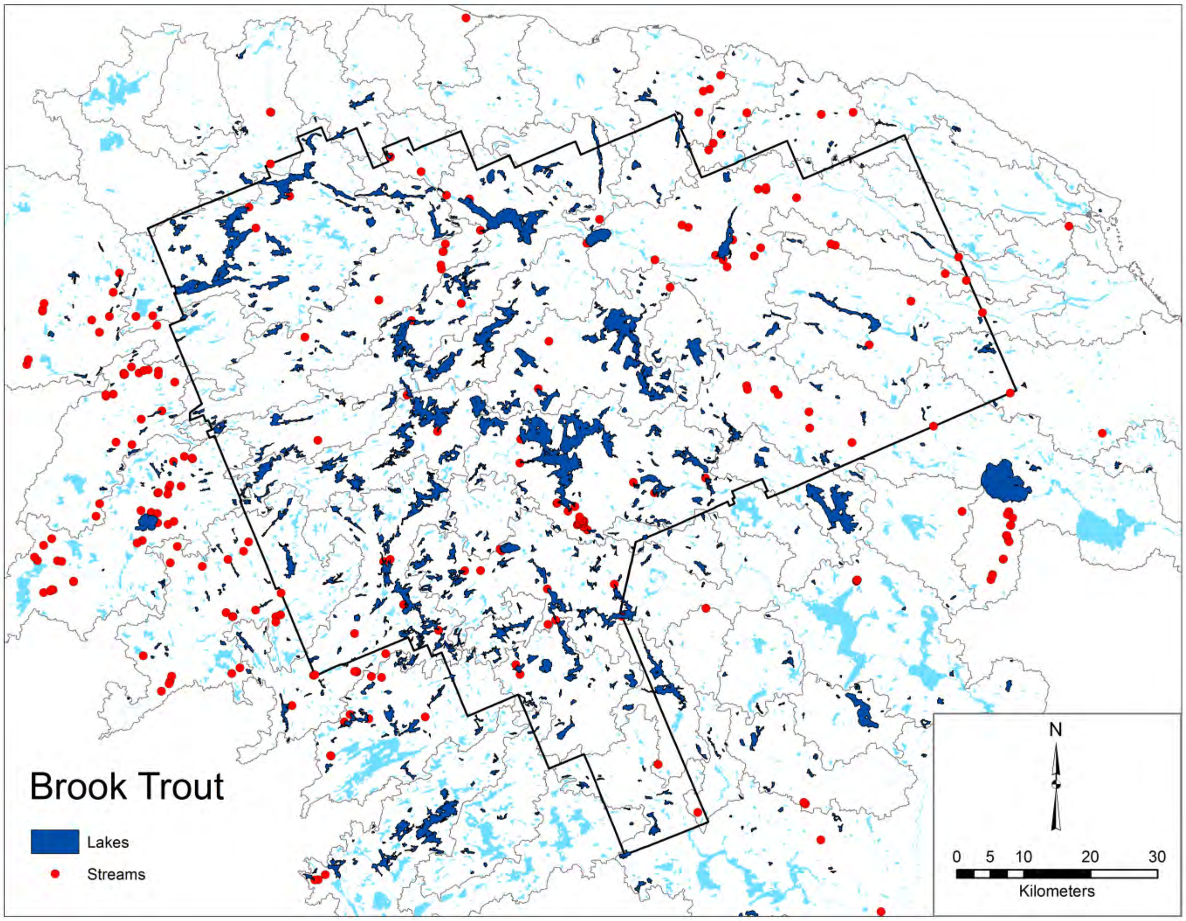


Figure 42. Brook trout distribution in Algonquin Park lakes (dark blue) and streams (red) as well as adjacent watersheds.

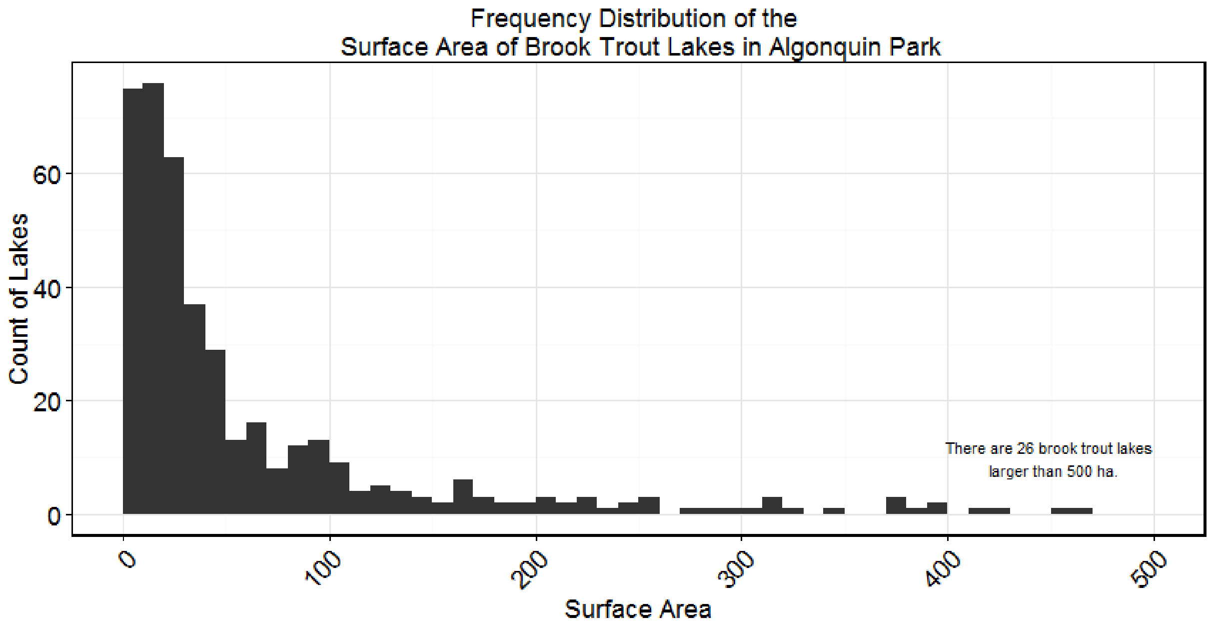


Figure 43. The distribution of lake surface area (hectares) of brook trout lakes in Algonquin Park.

For brook trout in lakes with smallmouth bass, the occurrence of bass imposes a risk of predation on several early life stages of brook trout including young brook trout inshore or other life stages near the thermocline. The presence of bass can lead to reductions in brook trout abundance. Figure 44 indicates the Algonquin Park lakes where brook trout co-occur with smallmouth bass. Fourteen percent (62/444) of all brook trout lakes in the park also has smallmouth bass present.

The presence of yellow perch imposes a competitive risk on brook trout growth through competition for benthic prey in lakes with both brook trout and yellow perch. Without yellow perch, brook trout are able to acquire food from several trophic levels including inshore benthic invertebrates, small prey fish, and planktonic food [(55,56)]. When yellow perch are present, the wide range of prey options for brook trout is reduced because perch can capture several prey categories more efficiently especially benthic invertebrates. The prey field for brook trout becomes truncated as a result and their growth is reduced. This also appears to affect density of brook trout with reduced numbers of brook trout in lakes with yellow perch relative to lakes without yellow perch [(55)]. Overall, the presence of yellow perch shifts brook trout production from primarily benthic to pelagic food webs. Figure 45 shows that yellow perch and brook trout co-occur in lakes in several watersheds of Algonquin Park. Yellow perch are present in 45% of all brook trout lakes in Algonquin Park.

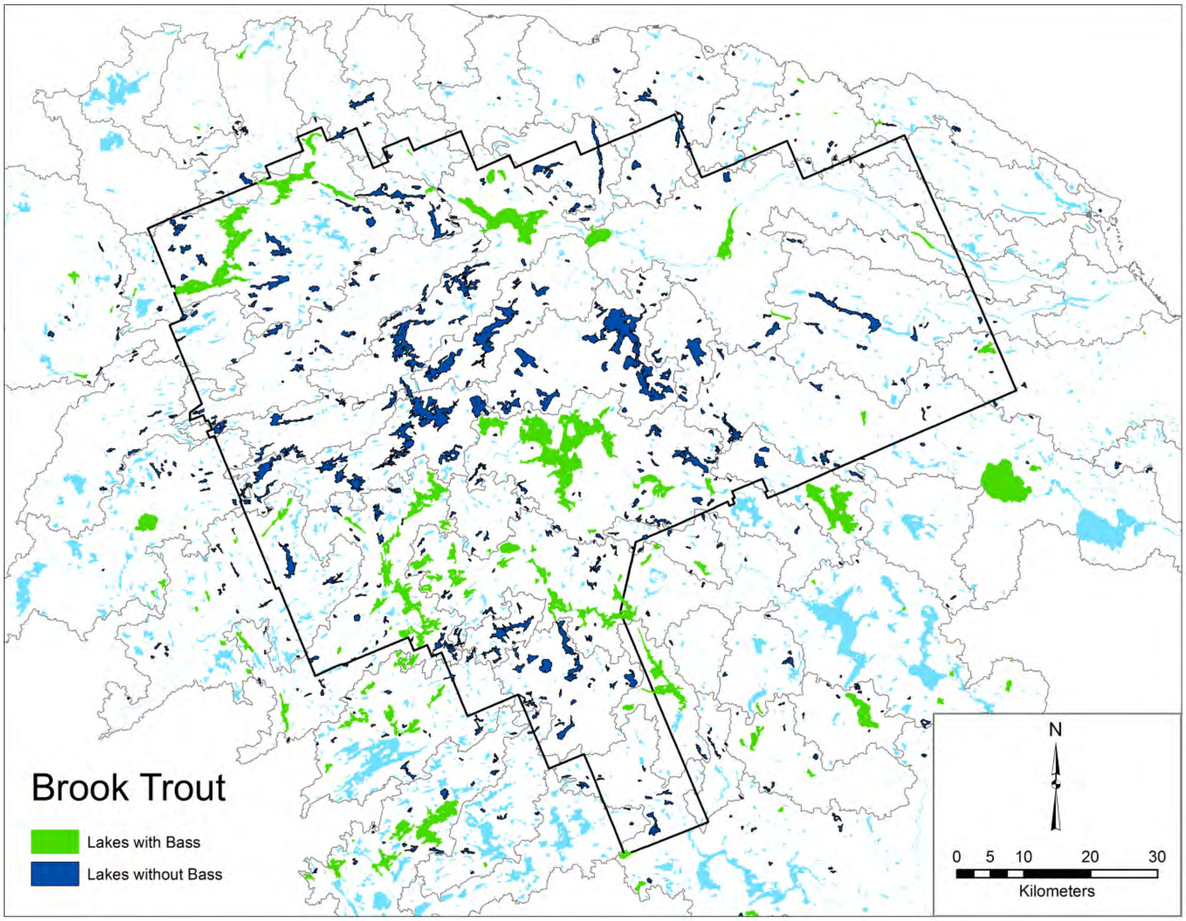


Figure 44. Brook trout lakes in Algonquin Park and adjacent watersheds partitioned according to the presence (green, brook trout lakes with smallmouth bass) or absence of smallmouth bass (dark blue, brook trout lakes without smallmouth bass).

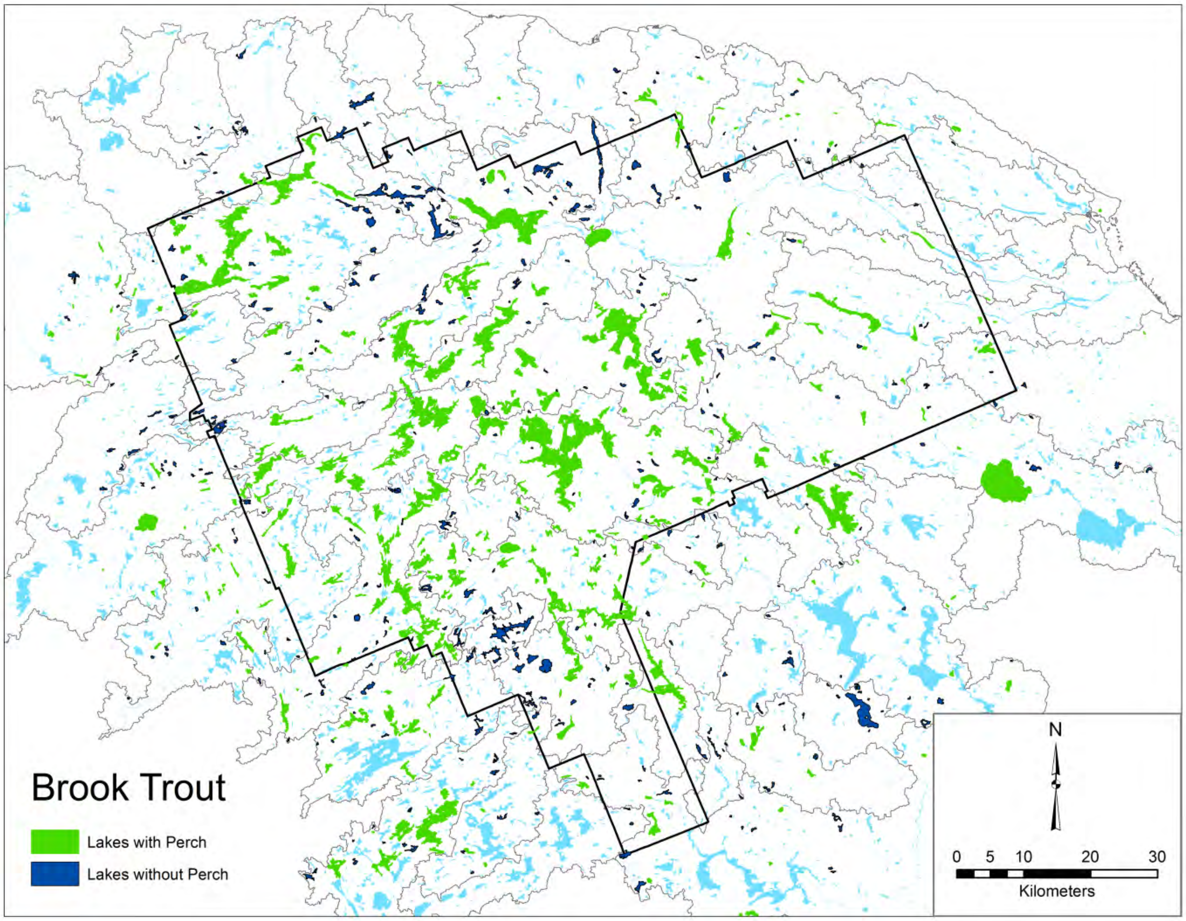


Figure 45. Brook trout lakes in Algonquin Park and adjacent watersheds partitioned according to the presence (green, brook trout lakes with yellow perch) or absence of yellow perch (dark blue, brook trout lakes without perch).

Lake whitefish and cisco — the Coregonines

Lake whitefish and cisco are native species to Algonquin Park belonging to the genus *Coregonus*. It is a genus of fish distributed widely in the northern hemisphere with species found in North America, Europe, and Asia. They belong to the subfamily Coregoninae (leading to the Coregonine label) of the larger family Salmonidae. Lake whitefish are typically linked to the benthic food web of lakes and occupy deeper colder water in summer months. Cisco are linked to the pelagic food web, live in open water environments of most lakes and occupy the boundary area between warm and cold lake water as well as deeper colder water of lakes during summer months.

The native distributions of the 2 species in Algonquin Park are informative with respect to their relative timing of appearance on the Algonquin Park landscape. Lake whitefish are found in many large lakes of the park (N=74) from watersheds in the south to the north boundary of the park (Figure 46). In contrast, the native distribution of cisco includes watersheds in the northern half of the park only (Figure 46). For both species, there are lakes with only lake whitefish and lakes with only cisco within their park distribution. This pattern indicates that lake whitefish arrived on the Algonquin Park landscape early after glacial retreat and occupied many watersheds on a north-south gradient. There are watersheds with lakes of adequate depth for lake whitefish in the south-central areas of the park that nonetheless were not accessible for lake whitefish.

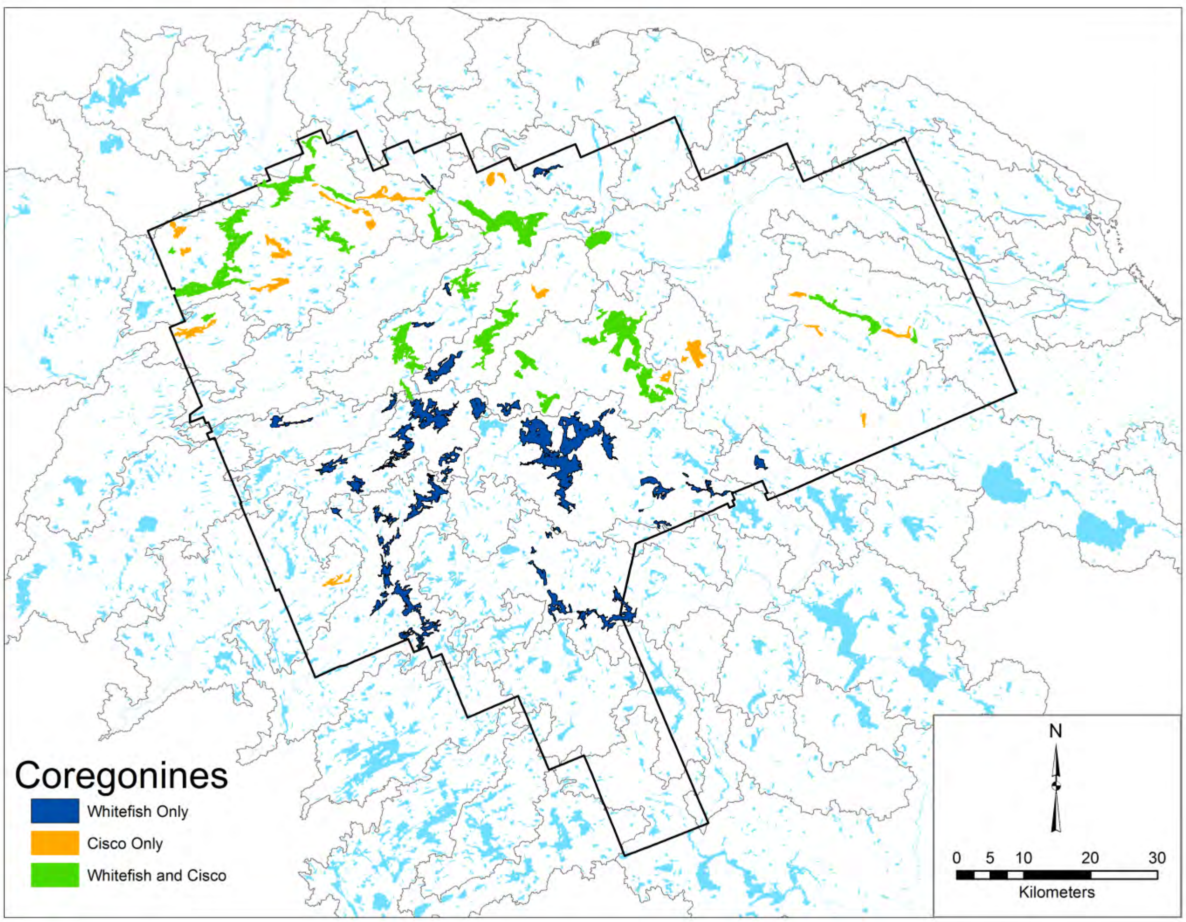


Figure 46. The historic distribution of lake whitefish (dark blue), cisco (yellow), or both species co-occurring (green) in Algonquin Park lakes. Only lakes within Algonquin Park are shown because of the lack of historical information on patterns outside of the park. Blackfin cisco species complex is not shown in this figure.

Cisco native distribution does not match the north-south pattern of lake whitefish distribution. Cisco occurrence in the northern half of the park points to a later arrival than lake whitefish on the Algonquin Park landscape (Figure 46). A native distribution in the northern half of the park points to the time period when Main Phase Lake Algonquin was routing through the northern watersheds as to when this species entered the park landscape (Figure 5).

The different pattern of lake occupancy between the 2 species resulted in lakes where both co-occur and lakes with only 1 of the species present (Figure 46). This has direct implications for biodiversity of these species in Algonquin Park. When both species co-occur, lake whitefish occupies its benthic trophic position in a lake food web and cisco occupies its normal pelagic trophic position[54]. Cisco is a more efficient plankton forager than lake whitefish in the pelagic zone of lakes while lake whitefish is a more efficient benthic forager than cisco on the bottom habitat of lakes. When cisco is present, lake whitefish do not diversify away from their benthic food web.

When cisco are absent from lake food webs, lake whitefish have the potential to occupy the pelagic zone and evolve lake-specific species pairs — one the typical benthic foraging lake whitefish and the other the pelagic foraging lake whitefish occupying the niche normally filled by cisco [57]. The pelagic form (labelled limnetic) is smaller and slower growing than the normal benthic form (labelled benthic) of lake whitefish. The presence of limnetic forms of lake whitefish is a demonstration of evolution on an island (lake surrounded by a sea of land) through diversification of their foraging niche in a process known as ecological speciation [57]. There are 18 lakes with species pairs of lake whitefish in Canada [58]. Some cases represent double invasion of whitefish from different source populations or species [58], with 6 lakes containing limnetic and benthic pairs stemming from a common glacial refuge[58].

In Algonquin Park, there are 2 lakes that fit the limnetic/benthic evolutionary model with only one of the lakes recognized as such. Lake Opeongo is listed among the 18 lakes as containing a species pair of lake whitefish, with 1 being a smaller slow growing form [58,59]. Surveys in recent years have provided clear evidence of a species pair of lake whitefish in Big Trout Lake. This discovery is not yet published but the size, slow growth, and pelagic habitat occupied by the limnetic form are all consistent with the ecological speciation phenomenon for this species [57,58].

A third lake in Algonquin Park presents a unique situation for lake whitefish in Canada. Lake LaMuir has only a pelagic form of lake whitefish without a benthic foraging form present. Repeated surveys of this lake have failed to capture benthic lake whitefish pointing to the uniqueness of this lake ecosystem. The limnetic only occurrence is unique and so has not yet been evaluated as a designatable unit as have other limnetic/benthic pairs for whitefish [58].

Finally, some lakes have small-bodied (less than 23 cm in length) lake whitefish occupying both the open water and benthic habitats of lakes (eg., Misty Lake, Burnt Island Lake). The presence of small lake whitefish in all lake habitats is a new discovery and demonstrates how flexible lake whitefish life history can be in different aquatic food webs of Algonquin Park.

The rarer outcome occurs in the absence of lake whitefish. In this circumstance, the diversification of cisco into the lake whitefish trophic benthic niche is possible but rare [57]. White Partridge Lake does not have lake whitefish but does have 2 functional species of cisco. One is the pelagic foraging species consuming zooplankton while the other is a bottom feeding form occupying the deeper habitat in White Partridge Lake.

Over 50 years ago, cisco was introduced to Lake Opeongo, Canoe Lake, and Smoke Lake to improve lake trout productivity for recreational fishing. From that time, cisco have spread downstream of Lake Opeongo to more fully occupy lakes of the Opeongo River watershed while cisco introduced to Smoke Lake appear to have spread further into the Muskoka River watershed in the park (Figure 47).

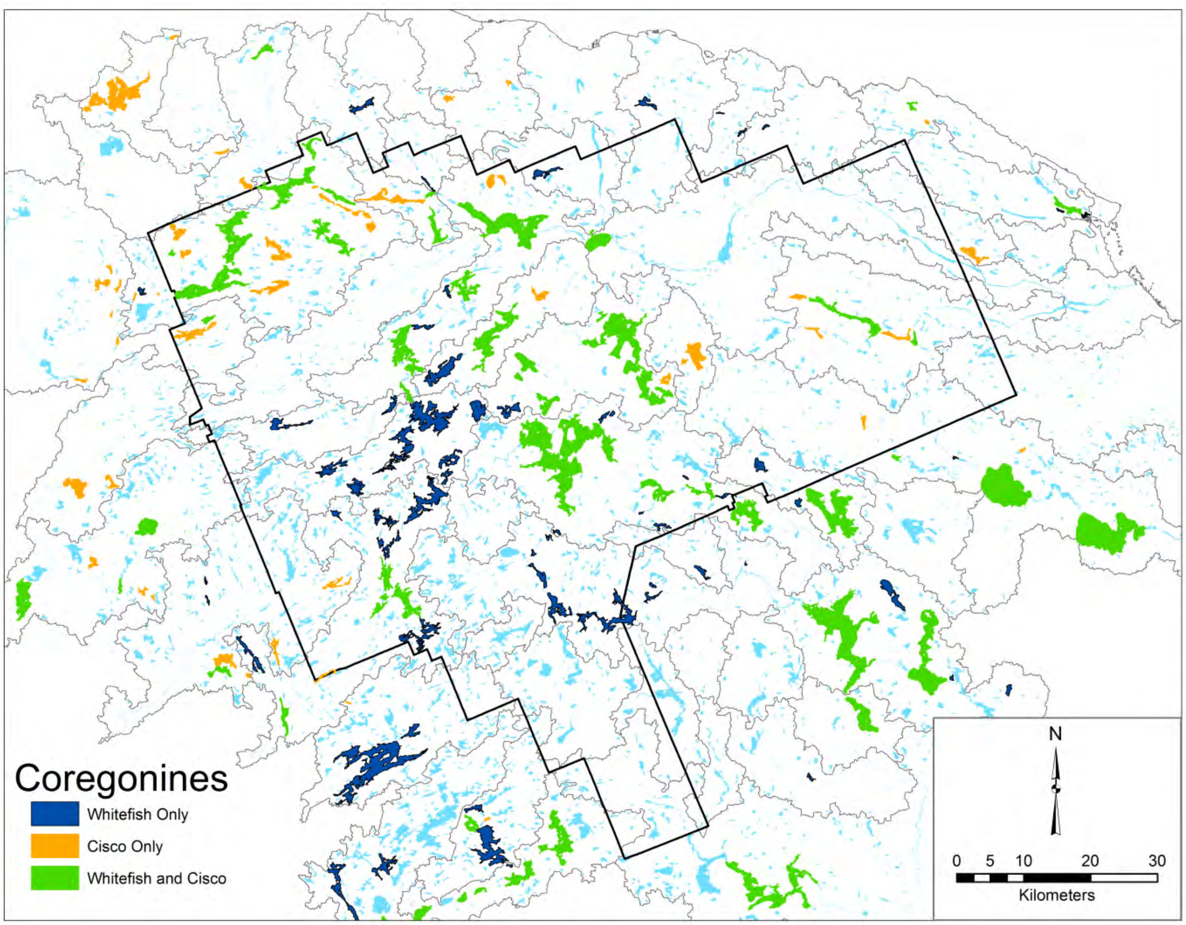


Figure 47. The current lake distribution of lakes with lake whitefish only (dark blue), cisco only (yellow), or both species co-occurring (green).

Blackfin cisco species complex

Blackfin cisco is 1 of 6 deepwater cisco species of the Laurentian Great Lakes [60]. They were abundant in Lakes Huron and Michigan early in the 20th century but were extirpated due to overfishing and species invasions including sea lamprey and other planktivorous species of fish that entered the Great Lakes. This species fed exclusively on *Mysis diluviana* in the Great Lakes and were captured in deep areas. Loss of this species from the Laurentian Great Lakes has led to the red listing of blackfin cisco as extinct by the International Union on the Conservation of Nature (IUCN) and as data deficient in Canada (Committee on the Status of Endangered Wildlife in Canada). They are occasionally captured in Lake Nipigon [61].

In 2009 and 2010, blackfin cisco was found in several lakes of the Petawawa River system and the Amable du Fond River system (Figure 48). The lakes also contain *Mysis diluviana* and this planktonic predator was present in the stomachs of captured blackfin cisco. Their distribution is limited to areas that were part of the Main Phase Lake Algonquin drainage route (Figure 5). Recent surveys of North Tea, Manitou, Kioshkokwi and Lauder Lakes of the Amable du Fond watershed did not detect the blackfin cisco species complex.

A more complete understanding of the factors driving cisco diversification is an active area of research with 2 leading hypotheses. One hypothesis focuses on the evolutionary model used to describe diversification of lake whitefish through ecological speciation within lake ecosystems. For cisco species, the diversification can lead to more than 2 species pairs in the Laurentian Great Lakes or a species pair in inland lakes. If the presence of *Mysis diluviana* was the driving factor in producing the wide prey field for blackfin cisco then lakes with *Mysis diluviana* might be occupied by blackfin cisco. An alternative hypothesis is one based on the geographic distribution of different cisco species given differences in colonization timing. In Algonquin Park, cisco (*Coregonus artedi*) has a wider distribution among lakes covering a greater elevation gradient than blackfin cisco (*Coregonus nigripinnis*). In this alternative view, different species are based on the historical distribution of species stemming from past events. In the case of the blackfin cisco, the historical drainage patterns of glacial Lake Algonquin, and timing of these drainage patterns including flow connections among glacial lakes (Figure 5), is a competing explanation for the occurrence of blackfin cisco in lakes with cisco and lake whitefish. Since blackfin cisco have a more restricted distribution than cisco then it implies that blackfin cisco arrived on the Algonquin Park landscape later than cisco. Until one of these hypotheses is supported or refuted, the discovery of this species is referred to as the blackfin species complex.

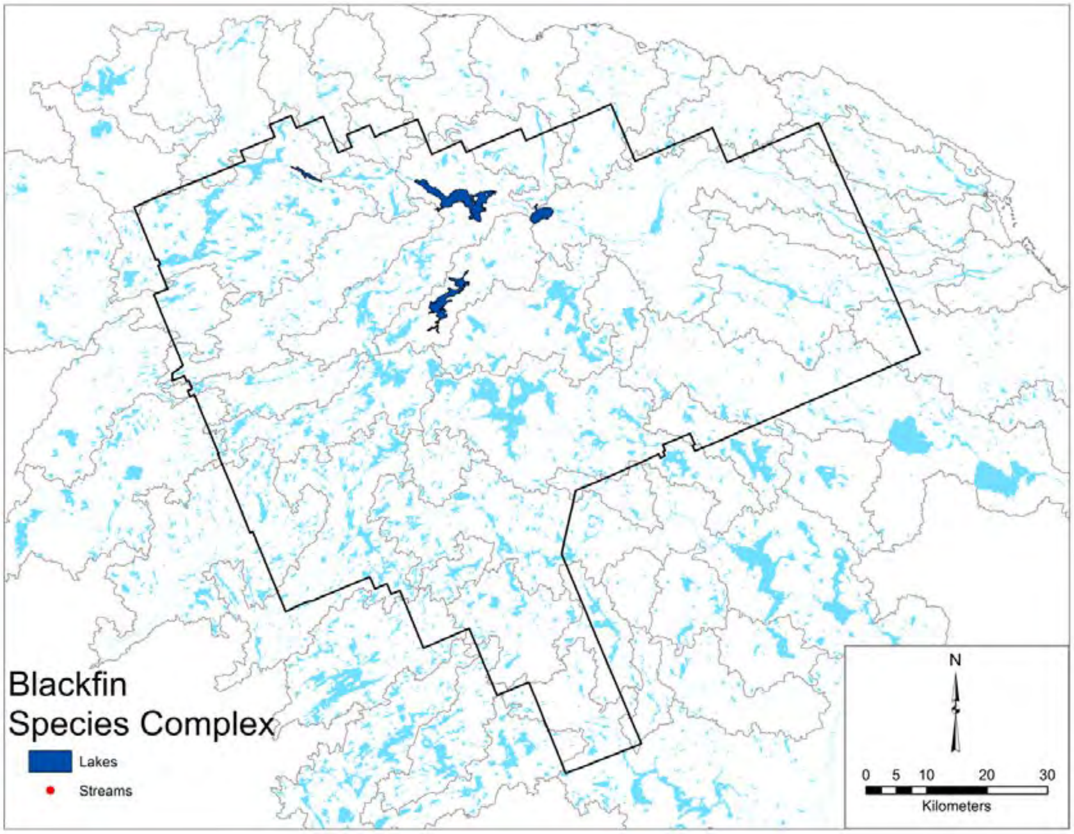


Figure 48. The distribution of the blackfin cisco species complex.

Burbot (or ling)

Burbot is a freshwater member of the cod family. It has a worldwide circumboreal distribution that includes North America, Asia, and Europe. It is a species occupying deeper cold waters in lakes of Algonquin Park but is known to travel river systems during cold periods of the year (Figure 49). Its food web is largely located in the benthic zone of lakes where it is a top predator on fish such sculpins. Burbot are generally inactive during the day and occupy burrows or troughs on the lake bottom and become active foragers at night [62]. Occasionally, burbot have been captured at night in the pelagic zone presumably foraging on open water fish. Juvenile burbot may occupy the nearshore zones of lakes. Adults have the unusual habitat of spawning in February under the ice of Algonquin Park lakes.

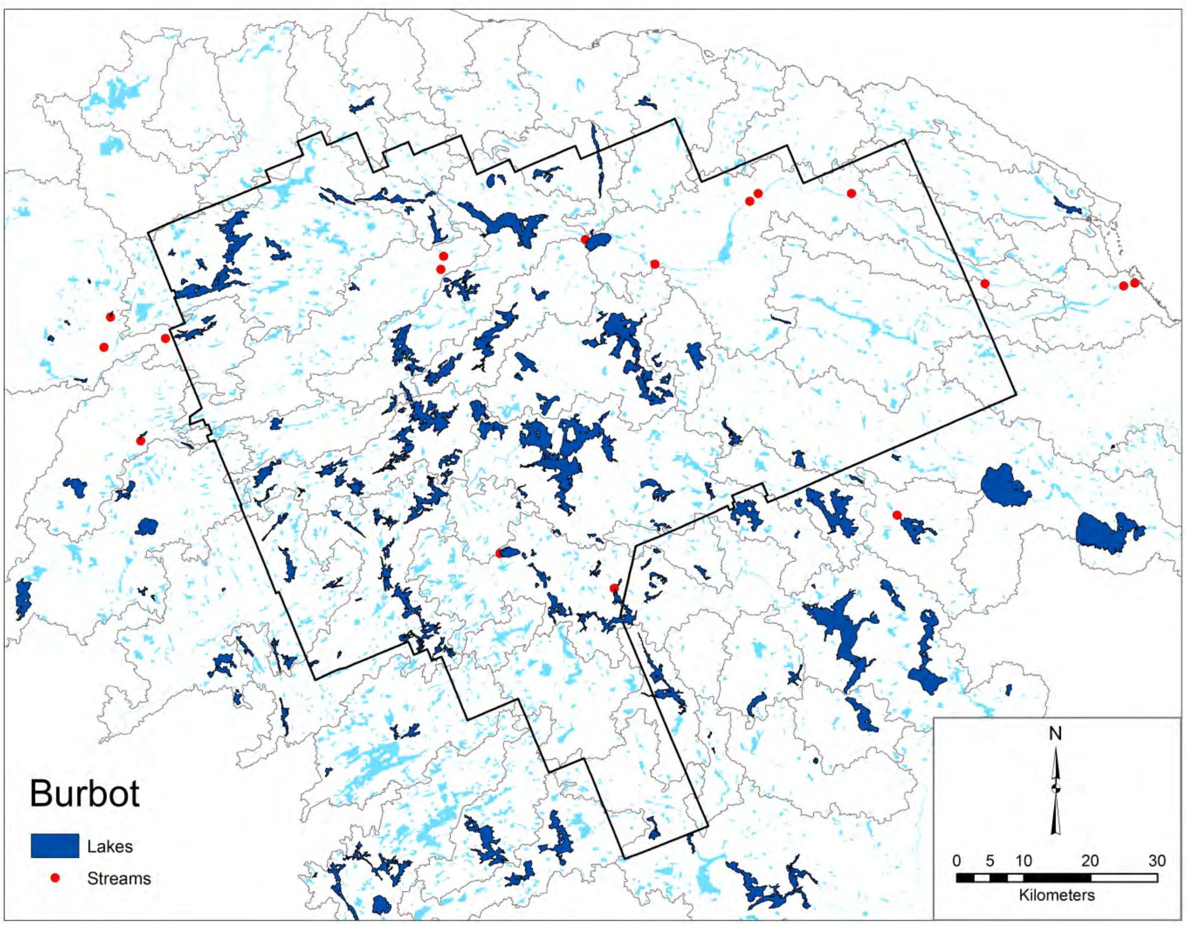


Figure 49. The distribution of burbot in lakes of Algonquin Park and adjacent watersheds.

Smallmouth bass

Smallmouth bass and several other predatory fish were reported in Lake Traverse as a native species in 1936 [63]. The report indicated smallmouth bass, muskellunge, walleye and rock bass occupied Lake Traverse as native species and that all lakes above Traverse were trout waters [63]. The elevation of the Petawawa River entering Lake Traverse is 255 metres and this criterion was applied as the elevation point below which natural bass populations exist through the process of post-glacial movements. Smallmouth bass populations were introduced above this elevation in Algonquin Park, starting with Cache Lake in 1899 [64] and continuing in several Highway 60 corridor lakes in the following decades. Smallmouth bass occupy 89 lakes in the park (Figure 50).

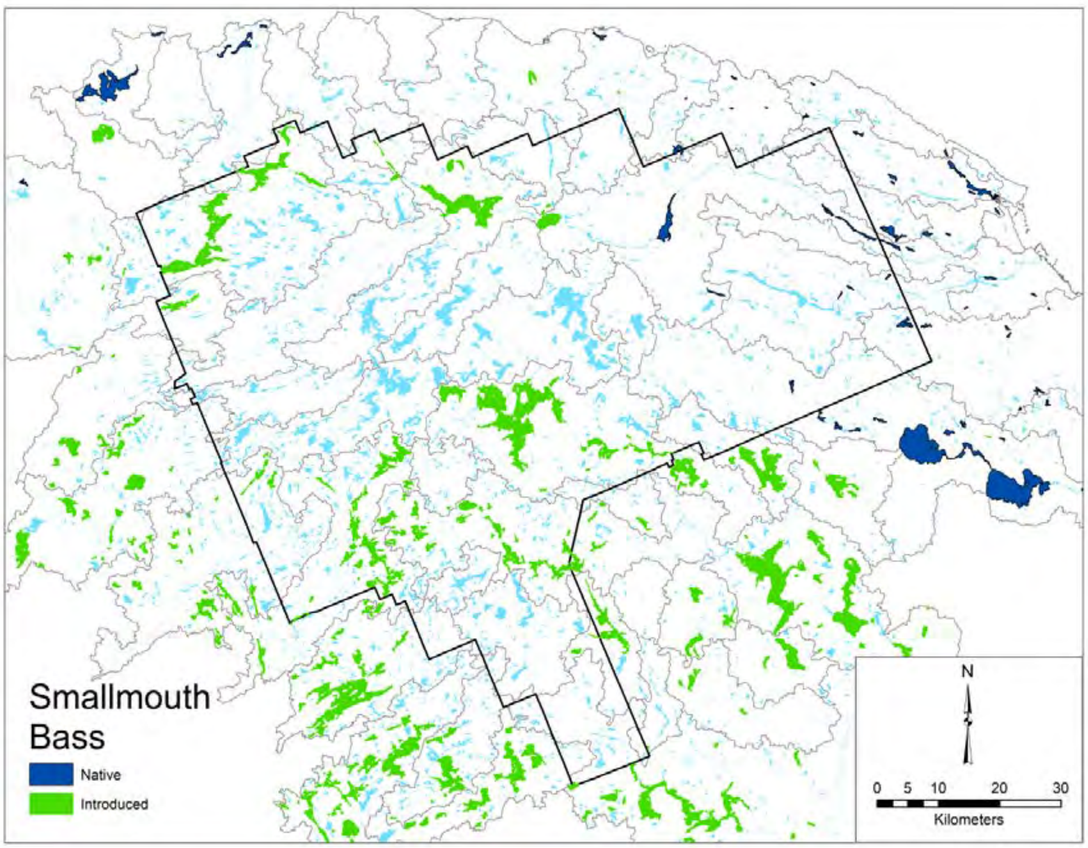


Figure 50. The distribution of smallmouth bass in lakes inside and adjacent to Algonquin Park. The original distribution of smallmouth bass in lakes (dark blue) is based on the 255 metre elevation described by Dymond (1936) and are distinguished from lakes with introduced smallmouth bass (green).

Fish in Algonquin Park and climate change

The average annual air temperature increased in Algonquin Park in the 20th century and is projected to rise through the 21st century. From a projected increase of 1.3 to 2.5°C in the 2020s, to a 2.0–7.1°C by mid-century, and finally a 3.3 to 10.6°C rise in the 2080s [(37)], this increase will inevitably lead to increases in water temperatures of lakes, rivers, and streams of Algonquin Park. For most of Canada, water temperature by the year 2100 will increase by 5–10°C [(65)]. Currently most lake surface temperatures in mid-summer are in the range of 20–25°C but will shift to a higher range of 25–30°C by 2100 [(65)]. Climate change will affect all ecosystems in Algonquin Park including aquatic ecosystems.

Ice out dates for Sproule Bay, Lake Opeongo are occurring earlier now than in the 1960s and ice duration through winter is becoming shorter. The evidence supporting a warming climate for Algonquin Park is clear and given the climate position of the park (Figure 34), the question is when will Algonquin Park cease to be a cool climate island in a warmer southern Ontario landscape? Corresponding changes in lake physics that can be expected to occur with a warming climate for Algonquin Park include: 1) timing of seasonal lake warming and cooling: 2) duration of seasonal thermal stratification; 3) oxygen exchange between lake and atmosphere, and 4) the strength of winds contributing to mixing of surface waters are among many limnological parameters that will shift with a warming climate this century [(30)].

Water temperature affects fish at several levels. It directly influences metabolism and physiological performance, timing of seasonally important events (e.g., spawning) and fish habitat volume defined by species-specific preferred temperatures. Water temperature can indirectly affect fish in many ways including the timing and productivity of prey availability, the ability to disperse and occupy new watersheds, and the production of cohorts or year-classes.

Several fish species found in Algonquin Park have been the focus of analyses on potential changes that can be expected with a warming climate. By 2050, under accepted models for predicting climate change, brook trout distribution will decline by 49% from its current watershed distribution in Canada [(66)]. This decline will not be felt acutely in Algonquin Park since projections of watershed-scale declines indicate that the Algonquin Park landscape will retain brook trout habitat in its watersheds [(63)]. However, Algonquin Park will be an increasingly isolated landscape from the wider distribution of brook trout in the decades to come [(66; 65)].

The projected reduction of brook trout distribution in Canada is paralleled by projected reductions in the southern extremes of its North American distribution. To maintain access to cool stream temperatures with groundwater, brook trout occupy watersheds at a minimum of 640 m in elevation in their southern periphery of Georgia and North

Carolina [67]. Under climate warming projections similar cool temperature regimes will exist at 714 m in elevation in the future which will effectively reduce brook trout habitat in its southern range. In southern Ontario streams, brook trout do not cross a temperature boundary of 24°C and reside in upstream areas to avoid warm seasonal temperatures [68]. Under climate warming the 24°C boundary moves upstream due to overall warmer air and water temperatures and effectively reduces brook trout stream habitat by 30–40% [68]. Climate warming projections point to clear range reductions for brook trout in the 21st century.

In contrast, smallmouth bass is projected to substantially expand their Canadian distribution by 2050 [66]. Smallmouth bass year-class, the relative abundance of a cohort produced in a single year, is related to summer conditions such that warm summers produce larger year-classes than cooler summers [69]. The mechanism producing this pattern is the growth of young smallmouth bass in their first summer. Under warm summer conditions, young-of-year smallmouth bass reach a fall size sufficient to survive their first winter period when they are inactive and rely on stored food energy [32]. Without good growing conditions young bass are not able to reach a size sufficient to survive on stored energy reserves and the outcome is a reduced year-class size for that particular year. For many year-classes, young-of-year size distributions are a mix of individuals capable of surviving and smaller individuals unable to survive the first winter. Summer warming conditions also determine the timing of nesting in smallmouth bass with large individuals preceding small individuals in the seasonal timing of reproduction [35]. Large male smallmouth bass also have greater nest survival and appear to contribute more to year-classes than small males [70]. For Algonquin Park, climate warming projections strongly indicate increased production of smallmouth bass year-classes. A similar analysis of largemouth bass has not been completed but since this species has similar temperature dependencies as smallmouth bass, then climate warming will likely favour largemouth bass production as well.

For lake trout, the effects of climate change are related to the physics of lakes and how this changes under warming conditions. Warmer springs and summers produce an earlier onset of thermal stratification in lakes through the formation of the thermocline — the boundary between warm surface waters (ie., epilimnion) and deeper cold waters (ie., *hypolimnion*) of lakes. The depth of a thermocline in a given year is a function of warming (summer temperatures) and mixing (summer winds) in the water column. The water density gradient resulting from formation of a thermocline prevents mixing between warm epilimnetic waters and deeper hypolimnetic water and thus reduces or eliminates oxygen exchange between the 2 lake layers. Once the lake thermocline is established oxygen concentrations in the hypolimnion effectively represent all the oxygen available to cold water fish living in deeper areas of lakes. The oxygen in the hypolimnion is not replenished until lakes cool in the fall to an extent that allows surface and deep water to mix at a common cold temperature. The length of time a thermocline remains in a lake affects oxygen concentration because the entire food web in deeper areas of lakes is dependent on the oxygen locked in at the time of thermal stratification. Climate warming models all point to shorter durations of lake ice cover and longer periods of thermal stratification. The depletion of dissolved oxygen in the hypolimnion projected to occur in pre-Cambrian shield lakes will be based on lake size with smaller lakes at greater risk than larger lakes (71).

Lake trout prefer cold temperatures where growth is maximized in the range of 10–12°C. Lake trout begin feeding in shallow areas of lakes after ice-out and subsequently track the deepening thermocline as stratification develops during spring and summer. Lake trout growth in Lake Opeongo is reduced in years with early stratification because it reduces foraging opportunities for fish after ice-out and before summer when feeding is reduced (72). Since warming will affect lake physics and the duration of the thermocline, several general projections are made with respect to risk for lake trout lakes (71, 73). Lake trout populations at higher risk occur in smaller lakes on southerly areas of pre-Cambrian shield landscapes. Climate change models also project declining wind events during the warm season. With lower winds and less mixing, thermal stratification will establish at shallower depths and lead to an increase in hypolimnetic habitat for lake trout. Generally, in deeper pre-Cambrian shield lakes there will be less risk for lake trout populations due to climate change. Other factors such as drying conditions, changes in natural organic inputs to lakes and harvest levels can combine to amplify the effects of climate change for lake trout outlined here (71,73).

In Wisconsin, climate change models project similar lake temperature changes and therefore similar risk factors based on changes in lake physics for other cold water fish species. Cisco populations in Wisconsin are projected to decline by 25–70%, depending on warming models, over the span of the 21st century (74).

There are fewer analyses of climate change effects for fish in stream and river habitats compared to lake or whole watershed modelling. Generally, the effect of climate change will be determined in running waters based on increasing air temperatures and the relative contribution of groundwater to the hydrology of a watershed (34). Watersheds with high groundwater discharges will be relatively unaffected when compared to those with low groundwater discharge.

The pattern of loss will be through a reduction in availability of preferred temperatures leading to a loss of stream habitat available to brook trout (68). In Wisconsin, located at similar latitudes to Algonquin Park and with a similar fish fauna, the potential loss of stream habitat has been assessed for different fish species (75). The assessment was based on several hydrologic and landscape parameters as a means of classifying change in streams from climate warming. Stream models included parameters for proximity to lakes, topography and geology, state climate patterns, land cover types, stream flow, and water temperature(75). Table 8 lists fish species common to streams in both Algonquin Park and Wisconsin and the projected loss of stream kilometres under climate warming scenarios. As was the case for landscape analyses in Canadian setting, different fish species will respond by increasing or decreasing the extent of stream occupancy. Consistent with other analyses of brook trout [(66,67,68)], there will be extensive loss of stream habitats for this species in Wisconsin including a loss of almost all brook trout stream habitat under moderate warming models by mid-21st century (Table 8 [(75)]). Given the wide distribution of brook trout in 4th order watersheds of Algonquin Park, including occurrence at finer scales [(76)], then warming on the Algonquin Park landscape will limit brook trout stream habitat by mid-century. How this occurs among the different watersheds of the park will be a function of the relative contribution of groundwater to flow at particular sites [(66)]. Since surficial groundwater temperature approximates average annual air temperature then climate warming projections for Algonquin Park for mid-century (average air temperature, 2.0–7.1°C [(37)]) point to a fundamental change for brook trout on the Algonquin Park landscape.

For small cyprinid species such as common shiner, northern redbelly dace, northern pearl dace, and creek chub there will be extensive losses of stream habitat under moderate scenarios of warming in Wisconsin. Although listed as warm water species, each of them can be captured soon after ice out in lakes and streams of Algonquin Park where they are commonly found (Figures 54–108). There projected stream loss in Wisconsin nearly matches that for brook trout (Table 8). Less is known about their groundwater requirements or upper lethal temperatures. Other cyprinid species such as brassy minnow, golden shiner and bluntnose minnow will show little change in stream distribution following climate change (Table 8).

Other species such as channel catfish, pumpkinseed sunfish, largemouth bass, and smallmouth bass are expected to increase their stream occupancy under climate warming projections in Wisconsin streams (Table 8). Whether this pattern occurs in Algonquin Park will be a function of access by these species to watersheds. Factors affecting year-class size in smallmouth bass are probably the same for other species of fish with parental care of offspring after spawning. At a minimum, strong year-classes of these species will likely occur even without expansion of stream occupancy in the park.

Table 8. The increase (% positive) or decrease (% negative) in Wisconsin's total stream length due to climate warming by mid-21st century. Two scenarios for climate warming under limited (1.0°C) to moderate (3.0°C) air temperature increases are shown. Stream and river fish species listed here are shared between Wisconsin and Algonquin Park [75].

Common name	Species name	Percent change in stream length occupied — limited warming	Percent change in stream length occupied — moderate warming
Brassy minnow	*Hybognathus hankinsoni*	-0.4 %	-4.4 %
Common shiner	*Luxilus cornutus*	-29.0	-77.0
Northern pearl dace	*Margariscus nachtriebi*	-28.1	-80.4
Golden shiner	*Notemigonus crysoleucas*	0	0
Blacknose shiner	*Notropis heterolepis*	-37.8	-95.5
Red sided dace	*Chrosomus eos*	-43.6	-99.8
Bluntnose minnow	*Pimephales notatus*	+2.6	+2.6
Fathead minnow	*Pimephales promelas*	-4.3	-17.6
Longnose dace	*Rhinichthys cataractae*	-26.2	-80.2
Creek chub	*Semotilus atromaculatus*	-12.6	-28.7

Common name	Species name	Percent change in stream length occupied — limited warming	Percent change in stream length occupied — moderate warming
Common sucker	*Catostomus commersoni*	-20.3	-60.9
Channel catfish	*Ictalurus punctatus*	+16.8	+32.6
Brook trout	*Salvelinus fontinalis*	-43.6	-94.4
Burbot	*Lota lota*	-53.3	-100
Mottled sculpin	*Cottus bairdii*	-21.9	-64.9
Logperch	*Percina caprodes*	0	+20.5
Rock bass	*Ambloplites rupestris*	0	0
Pumpkinseed sunfish	*Lepomis gibbosus*	+4.3	+15.5
Largemouth bass	*Micropterus salmoides*	+34.3	+34.3
Smallmouth bass	*Micropterus dolomieu*	0	+33.4

Fish introductions in Algonquin Park

Introductions and lake food webs: Top predators

Fish introductions into the lakes of Algonquin Park have occurred over the past century beginning with smallmouth bass in Cache Lake in 1899 [64]. Cache Lake was probably chosen because of the concentration of tourists residing in lodges in the area and the corresponding demand for angling. Authorized introductions of species were made to provide angling opportunities for the public, as was the case for smallmouth bass. Although smallmouth bass is a native species of Algonquin Park, its natural, post-glacial distribution did not include most watersheds in the park. From the first introduction smallmouth bass, and others that followed, this species spread into other lakes of Algonquin Park. For Lake Opeongo, the first smallmouth bass was caught in 1928 [77]. The basic lesson of fish introductions, whether planned to meet a management agency goal or unplanned, is that an introduction in one lake potentially leads to spread through watersheds into other lakes.

Stocking predatory fish represented a goal of resource management agencies to bring angling opportunities to a public showing increased interests in outdoor activities at the time. In Algonquin Park, access to interior lakes was limited in the early 20th century so providing angling opportunities along the railroad and road corridor was a priority. Indeed, the Harkness Laboratory of Fisheries Research on Lake Opeongo was established in 1936 largely because of uncertainty in how a more modern road system, increasing access to a family car, and a corresponding increase in demand for leisure time would affect the sustainability of lake trout and brook trout fisheries. The earliest report (from 1935) stemming from the Cache Lake stocking of smallmouth bass noted the loss of small inshore fish in a span of twenty years and the possible competition with native lake trout that could occur from this reduction [64]. This interaction would be confirmed decades later [78,79,80].

In more recent decades, unauthorized introductions of other predatory fish species have occurred in several watersheds of Algonquin Park. Many of the unauthorized introductions occurred in the past 30 years. This includes northern pike, largemouth bass, walleye, smallmouth bass, and rock bass. For walleye and smallmouth bass, their native distribution included Lake Traverse and waters below this lake in the Petawawa River system [63]. It did not include lake locations in other areas of the park. For rock bass, lake occupancy in southern areas of the park represent introduced populations. In the Amable du Fond River watershed, in the northwest corner of Algonquin Park, rock bass distribution may represent a native distribution because it covers many lakes at different elevations including some remote lakes. Resolving the origins of rock bass in this area of the park remains to be done.

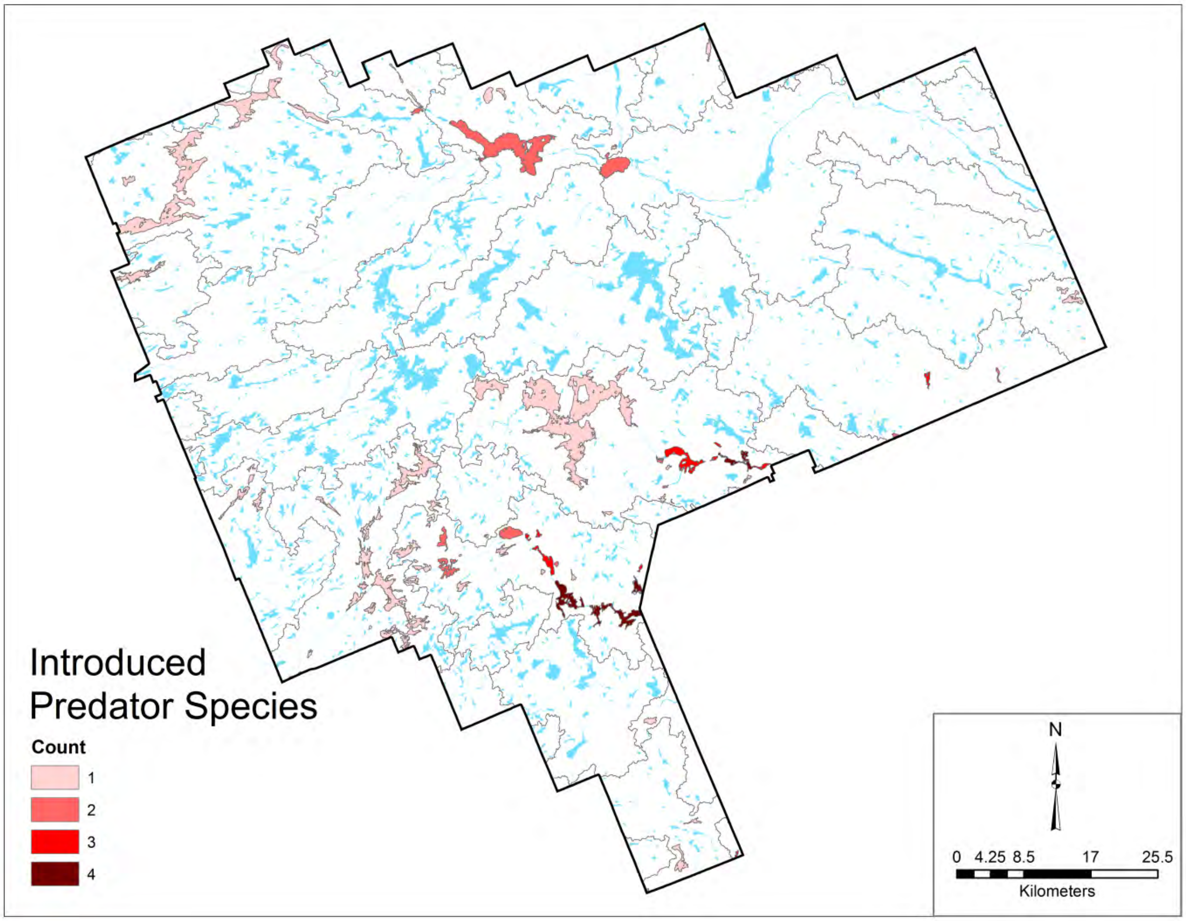


Figure 51. A map of lakes in Algonquin with introduced predatory fish (authorized or unauthorized). Lakes are coloured based on the number of species introduced with smallmouth bass being the most widespread. Smallmouth bass and walleye in Traverse Lake are not included because of historical descriptions of their native distribution [63]. Rock bass in the Amable du Fond watershed are not included because of the uncertainty regarding their native status.

Introducing predatory fish species has consequences for aquatic food webs. Biodiversity and the functioning of natural aquatic food webs are affected by these introductions. Introductions of bass (smallmouth, largemouth, and rock bass) leads to: 1) a reduction in species richness in lakes through the extirpation of small-bodied fish species [81,82]; 2) a loss of species diversity in native fish assemblages among different watersheds[79,83,84], and 3) an alteration of food web structure because introduced predators are able to successfully compete for positions in food webs otherwise occupied by native species such as lake trout[78,80].

This is especially the case for Class 1 lake trout lakes where there is an absence of a pelagic prey fish for lake trout to consume. In the absence of bass, lake trout in Class 1 lakes consume zooplankton and inshore fish as a diet. When introduced, bass occupy the nearshore zone, consume inshore fish production and cause lake trout to feed more on zooplankton [78,82]. This loss of trophic position reduces the size of lake trout [78], a concern expressed initially in 1935 for Cache Lake [64]. When smallmouth bass are removed from a lake, lake trout are able to re-capture their trophic position in a lake food web [85].

Climate warming is occurring across the Algonquin Park landscape in recent decades and after the early introductions of smallmouth bass. One consequence of bass introductions that could not have been anticipated early in the 20th century is their response to climate warming. The production of smallmouth bass cohorts is driven by the warmth of their first summer and subsequently by the severity of their first winter prior to age 1 [32,69]. The spawning period of smallmouth bass is also driven by spring warming conditions with warmer, earlier springs resulting in earlier spawning seasons [35,70]. As a result, cohort production rises under warm conditions that are favourable for growth and survival of young bass and declines under colder conditions [86]. Because of this link smallmouth bass are responding positively to climate warming and will continue to do so. The implications for this trend are significant. As warmer conditions occur over larger areas of Ontario's landscape, the climate patterns that limited smallmouth bass distribution in the past will shift northward leading to an expanding range for this species [33,87]. Numerous studies point to the negative effects of smallmouth bass on biodiversity and food webs of native fish species [66,80,82,88], including the direct effects on lake trout and their supporting food webs [78,88]. Expansion of smallmouth bass or other species of bass currently found in a limited number of watersheds will have negative consequences on native fish and their food webs.

While other predatory species of fish will have similar top-down effects on aquatic food webs, research on their specific effects is not as complete as with the effects associated with bass introductions. The same effects are expected including spread through watersheds from points of introduction, sharp reductions in native species of fish, and alterations of natural predator-prey relationships [89].

Introductions and lake food webs: Pelagic prey fish

Introduction of pelagic prey fish has consequences for aquatic ecosystems as well. In this instance, Algonquin Park has 2 examples of the fundamental processes that lead to food web change. One is competition between cisco and other pelagic fish like lake whitefish and the other is predation by rainbow smelt on larval stages of fish in the open water habitat of lakes.

Cisco

Cisco was introduced in the 1950s to provide a prey fish for lake trout to sustain production following increased angler demand at the time. The stocking of cisco in Lake Opeongo, Canoe Lake, Tea Lake, and Smoke Lake was a response to this concern. As previously outlined, a unique feature of the Algonquin Park landscape is the geographic distribution of *coregonines* with southern watersheds of the park historically containing only lake whitefish. Only Lake Opeongo was investigated and found to possess 2 forms of lake whitefish while the other lakes of the southern park region were not surveyed for this phenomenon (59).

Rainbow smelt

Rainbow smelt is a pelagic species not native to Algonquin Park. Introduction of this species in the park is based on its use as bait by anglers. Currently rainbow smelt are in the large lakes of the Amable du Fond River system in the northwest region of Algonquin Park (Kioshkokwi , Manitou, and North Tea) (Figure 52). In recent years, rainbow smelt have been detected initially in Tim Lake and subsequently downstream in Rosebary Lake of the Tim River system. The Tim River connects with the upper Petawawa River system (Figures 16, 19) making the introduction of rainbow smelt in Tim Lake a high risk for lakes of the Petawawa River watershed. Its discovery in Rosebary Lake in 2011 confirms its movement downstream. In 2016, a rainbow smelt was captured in Catfish Lake (same watershed as Rosebary Lake) demonstrating that downstream movement of this species can be extensive in relatively few years. In general, the spread of invasive rainbow smelt is predicted to expand in Ontario including many lakes in Algonquin Park based on lake factors such as maximum depth, surface area and water clarity (90). This analysis assumed equal access via bait introductions across the landscape — limiting bait access limits rainbow smelt introductions (90).

The risk from rainbow smelt is based on their pelagic feeding and consumption of zooplankton and larval stages of native fish living in the same open water habitat. Rainbow smelt greatly reduce large zooplankton at the base of a lake's food web (91). Across the cold water tier of lakes in northern United States and in Canada, rainbow smelt have spread and threaten populations of native species such as cisco and other coregonines with extirpation (74,90). This phenomenon has been documented in several lakes in detail (92), including similar effects on walleye (93).

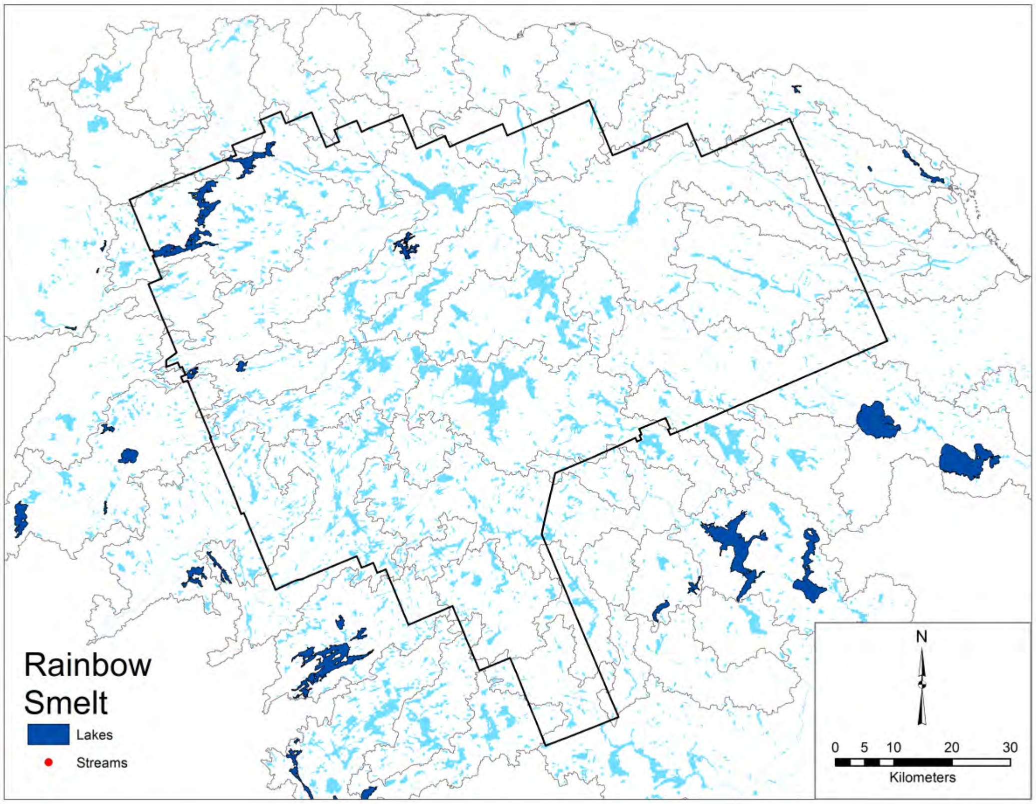


Figure 52. The distribution of rainbow smelt in Algonquin Provincial Park and adjacent watersheds.

Introductions and lake food webs: Baitfish

The negative effects of rainbow smelt on coregonine biodiversity are clear and arise from the use of smelt as bait and their subsequent spread through watersheds to other lakes away from the point of introduction. Cisco are efficient competitors and when introduced can displace and extirpate pelagic forms of lake whitefish.

Other species of small fish are used as bait in Ontario and in many cases they represent species native to the province. In Algonquin Park, it is difficult to distinguish past bait introductions of species already native to the park landscape. In some cases this can be done by considering their mapped distribution. Spottail shiner and emerald shiner are 2 examples where their current park distribution is restricted to isolated areas where otherwise they are absent from the landscape. The native distribution of the 2 species is in areas away from the Algonquin Park landscape. In the past, given the widespread use of live bait in Algonquin Park it is likely that there were introductions of species native to Algonquin Park.

The lesson of all past fish introductions is that food web changes in lake ecosystems can result with effects occurring at different trophic levels and with biodiversity consequences.

Aquatic species-at-risk in Algonquin Park

Designating a species to be at risk (e.g., endangered, threatened, vulnerable, etc.) or extinct is a decision process based on several criteria. Criteria can include sharp declines in numbers of adults or population density, loss of separate populations leading to a spatial decline at a landscape level, rarity (few populations exist), and the likelihood of re-colonization or a rescue effect can all be considered in the decision process. Federally, this process is conducted by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

There are several fish species currently under a designated status in Algonquin Park with one, American eel, no longer detected within the park boundary. The lakes where historical records indicate eel was present are shown in Figure 53, the section on Fish Species Distribution Maps, and are listed in Table 9.

Lake Opeongo is listed under the lake whitefish designatable unit category because of the presence of limnetic and benthic forms of this species. Recently, a similar limnetic/benthic pair of lake whitefish were found in Big Trout Lake. Finally, the lake whitefish in Lake LaMuir are limnetic form but without the presence of a benthic form of whitefish. Neither the whitefish in Big Trout Lake nor Lake LaMuir have been evaluated by the Freshwater Fishes Subcommittee of COSEWIC and do not have an official

COSEWIC designation at this time. Since all other speciation phenomena of this type are listed as designatable units [(58)], then it is important to highlight these sites here.

Blackfin cisco (species complex) were detected in several lakes once inundated by glacial Lake Algonquin. Not all lakes with *Mysis* as an indicator of Lake Algonquin coverage contain blackfin cisco pointing to the need for more research into the ecology and evolution of this occurrence in Algonquin Park. Currently, both Canada and Ontario list this species as data deficient. The International Union on the Conservation of Nature have red-listed this species as extinct.

Currently, the shortjaw cisco (*Coregonus zenithicus*) is listed as being present in White Partridge Lake. Recent genetic analysis and body shape analysis indicates different forms (or ecotypes) of cisco in this lake, one a benthic form and the other(s) as pelagic forms[94]. The cisco ecotypes in White Partridge Lake are more related to each other than to other cisco populations as are other cases of shortjaw cisco in other inland lakes[94]. Evidence now indicates that shortjaw cisco as a species is not a designation that should be applied across inland lakes. The ecotype thought to be shortjaw cisco is an example of island evolution repeated across inland lakes.

The deepwater sculpin (*Myoxocephalus thompsonii*) is a glacial relic similar to other species in the Petawawa River system. It was detected once in Cedar Lake and has not been detected in subsequent surveys.

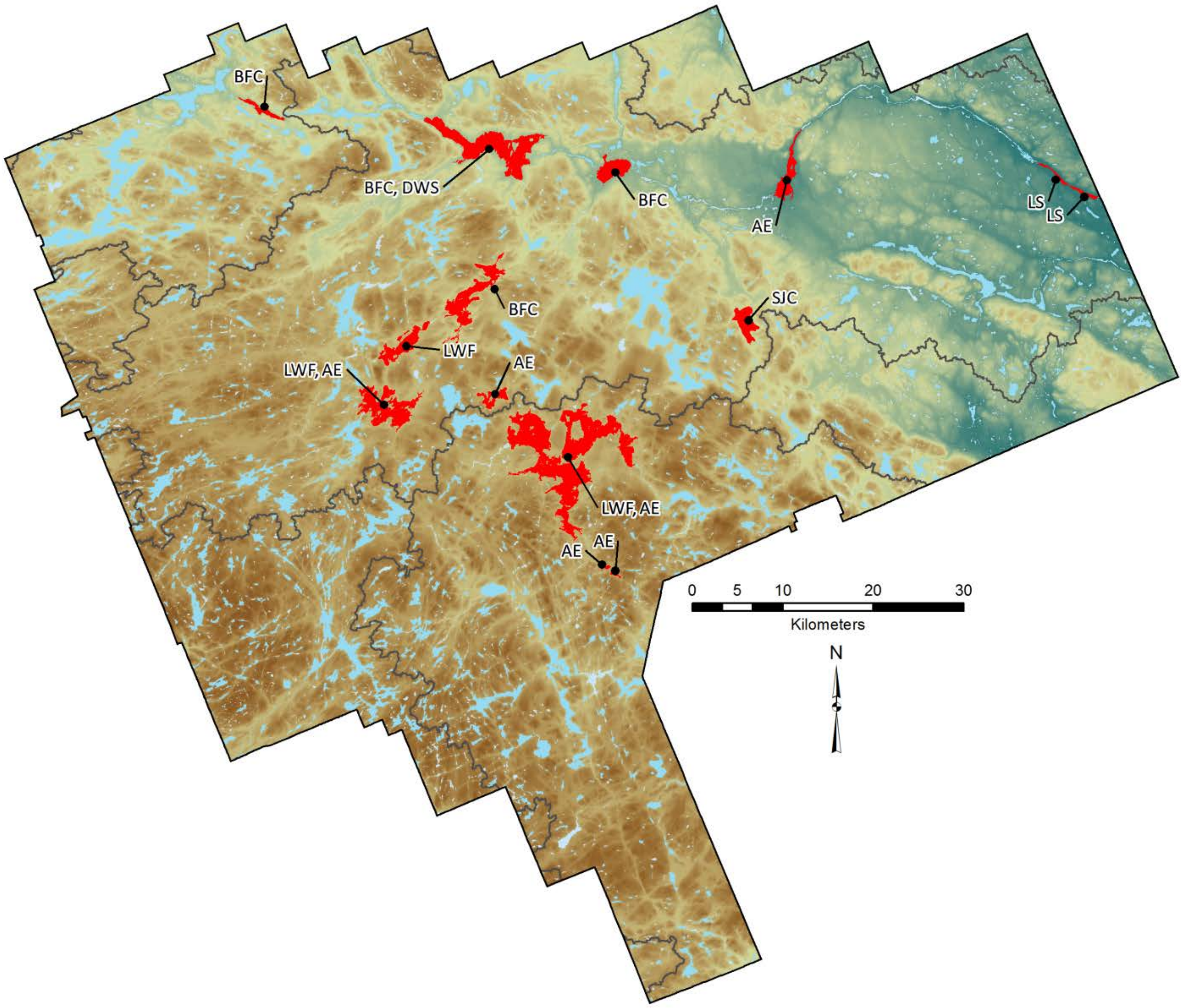


Figure 53. The distribution of lakes within Algonquin Park with existing and historic populations of fish species at risk. AE=American eel, BFC=blackfin cisco, SJC=shortjaw cisco, LS=lake sturgeon, DWS=deepwater sculpin, LWF=lake whitefish.

Table 9. A list of the aquatic species at risk (fishes) in Algonquin Provincial Park and their status under provincial and federal species at risk legislation, and international classification. American eel has not been detected in several decades in Algonquin Park. The listing of American eel here is for historical purposes.

Species	Lakes	Status		
		Ontario SAR*	COSEWIC**	IUCN*** red list
American eel	Lake Traverse Redrock Lake Costello Lake Brewer Lake Opeongo Lake Big Trout Lake	Endangered	Threatened	Endangered
Blackfin cisco	Cedar Lake Mink Lake Hogan Lake Radiant Lake	Data deficient	Data deficient	Extinct
Shortjaw cisco	White Partridge Lake	Threatened	Threatened	Vulnerable
Lake sturgeon	Smith Lake McManus Lake	Threatened	Threatened	Least concern
Lake whitefish	Big Trout Lake Opeongo Lake Lake La Muir			
Deepwater sculpin	Cedar Lake	Nil	Special concern	Least concern

*species at risk, ** Committee on the Status of Endangered Wildlife in Canada *** International Union on the Conservation of Nature

Brook trout in Algonquin Park — Unpacking the database

The distribution of brook trout among Algonquin Park watersheds represents one of the highest concentrations of brook trout populations in Ontario. It is recognized as an important representative feature of the park and persists largely because of limited access and relatively few species introductions across the landscape. Despite this level of protection, there are species introductions that put at risk brook trout populations in several watersheds. Mapping the distribution of brook trout in Algonquin Park is important to better understand their overall distribution and to address relative risk when mapped along with invasive species.

Mapping the distribution of brook trout or any other fish species, requires data on their occurrence in Algonquin Park to assess the proximity of introduced species or to better understand the ecology of brook trout at a landscape scale. The mapped distribution of any species in the park represents the accumulated observations of occurrence from surveys including creel surveys, faunal surveys, and other monitoring activity over a period of years. The distribution maps represent long-term observations.

Long-term observations of brook trout occurrence represent a case study in the content of any distribution map. The map of brook trout distribution represents several decades of observation in Algonquin Park beginning in the 1920s and continuing until today (Table 10). It comprises several data sources including: 1) Historic files from the Royal Ontario Museum; 2) Compilations of data records from past surveys conducted by staff of the Harkness Laboratory of Fisheries Research; 3) Algonquin Fisheries Assessment Unit; 4) Aquatic Habitat Inventory database from the 1970s; 5) personal observations by qualified individuals, and 6) a range of historical information including data entered into older fish databases within MNRF and the Royal Ontario Museum. In total there are 2,174 records of brook trout in 444 lakes in Algonquin Park indicating that many lakes have multiple records of brook trout occurrence. Approximately 80% of occurrence records are prior to 1980 or unknown.

The breakdown of when the records of brook trout detection occurred in different decades is summarized in Table 11. Of the total 444 brook trout lakes in Algonquin Park, 167 have 1 record of occurrence while 47 lakes have records of 10 to 20 detections. Eight lakes have over 30 brook trout detections with 4 of those lakes surveyed in this decade (2010s). This is a typical pattern for fish distribution records in Algonquin Park.

The fish distribution maps (Figures 54-108 for Algonquin Park are built on a century of observation and monitoring.

Table 10. The decade of last detection of book trout occurrence in the 444 brook trout lakes of Algonquin Park

Decade	# of lakes
Unknown	69
1920	1
1930	9
1940	42
1950	58
1960	75
1970	90
1980	15
1990	8
2000	13
2010	67

Table 11. Distribution of decade of last observation by the number of observations in the brook trout records for Algonquin Park. The table is read as follows: Lakes with 4 observation records of brook trout sum to 24 lakes where 2/24 lakes had last observations recorded in the 1930s, 9/24 had last observations in the 1960s and 5/24 lakes in the 2010s, etc.

# of observation records	# of lakes	Decade of last observation										
		Unknown	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010
1	167	*65*	1	4	10	19	24	34	2			8
2	71			2	10	13	15	13	3	1	1	13
3	42	*1*		1	6	8	6	10	2	2		6
4	24			2	2		9	5	1			5
5	30				3	5	4	8	3	1	1	5
6	16				3	2	6					5
7	12				1	1	2	4			1	3
8	11				3	1	1	3		1		2
9	9				1	1	1	1	1	1	1	2
10 to 20	47				3	7	7	9	3	2	5	12
20 to 30	7							2	1		2	2
30 +	8					1		1			2	4

* Numbers in bold comprise the 101 lakes listed in Table 13; numbers in italics represent the list of lakes in Table 15, the remaining are listed in Table 14.

Fish species distribution maps for Algonquin Park and associated watersheds

The distribution fish species in lakes and streams of fourth order watersheds in Algonquin Park (and adjacent to Algonquin Park based on data availability), are provided in a series of maps. Lake locations for fish species are shown as dark blue and stream locations as red. Watershed boundaries are shown as light grey. Lakes without a detection of a species are left as light blue to retain the overall lake distribution for Algonquin Park. The distribution maps represent the presence of a given species from the mid-1930s when fish species distributions were initially mapped through to field surveys as of 2014. The maps combine lake surveys over the past decades (mid-1930s onwards) and stream surveys conducted by the Royal Ontario Museum (ROM) in 1989-91. The ROM survey locations were cross-referenced with field maps and data sheets from that survey. Lake data from the lake habitat inventory surveys, Algonquin Fisheries Assessment Unit, Harkness Laboratory of Fisheries Research, and ROM records were amalgamated.

The maps do not reflect current distribution for some species such as American eel. In this case, the mapped distribution of American eel is based on data from the first decades of survey effort. American eel has not been detected in the park for several decades.

The presence of a species is not an indication of abundance in any location. A species may be relatively widespread but infrequently captured in some or all watersheds where it occurs. The 2 species of suckers are an example of this pattern. White sucker is widespread throughout Algonquin Park being found in lakes, rivers and streams. The number of white sucker captured in any location is variable from being commonly observed in many lake surveys to relatively uncommon. Longnose sucker is found in many watersheds but can be very rarely observed or undetected for decades in some watersheds and common in others.

Other species are difficult to detect regardless of their abundance. Species of sculpin are fish that live on the bottom of lakes or streams and appear to be relatively rare in Algonquin Park. Slimy sculpin, mottled sculpin, and spoonhead sculpin are difficult to detect unless a particular trapping procedure is employed in summer months. When used, sculpin traps locate these species in many lakes including all lake trout lakes surveyed in recent years.

Each map is labelled with the common name of the fish. Scientific names for each species and its MNRF code are listed in Table 12. The data sources for this series of maps are listed below:

Table 12. The list of fish species in Algonquin Park including species code designation used in Ministry of Natural Resources and Forestry, common name and scientific name. Names follow the most recent update of Names of Fishes (2013) from the American Fisheries Society.

Species code	Common name	Scientific name
31	Lake sturgeon	*Acipenser fulvescens*
80	Brook trout	*Salvelinus fontinalis*
81	Lake trout	*Salvelinus namaycush*
91	Lake whitefish	*Coregonus clupeaformis*
92	Longjaw cisco	*Coregonus alpenae*
93	Lake cisco	*Coregonus artedi*
97	Blackfin cisco	*Coregonus nigripinnis*
100	Shortjaw cisco	*Coregonus zenithicus*
102	Round whitefish	*Prosopium cylindraceum*
121	Rainbow smelt	*Osmerus mordax*
131	Northern pike	*Esox lucius*
132	Muskellunge	*Esox masquinongy*
141	Central mudminnow	*Umbra limi*
162	Longnose sucker	*Catostomus catostomus*
163	White sucker	*Catostomus commersoni*
168	Silver redhorse	*Moxostoma anisurum*
171	Shorthead redhorse	*Moxostoma macrolepidotum*
172	Greater redhorse	*Moxostoma valenciennesi*

Species code	Common name	Scientific name
182	Northern redbelly edace	*Chrosomus eos*
183	Finescale dace	*Chrosomus neogaeus*
185	Lake chub	*Couesius plumbeus*
189	Brassy minnow	*Hybognathus hankinsoni*
192	Hornyhead chub	*Nocomis biguttatus*
194	Golden shiner	*Notemigonus crysoleucas*
196	Emerald shiner	*Notropis atherinoides*
198	Common shiner	*Luxilus cornutus*
199	Blackchin shiner	*Notropis heterodon*
200	Blacknose shiner	*Notropis heterolepis*
201	Spottail shiner	*Notropis hudsonius*
202	Rosyface shiner	*Notropis rubellus*
206	Mimic shiner	*Notropis volucellus*
208	Bluntnose minnow	*Pimephales notatus*
209	Fathead minnow	*Pimephales promelas*
210	Blacknose dace	*Rhinichthys atratulus*
211	Longnose dace	*Rhinichthys cataractae*
212	Creek chub	*Semotilus atromaculatus*
213	Fallfish	*Semotilus corporalis*
214	Northern pearl dace	*Margariscus nachtriebi*

Species code	Common name	Scientific name
233	Brown bullhead	*Ameiurus nebulosus*
234	Channel catfish	*Ictalurus punctatus*
251	American eel	*Anguilla rostrata*
271	Burbot	*Lota lota*
281	Brook stickleback	*Culaea inconstans*
282	Threespine stickleback	*Gasterosteus aculeatus*
283	Ninespine stickleback	*Pungitius pungitius*
291	Trout-perch	*Percopsis omiscomaycus*
311	Rock bass	*Ambloplites rupestris*
313	Pumpkinseed	*Lepomis gibbosus*
314	Bluegill	*Lepomis macrochirus*
316	Smallmouth bass	*Micropterus dolomieu*
317	Largemouth bass	*Micropterus salmoides*
331	Yellow perch	*Perca flavescens*
334	Walleye	*Stizostedion vitreum*
338	Iowa darter	*Etheostoma exile*
341	Johnny darter	*Etheostoma nigrum*
342	Logperch	*Percina caprodes*
381	Mottled sculpin	*Cottus bairdi*
382	Slimy sculpin	*Cottus cognatus*

Species code	Common name	Scientific name
383	Spoonhead sculpin	*Cottus ricei*
384	Deepwater sculpin	*Myoxocephalus thompsoni*

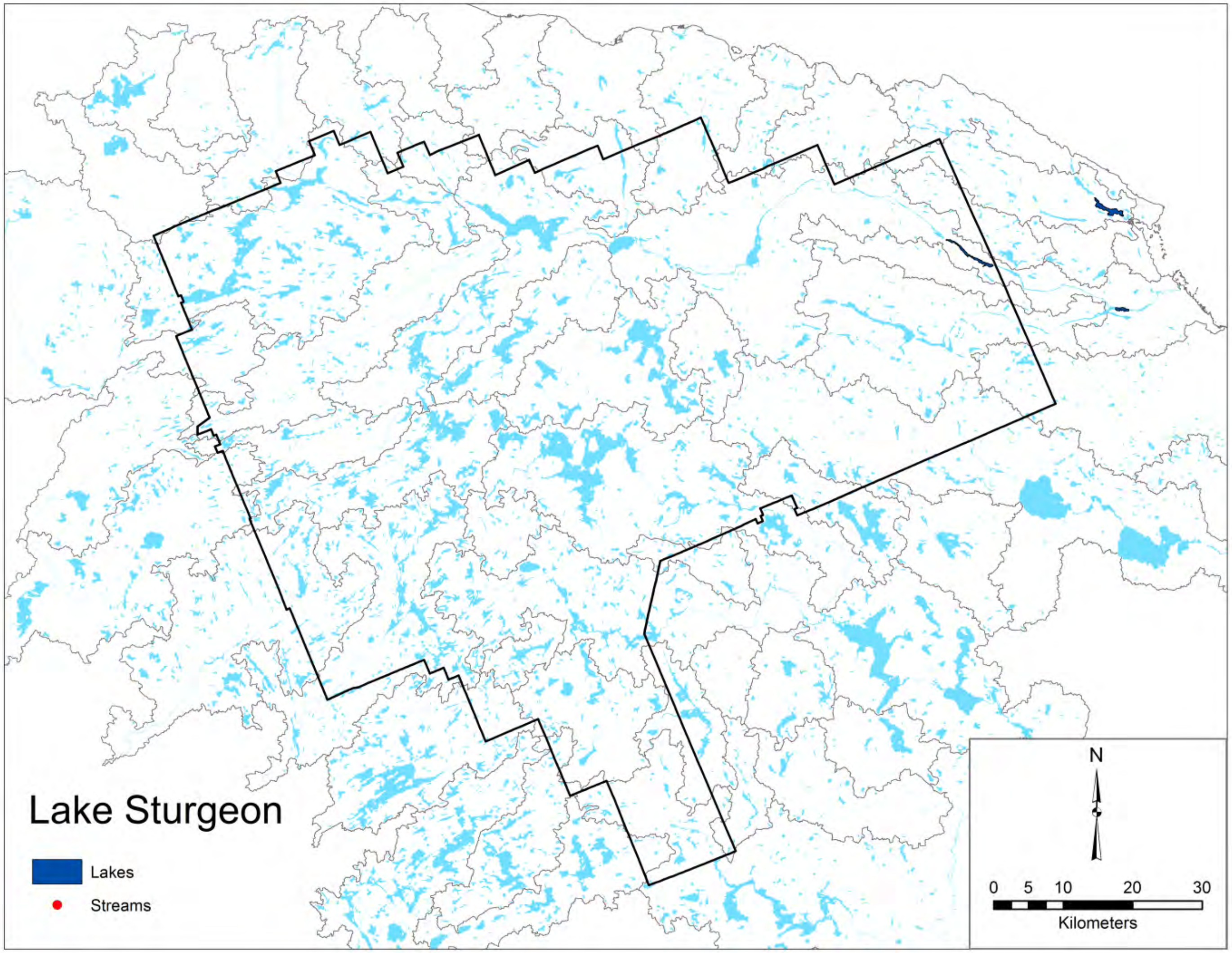


Figure 54. The distribution of lake sturgeon in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

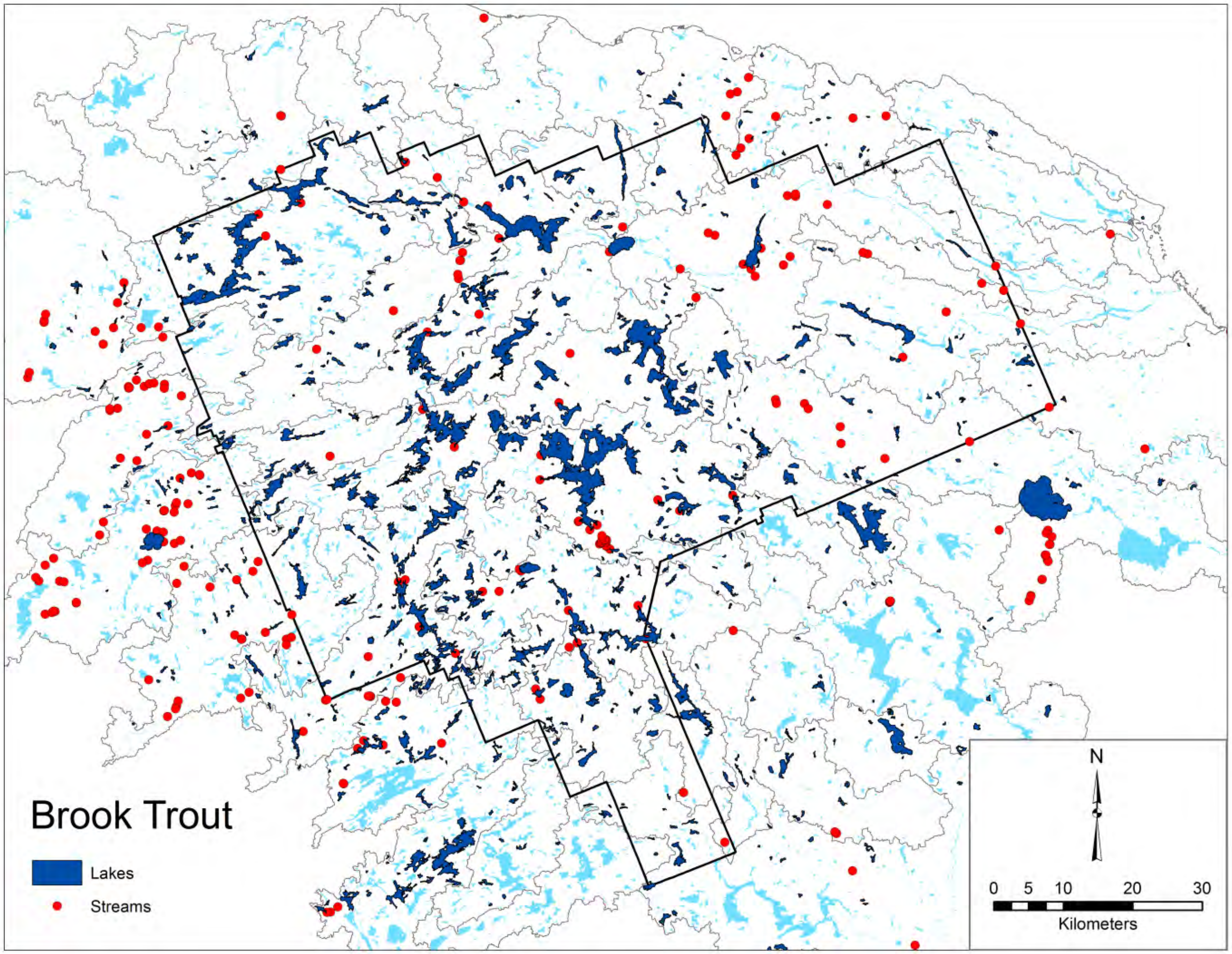


Figure 55. The distribution of brook trout in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

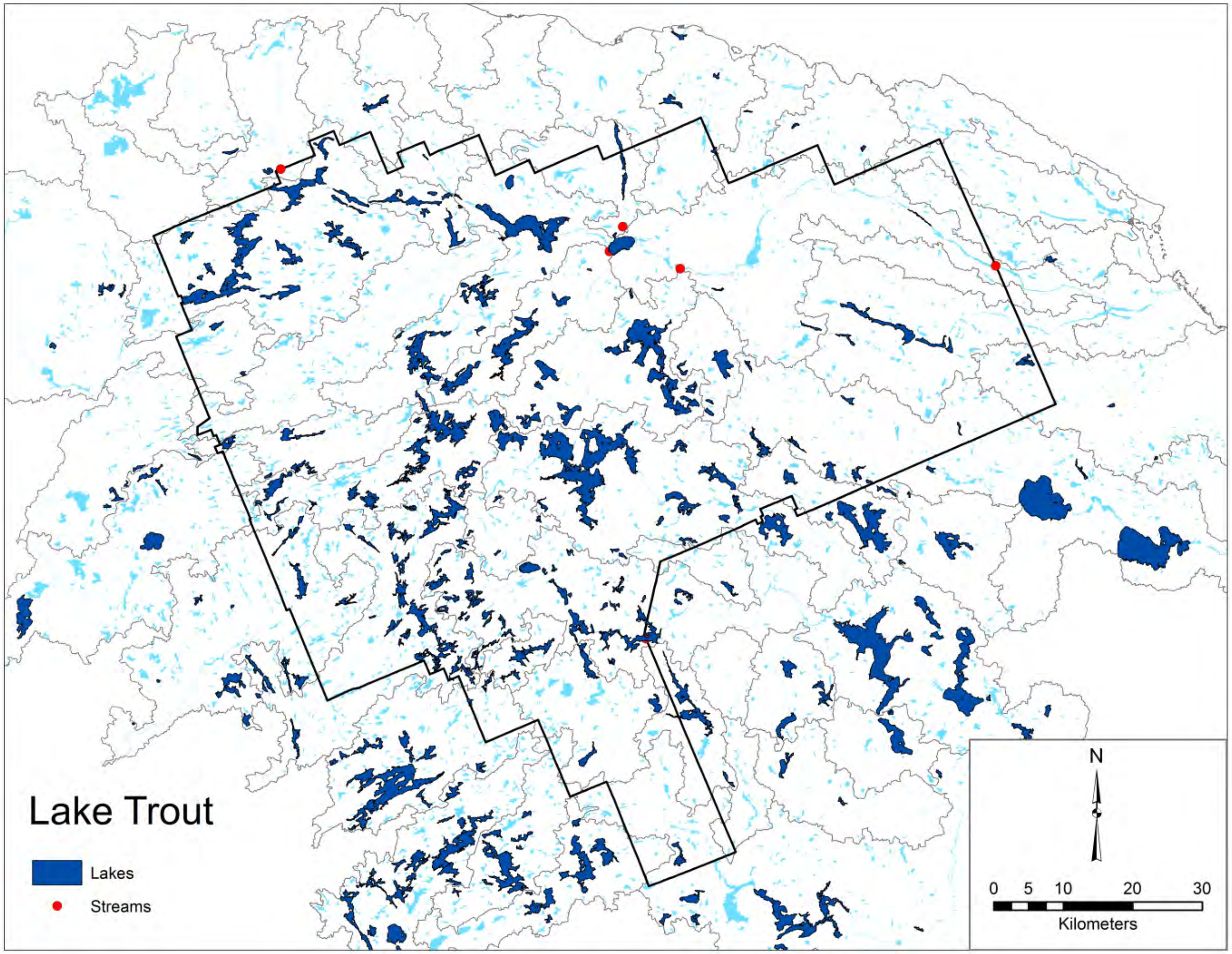


Figure 56. The distribution of lake trout in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

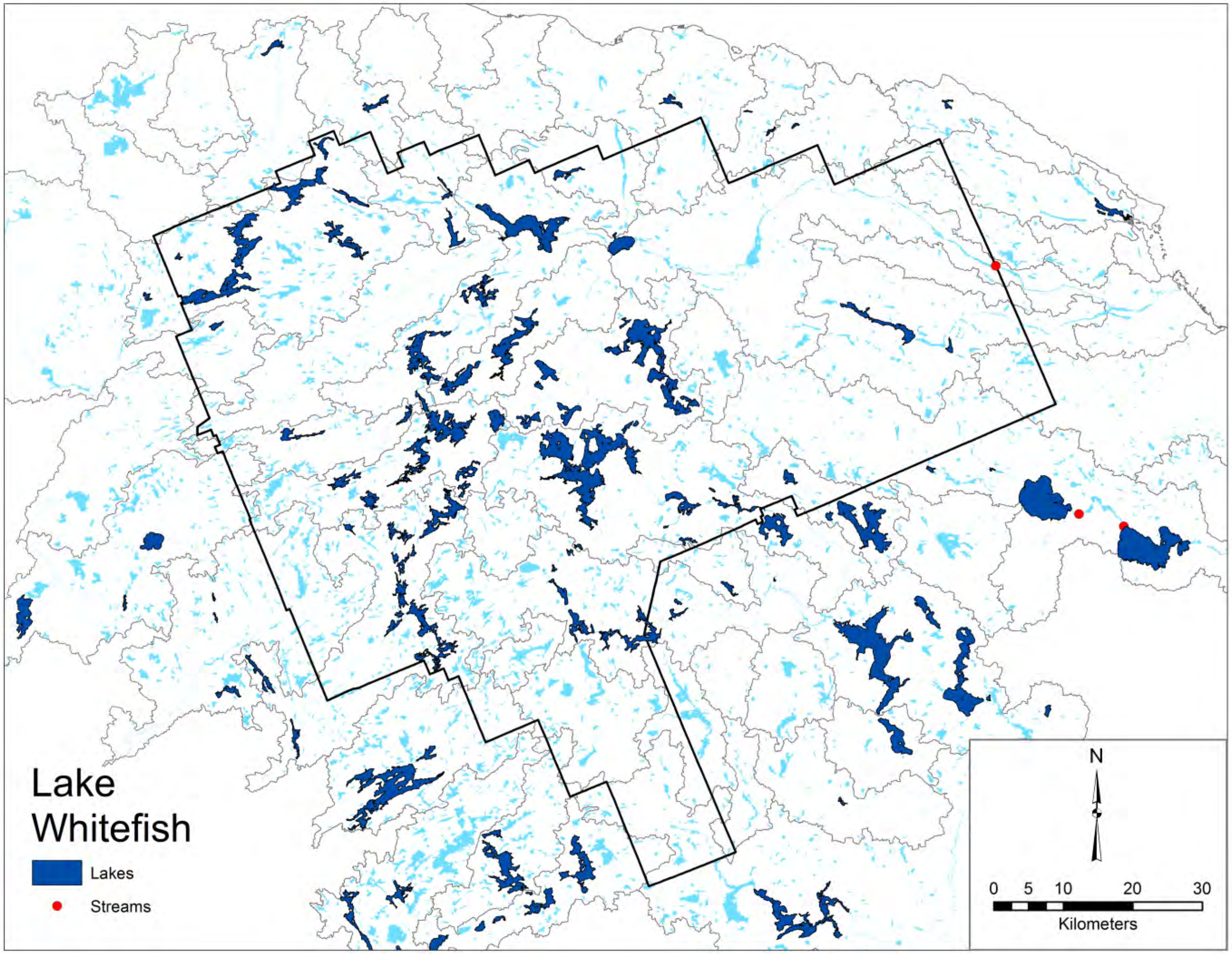


Figure 57. The distribution of lake whitefish in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

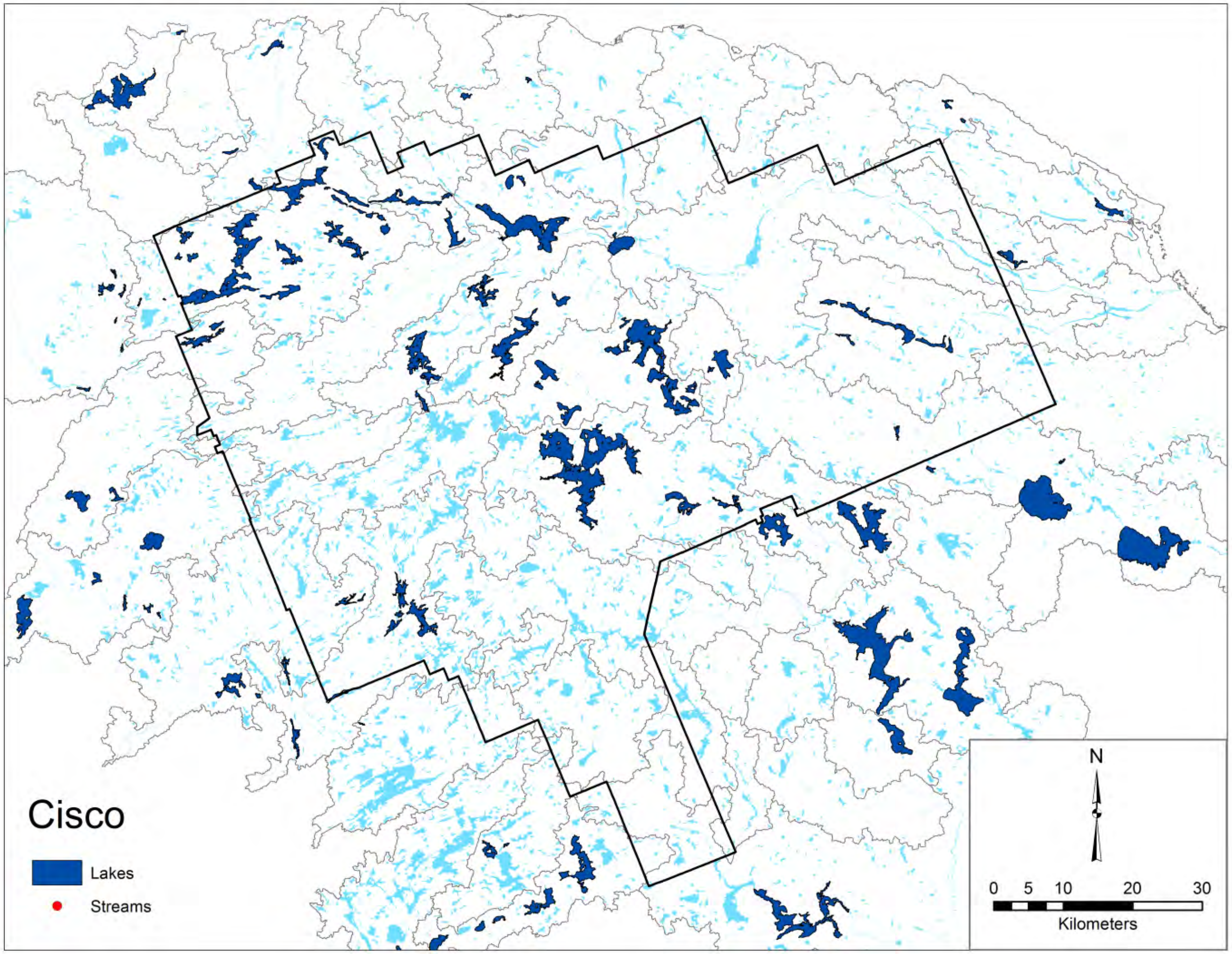


Figure 58. The distribution of cisco in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

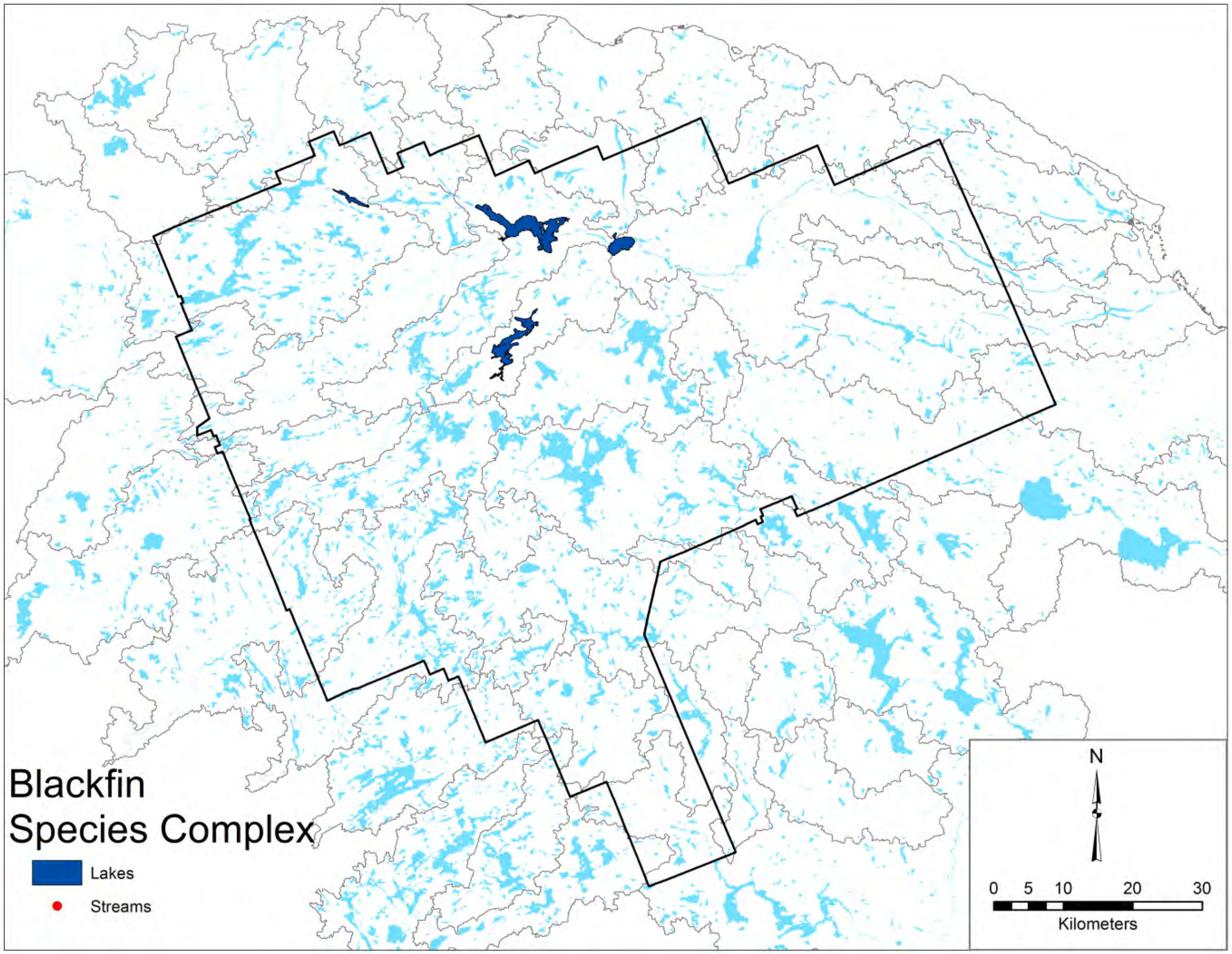


Figure 59. The distribution of blackfin species in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

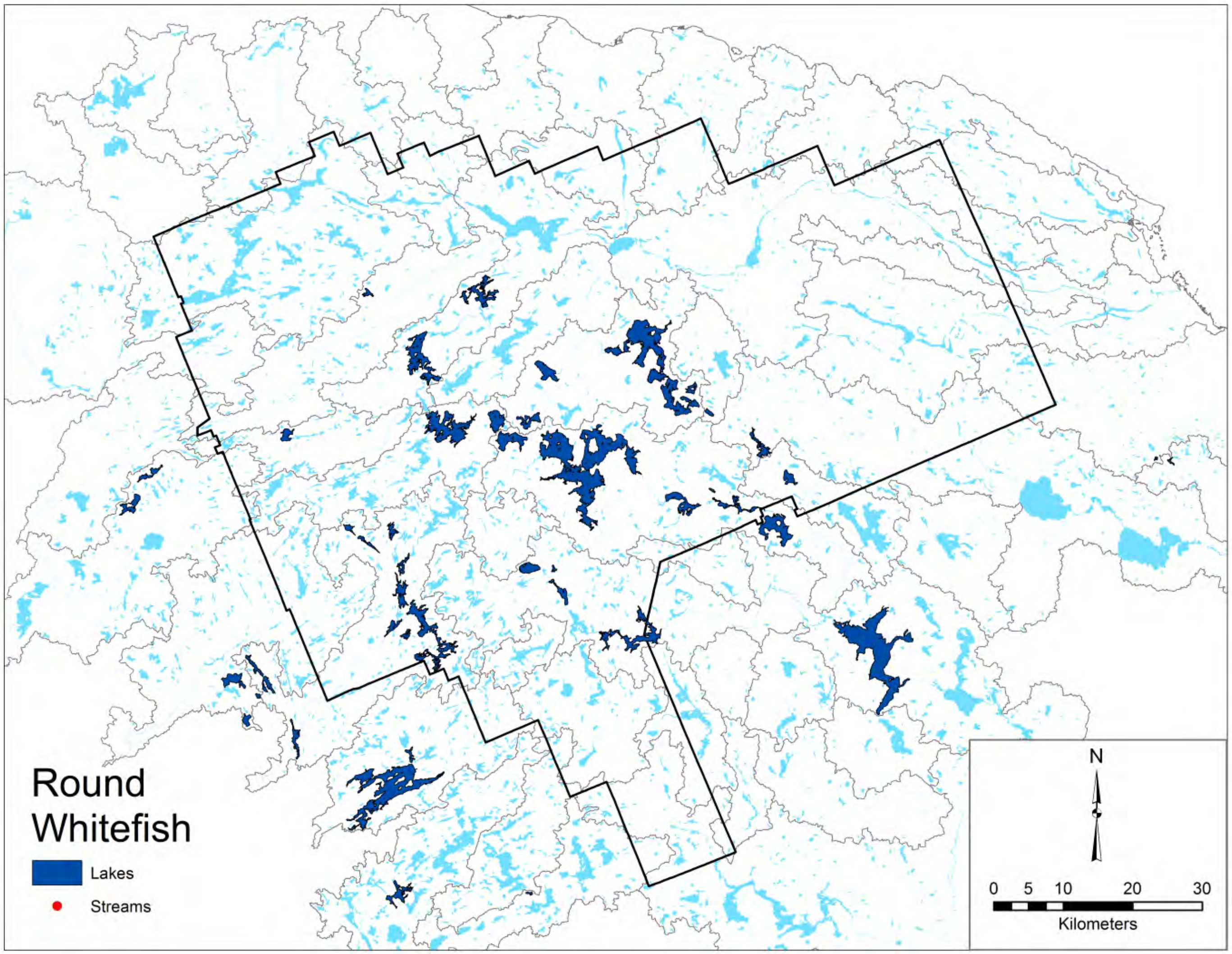


Figure 60. The distribution of round whitefish in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

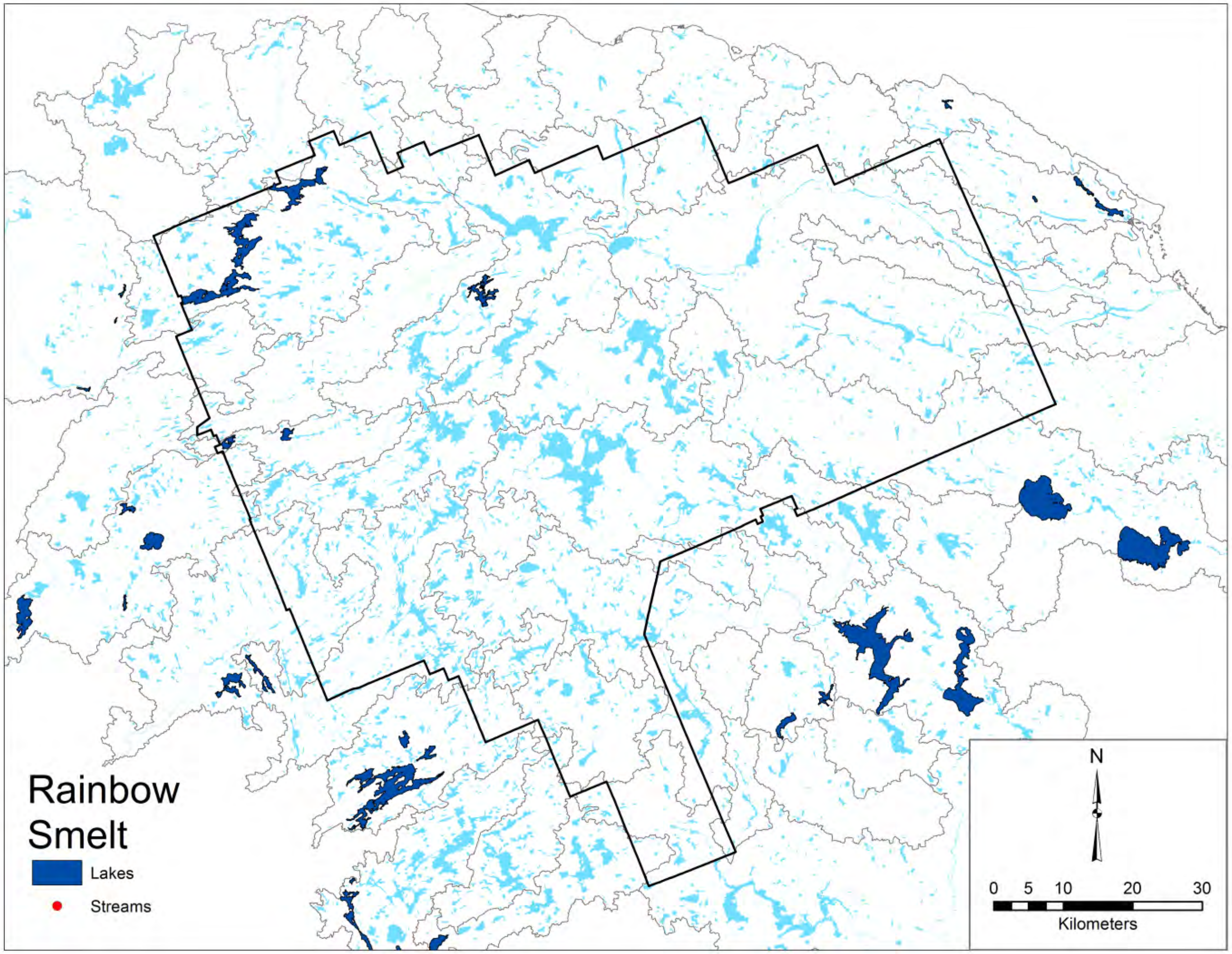


Figure 61. The distribution of rainbow smelt in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

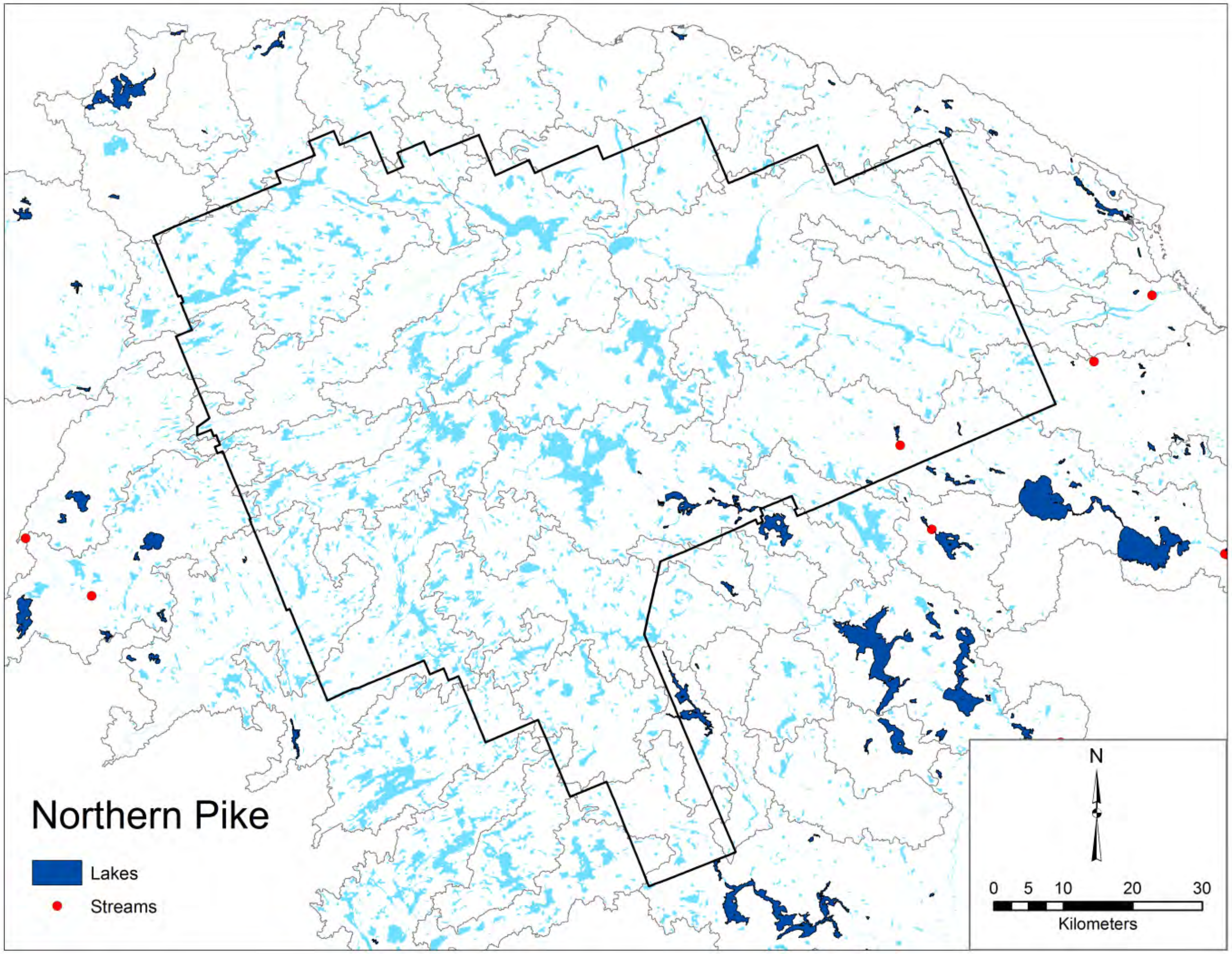


Figure 62. The distribution of northern pike in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

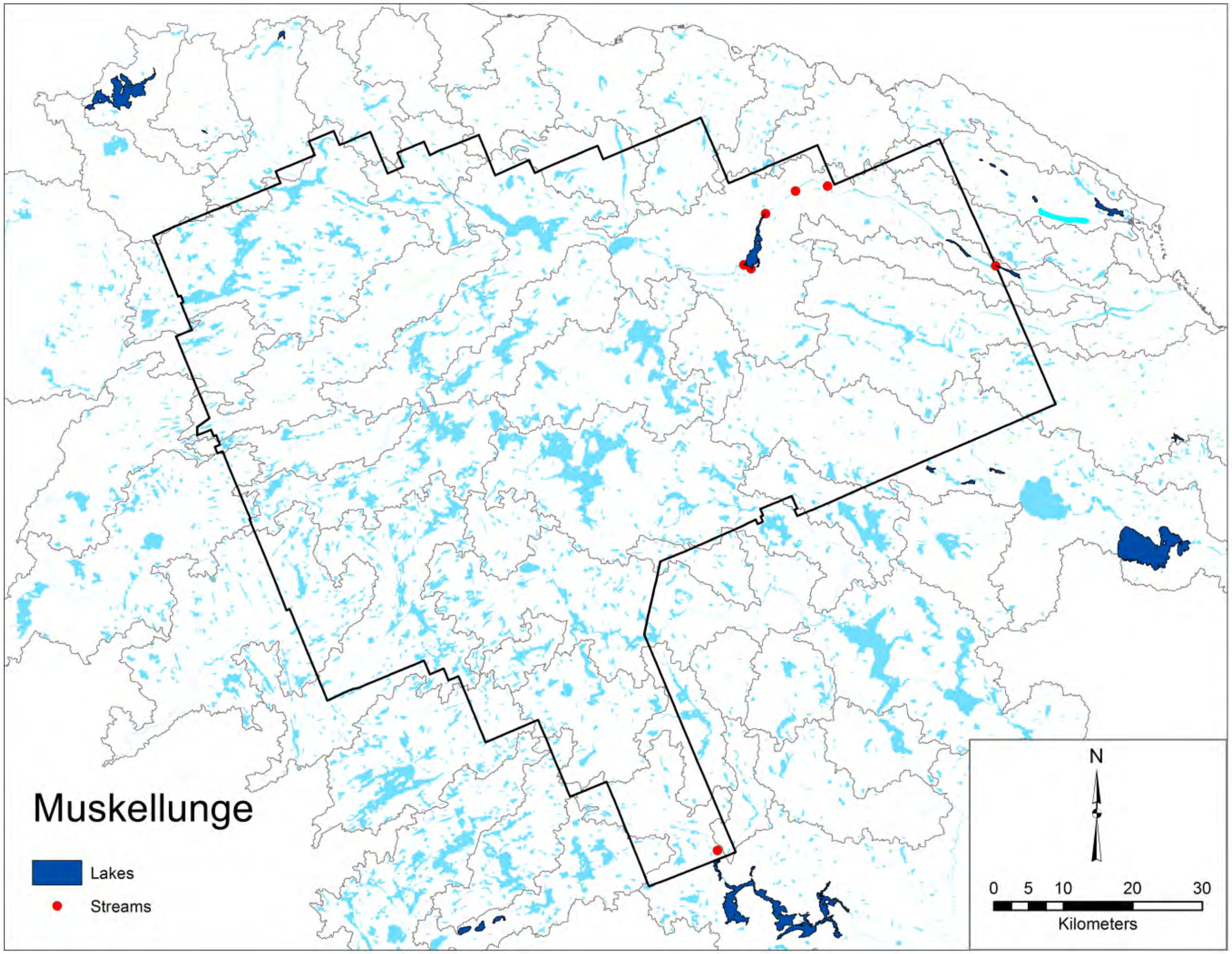


Figure 63. The distribution of muskellunge in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

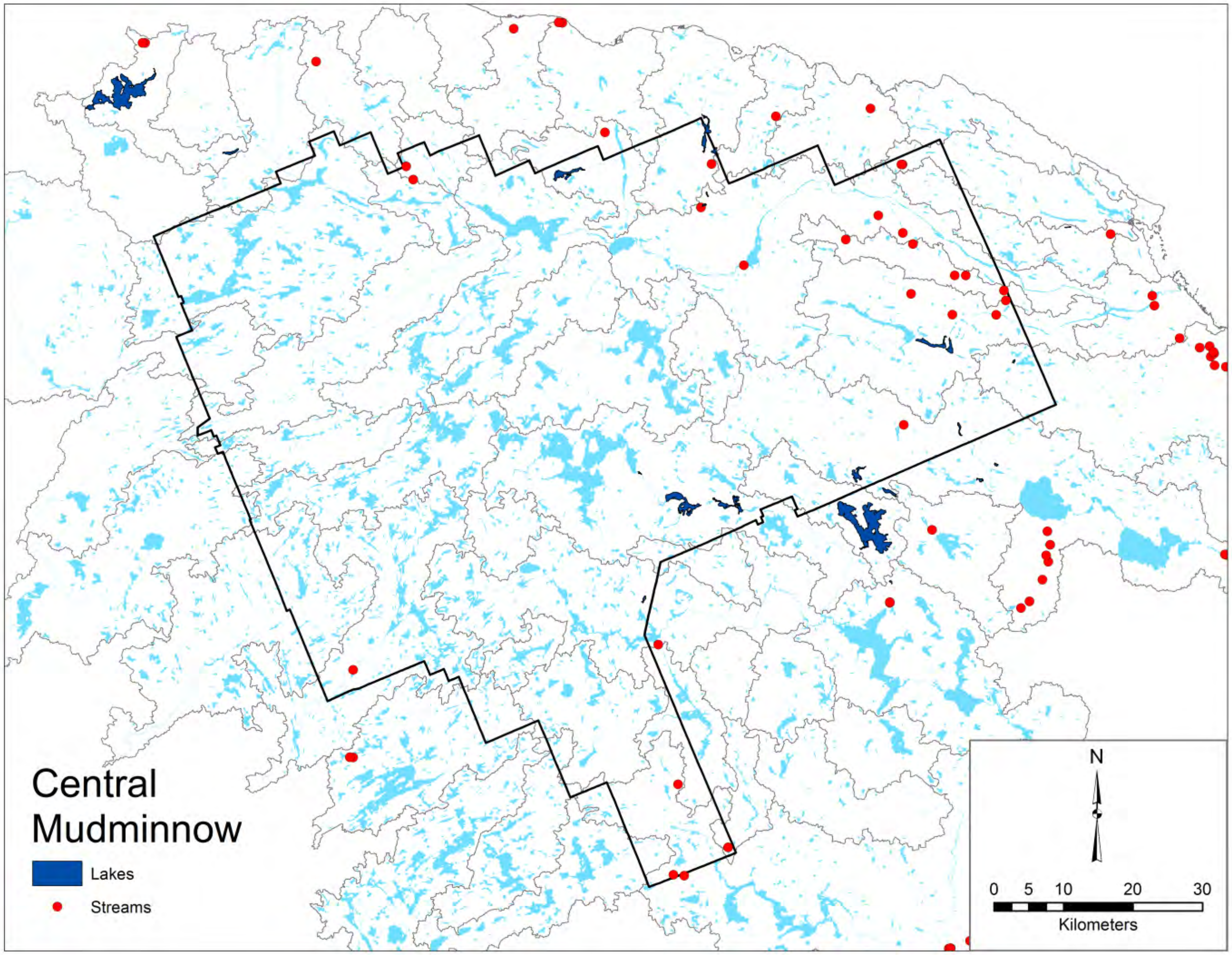


Figure 64. The distribution of central mudminnow in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

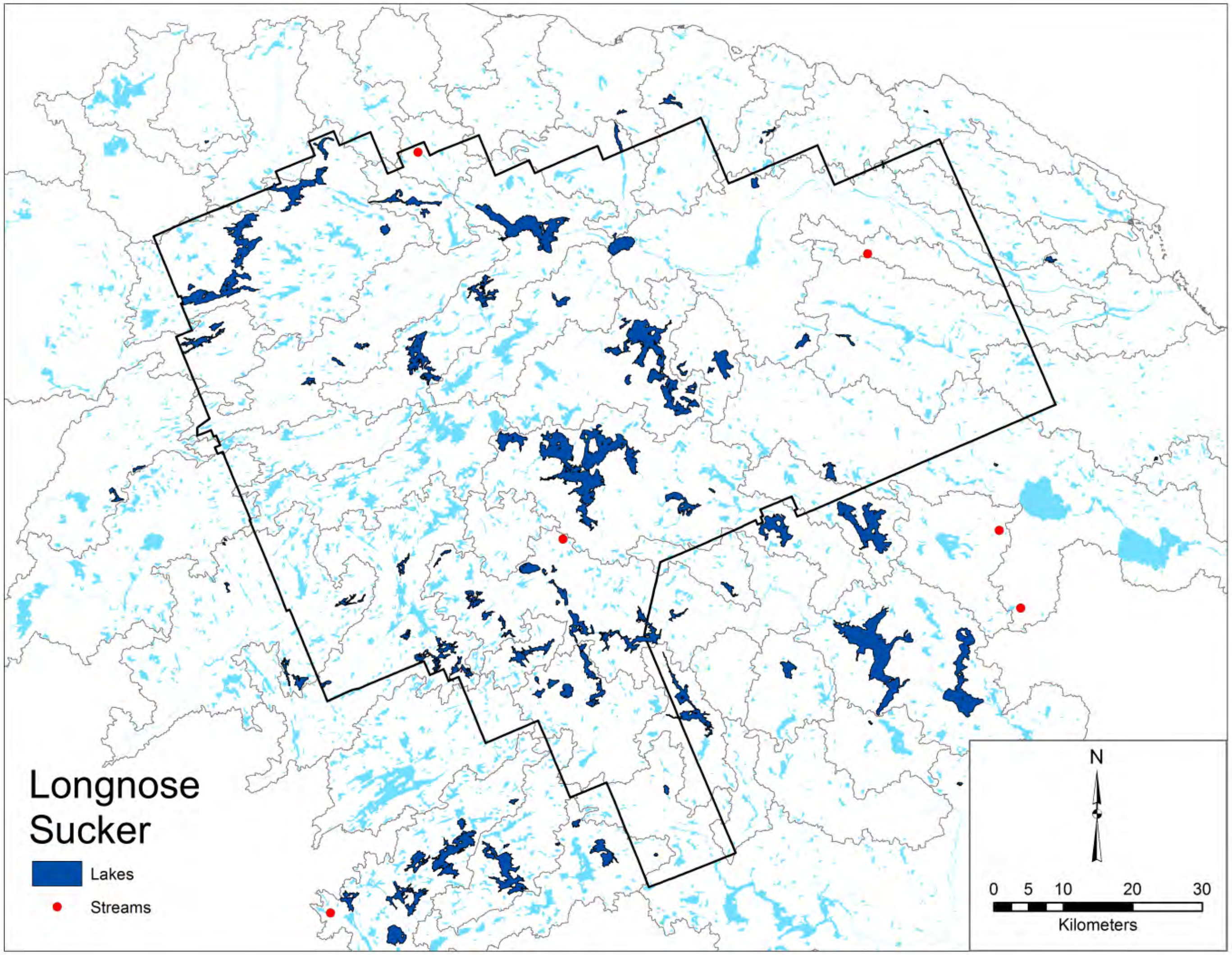


Figure 65. The distribution of longnose sucker in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

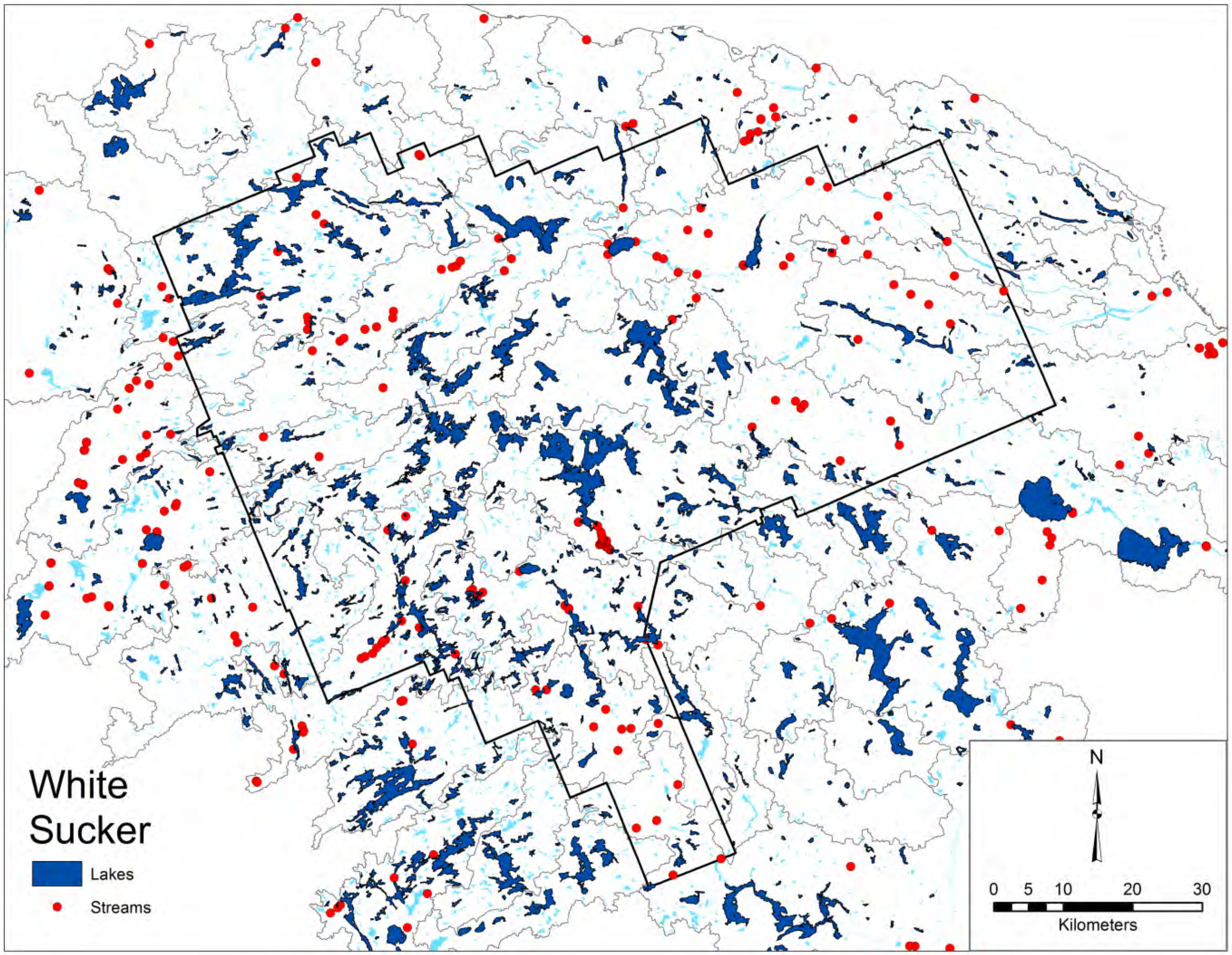


Figure 66. The distribution of white sucker in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

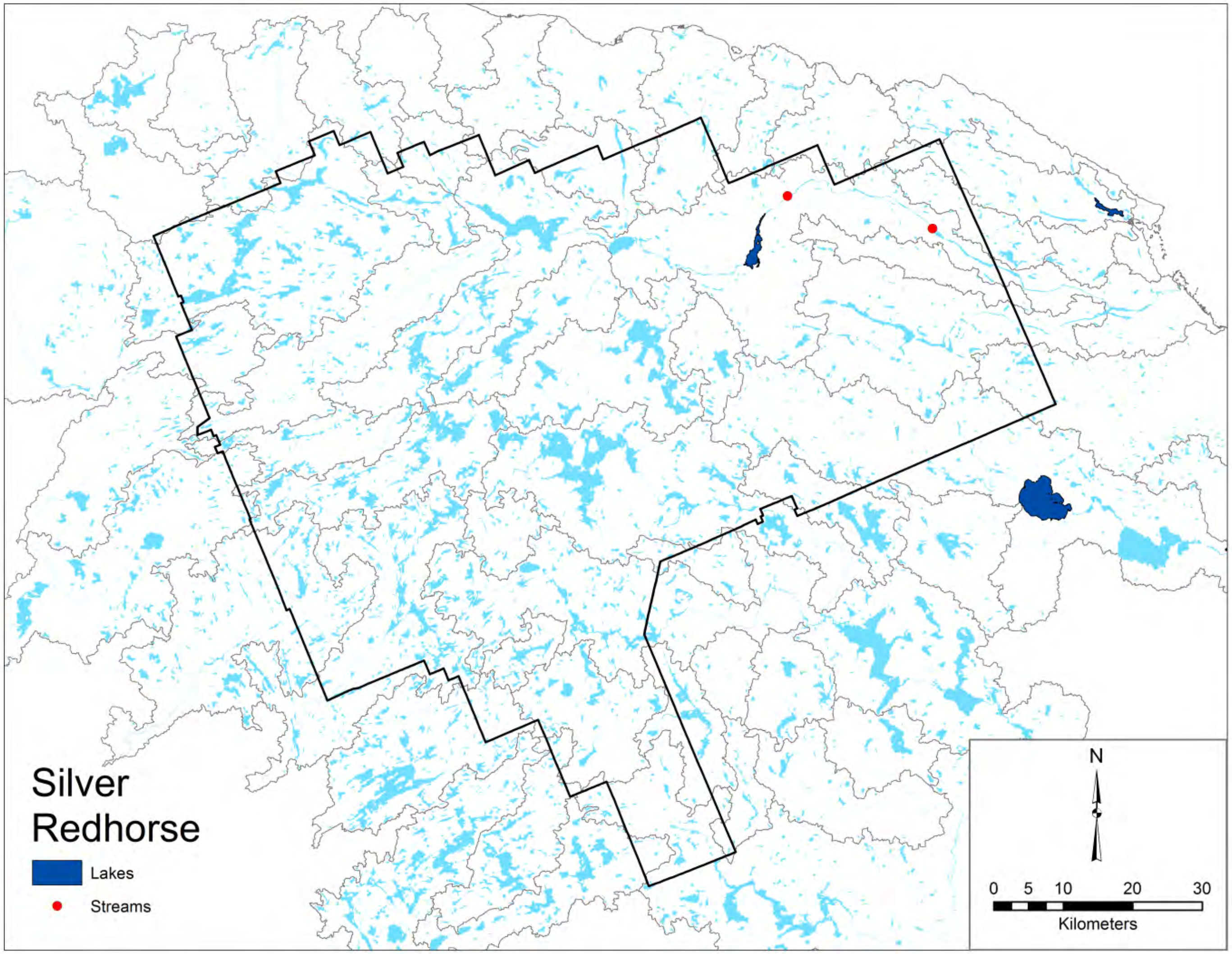


Figure 67. The distribution of silver redhorse in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

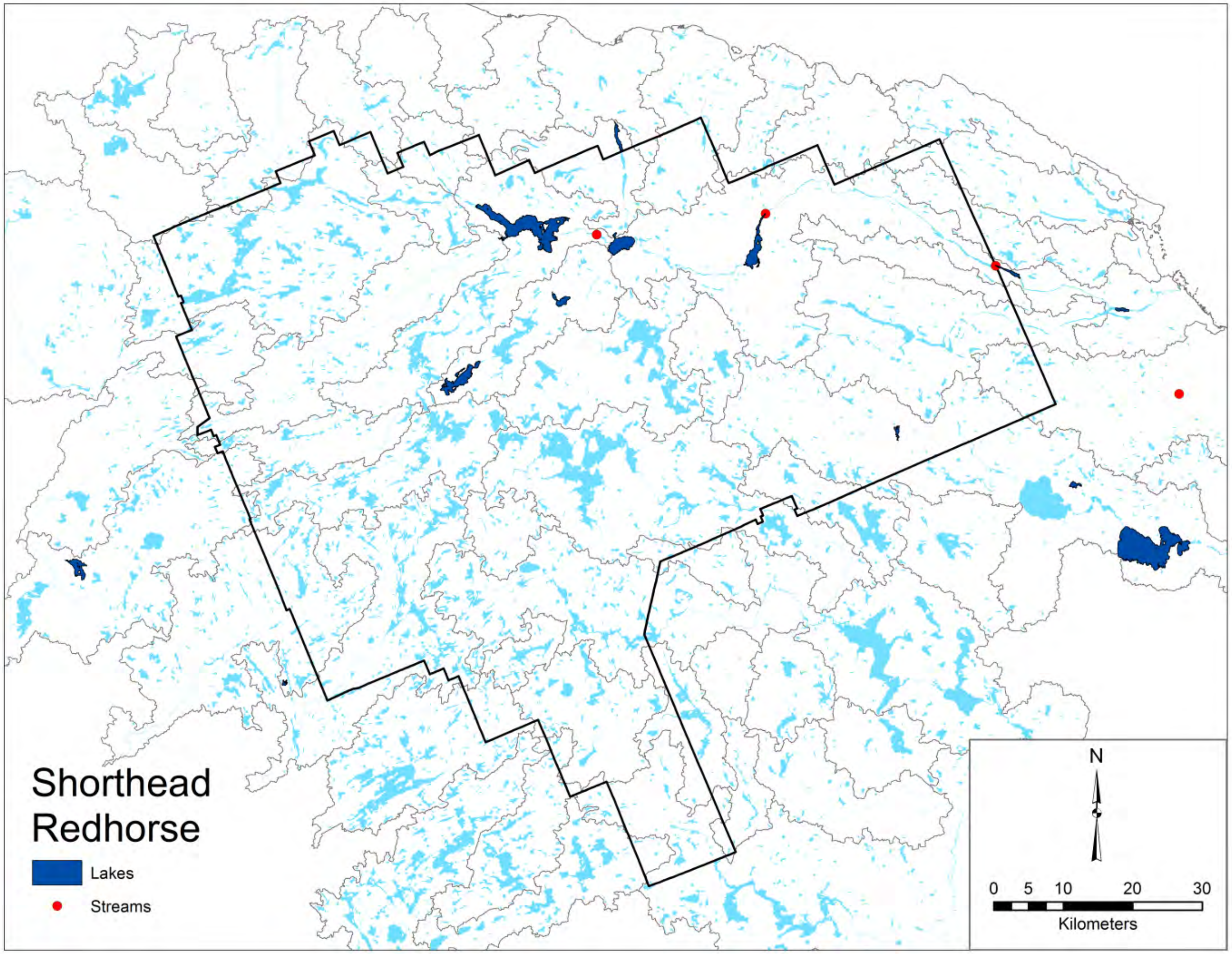


Figure 68. The distribution of shorthead redhorse in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

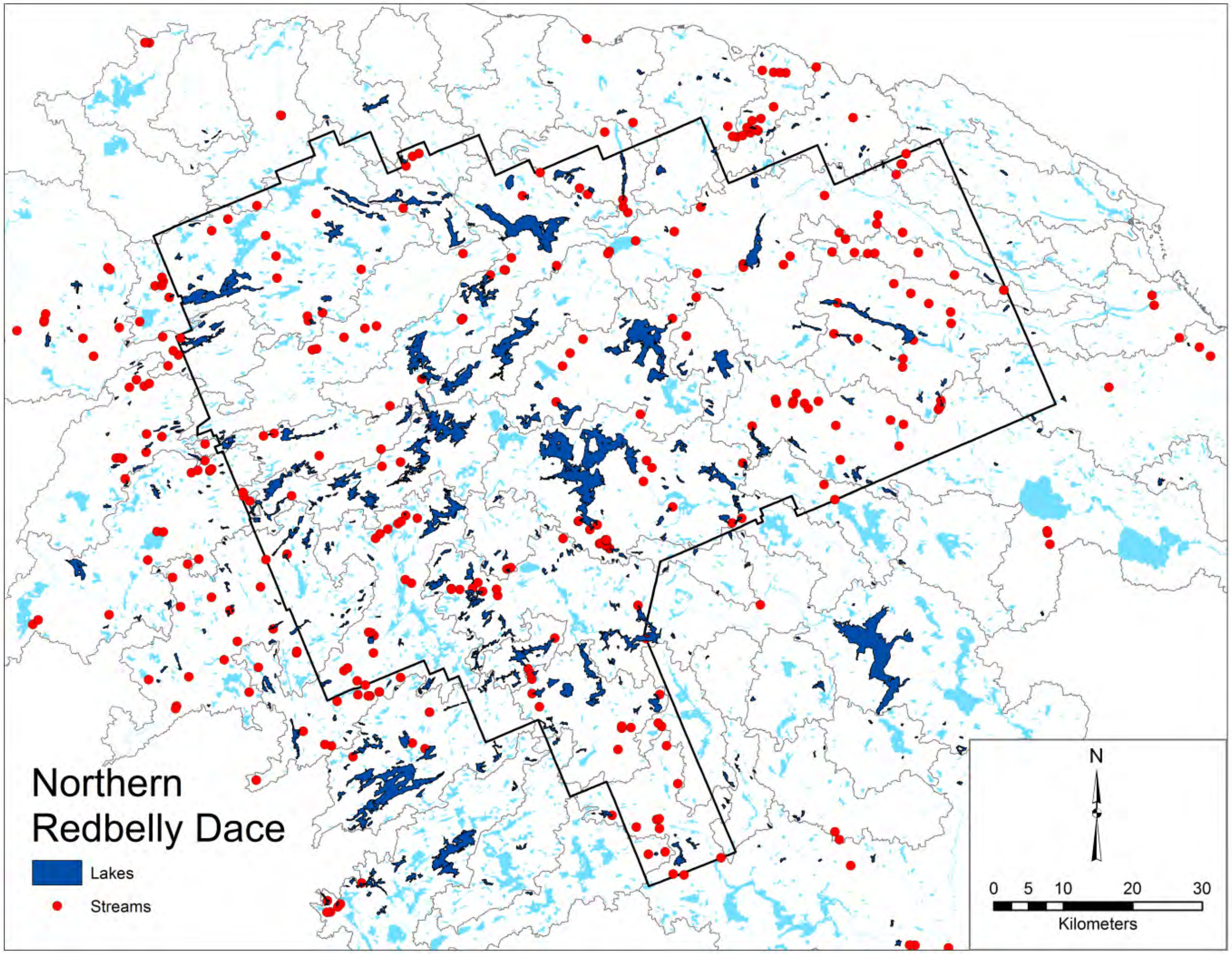


Figure 69. The distribution of northern redbelly dace in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

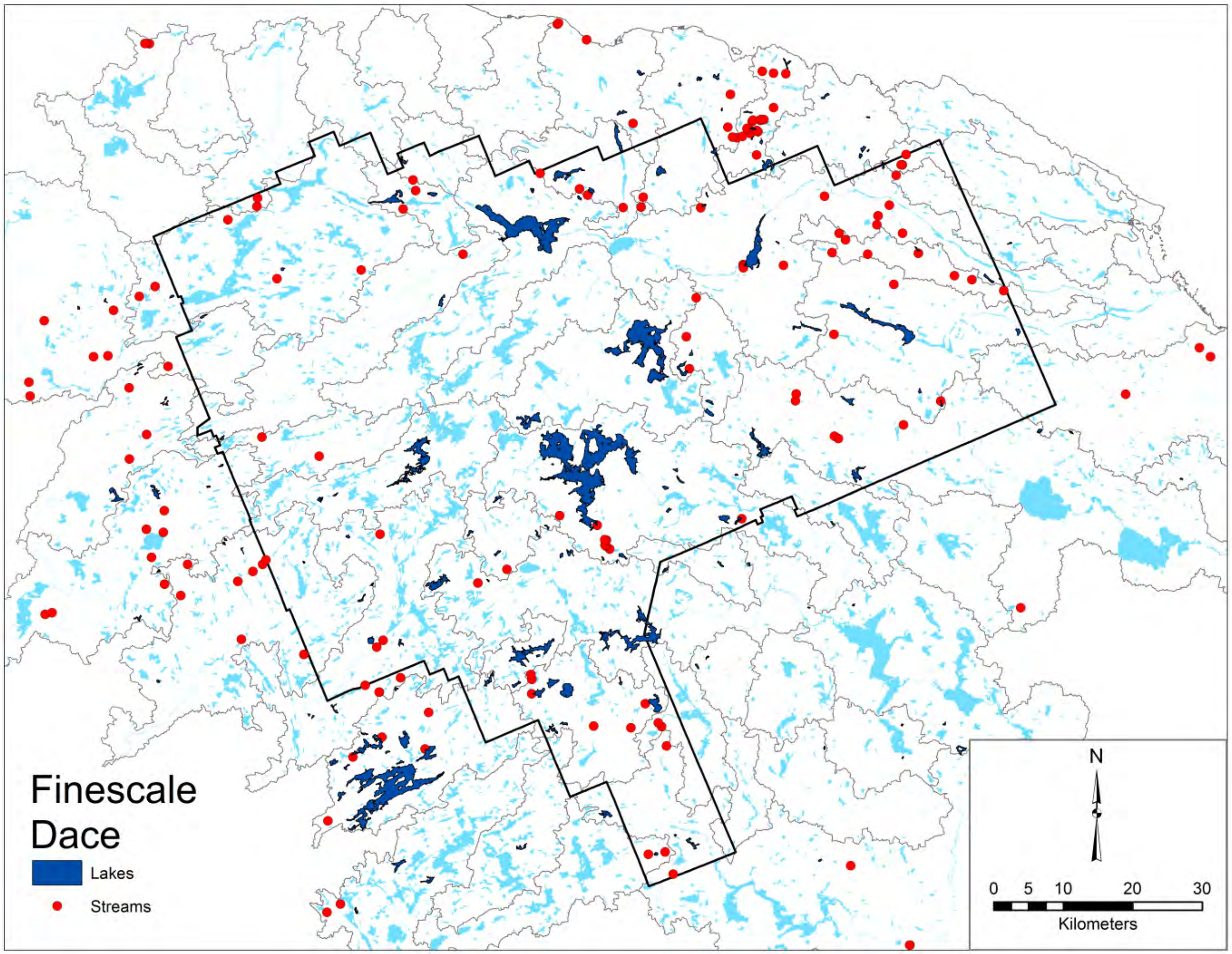


Figure 70. The distribution of finescale dace in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

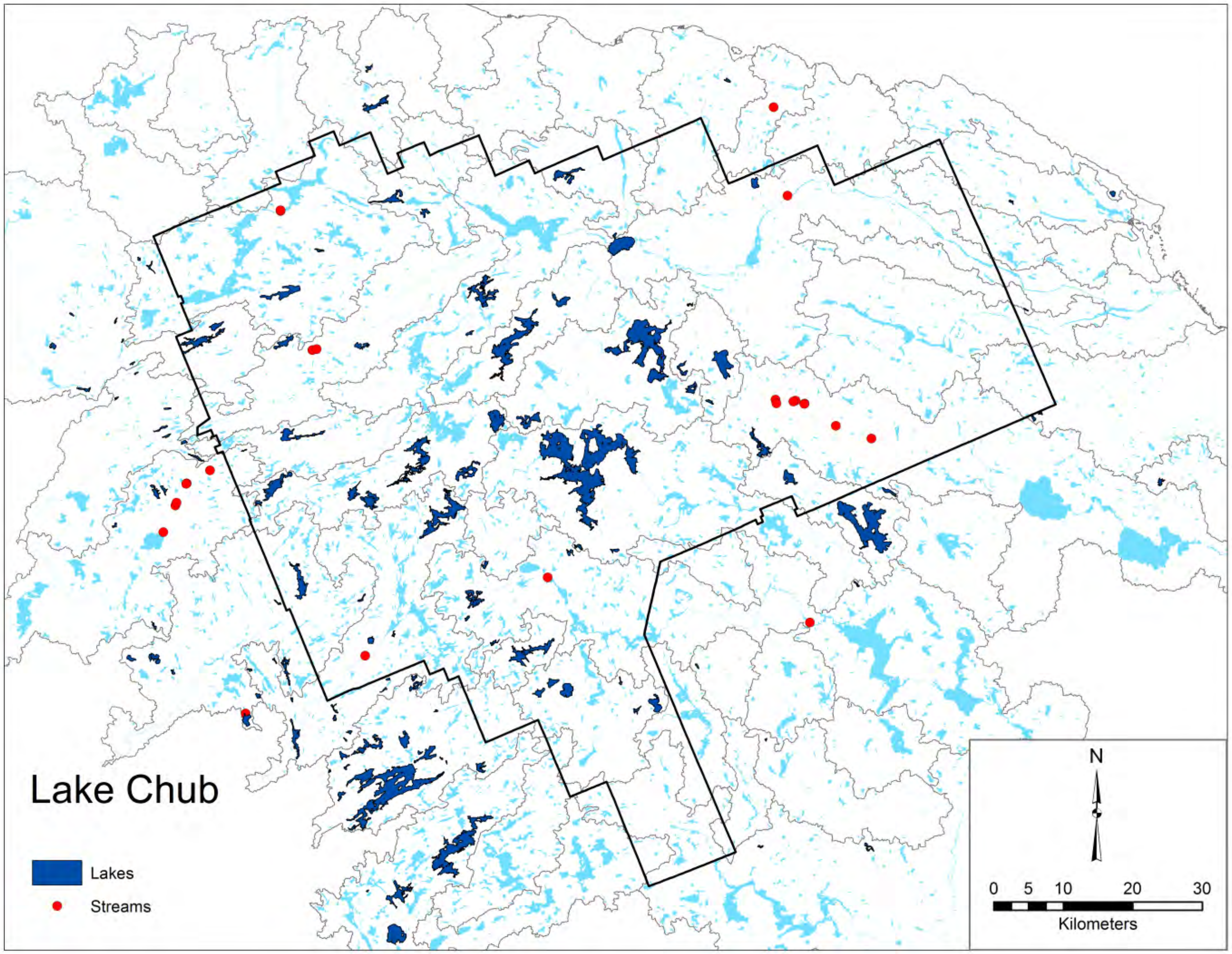


Figure 71. The distribution of lake chub in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

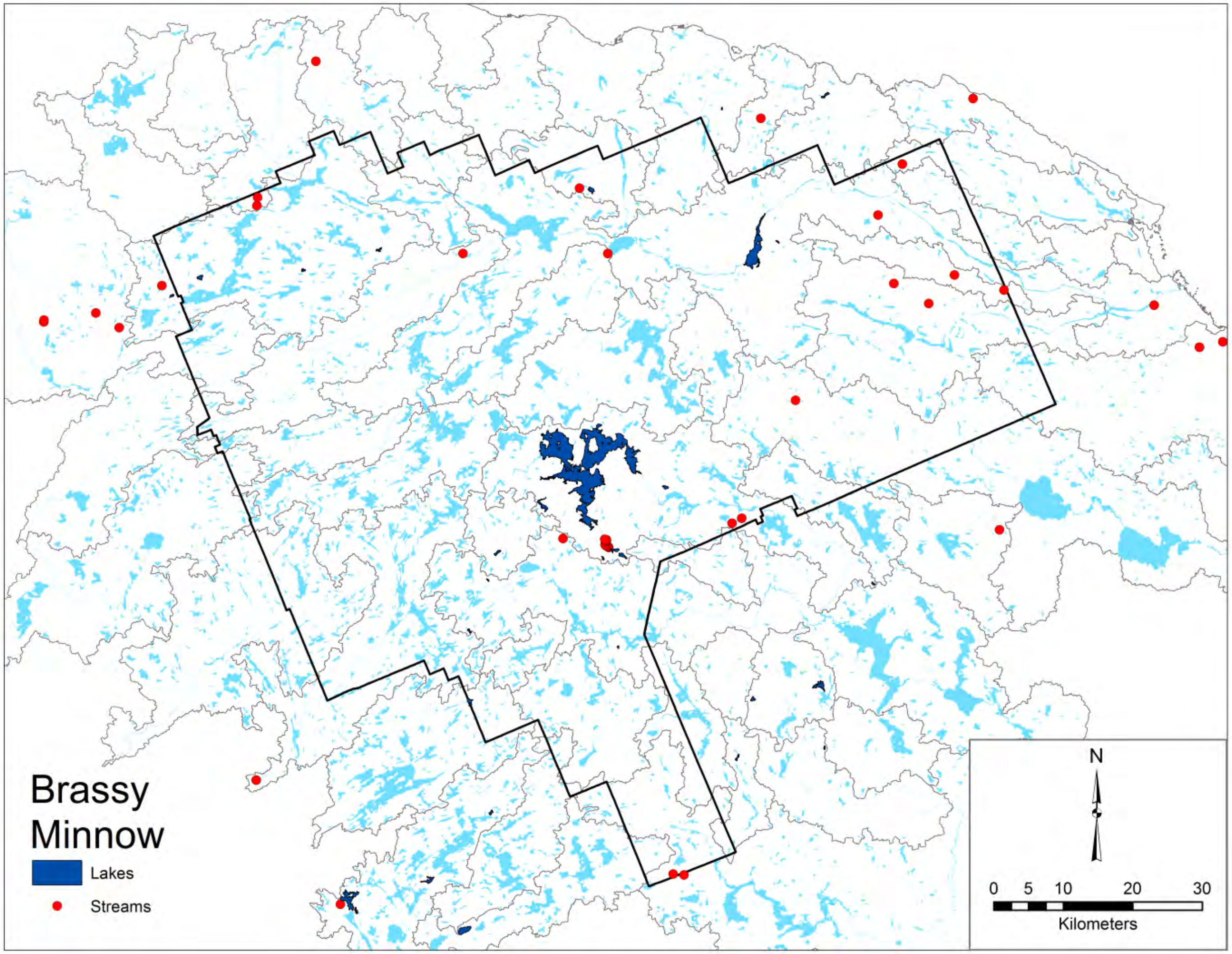


Figure 72. The distribution of brassy minnow in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

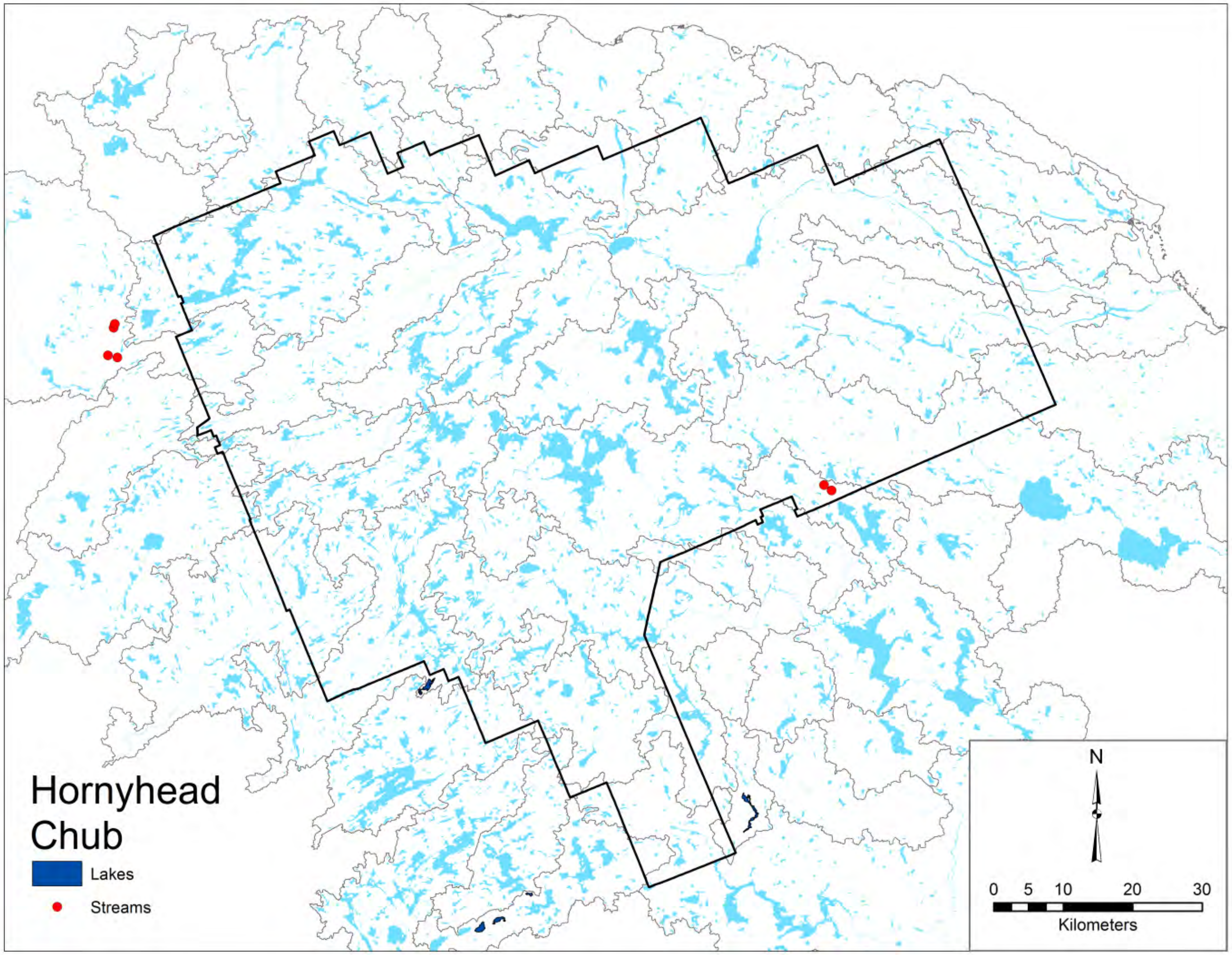


Figure 73. The distribution of hornyhead chub in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

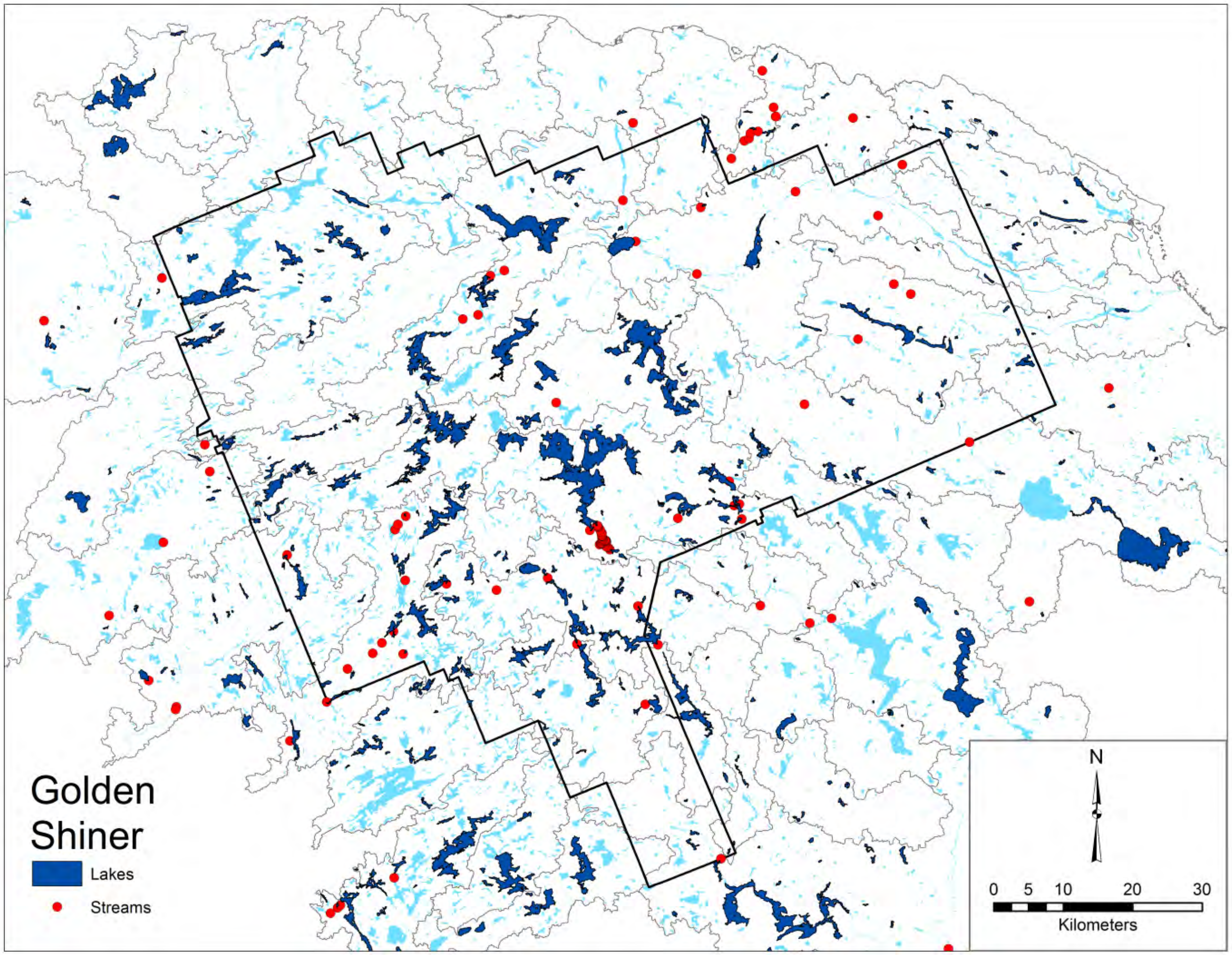


Figure 74. The distribution of golden shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

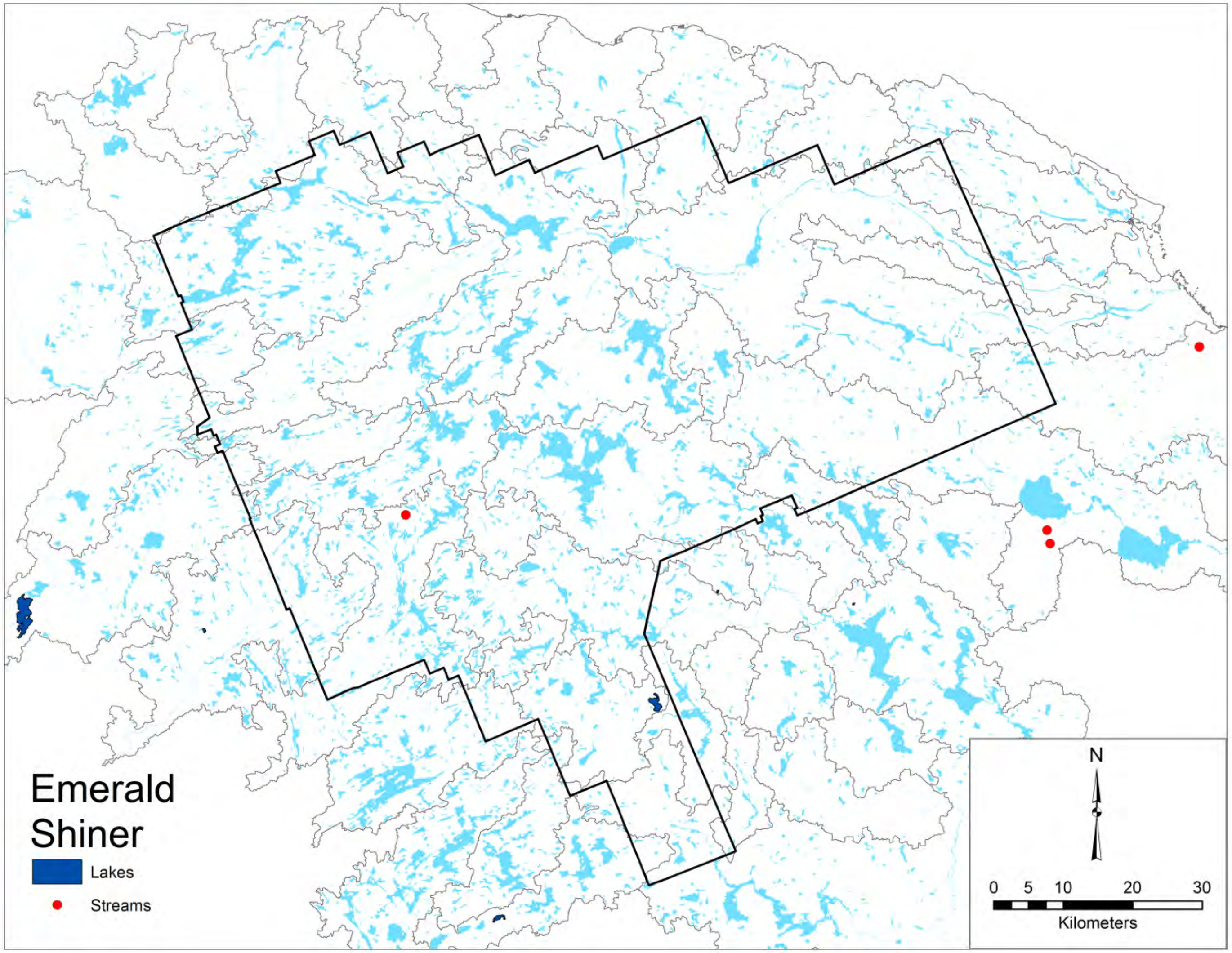


Figure 75. The distribution of emerald shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

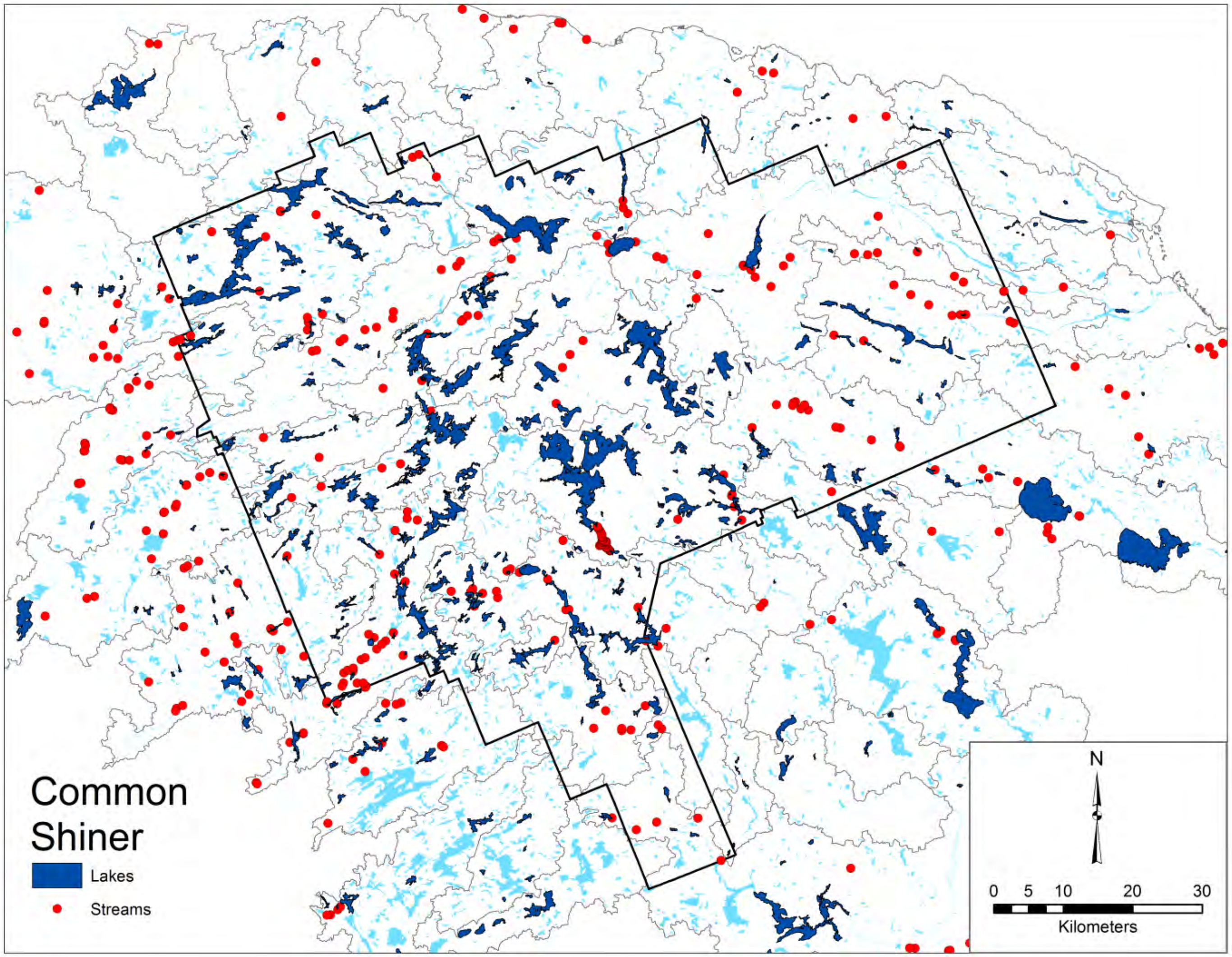


Figure 76. The distribution of common shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

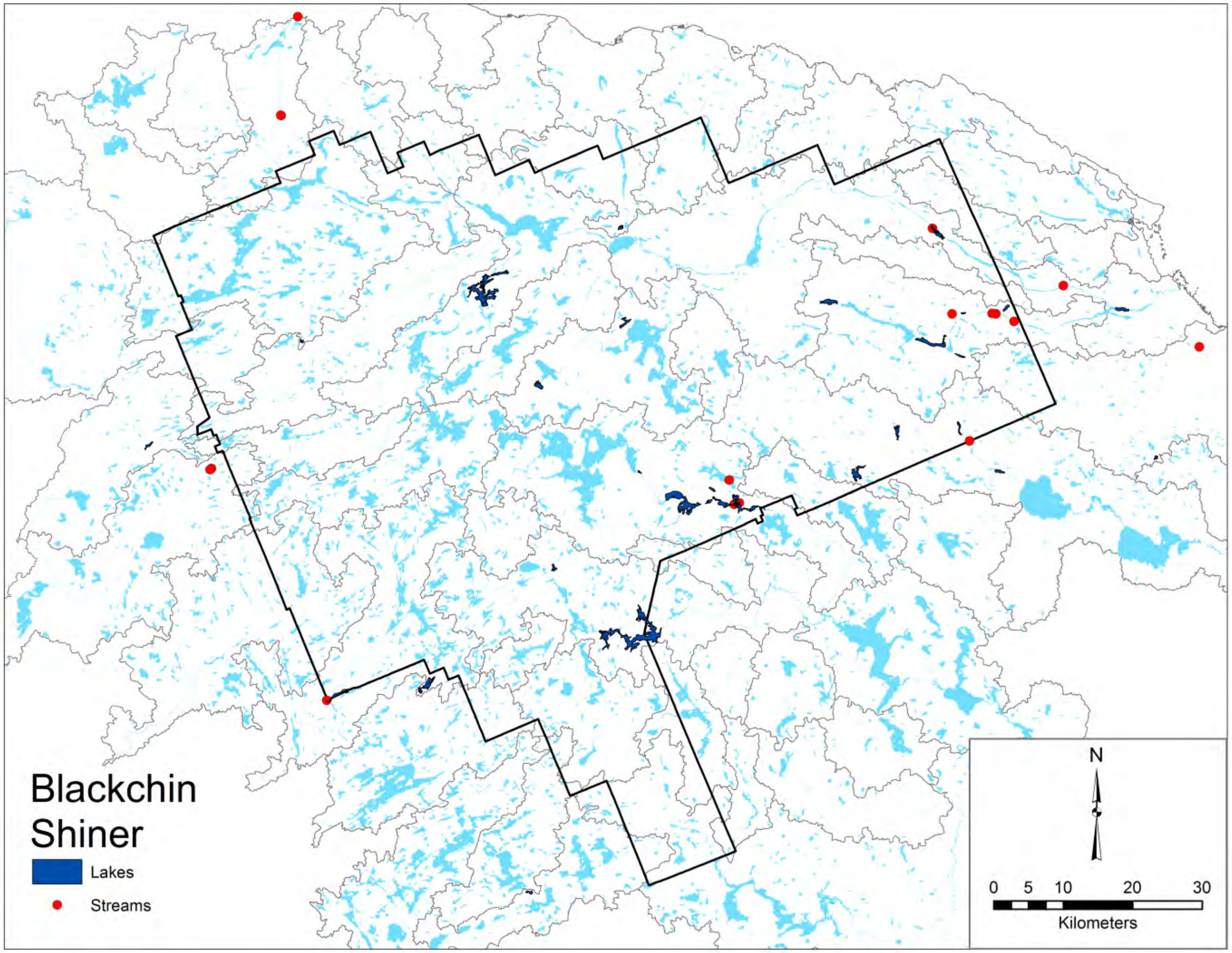


Figure 77. The distribution of blackchin shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

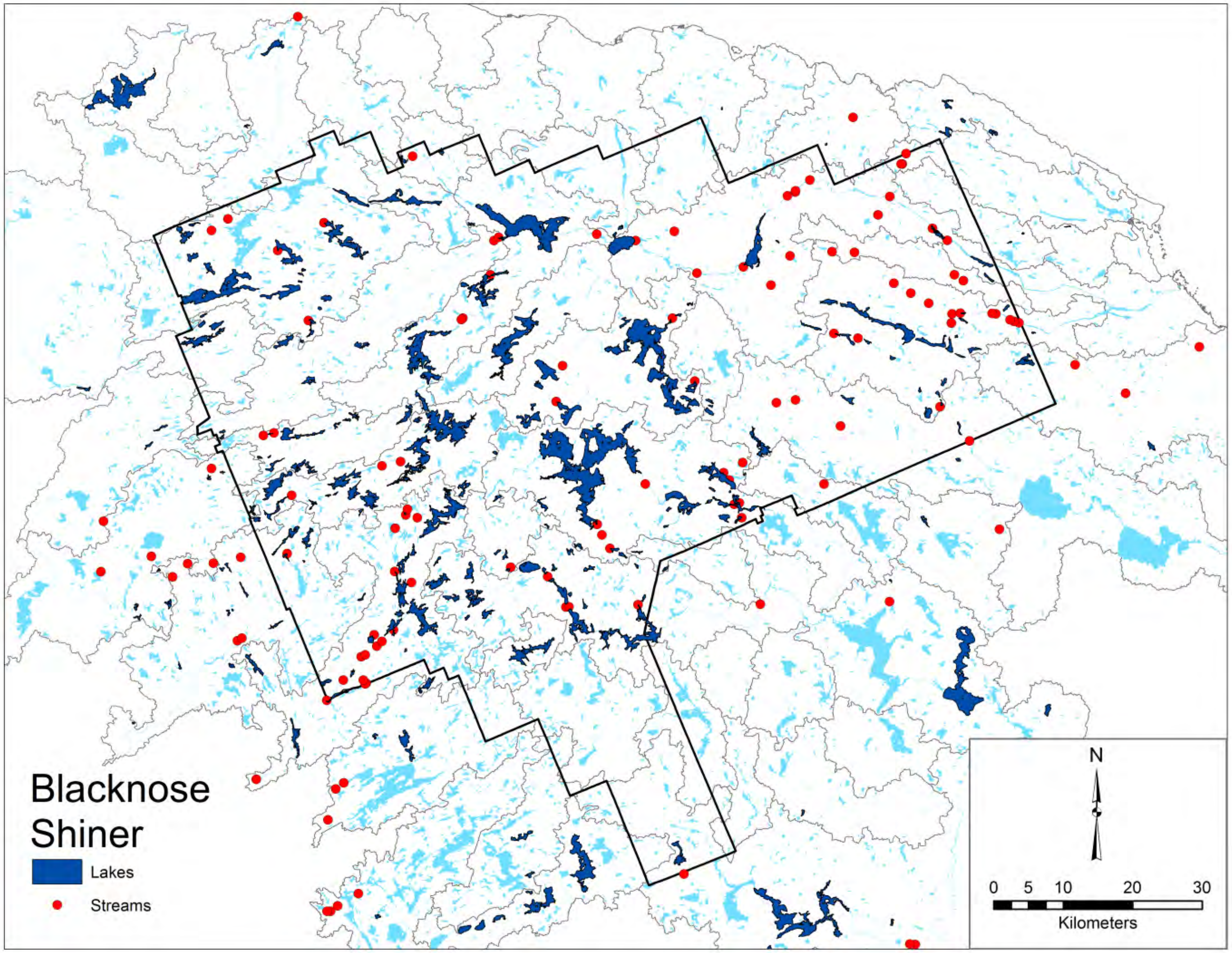


Figure 78. The distribution of blacknose shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

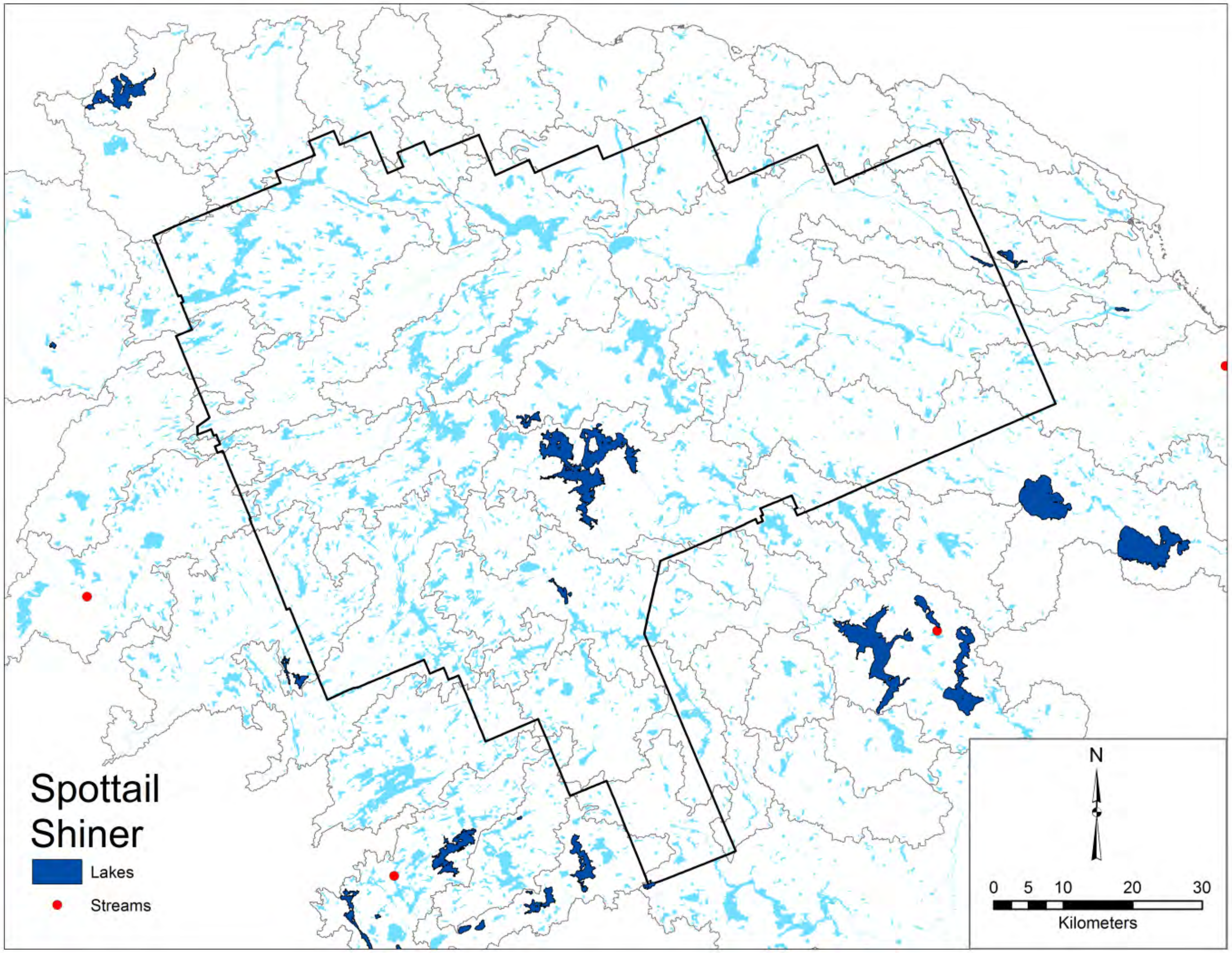


Figure 79. The distribution of spottail shiner in Algonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

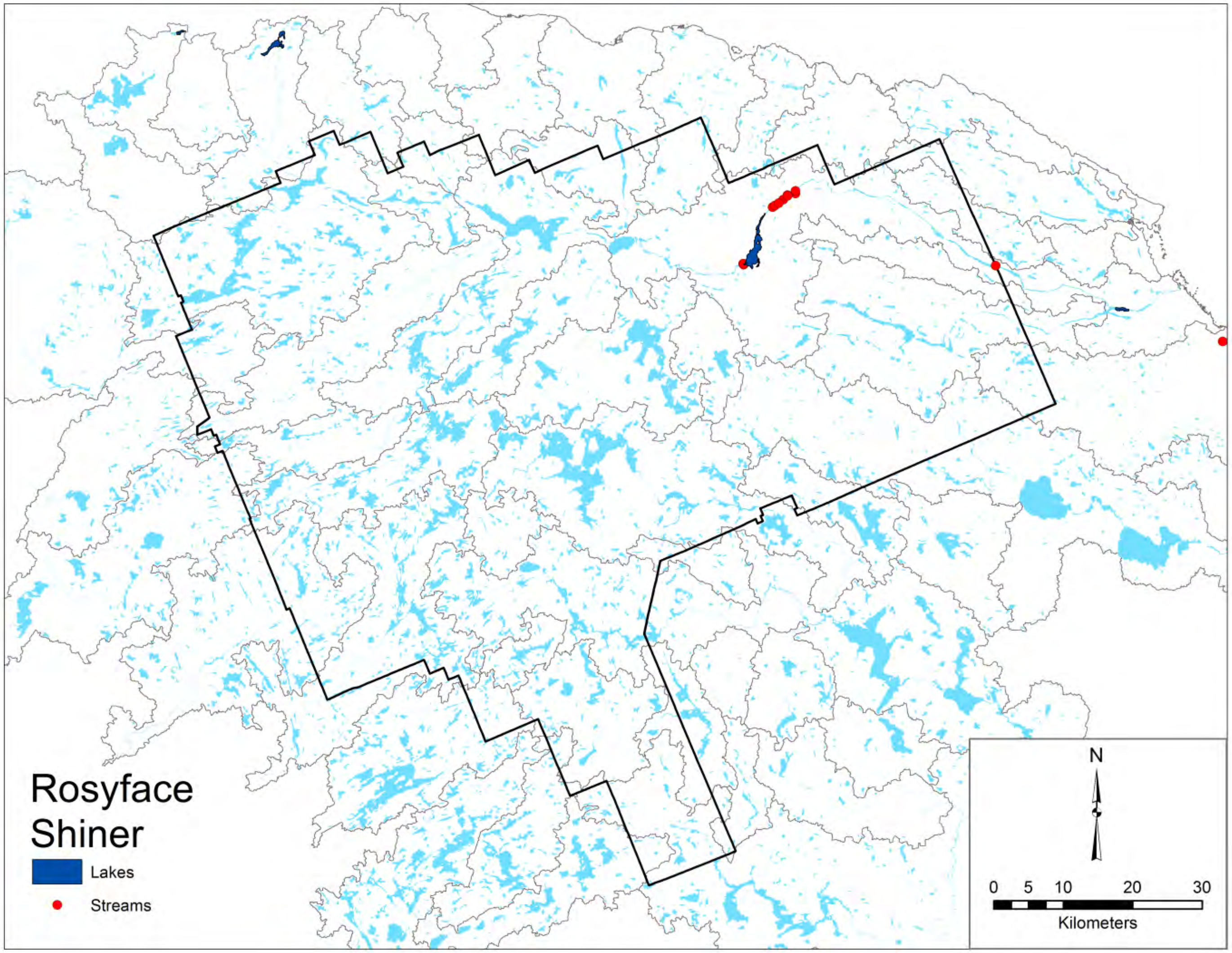


Figure 80. The distribution of rosyface shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

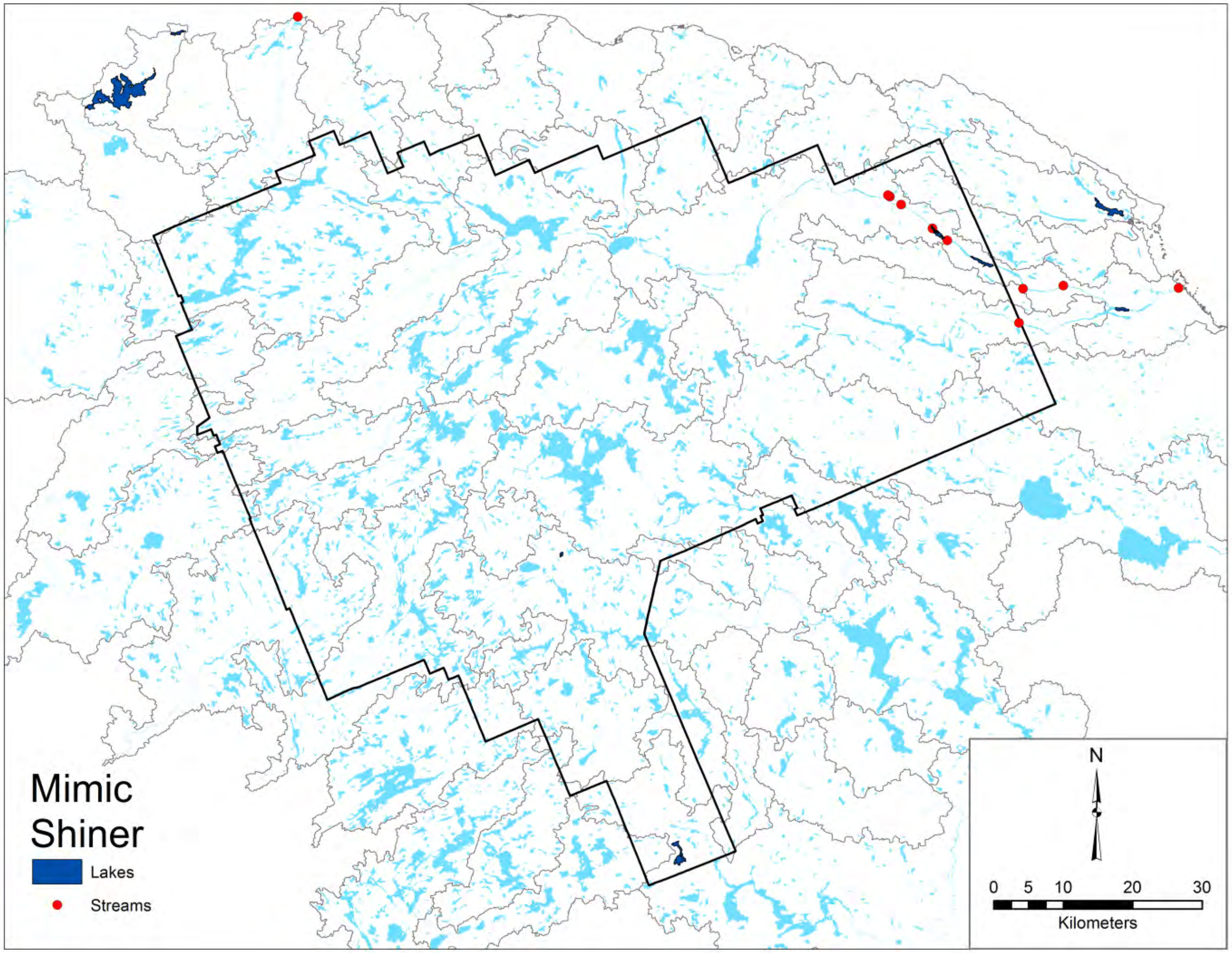


Figure 81. The distribution of mimic shiner in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

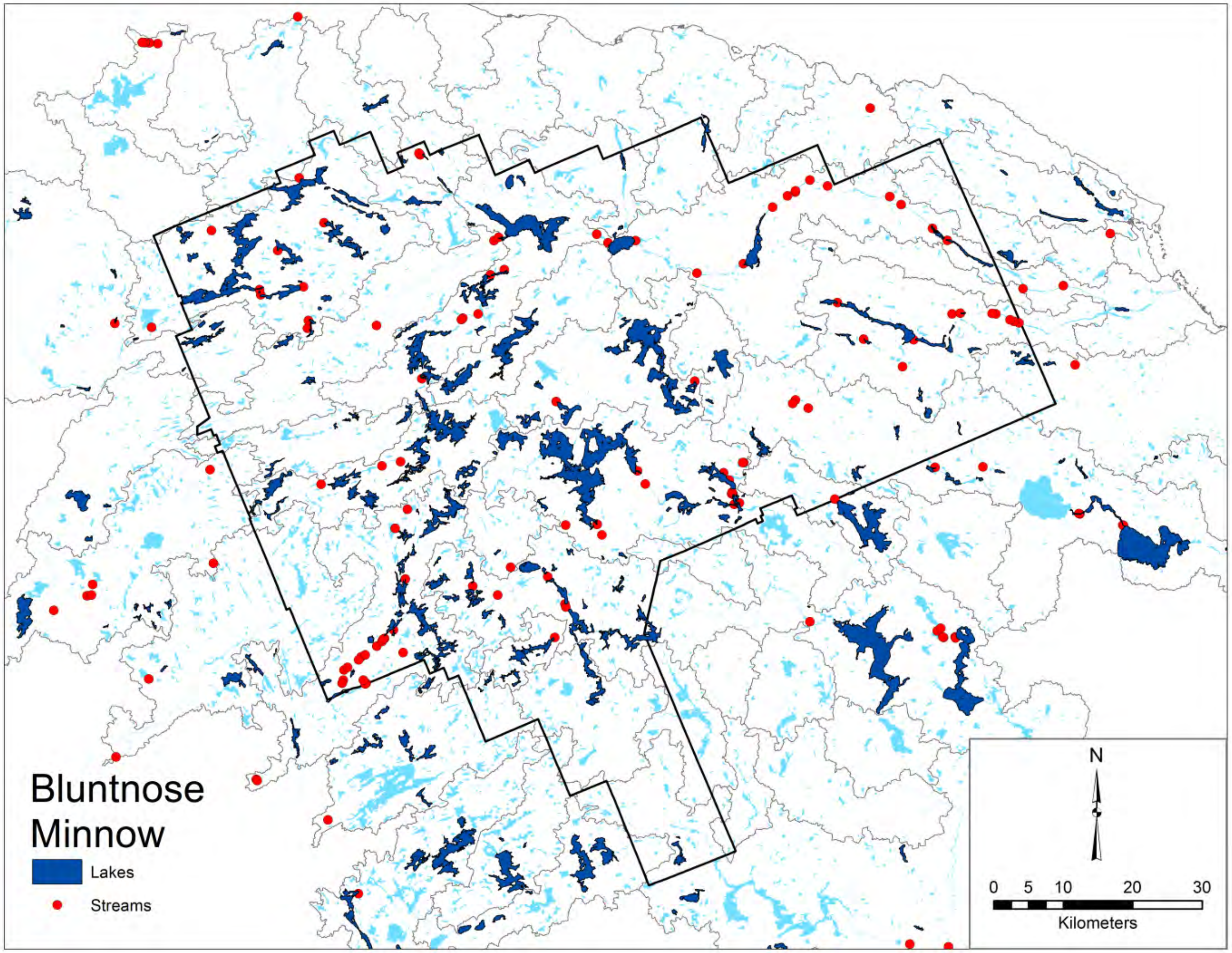


Figure 82. The distribution of bluntnose minnow in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

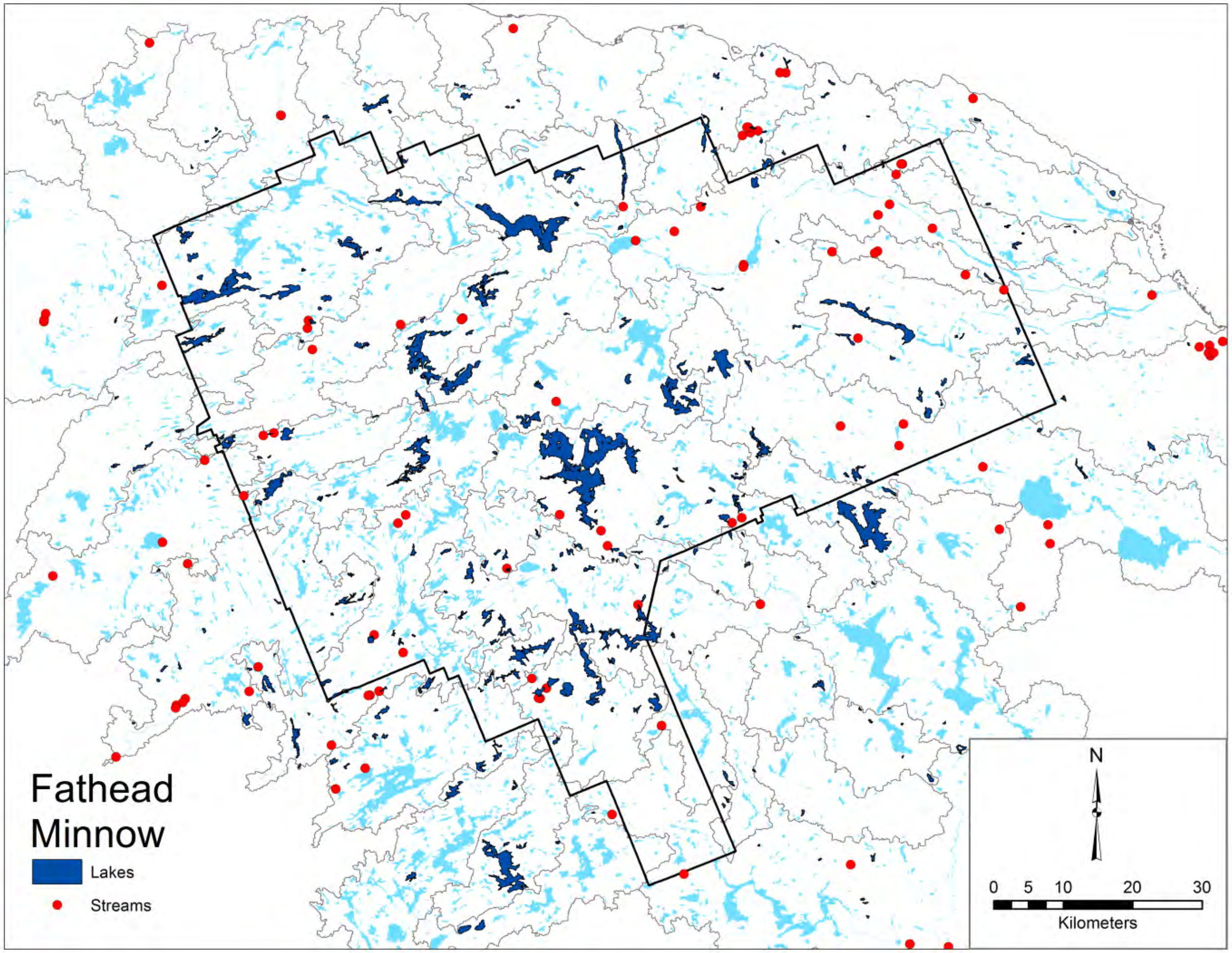


Figure 83. The distribution of fathead minnow in Algonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

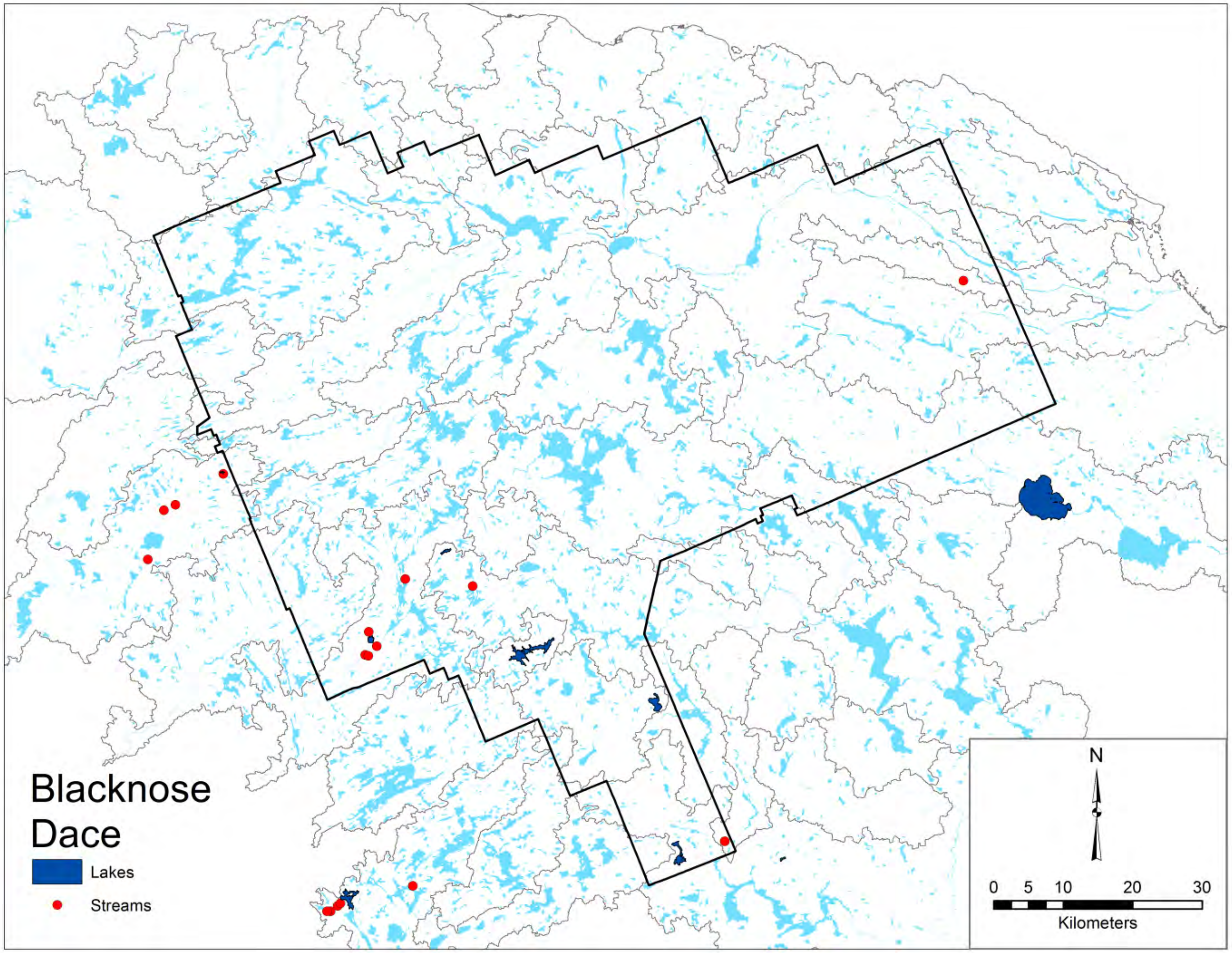


Figure 84. The distribution of blacknose dace in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

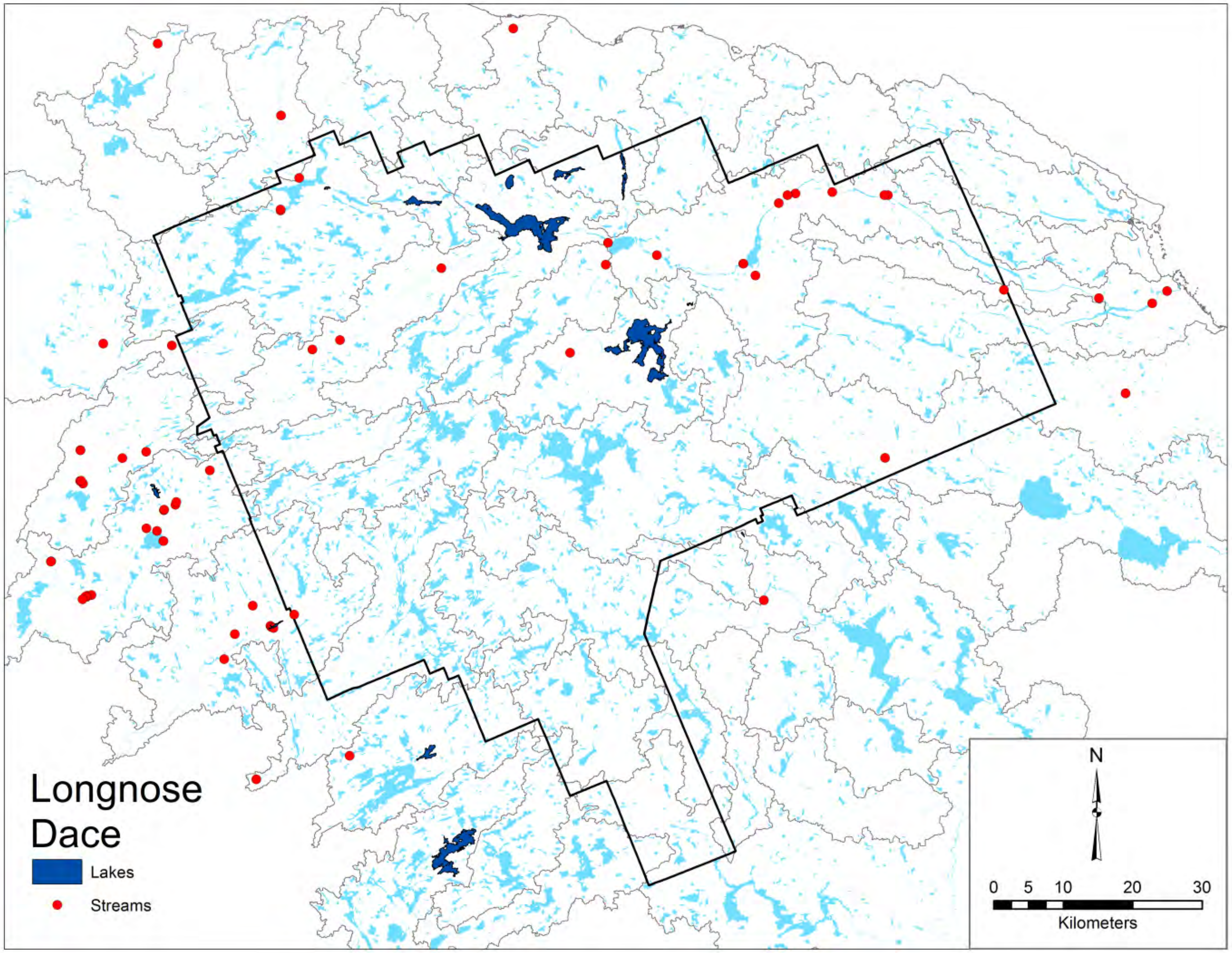


Figure 85. The distribution of longnose dace in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

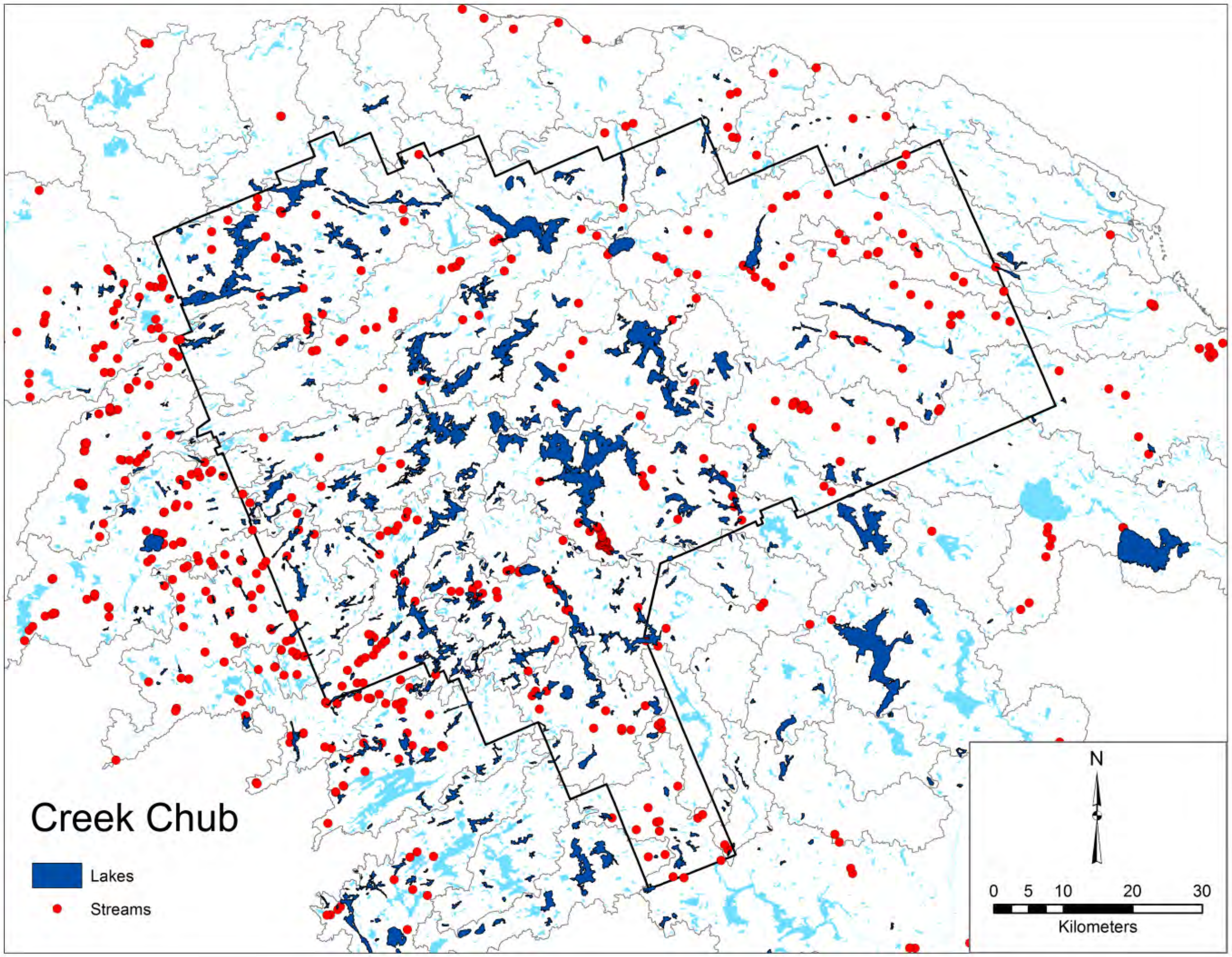


Figure 86. The distribution of creek chub in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

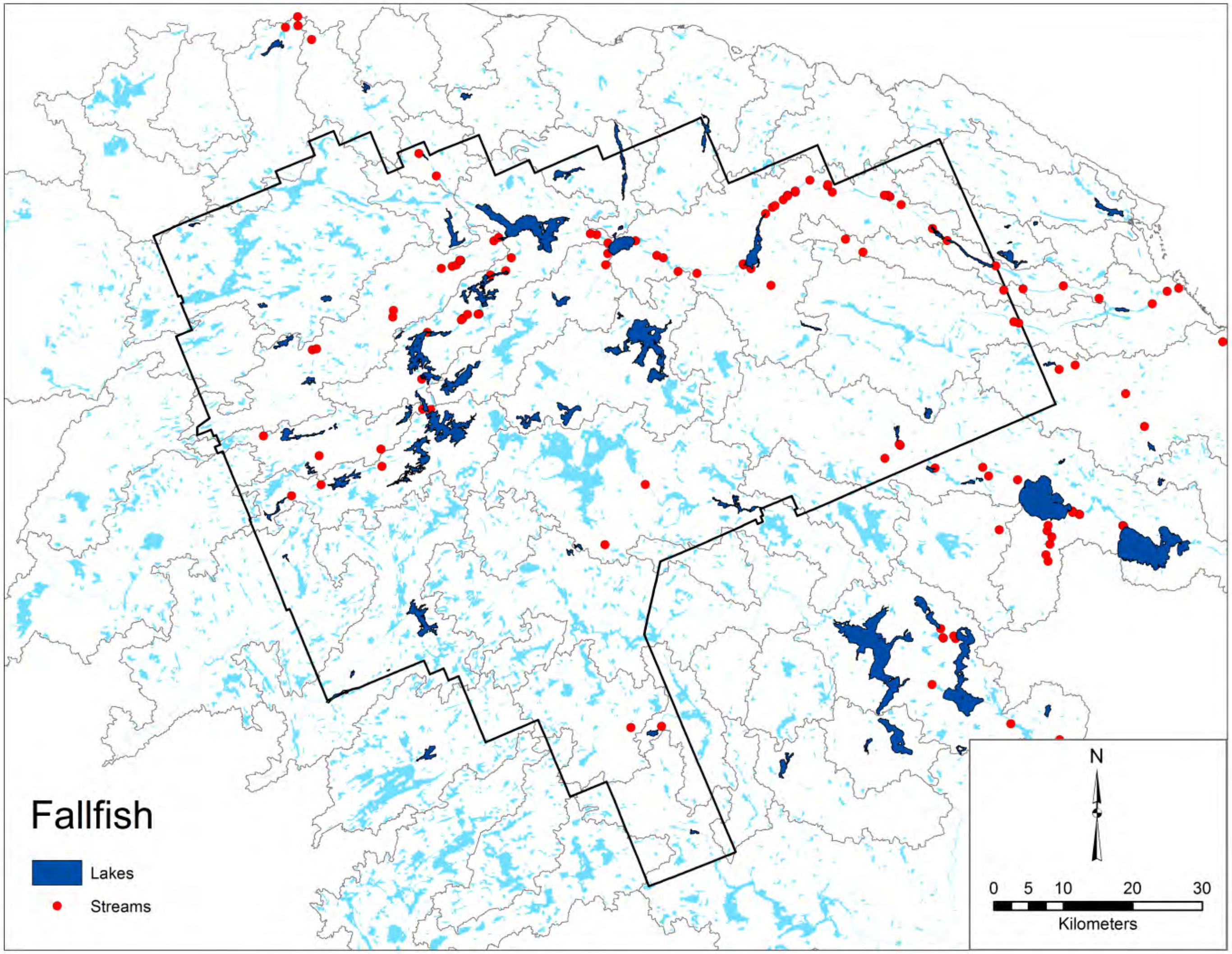


Figure 87. The distribution of fallfish in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

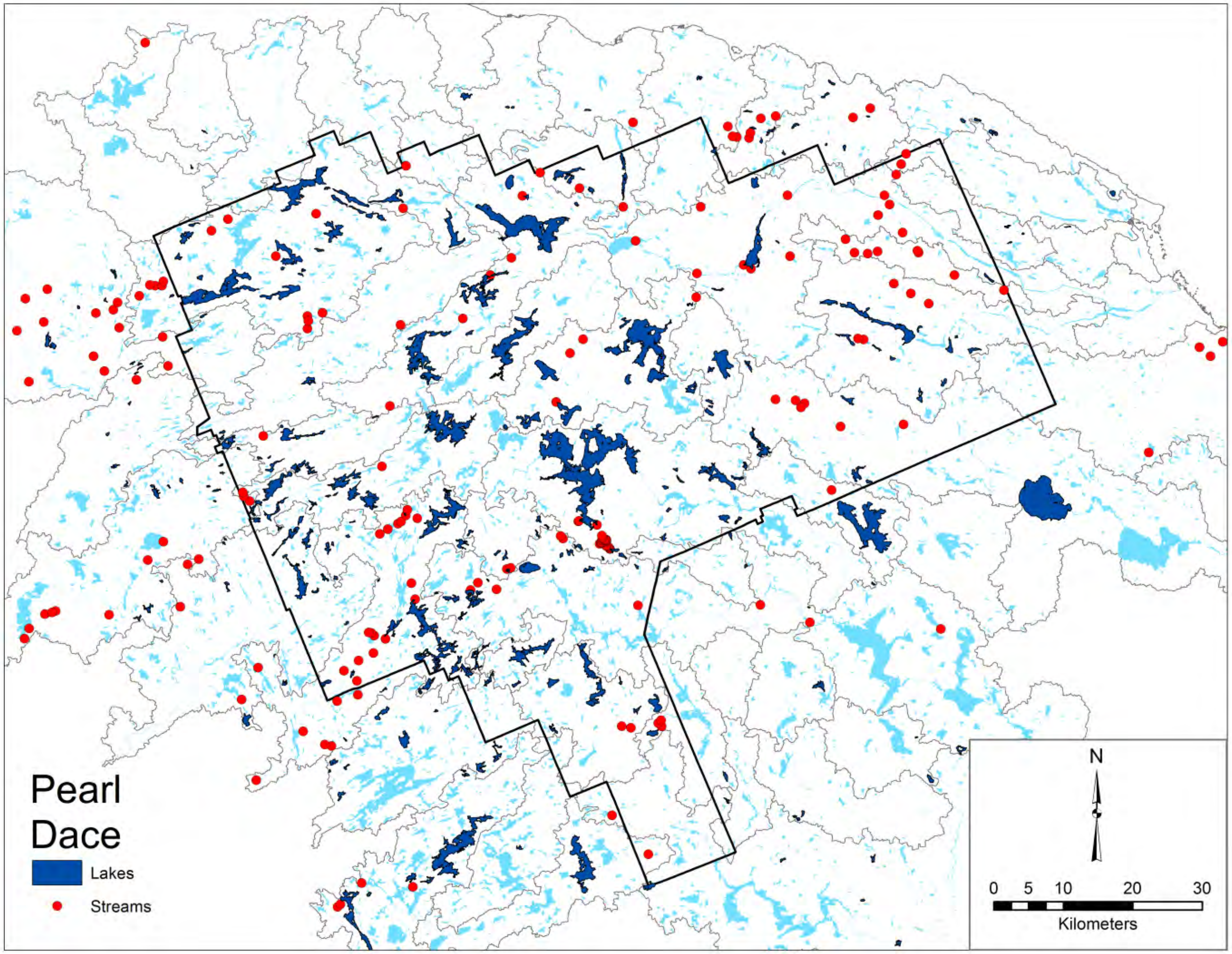


Figure 88. The distribution of pearl dace in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

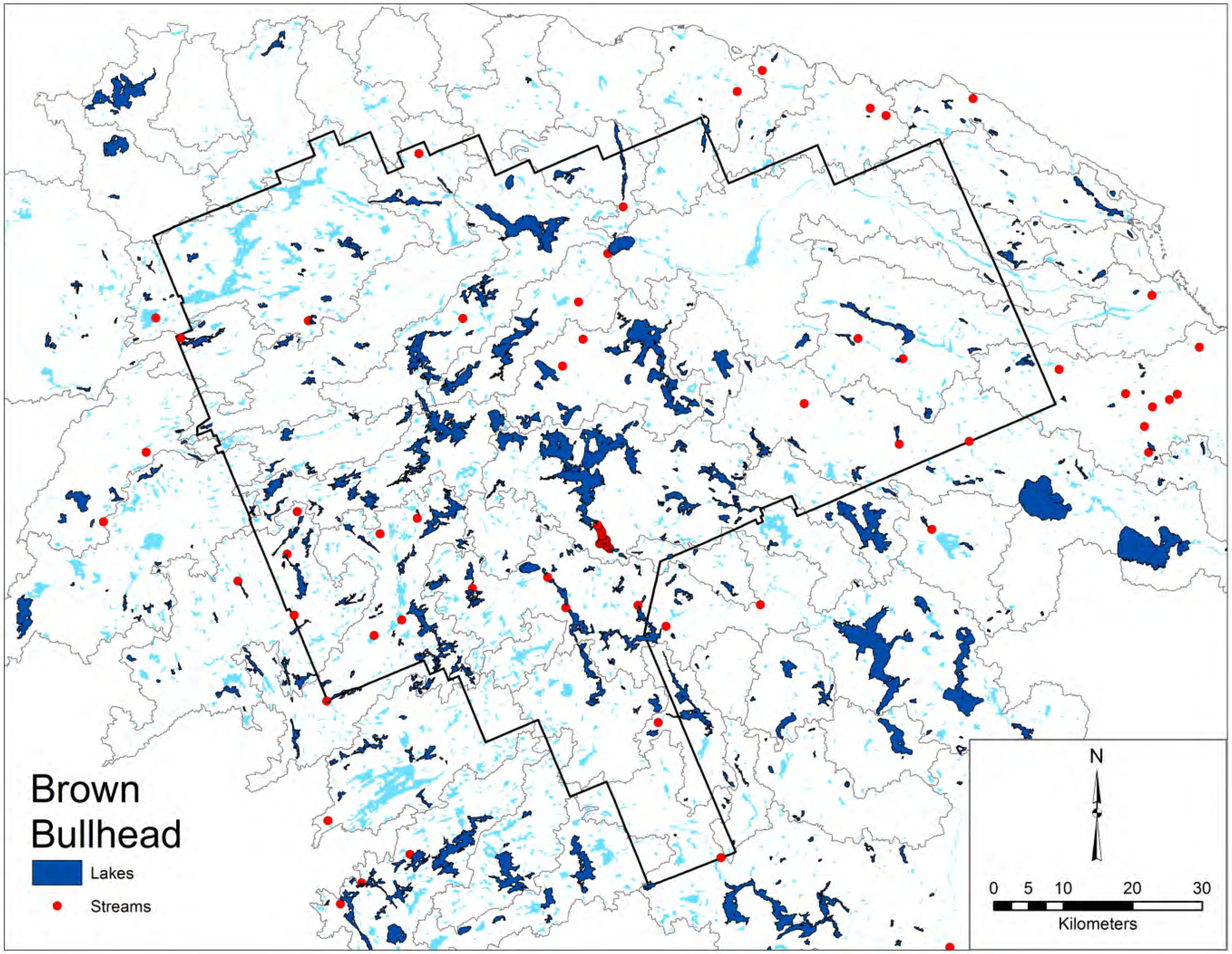


Figure 89. The distribution of brown bullhead in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

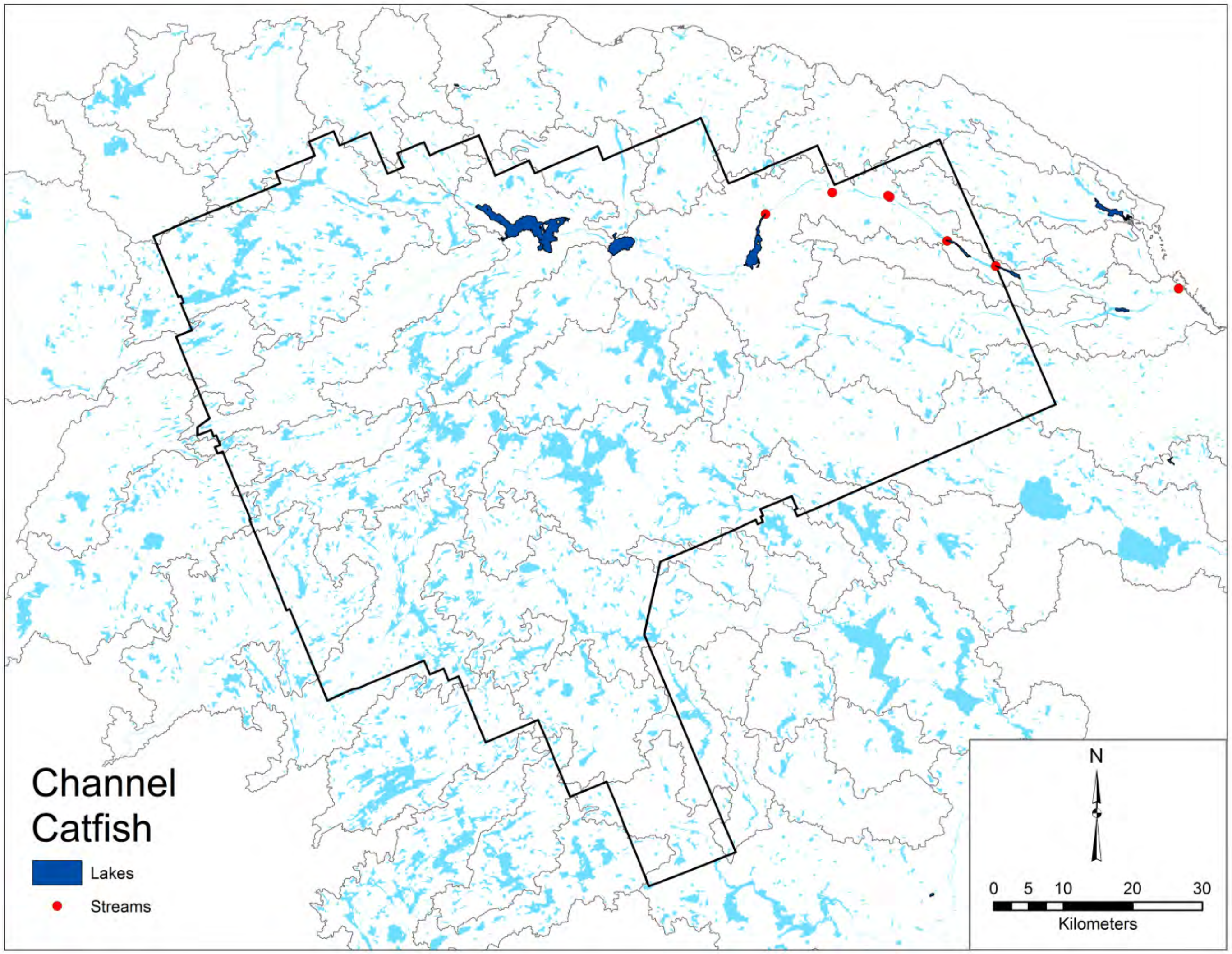


Figure 90. The distribution of channel catfish in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

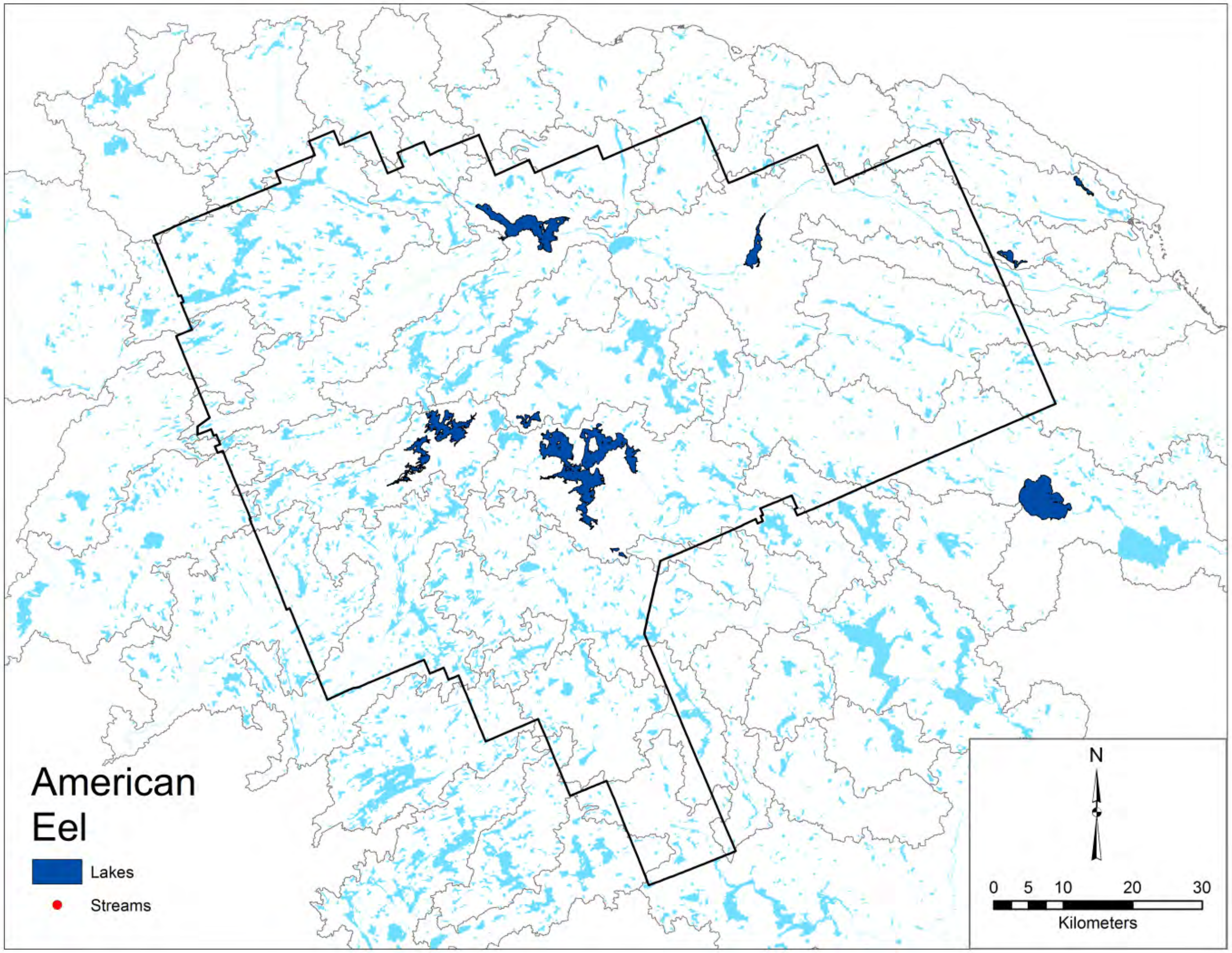


Figure 91. The distribution of American eel in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

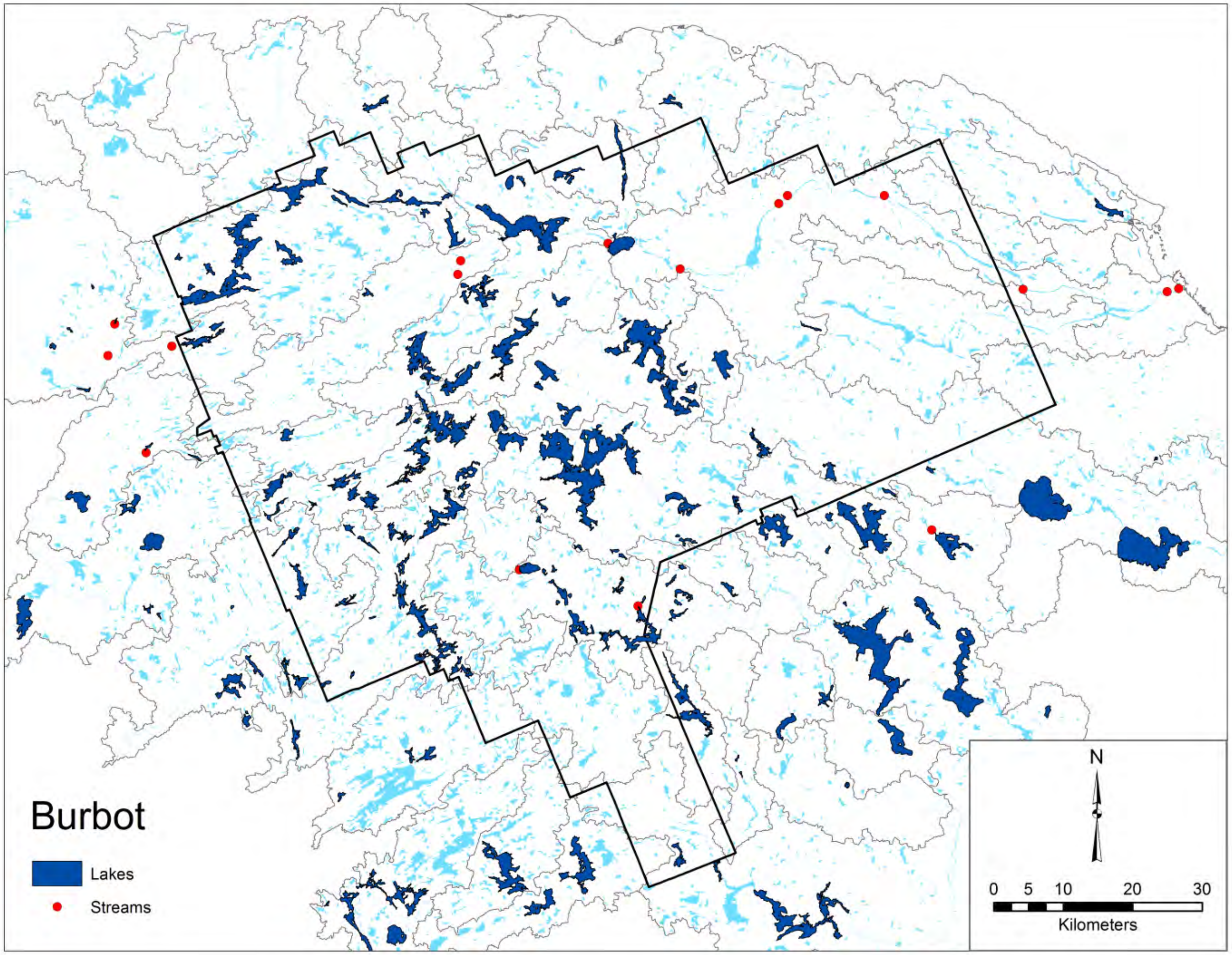


Figure 92. The distribution of burbot in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

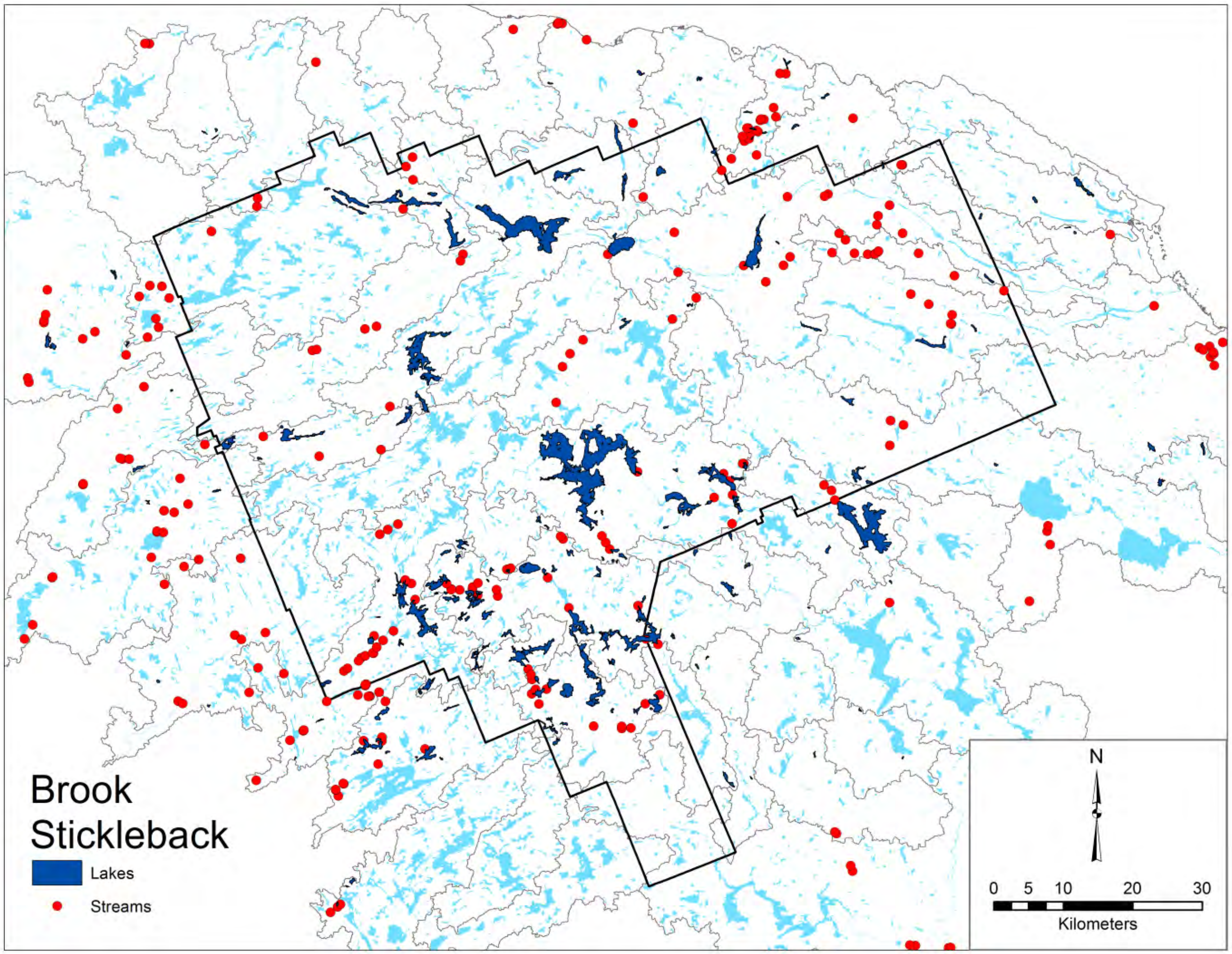


Figure 93. The distribution of brook stickleback in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

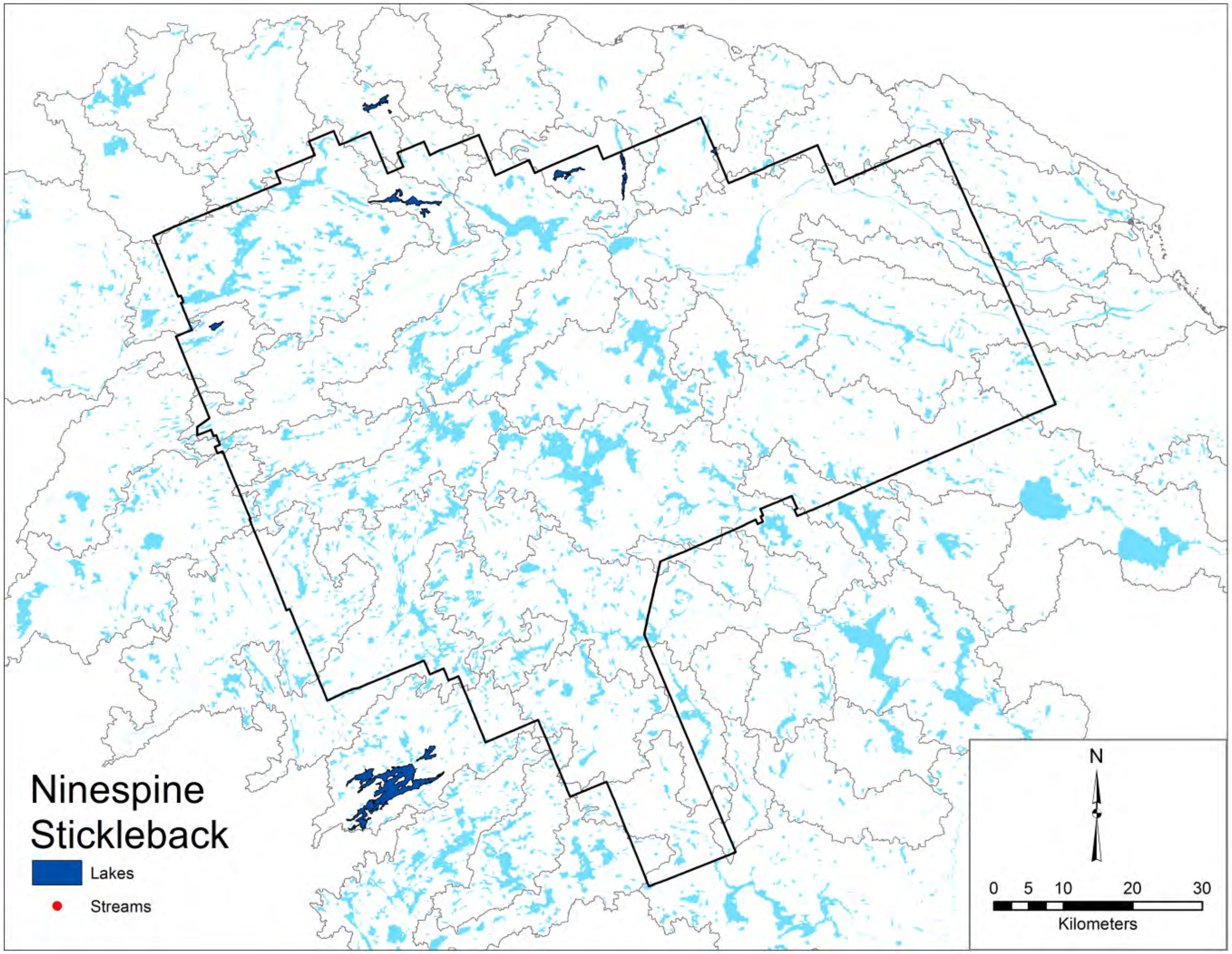


Figure 94. The distribution of ninespine stickleback in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

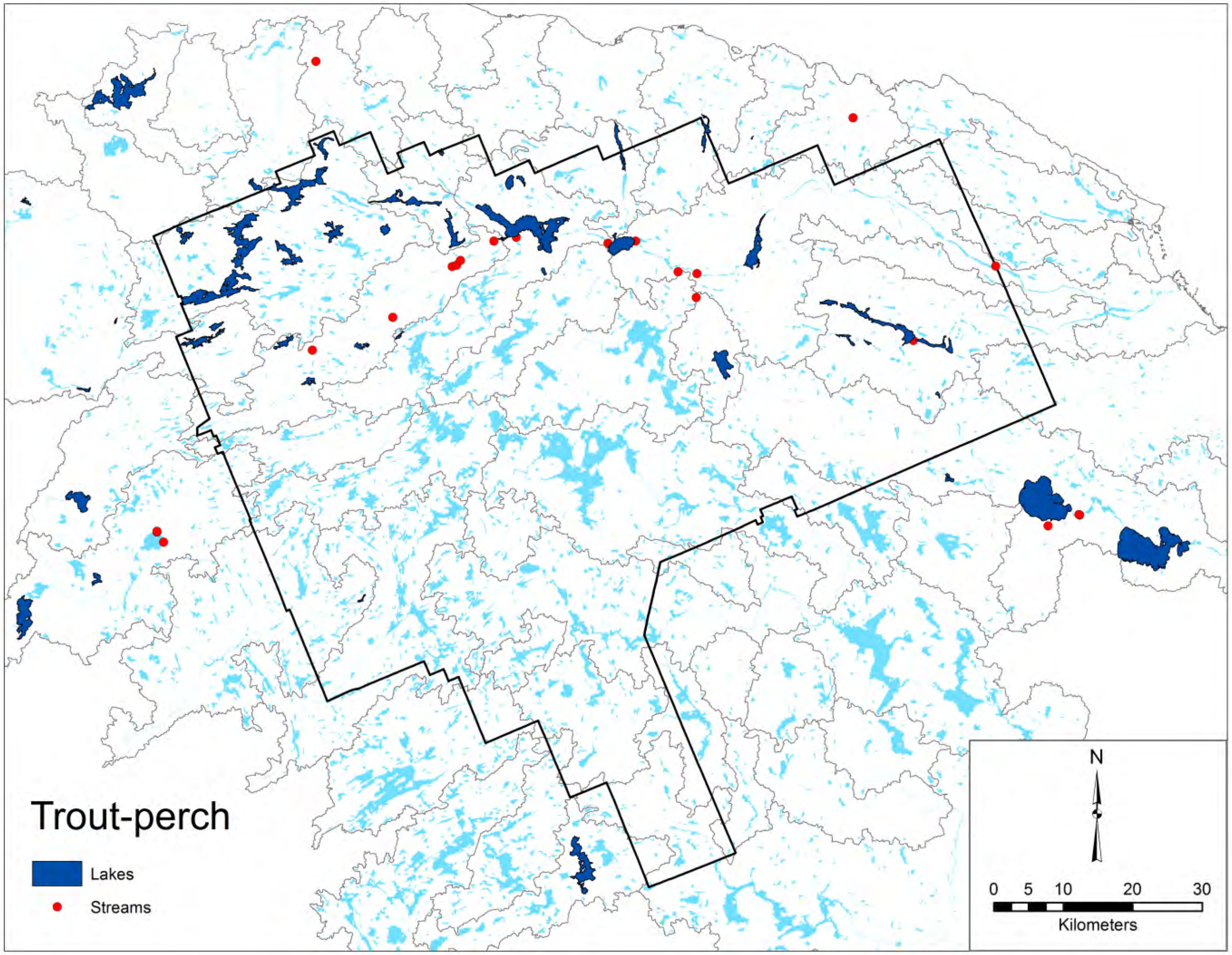


Figure 95. The distribution of trout-perch in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

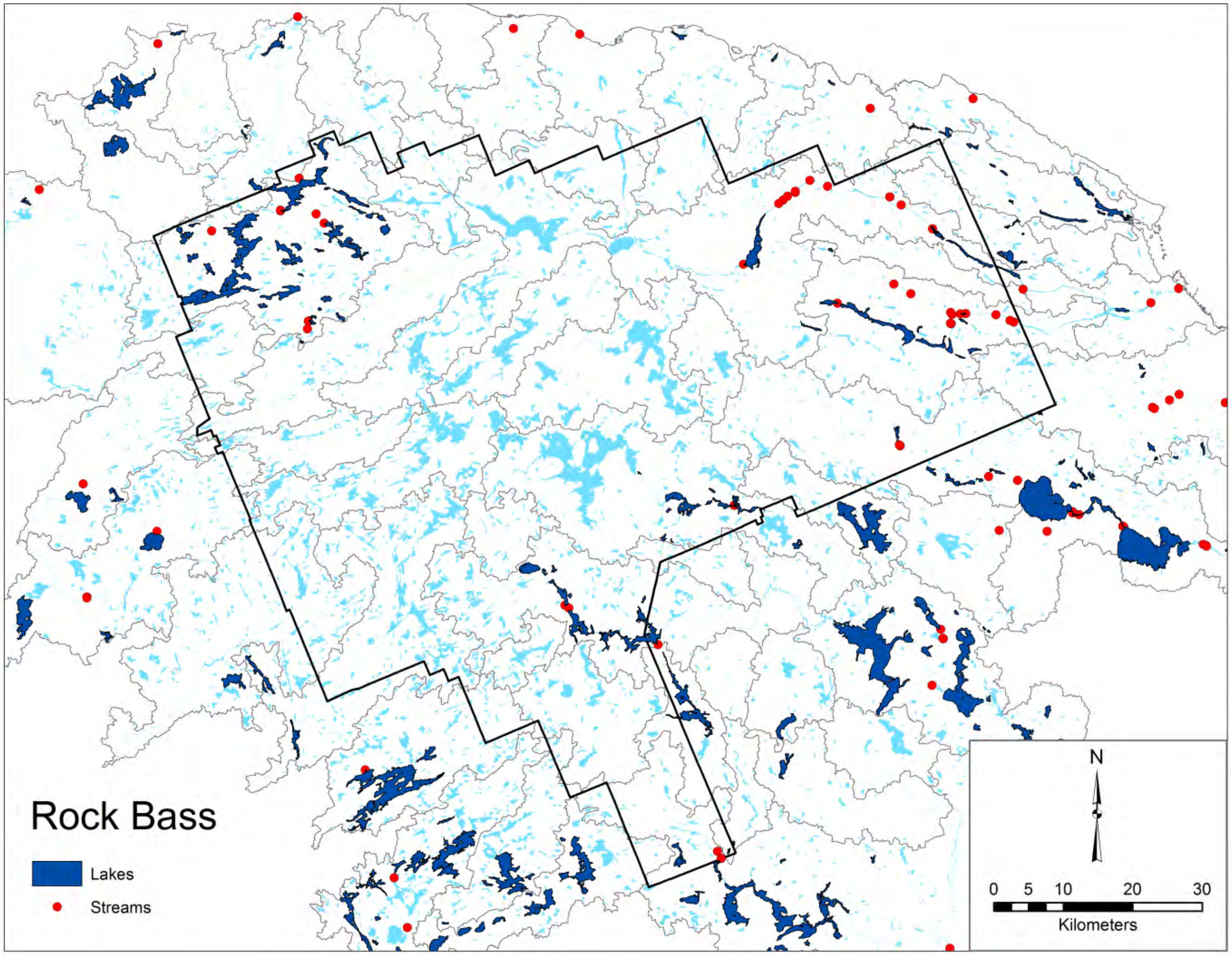


Figure 96. The distribution of rock bass in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

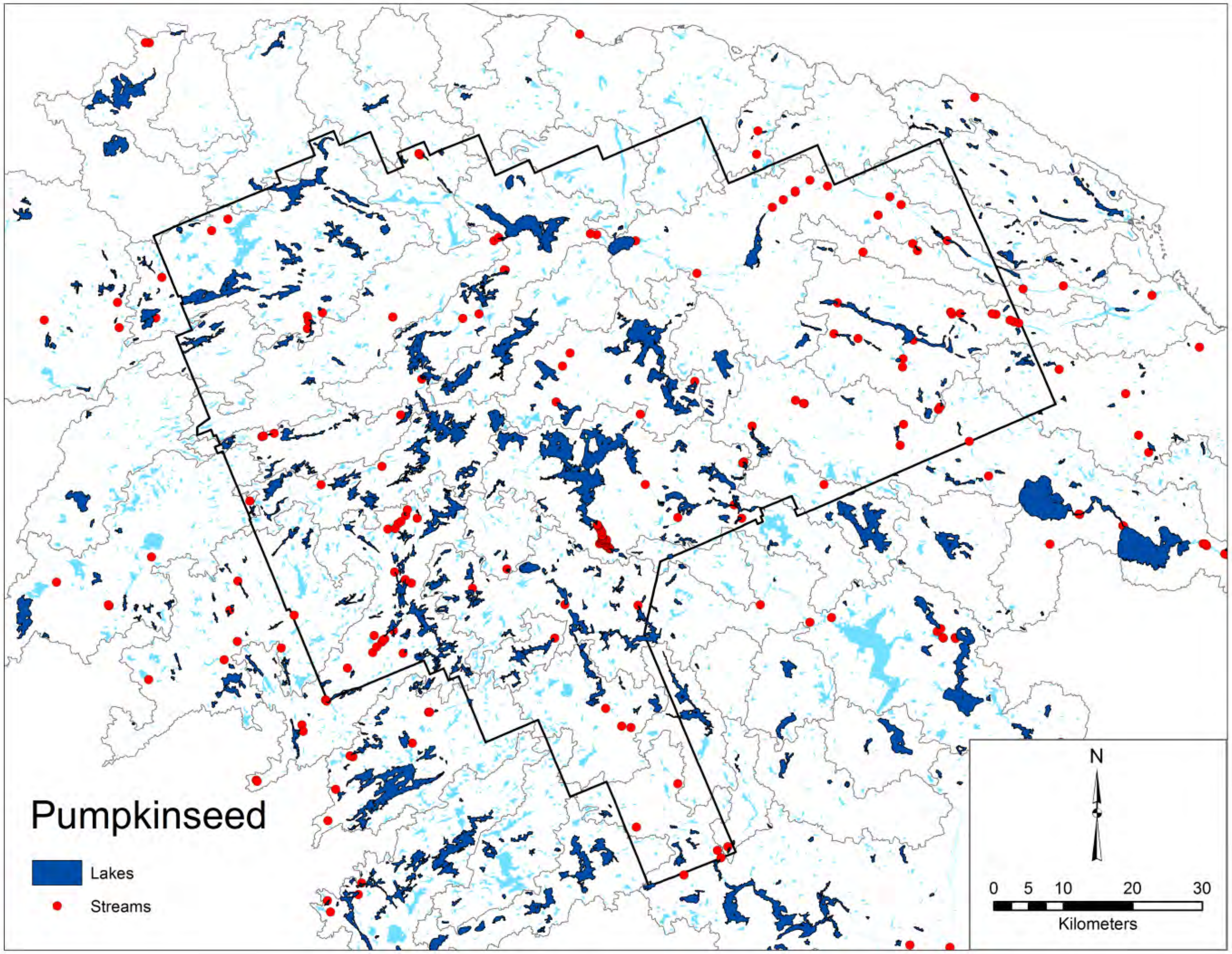


Figure 97. The distribution of pumpkinseed in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

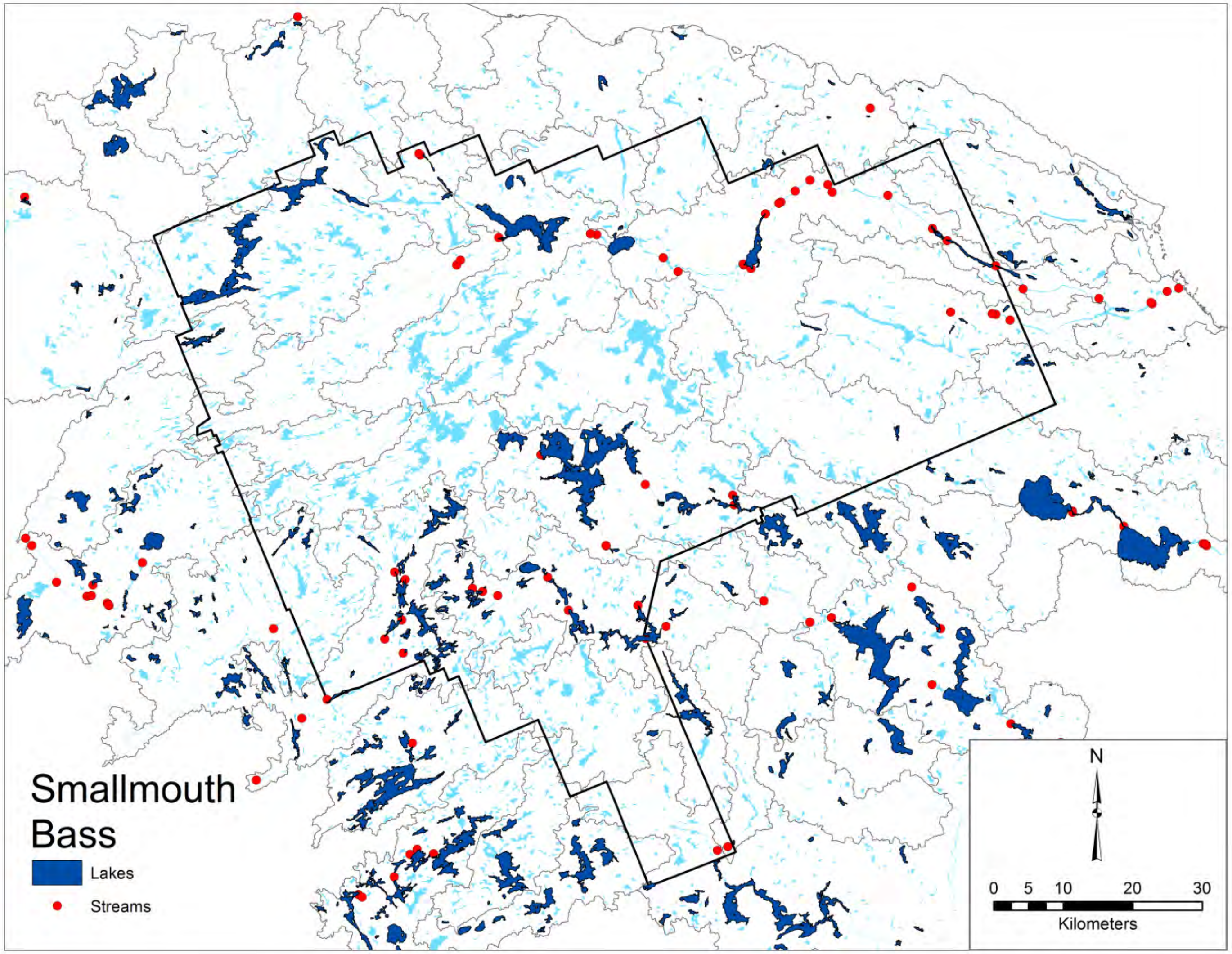


Figure 98. The distribution of smallmouth bass in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

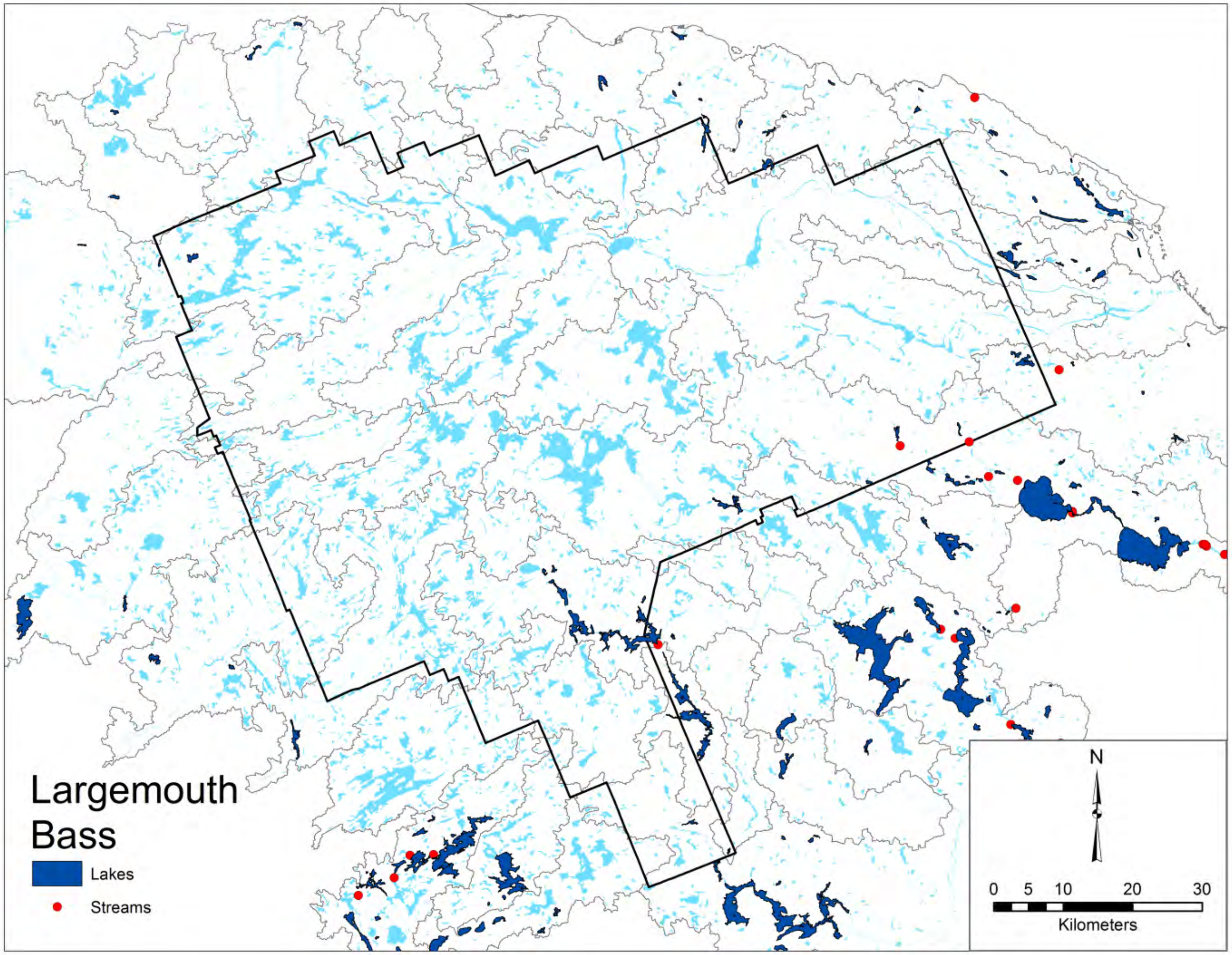


Figure 99. The distribution of largemouth bass in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

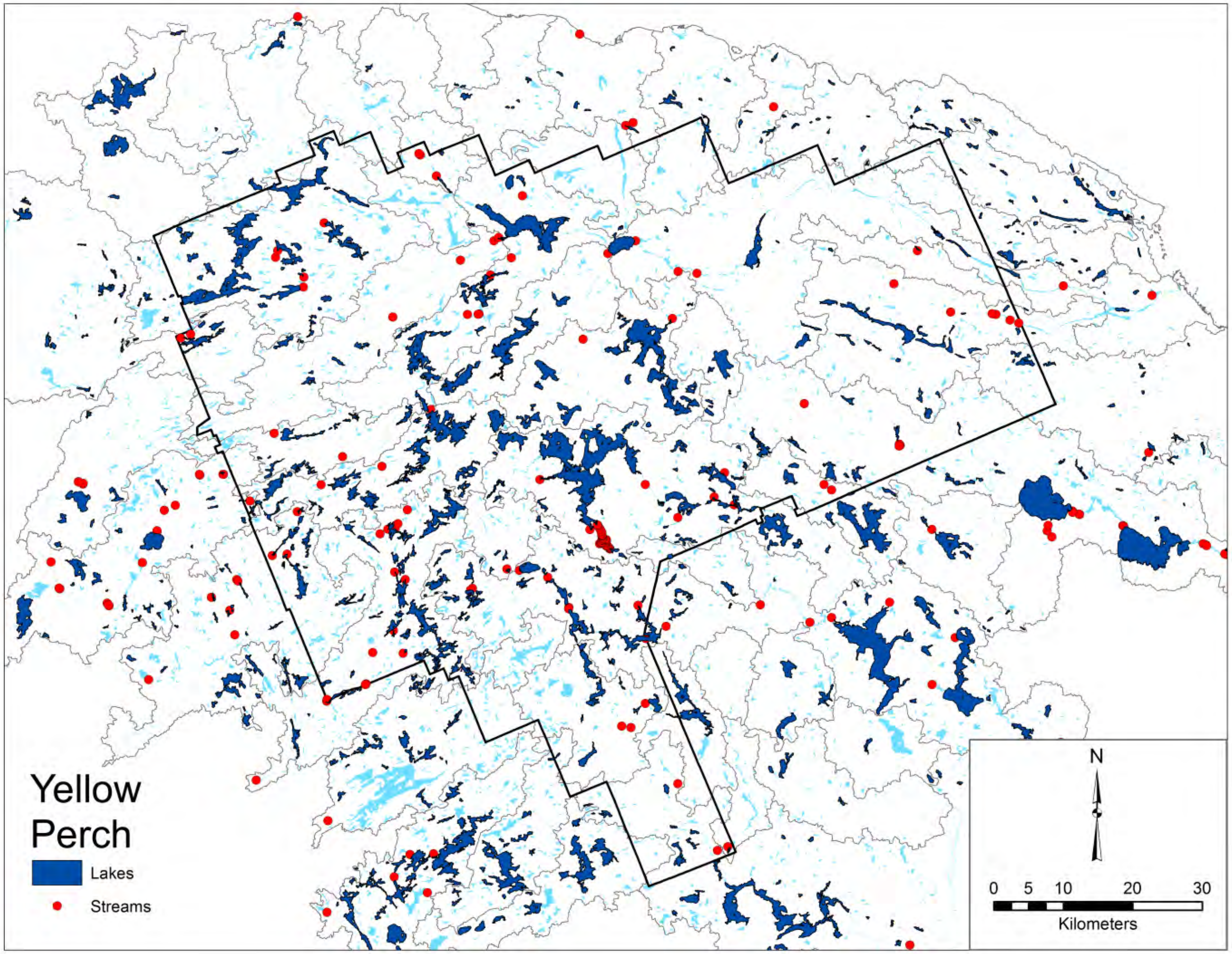


Figure 100. The distribution of yellow perch in Algonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

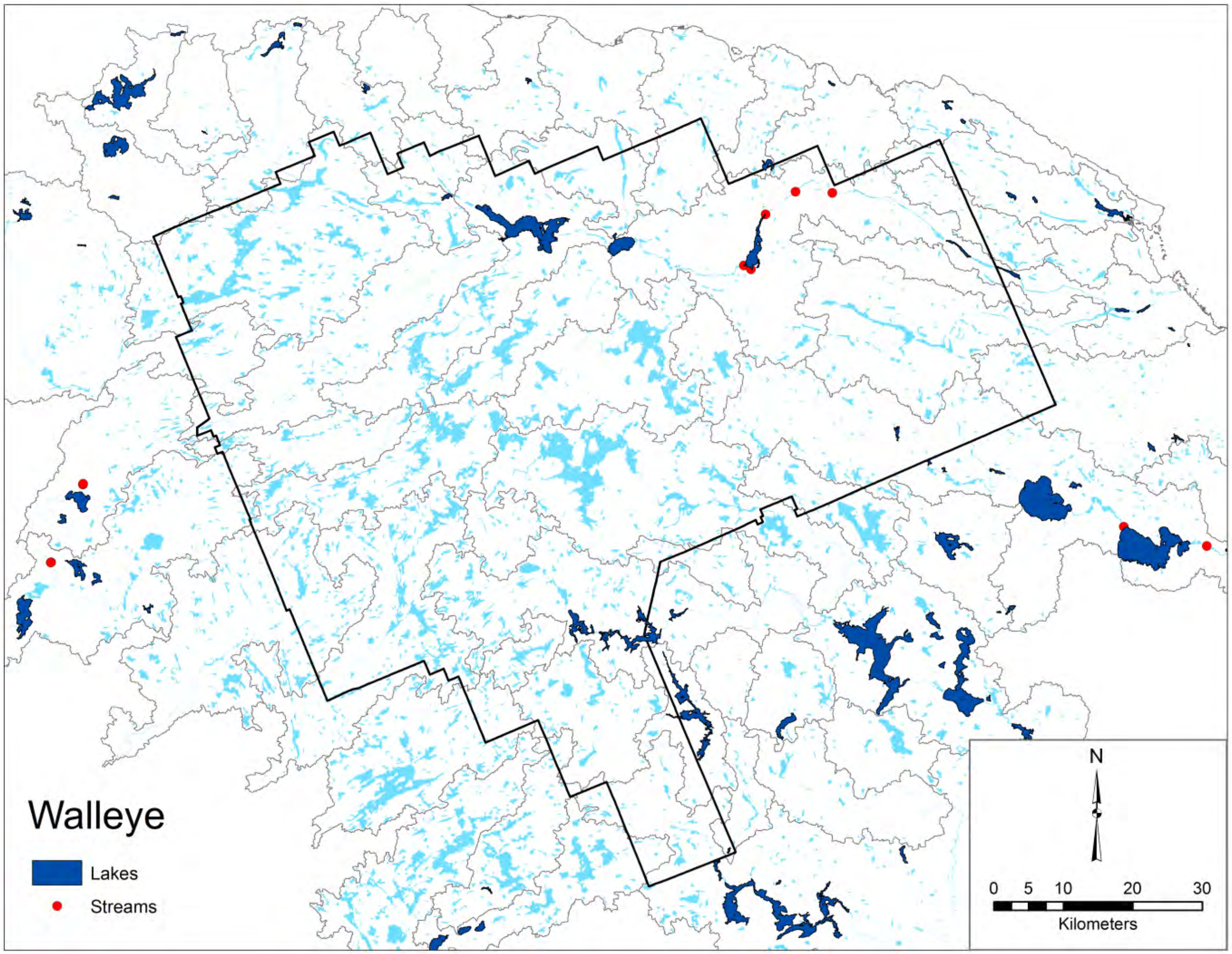


Figure 101. The distribution of walleye in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

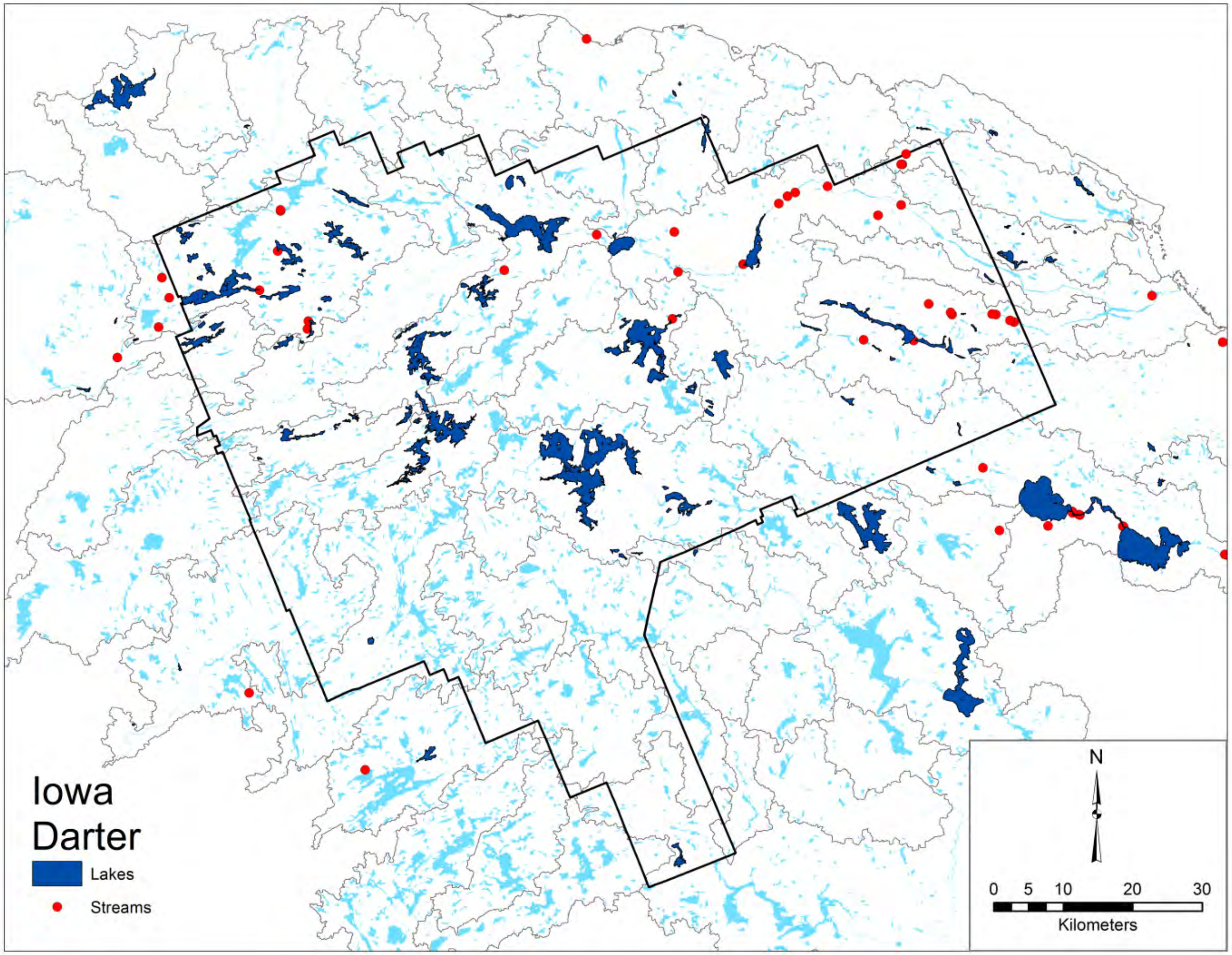


Figure 102. The distribution of Iowa darter in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

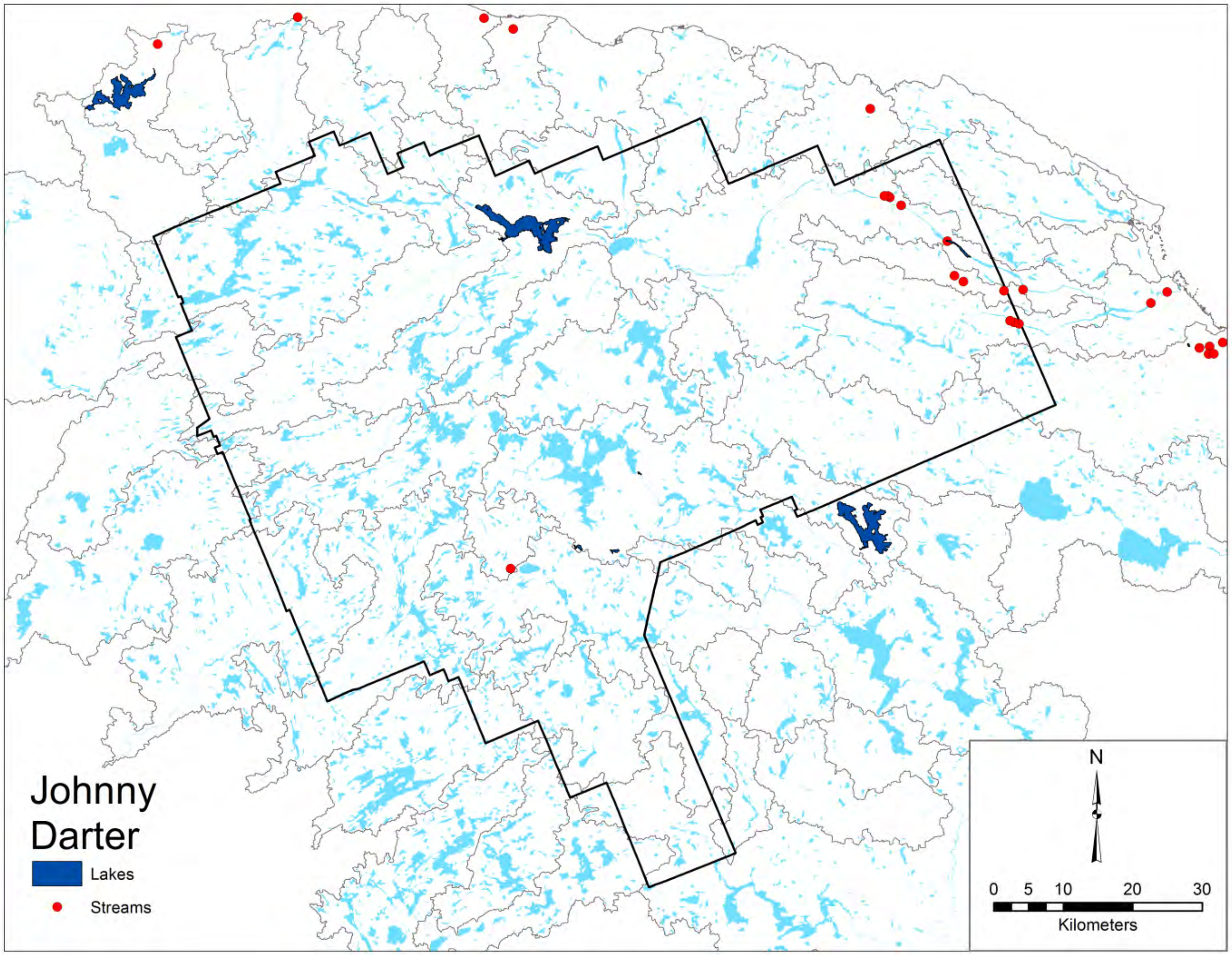


Figure 103. The distribution of Johnny darter in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

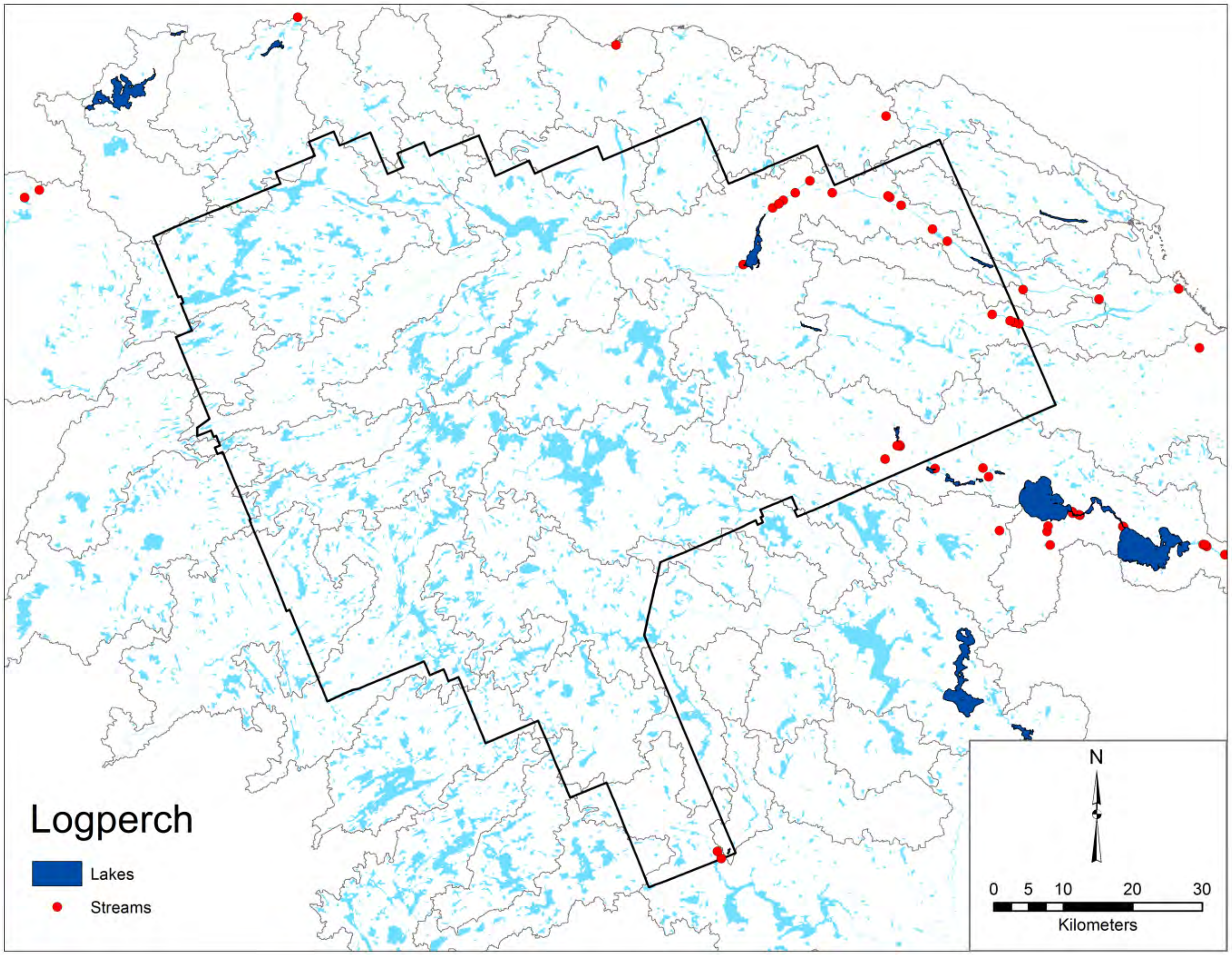


Figure 104. The distribution of logperch in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

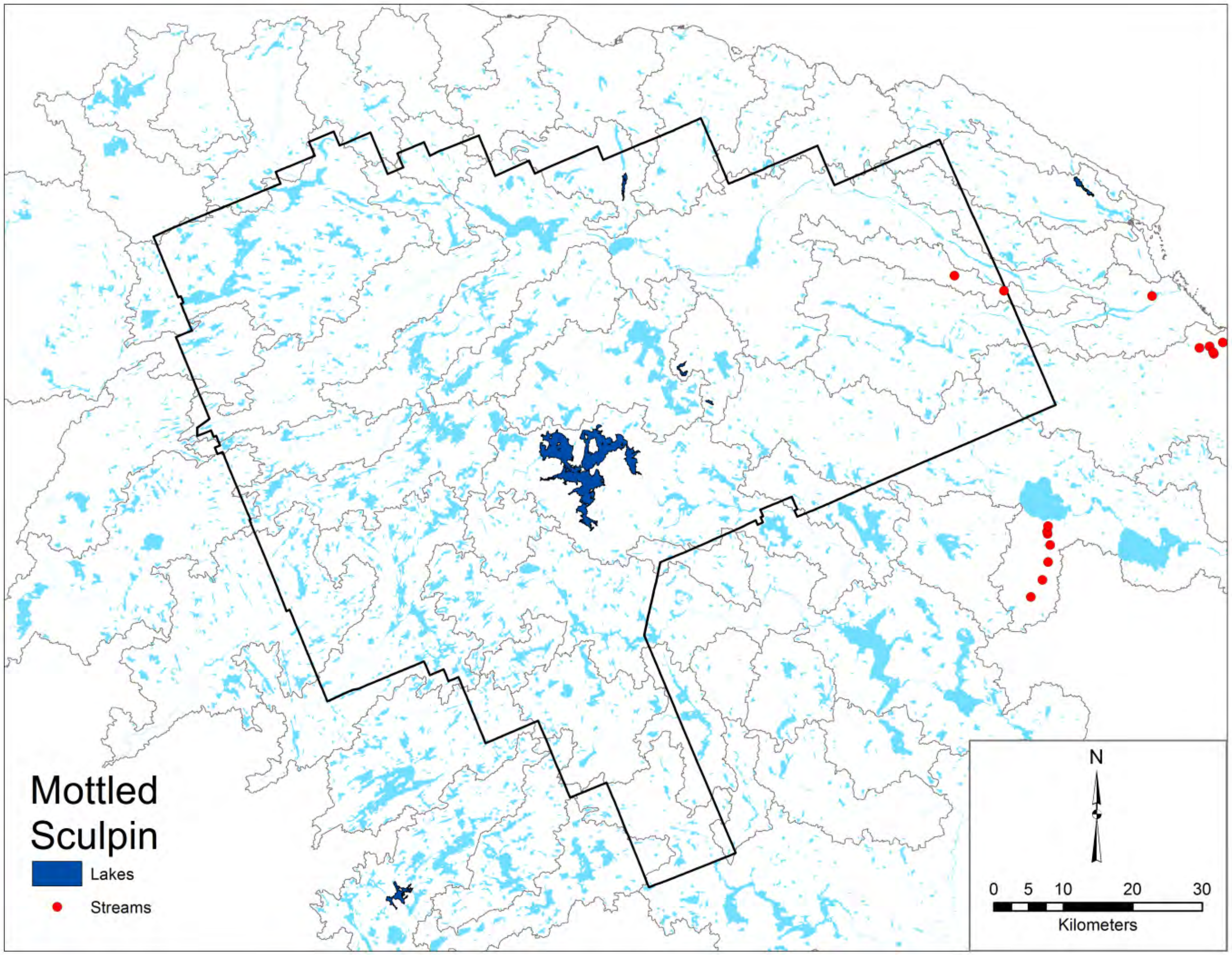


Figure 105. The distribution of mottled sculpin in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

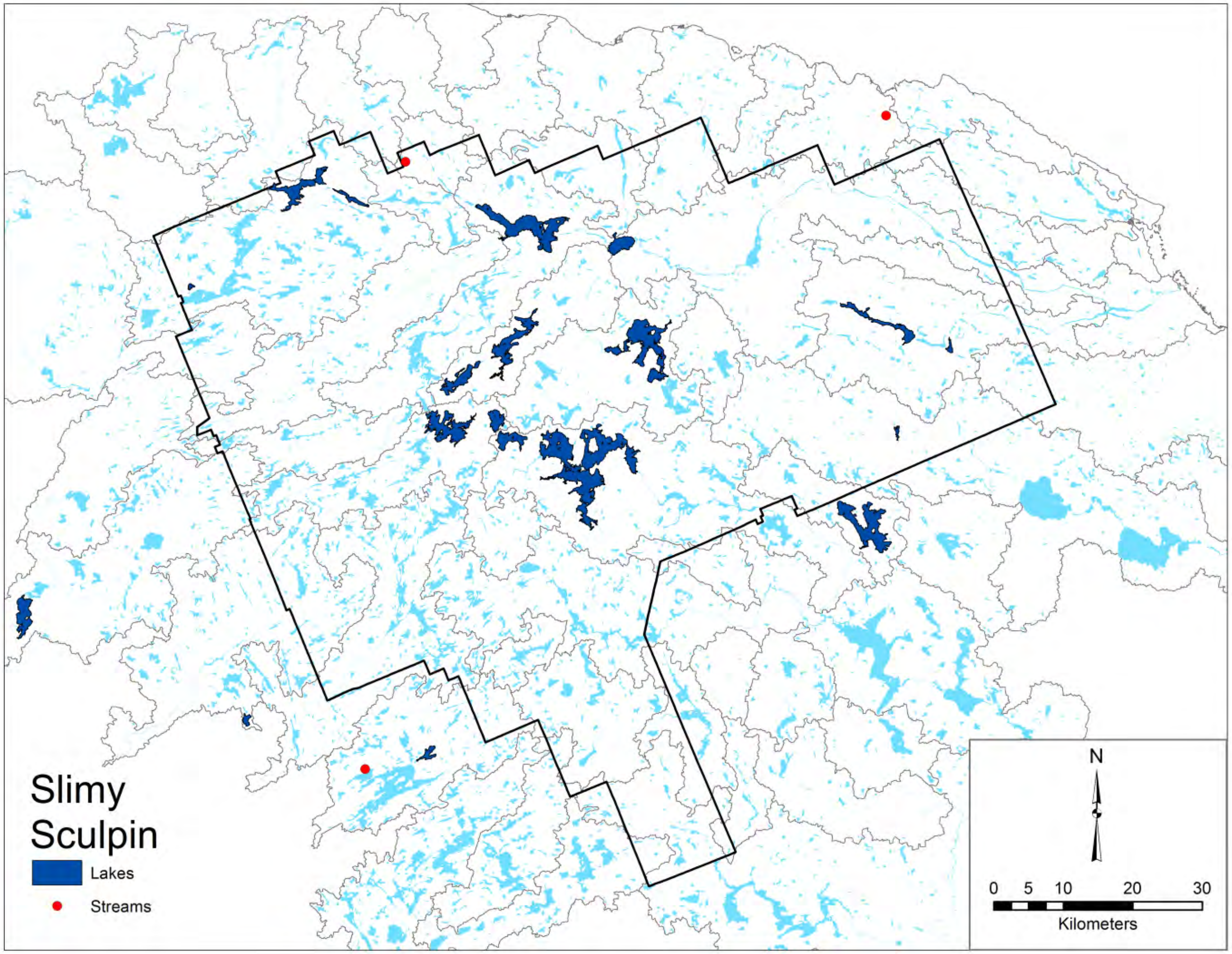


Figure 106. The distribution of slimy sculpin in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

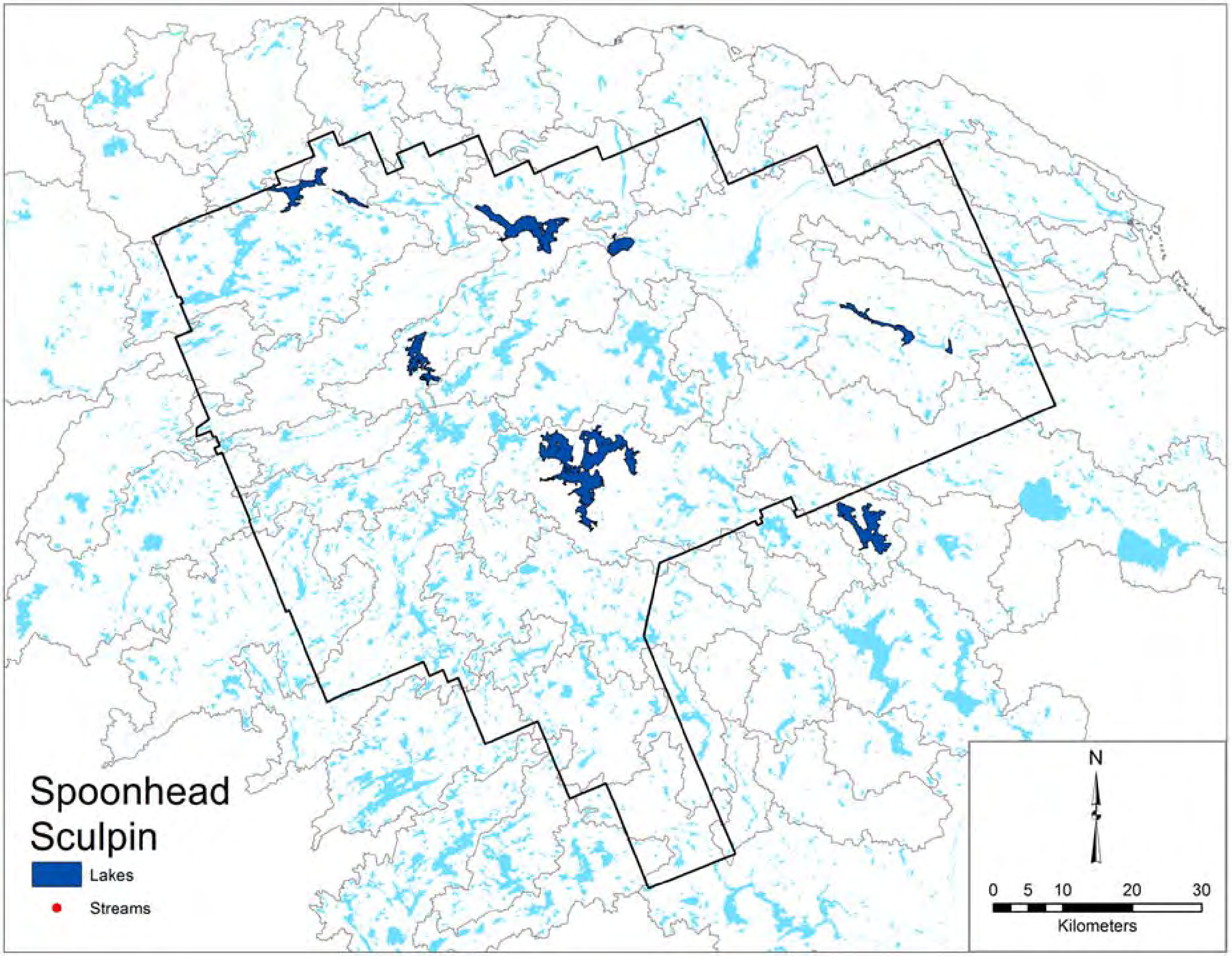


Figure 107. The distribution of spoonhead sculpin in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys. *Spoonhead sculpin in Lake Opeongo is likely a misidentified slimy sculpin. A lake-wide survey of Lake Opeongo revealed only slimy sculpin (N=150 sculpins) based on the absence of palatine teeth in each specimen.

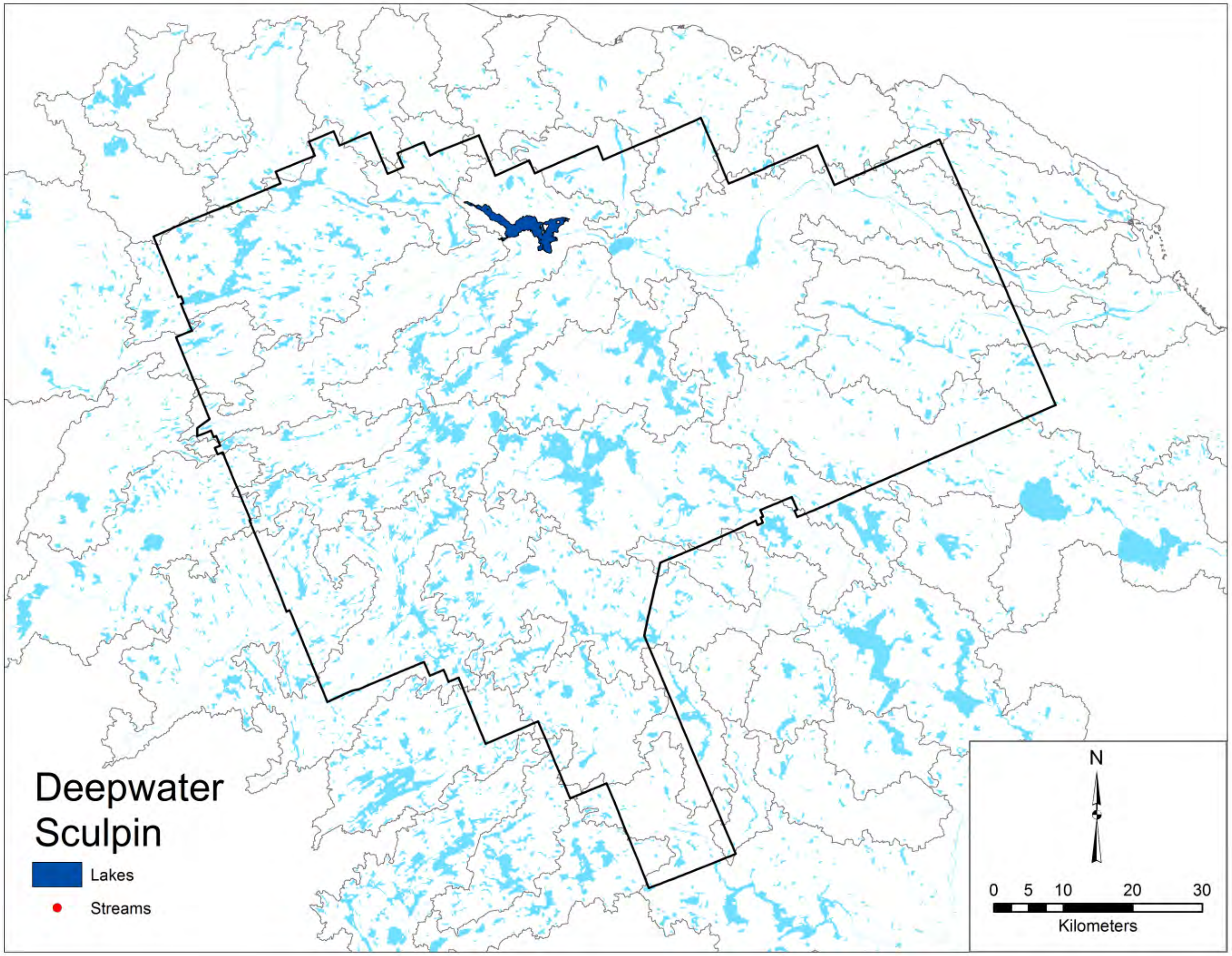


Figure 108. The distribution of deepwater sculpin in Alqonquin Park and surrounding area showing lake (dark blue) and river (red) occurrences. Locations based on fish surveys.

Glossary

Benthic or benthic zone: Lake bottom that is inshore or offshore. The ecosystem comprised of organic and/or inorganic substrate and associated organisms.

Biomagnification: The increase in concentration of contaminants that occurs with increasing trophic position in food webs.

Calibrated years before present (cal yrs BP): Dating of material from the past 50,000 years can be done through estimating the concentration of the carbon 14 isotope (^{14}C) with higher concentrations of ^{14}C representing more recent times. There is not a 1:1 relationship between ^{14}C years and calendar years. Converting ^{14}C dating to calibrated years requires a conversion that accounts for non-linearity in ^{14}C patterns over time. The non-linearity stems from variation in atmospheric production of ^{14}C because of variation in solar activity and Earth's geomagnetic field as well changes in ^{14}C concentration in ecosystems due to the carbon cycle. The calibration model of Fairbanks et al (2005; website: ldeo.columbia.edu/research/ocean-climate-physics) based on coral aging was used to convert literature estimates of ^{14}C ages of glacial events to calibrated calendar years. Readers interested in further reading on glacial history of Ontario and Canada should be aware that scientific literature in recent years reports ages as both ^{14}C age (ka BP) and calibrated years (cal kyr BP) or as calibrated years. Older literature only reports on ^{14}C ages (ka BP) without consistent conversion to calibrated years or an explicit description that age is based on ^{14}C ages. For example, an age of 11.8 ka BP (=11,800 ^{14}C years before present) converts to 13,650 cal yr BP using the Fairbanks et al. model (ie., 13.65 cal kyr BP).

Cisco: A species of fish belonging to the genus *Coregonus*, specifically *Coregonus artedi*. In the past it was referred to as lake herring or lake cisco. Cisco(es) can also refer other species of cisco that can be found in the Laurentian Great Lakes.

Coregonines: Referring to the sub-family Coregoninae of the family Salmonidae. Fish in this group are the Lake Whitefish, different species of cisco and round whitefish. For comparison, the salmonines belong to the sub-family Salmoninae of the family Salmonidae and contain all the trout, salmon and charr species.

Diamicton tills: Diamicton is a geological term for deposits that are poorly sorted, contain a wide range of particle sizes suspended in a mud matrix, but without necessarily knowing the origin of the deposits. Tills are glacial deposits so referring to a surficial geology category as diamicton tills is indicating that the deposits are of glacial origin and it is comprised of material ranging from clay to boulders in size. Large boulders left by retreating glaciers, known as glacial erratics, may be part of till complexes.

Esker: a long ridge of gravel and rock material deposited by a melt water stream flowing beneath a glacier.

Food webs: The network of connections among predators and prey in ecosystems. Almost all food webs begin by converting the sun's energy through photosynthesis to plant material (ie., primary production). After this step, consumers of primary production are labelled as primary consumers, secondary consumers, tertiary consumers, etc., depending on how many consumer steps there are between primary production and consumption of food. Omnivores feed at different consumer levels including primary production. In lake ecosystems, primary production is initially consumed by zooplankton species in the pelagic zone or by invertebrates in the nearshore zone. The sun's energy finally reaches Algonquin Park fish when species such as lake trout eat fish and/or invertebrates. Food webs can change from lake-to-lake depending the species present leading to differences among lakes in food web structure.

Glacial lake: A lake bounded in part by a glacial ice front that may or may not be receding. Other coastal areas of glacial lakes have a height of land serving as the balance of the coastal perimeter of the lake. The story of glacial retreat and associated glacial lakes is often described in terms of the large lakes that formed and were lost through runoff. Many smaller lakes were formed as well but because these lakes are difficult to reconstruct today there is little written about them. The large glacial lakes referred to in this report are among the largest lakes ever found in North America and so are referred to as Glacial Great Lakes.

Hypolimnion: The deep cold water of a thermally stratified lake during the warm months of the year. Lakes become thermally stratified during spring and summer under the influence of heating and mixing due to wind. The epilimnion of a lake is the zone of warm surface waters. The metalimnion is the transition zone from warm to deeper cold water and where the thermocline is located — the sharp density gradient of water under stratified conditions. The hypolimnion is situated below the metalimnion. In Algonquin Park, deep lakes become thermally stratified while small lakes and ponds may warm throughout the water column. Thermal stratification develops in spring of each year and ends in the fall when water temperatures cool sufficiently to become mixed throughout. At this point, lakes are said to turn over.

Interpolation: The estimation of surface values at unsampled points based on known surface values of surrounding points. Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion, or other spatially-based phenomena. Interpolation is commonly a raster operation, but it can also be done in a vector environment using a TIN surface model. There are several well-known interpolation techniques, including spline and kriging.

Kame: A kame is a mound-like feature formed by sand, gravel or till that accumulates in a depression of a retreating glacier. When the glacier melts the material is deposited as a kame on the land surface. Kames may be formed as a delta from sediment flowing off the snout of a retreating glacier. Therefore one edge of a kame delta is an ice-contact zone with the glacier while the other is where melt water flowed over and sorted sediment material.

Kriging: An interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points. Kriging is unique among the interpolation methods in that it provides an easy method for characterizing the variance, or the precision, of predictions. Kriging is based on regionalized variable theory, which assumes that the spatial variation in the data being modelled is homogeneous across the surface. That is, the same pattern of variation can be observed at all locations on the surface. Kriging was named for the South African mining engineer Danie G. Krige (1919–2013.)

Laurentide Ice Sheet (LIS): The glacial ice covering most of Canada during the Wisconsin glacial period. The Wisconsin glacial period is the latest of several glacial periods that have cyclically covered northern North America over the past 2.5 million years. The Pleistocene period in quaternary science is named for this era of repeated continental glaciation. The Pleistocene era ended approximately 12,500 cal yrs BP with the first outburst of Lake Agassiz to the Arctic Ocean via the Mackenzie River in northern Canada. This outburst was recorded in locations around the world through various climate proxies indicating cooler, drier periods. It is especially clear in Greenland ice cores that are used to reconstruct Pleistocene episodes.

Pelagic or Pelagic Zone: The volume of a lake regarded as open water. This volume is away from shore and off the bottom of a lake.

Phenology: The seasonal timing of biological events such as spring flowering or spawning times for fish species. The phenology of events is driven by weather patterns on an annual basis and remains relatively constant, advances or retreats on the calendar depending on climate patterns.

Prey field: The size range of food items for predatory fish. Predatory fish in lakes with small food items (e.g., bottom invertebrates) and limited or no prey fish are said to have a truncated prey field. Predatory fish in lakes with accessible prey fish and small food items have a wider prey field.

Spillway: Glacial spillways are valleys formed by large volumes of water from a melting glacier.

Trout, salmon, or charr: Names of trout, salmon and charr can be confusing when attempting to distinguish among species using Latin-based species names vs. common names. Readers may be amused, confused, or both in sorting out the differences. The trout genus is *Salmo*, the salmon genus is *Oncorynchus* and the charr genus is *Salvelinus*. Algonquin Park has lake trout and brook trout (also referred to as speckle trout in Ontario) among its native fish species. Both are members of the charr genus *Salvelinus* and are not true trout, but are related to arctic charr. Rainbow trout and cutthroat trout are members of the Pacific salmon genus *Oncorynchus* as are coho salmon, pink salmon, sockeye salmon, and chinook salmon. Atlantic salmon is a member of the trout genus *Salmo* as is the brown trout. Differences in common use of the labels trout, salmon or charr reflect historical and regional names applied by European settlers when they first encountered one of the species. Readers pursuing further information on lake trout and brook trout may encounter descriptions of these species as charr.

Trophic position: The position of an organism in a food web as a function of prey levels between it and primary production. Individual predatory fish have a relatively high trophic position because they eat smaller fish, small fish in turn eat zooplankton, and zooplankton in turn eats phytoplankton. Trophic positions are specific to individual ecosystems and not species alone. For example, lake trout can vary in their trophic position depending on their prey field resulting in larger prey fields producing larger lake trout with a higher trophic. There are individual differences among members of a population in trophic position based on the extent of specialization in feeding within a lake population. Big fish eats little fish is a statement about trophic position and part of a food web.

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Data Sources/Documentation

Link to the Primary Watershed

Link to the Secondary Watershed

Link to the Tertiary Watershed

Link to the Quaternary Watershed

Appendices

List of brook trout lakes in Algonquin Park

Table 13. Waterbodies meeting the criteria of having more than 1 brook trout observation where the last observation has been since 1979, or waterbodies having had at least 1 observation since 2010 (n=101 lakes).

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
8	Animoosh Lake	17–7225–50724	2010
2	Beaverpaw Lake	17–6657–50775	2010
2	Behan Lake	17–6694–50850	2010
9	Bena Lake	17–6785–50371	1990
15	Big Porcupine Lake	17–6867–50357	1990
6	Big Trout Lake	17–6849–50701	2010
14	Biggar Lake	17–6610–50894	2010
23	Billy Lake	17–7247–50572	1980
4	Birchcliffe Lake	17–6673–50887	2010
12	Booth Lake	17–7191–50596	1990
1	Bouillon Lake	17–6603–50866	2010
8	Burntroot Lake	17–6801–50811	2010
1	Browse Lake	17–6682–50813	2016
2	Byers Lake	17–7204–50121	1990
2	Calm Lake	17–6667–50868	2010
14	Canoe Lake	17–6782–50464	1980

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
9	Carl Wilson Lake	17–6852–50986	2010
6	Carcajou Lake	18–2766–50828	2010
7	Catfish Lake	17–6896–50895	2010
19	Cauchon Lake	17–6765–51031	2000
3	Cauliflower Lake	17–7147–50305	1990
25	Cedar Lake	17–6953–50993	2010
23	Charles Lake	17–7018–50865	2010
3	Chipmunk Lake	17–7180–50625	1980
4	Clydegale Lake	17–7069–50321	2010
11	Costello Lake	17–7089–50526	2000
2	Coldspring Lake	17–6690–50798	2010
1	Creation Lake	17–6631–50793	2016
64	Dickson Lake	17–7171–50733	2010
2	Dividing Lake	17–6878–50318	2010
5	Farncomb Lake	17–7106–50854	2010
2	Finch Lake	17–7094–50863	2010
5	Florence Lake	17–6974–50349	2010
5	Fools Lake	17–6920–50600	1980
5	Frank Lake	17–6977–50341	2010
1	Frost Lake	17–6994–50266	2010

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
4	Gibson Lake	17–6614–50825	2010
5	Grand Lake	18–2820–50842	2010
2	Grizzly Lake	17–6992–50841	2010
4	Groundhog Lake	17–6728–50536	1980
2	Hailstorm Lake	17–6913–50610	1980
10	Harry Lake	17–6999–50336	2010
2	Hiram Lake	17–6980–50572	2010
14	Hogan Lake	17–6942–50832	2010
6	Lake La Muir	17–6869–50771	2010
3	Kelly Lake	17–6681–50832	2010
39	Lake Lavieille	17–7137–50829	2010
11	Lake Louisa	17–6968–50383	2000
2	Lauder Lake	17–6674–51109	2010
2	Little Canoe Lake	17–7036–50286	2010
7	Little Lake	17–6812–51026	2000
3	Little Cauliflower Lake	17–7121–50295	1990
35	Little Crooked Lake	17–7183–50785	2010
16	Little Dickson Lake	17–7196–50760	2010
9	Little Mykiss Lake	17–7168–50624	1980

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
5	Loft Lake	17–6742–50518	1980
3	Loontail Lake	17–6648–50770	1980
7	Longer Lake	17–6808–50747	2010
5	McKaskill Lake	17–7300–50677	2010
19	Manitou Lake	17–6548–50975	2010
3	Meda Lake	17–6576–50884	2010
11	Merchant Lake	17–6920–50712	2010
5	Mink Lake	17–6710–51031	1990
2	Misty Lake	17–6707–50633	2010
13	Mouse Lake	17–6758–50987	2010
15	Mykiss Lake	17–7155–50605	2010
15	Myra Lake	17–7062–50582	1980
3	Nadine Lake	17–6757–50908	2010
1	New Lake	TBD	2010
2	NL	17–6915–50495	2000
5	North Branch Lake	17–7281–50791	2010
8	North Tea Lake	17–6524–50894	2010
44	Opeongo Lake	17–7048–50649	2010
2	Osler Lake	17–6731–50908	2010
2	Pauwatine Lake	17–6577–50866	2010

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
3	Philip Lake	17–7012–50882	2010
26	Radiant Lake	17–7100–50965	2000
5	Ralph Bice Lake	17–6600–50619	1980
90	Redrock Lake	17–6966–50710	2000
4	Rence Lake	17–6981–50321	2010
1	Robinson Lake	17–6797–50855	2010
15	Rock Lake	17–7039–50418	2010
5	Rosebary Lake	17–6616–50692	2010
8	RYAN Lake	17–7266–50629	1990
2	Sasajewun Lake	17–6937–50506	1980
14	Scott Lake	17–6780–50393	2010
18	Shallnot Lake	17–7295–50603	2000
12	Smoke Lake	17–6811–50426	2000
1	South Galip Lake	17–7000–50268	2010
2	Stretch Lake	17–6816–51095	2010
9	Stringer Lake	17–6947–50334	2000
1	Thompson Lake		2010
6	Three Mile Lake	17–6625–50948	2010
2	Upper Redstone Lake	17–7005–50251	1980

# of Observations	Waterbody name	Waterbody_LID*	Decade last observed
4	WaterclearLake	17–6719–51015	2010
15	Welcome Lake	17–7022–50324	2010
35	Westward Lake	17–6738–50397	2000
14	Whitefish Lake	17–7010–50468	2010
2	Whiskey Jack Lake	17–6785–50835	2010
23	White Partridge Lake	17–7244–50795	2000
5	Whitney Lake	17–7120–50502	2000

* Lake identification — a provincial lake site identifier for geographic location

Table 14. Waterbodies with brook trout occurrence observations where date of last observation is 1979 or earlier, or where prior to 1989 there has only been 1 observation ever (n=277 lakes).

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
8	Acanthus Lake	17–7024–51027	1940
5	Adrienne Lake	17–6945–50672	1960
6	Airy Lake	17–7169–50517	1960
2	Allan Lake	17–7101–51085	1970
4	Alluring Lake	17–7226–50740	1960
1	Amikeus Lake	17–7072–50514	1940
2	Aura Lee Lake	17–6869–51041	1940

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Babu Joe Lake	17–6806–50539	1950
1	Bailey Lake	17–7178–50538	1970
3	Baldwin Lake	17–6996–50711	1950
1	Band Lake	17–7180–50548	1970
5	Barron Lake	18–2703–50825	1950
1	Basin Lake	18–2827–50683	1940
2	Bates Lake	17–6977–50897	1950
2	Batise Lake	18–2695–50777	1950
2	Big Bissett Lake	17–7222–51132	1970
23	Big Crow Lake	17–6991–50783	1970
5	Big George Lake	17–7064–51010	1970
5	Big Red Lake	17–7276–50635	1970
4	Bijou Lake	17–6557–50624	1960
1	Bills Lake (NL)	17–7142–50298	1970
3	Bird Lake	17–6900–50875	1940
1	Bisset Lake	17–7154–51073	1970
11	Blackfox Lake	17–6975–50544	1960
1	Bob Lake (NL)	17–6969–50481	1970
3	Bonasa Lake	17–6828–50670	1940
1	Bonnechere Lake	17–6889–50367	1940

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Boot Lake	17–7193–50542	1940
1	Border Lake (NL)	17–7264–50635	1970
1	Branch Lake	17–7174–50128	1960
1	Brant Lake	17–6921–51042	1970
1	Breezy Lake	18–2755–50627	1930
11	Brewer Lake	17–7100–50518	1950
3	Bruce Lake	17–6836–50496	1960
10	Brule Lake	17–6705–50558	1970
10	Bud Lake	17–7108–50489	1970
26	Bug Lake	17–6870–51022	1970
18	Burnt Island Lake	17–6840–50576	1940
31	Cache Lake	17–6886–50457	1950
3	Calumet Lake	17–6895–50843	1970
2	Camp Five Lake	17–6884–50986	1960
1	Camp Lake	17–7086–50295	1970
14	Canisbay Lake	17–6881–50495	1970
10	Casey Lake	17–6611–50552	1940
1	Castalia Lake (NL)	17–7125–50497	1970
6	Cat Lake	17–7227–50733	1960
2	Cecil Lake	17–6955–50358	1960

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Charr Lake	17–6487–50845	1960
1	Chateau Lake	17–7310–51085	1970
1	Chewink Lake	17–7268–50674	1960
3	Chickaree Lake	17–6931–50703	1950
2	Cinderella Lake	17–6977–50896	1950
17	Clarke Lake	17–7131–50456	1950
1	Cloud Lake	17–7031–50472	1970
2	Club Lake	17–6745–51011	1970
9	Coon Lake	17–7024–50461	1960
8	Cuckoo Lake	17–6880–50838	1940
4	Daisy Lake	17–6602–50581	1940
5	David Lake	17–6590–50633	1970
3	Delano Lake	17–6877–50428	1970
3	Diver Lake	17–6944–50709	1960
1	Dove Lake	17–7294–50658	1960
3	Drummer Lake	17–6744–50444	1950
1	Duckpond Lake	17–7257–50566	1970
3	Ermine Lake	17–6669–50331	1950
1	Eucalia Lake	17–7017–50502	1970
1	Eustache Lake	17–7235–50905	1940

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Fairy Lake	17–7256–50701	1960
1	Farm Bay Lake	17–7094–50386	1970
1	Fassett Lake	17–6471–50976	1970
3	Faya AA Lake	17–6938–50468	1950
1	Fisher Lake	17–7036–50471	1960
4	Fog Lake	17–7246–50609	1960
1	Fork Lake	17–7068–50495	1940
15	Found Lake	17–6845–50465	1960
1	Fourcorner Lake	17–7139–50042	1960
2	Foys Lake	18–2760–50735	1960
5	Francis Lake	18–2740–50956	1940
1	Fraser Lake	17–7088–50445	1940
1	Frontier Lake	18–2997–50897	1950
7	Galeairy Lake	17–7110–50392	1960
1	Gem Lake	17–7054–50394	1960
1	Gerald Lake	17–7193–51014	1950
5	Ghost Lake	17–6999–51027	1970
3	Gill Lake	17–6770–50445	1940
10	Gilmour Lake	17–6937–51056	1970
5	Glacier Lake	17–6871–50985	1960

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
6	Godda Lake	17–7155–50569	1940
2	Gorse Lake	18–2875–50734	1960
2	Gouinlock Lake	17–6815–51013	1950
3	Greenleaf Lake	18–2715–50845	1940
8	Gull ULL Lake	17–6883–51004	1960
2	Hambone Lake	17–6576–50594	1940
8	Happy Isle Lake	17–6941–50691	1940
4	Hartley Lake	17–7078–50584	1960
1	Hayes Lake	17–6836–50854	1960
5	Head Lake	17–6903–50431	1950
12	Heron Lake	17–6711–50348	1960
1	Hiah Lake	17–6631–50756	1950
3	Hiawatha Lake	17–6785–50816	1960
2	Hidden Lake	17–7269–50702	1960
1	Hidden Lake (Joe Lake) (NL)	17–6819–50364	1970
5	Hilliard Lake	17–6869–50432	1950
2	Hilly Lake	17–6746–50352	1950
2	Hogsback Lake	18–2847–51050	1950
4	Iris Lake	17–6880–50551	1970

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
6	Jack Lake	17–6911–50505	1960
5	Jake Lake	17–6906–50483	1960
1	Jeepi Lake	17–6499–50864	1950
10	Joe Lake	17–6781–50506	1950
2	Kakasamic Lake	17–6481–50948	1960
4	Kathlyn Lake	17–6924–50523	1930
14	Kearney Lake	17–7001–50500	1960
2	Kennedy Lake	17–6725–50819	1970
1	Kingscote Lake	17–7185–50089	1970
3	Kioshkokwi Lake	17–6636–51050	1940
17	Lake of Two Rivers	17–6966–50501	1950
8	Lake St. Anthony	17–7092–50510	1970
2	Lake Traverse	17–7291–50955	1930
2	Langford Lake	17–6998–50656	1960
4	Lantern Lake	17–6924–50950	1970
6	Laurel Lake	17–6847–51035	1950
3	Lavaque Lake	17–7197–50885	1940
4	Lawrence Lake	17–6935–50408	1960
1	Length Lake	18–2931–50814	1970
1	Little Billings Lake	17–7167–50171	1970

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Little Clear Lake	17–7113–50326	1960
6	Little Coon Lake	17–6883–50339	1950
11	Little Crow Lake	17–6980–50762	1970
1	Little Hay Lake	17–7144–50262	1960
9	Little Island Lake	17–6847–50441	1950
7	Little Joe Lake	17–6799–50523	1950
1	Little Lake	17–7233–51100	1950
1	Little Loxley Lake	17–6843–51060	1920
1	Little Marquardt Pond OND	17–7157–50160	1960
15	Little McCauley Lake	17–7122–50523	1950
1	Little Mink Lake	17–6676–51048	1970
11	Little Minnow Lake	17–7071–50581	1970
1	Little Osler Lake	17–6731–50907	1960
3	Little Percy Lake	17–7148–50089	1970
8	Little Trout Lake	17–6633–50646	1970
1	Longboot Lake	17–7146–50104	1960
5	Longbow Lake	17–6650–50692	1970
3	Loonskin Lake	17–7330–50797	1950
3	Lorne Lake	17–6505–50931	1970

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
11	Lost Dog Lake	17–6478–50906	1970
5	Lost Lake	18–2698–50851	1960
3	Louie Lake	18–2936–50991	1960
2	Lower Spectacle Lake	18–2838–50793	1960
5	Loxley Lake	17–6827–51039	1970
8	Luckless Lake	17–6872–50907	1970
7	Lynx Lake	17–6873–50890	1970
2	Madawaska Lake	17–7050–50228	1970
1	Magnetawan Lake	17–6568–50583	1970
7	Major Lake	17–7261–50553	1970
1	Margaret Lake	17–7067–50381	1950
2	Marie Lake	18–2922–50814	1970
17	Marmot Lake	17–7025–50619	1960
1	Marquart Pond	17–7157–50161	1960
3	Martin Lake	17–6979–50414	1960
1	Mathews Lake	18–2876–50946	1940
1	Mattowacka Lake	17–6460–50948	1960
2	McCraney Lake	17–6637–50481	1970
2	McIntosh Lake	17–6735–50597	1940

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
5	McNorton Lake	17–7251–50831	1940
2	Menona Lake	17–7077–50992	1950
2	Mergamser Lake	17–7025–51060	1970
2	Mew Lake	17–6936–50498	1960
2	Mikado Lake	17–6772–50371	1950
3	Mildred Lake	17–6979–50374	1970
1	Milon Lake	17–7146–50494	1960
1	Mishimokwa Lake	17–7037–51029	1950
2	Mole Lake	17–7163–50559	1940
3	Mubwayaka Lake	17–6596–50647	1970
3	Mudturtle Lake	17–7033–50749	1930
1	Murdock Lake	17–7034–50731	1950
2	Nahna Lake	17–6473–50812	1950
15	Nepawin Lake	17–6970–50733	1970
1	Nick Lake	17–7087–50696	1950
1	NL (Lake)	17–6908–50476	1970
1	NL (Lake)	17–7144–50647	1970
1	NL (Lake)	18–3002–50774	1970
1	Norm’s Lake	18–3019–50792	1970
1	North Depot Lake	17–7101–51050	1970

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	North Galipo Lake	17–6994–50283	1970
7	North Grace Lake	17–6940–50350	1970
3	North River Lake	17–7021–51069	1970
1	North Rouge Lake	17–7291–51055	1970
4	Number One Lake	18–3008–50823	1960
9	Oram Lake	17–7267–50570	1970
2	Otterpaw Lake	17–7218–51015	1960
2	Otterslide Lake	17–6876–50640	1940
6	Ouse Lake	17–6816–50461	1960
4	Owaissa Lake	17–7255–50609	1970
3	Parkline Lake	18–2836–51069	1970
11	Peck Lake	17–6832–50464	1960
11	Pen Lake	17–7049–50366	1960
5	Perley Lake	17–6835–50838	1970
6	Pine Lake	18–2780–50607	1960
2	Pinetree Lake	17–7094–50474	1940
1	Pipe Lake	17–6474–50845	1950
5	Potter Lake	17–6733–50536	1970
2	Presto Lake	17–7167–50644	1970
1	Pretty Lake	18–2752–50954	1950

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
4	Prottler Lake	17–7086–50365	1960
31	Proulx Lake	17–7024–50723	1970
1	Provoking Lake	17–6957–50478	1940
6	Queer Lake	17–6650–50642	1960
6	Ragged Lake	17–6839–50376	1940
2	Rain Lake	17–6619–50545	1940
10	Rainbow Lake	17–7003–50227	1940
1	Raja Lake	17–7159–50544	1950
2	Rana Lake	17–6960–51025	1960
1	Raven Lake	17–6834–50510	1960
11	Ravenau Lake	17–6924–50951	1970
1	Ray Lake	17–7186–50829	1950
2	Red Fox Lake	17–6992–50560	1970
3	Redpine Lake	17–6812–50780	1960
2	Reed Lake	17–7178–51051	1950
1	Namakootchie Lake	17–6744–50426	1980
2	Robin Lake	17–7275–50604	1970
7	Robitaille Lake	18–2764–50628	1940
2	Rockpine Lake	18–3018–50729	1950

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
4	Rod and Gun Lake	17–6941–50397	1970
2	Rosepond Lake	17–7036–50437	1960
1	Round Island Lake	17–7183–50679	1980
1	Roundbush Lake	18–2676–50647	1970
2	Rumley Lake	17–7169–50587	1970
1	Sam Lake	17–6773–50444	1970
2	Sandmartin Lake	17–7144–50549	1930
2	Sawyer Lake	17–6636–50569	1940
2	Scorch Lake	17–7200–50136	1960
7	Sec Lake	18–3016–50772	1960
4	Secret Lake	17–6933–50635	1960
1	Shad Lake	17–6462–50987	1970
1	Shada Lake	17–6483–50995	1960
1	Shippagew Lake	17–6790–50718	1930
6	Shirley Lake	17–7239–50633	1940
7	Shrew Lake	17–7277–50647	1970
1	Silver Lake	17–7087–50306	1960
1	Sitting Duck Lake	17–6981–50358	1960
1	Skinny Lake	17–7105–50159	1960
1	Skuce Lake	17–6730–50926	1960

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
2	Skunkitten Lake	17–7209–50181	1960
2	Smith Lake	18–2934–50936	1940
13	Source Lake	17–6834–50477	1950
4	Speckledtrout Lake	17–7007–50451	1960
5	Sproule Lake	17–7038–50532	1950
3	Square Lake	17–7324–50964	1950
4	St. Andrews Lake	18–2913–50800	1930
1	Stubby Lake	17–7105–50160	1960
1	Sundassa Lake	17–7227–50785	1930
5	Sunday Lake	17–7025–50524	1950
9	Tanamakoon Lake	17–6855–50457	1940
1	Tattler Lake	17–7156–50593	1970
14	Tea Lake	17–6768–50415	1950
3	Tecumseh Lake	17–6956–51058	1970
8	Tepee Lake	17–6774–50515	1950
1	Thomas Lake	17–7107–50773	1970
2	Tim Lake	17–6534–50681	1970
3	Timberwolf Lake	17–6711–50607	1970
1	Tip Up Lake	17–7127–50635	1970
1	Tom Thomson	17–6768–50553	1940

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
	Lake		
4	Trout Lake (White Trout)	17–6812–50651	1970
1	Turners Lake	18–2926–50695	1950
1	Upper Pine Lake	18–2912–50677	1930
1	Wabanah Lake	17–6553–50773	1950
1	Wee George Lake	17–7089–51011	1950
1	Wendigo Lake	17–7092–51120	1950
4	Wendigoes Lake	17–6989–50933	1940
2	West Harry Lake	17–6701–50451	1950
5	Whitegull Lake	17–6985–50590	1940
2	Wib Lake	17–6575–50921	1960
2	Windermere Lake	17–6805–51020	1940
2	Woodcock Lake	17–7159–50866	1950
3	Wright Lake	17–7108–50705	1950
1	Zigzag Lake	18–2926–50714	1950

* Lake identification — a provincial lake site identifier for geographic location

Table 15. Waterbodies where brook trout observations have been recorded but where the date of observation is unknown (n=66 lakes).

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Alserver Lake	18–2667–50631	NA
1	Avery's Lake	17–7075–50289	NA
1	Bearscat Lake (NL)		NA
1	Big Bob Lake	17–6503–50697	NA
1	Bluebell Lake	17–6772–50352	NA
1	Brain Lake	17–6790–51094	NA
1	Chibiabos Lake	17–6530–50679	NA
1	Clancy Lake		NA
1	Crotch Lake	17–7265–50594	NA
1	Dendroica Lake	17–6793–51001	NA
1	Devil Lake	17–6769–50945	NA
1	Devine Lake	17–6723–50721	NA
1	East Galipo Lake	17–7017–50277	NA
1	Fitz Lake	17–7192–51033	NA
3	Forest Bay Lake		NA
1	Frog Lake	18–2797–50719	NA
1	German Lake	17–7042–50239	NA

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Gipsy Lake	17–6965–50877	NA
1	Grosbeak Lake	17–6876–50819	NA
1	Guskewau Lake	17–6706–50387	NA
1	Hemlock Lake	17–6904–50746	NA
1	Indian Pipe Lake	17–6529–50698	NA
1	Ironwood Lake	17–6857–51003	NA
1	Kaween Lake	17–7158–50883	NA
1	Kinglet Lake	17–7272–50609	NA
1	Lee Lake	17–7177–50717	NA
1	Linda Lake	17–6867–50535	NA
1	Ling Lake	17–6863–50393	NA
1	Little Eagle Lake	17–6571–50569	NA
1	Little German Lake	17–7037–50249	NA
1	Little Tarn Lake	18–2888–50733	NA
1	Lost Coin Lake	17–7244–51016	NA
1	Macoun Lake	17–6835–50873	NA
1	Mallic Lake	17–7185–50866	NA
1	McGarvey Lake	17–6909–50339	NA
1	Medge Lake		NA
1	Medge Lake	17–6749–50432	NA

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Minnehaha Lake	17–6773–50798	NA
1	Moon Lake	17–7158–50902	NA
1	Muskrat Lake	17–7171–50532	NA
1	Narrowbag Lake	17–6924–50931	NA
1	Nool Lake	17–7020–50767	NA
1	North Cuckoo Lake	17–6862–50855	NA
1	Okahan Lake	17–7158–50884	NA
1	Onagun Lake	17–7086–50734	NA
1	Osprey Lake	17–7138–50735	NA
1	Owenee Lake	17–7053–50935	NA
1	Plumb Lake	17–6848–50873	NA
1	Pond (NL)		NA
1	Prong Lake	17–7268–50721	NA
1	Redhead Lake	17–6746–50815	NA
1	Redpole Lake	17–7267–50739	NA
1	Salvelinus Lake	17–6598–50551	NA
1	Saw–whet Lake	17–6697–50722	NA
1	Shawandasee Lake	17–6721–50333	NA
1	South Moccasin Lake	17–7062–50268	NA

# of Observations	Waterbody name	Waterbody_LID	Decade last observed
1	Stag Lake	17–6749–50722	NA
1	Sunbeam Lake	17–6792–50595	NA
1	Unknown Pond		NA
1	Upper Spectacle Lake	18–2825–50791	NA
1	Varley Lake	17–6871–50967	NA
1	Vulture Lake	17–6669–50794	NA
1	Wabamimi Lake	17–7050–51048	NA
1	Wabe Lake	17–7254–50757	NA
1	Weasel Lake	17–7140–51050	NA
1	West ES Galipo Lake	17–6986–50278	NA

* Lake identification — a provincial lake site identifier for geographic location

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