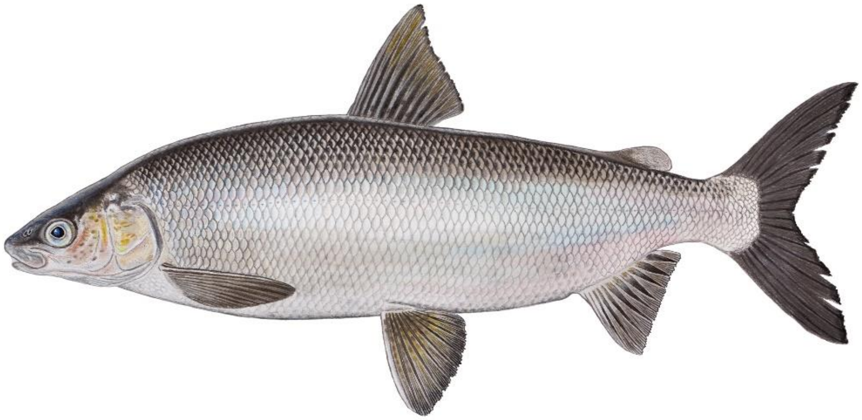
DRAFT Recovery Strategy for the Lake Whitefish (*Coregonus clupeaformis*) Opeongo Lake large- and small-bodied populations in Ontario



2023

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Declaration

The recovery strategy for the Lake Whitefish (*Coregonus clupeaformis*) Opeongo Lake large- and small-bodied populations was developed in accordance with the requirements of the *Endangered Species Act, 2007* (ESA). This recovery strategy has been prepared as advice to the Government of Ontario, other responsible jurisdictions and the many different constituencies that may be involved in recovering the species.

The recovery strategy does not necessarily represent the views of all individuals who provided advice or contributed to its preparation, or the official positions of the organizations with which the individuals are associated.

The recommended goals, objectives and recovery approaches identified in the strategy are based on the best available knowledge and are subject to revision as new information becomes available. Implementation of this strategy is subject to appropriations, priorities and budgetary constraints of the participating jurisdictions and organizations.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy.

Responsible jurisdictions

Ministry of the Environment, Conservation and Parks
Fisheries and Oceans Canada

Executive summary

Lake Whitefish (*Coregonus clupeaformis*) is a freshwater member of the family Salmonidae (Trouts and Salmons) occupying deep, coldwater lakes. It is silvery overall in colour with a greenish-brown back, whitish underside, and overhanging snout (an adaptation to bottom-feeding). Lake Whitefish populations across North America exhibit a remarkable range and variability of physical characters, and uniqueness in life history, which in rare cases has given rise to physically distinct and reproductively isolated “species pairs” within the same waterbody.

The presence of separate large- and small-bodied populations of Lake Whitefish in Opeongo Lake was first reported in 1943. Attributing a particular specimen of Lake Whitefish from Opeongo Lake to either the large- or small-bodied form often requires knowledge of several traits including (i) age, (ii) reproductive status, and (iii) length. The large- and small-bodied populations of Lake Whitefish in Opeongo Lake are each listed as threatened on the Species at Risk in Ontario List (Ontario Regulation 230/08) and are found only in Opeongo Lake, Algonquin Provincial Park, Ontario.

Lake Whitefish has historically been captured throughout Opeongo Lake in each of its four basins. Limited records from shallower bays reflect unsuitable oxythermal (i.e., oxygen and temperature) conditions during the summer. Studies have found that the likelihood of Lake Whitefish occupancy in Opeongo Lake during summer is greatest where temperatures range between 7.7 to 13.6 °C at depths between approximately 10 and 29 m.

Opeongo Lake is situated within a protected area (Algonquin Provincial Park) managed for the purposes of maintaining natural and cultural landscapes and supporting low-intensity recreational opportunities. Maintenance of ecological integrity is also the first priority for all planning and management of Ontario’s provincial parks per the *Provincial Parks and Conservation Reserves Act, 2006*. As a result, Lake Whitefish in Opeongo Lake are not considered vulnerable to habitat deterioration resulting from threats that emerge from human settlement and/or natural resource exploitation. The primary threats to the survival and recovery of Lake Whitefish in Opeongo Lake (listed in order of severity) include:

- accidental introduction of invasive aquatic invertebrates, particularly Spiny Water Flea (*Bythotrephes longimanus*)
- accidental or purposeful introduction of nonindigenous/predatory fish, particularly Rainbow Smelt (*Osmerus mordax*) and Northern Pike (*Esox lucius*)
- human-induced climate change, which may reduce habitat quantity, increase egg mortality, reduce prey availability, and increase the potential for harmful algal blooms
- incidental angler by-catch, the likelihood and intensity of which is low

It is generally believed that there are no confirmed limiting factors which pose a meaningful risk to the maintenance of self-sustaining populations of Lake Whitefish (both forms) in Opeongo Lake at this time. Upon further study, it may be determined that certain factors are indeed limiting for Lake Whitefish in Opeongo Lake, but only under restricted conditions.

Despite considerable historical and recent research interest, there are several gaps in current knowledge surrounding Lake Whitefish in Opeongo Lake that would benefit from further research and assessment. Most existing records represent large-bodied individuals due to biases introduced through sampling methodologies (i.e., gillnet mesh size). Knowledge gaps include precise population estimates and trends, changes in habitat use across seasons and life stages, locations of spawning habitat, larval life-history, and predator-prey interactions.

The recommended long term recovery goal for Lake Whitefish (large- and small-bodied populations) in Opeongo Lake is to maintain self-sustaining populations of both forms. Recommended protection and recovery objectives are as follows:

1. Minimize risk of introducing aquatic invasive and predatory species.
2. Refine population abundance estimates and project trends.
3. Clarify patterns in habitat occupancy for all life stages to inform habitat protection.
4. Clarify trophic niche and diet to inform recovery efforts.
5. Monitor key water quality parameters to inform recovery efforts.
6. Promote awareness of large- and small-bodied Lake Whitefish in Opeongo Lake and the threats facing them.

Given significant knowledge gaps in life history and habitat occupation – both for Lake Whitefish in Opeongo Lake generally and the large- and small bodied forms individually – a habitat regulation may not be required at this time. Should a habitat regulation be developed in the future, it is recommended to include all portions of Opeongo Lake consisting of rocky shoals 10 to 50 m offshore with depths ranging from 3 to 5 m (i.e., suitable spawning and nursery habitat) and deep water areas with water depths ranging from 6 to 32 m (i.e., suitable feeding habitat for juveniles and adults). Implementation of the recovery approaches outlined herein will help to clarify the geospatial limits of Lake Whitefish habitat in Opeongo Lake and support future management, protection, and recovery of the species pair.

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1.0 Background information

1.1 Species assessment and classification

The following list provides assessment and classification information for the Lake Whitefish (*Coregonus clupeaformis*) Opeongo Lake large- and small-bodied populations. Note: The glossary provides definitions for abbreviations and technical terms in this document.

- SARO List Classification: Threatened
- SARO List History: Threatened (2022)
- COSEWIC Assessment History: Threatened (2018)
- SARA Schedule 1: No schedule, no status
- Conservation Status Rankings: G-rank: G5TNRQ; N-rank: NU; S-rank: SU

1.2 Species description and biology

Species description

Lake Whitefish (*Coregonus clupeaformis*) is a freshwater member of the family Salmonidae (Trouts and Salmons), subfamily Coregoninae (freshwater whitefishes). It was originally described by S. L. Mitchill in 1818 as *Salmo clupeaformis*, from a specimen originating in Lake Huron downstream of St. Marys Falls near Sault Ste. Marie (Scott and Crossman 1998). The etymology of the name *Coregonus clupeaformis* reflects the physical appearance of fish belonging to the population from which the specimen was taken; *Coregonus* derives its etymological meaning from two modern Greek words, “κόρη” (kore; pupil of the eye) and “γωνιά” (gonia; angle), referring to how the pupil tends to project forward towards the snout (Holm et al. 2021; Scott and Crossman 1998). The specific epithet *clupeaformis* is derived from “clupea” (herring) and “formis” (shaped), referencing its herring-like form.

Lake Whitefish is silvery overall in colour with a greenish-brown dorsal surface (back) and whitish underside (Scott and Crossman 1998). It has an elongate and somewhat laterally compressed body with large, cycloid (rounded and overlapping) scales covered by a thick layer of mucus. Its head is short with small eyes and an inferior mouth (i.e., the snout slightly overhangs and projects forward beyond the lower jaw), an adaptation to bottom-feeding. The single dorsal fin has 11 to 13 soft rays, the anal fin has 10 to 14 rays, and the caudal fin is deeply forked. Gill rakers (bony projections on the gill arch which aid in retaining food particles) range from 19 to 33 in number and are rarely fewer than 22 (Scott and Crossman 1998). Like other Salmonidae, Lake Whitefish possess an adipose fin (a soft, fleshy fin located behind the dorsal fin) and pelvic axillary process (a small, triangular appendage at the base of the pelvic fin). Reproductive males produce nuptial tubercles (raised bumps) on their flanks along the lateral line, which are less pronounced on females. Older individuals of both sexes may develop a discrete hump behind the head (Scott and Crossman 1998).

The presence of two distinguishable morphotypes of Lake Whitefish in Opeongo Lake – referred to herein as the large- and small-bodied “forms” or “populations” – was first described by Kennedy (1943). The two forms displayed obvious differences in size and age at maturation (i.e., exhibited unique growth curves), and (when considered together) showed a bimodal length distribution of reproductively mature fish. Fewer reproductively mature individuals were found between 130 and 190 millimeters (mm) standard length (SL) compared to those less than 130 mm (attributed to the small-bodied form) and greater than 190 mm (attributed to the large-bodied form) (Kennedy 1943). Based on current information, attributing a particular specimen of Lake Whitefish from Opeongo Lake to either the large- or small-bodied form typically relies on knowledge of (i) age, (ii) reproductive status, and/or (iii) length, as further described below.

- **Age:** Lake Whitefish (like other fishes) are reliably aged through inspection of otoliths (ear bone inside the heads of bony fish) which requires dissection. Annuli on scales (“year marks” imprinted in response to seasonal growth patterns) were historically used for aging (e.g., Kennedy 1943) and are suitable for aging sub-adults but not reproductively mature Lake Whitefish (M. Ridgway pers. comm. 2023).
- **Reproductive Status:** Maturity is easily confirmed in spawning fish which are actively releasing milt or roe. Individuals which are not actively spawning typically require dissection to confirm reproductive status (i.e., to inspect gonad development) since secondary reproductive characters (e.g., nuptial tubercles) are only weakly expressed in Lake Whitefish (M. Ridgway pers. comm. 2023).
- **Length:** Typically expressed as fork length (FL), which is measured from the tip of the snout to the fork of the tail. Historically (e.g., Kennedy 1943) SL was often used, which is measured from the tip of the snout to the end of the last vertebrae and does not include the caudal fin.

There is some overlap in characteristics for juveniles/young adults of the large-bodied form and most individuals of the small-bodied form, hence the need to consider multiple traits. Where all three traits (age, reproductive status, length) are known, a particular fish should be assignable to form without hesitation. Individuals displaying more distinctive or extreme characteristics may be assigned to form based on less information, as suggested by unpublished Ministry of Natural Resources and Forestry (MNRF) data from the 1980s and 2010s (referenced in Colm and Drake 2022). For example, a reproductively mature, two-year-old fish must represent the small-bodied form as the large-bodied form is not known to mature until at least age three. A reproductively mature, less than or equal to 170 mm FL fish also represents the small-bodied form given the bimodal size distribution, wherein a gap in mature individuals has been found between 180 and 190 mm FL. In these examples, knowledge of reproductive status is compared with either age or length to assign form (i.e., two separate traits are known).

Notwithstanding the above, there is disagreement amongst the historical and recent datasets regarding the precise numerical limits of maximum age, reproductive age, and length between forms (DFO 2022). Additional sampling is planned to clarify those characteristics (and the numerical limits between them) which will facilitate differentiation of the Lake Whitefish species pair in Opeongo Lake (M. Ridgway pers. comm. 2023).

Lake Whitefish shares Opeongo Lake with two other species of coregonines, including Round Whitefish (*Prosopium cylindraceum*) and Cisco (*C. artedi*). Round Whitefish has a single flap of skin between the nostrils (i.e., nostril flap) and a notch in the rear corner of the eyelid, whereas Lake Whitefish has two nostril-flaps and no eyelid notch. Cisco has a terminal snout which does not overhang the mouth and typically possesses more gill rakers (i.e., usually more than 32) than Lake Whitefish (Scott and Crossman 1998; Holm et al. 2021). Lake Whitefish larvae have historically been visually distinguished from Cisco based on the presence and position of melanophores (specialized cells filled with the dark pigment melanin) spanning the dorsal surface (Cucin and Faber 1985). A more recent study combining visual and genetic methods suggests that visual identification using morphometric characters alone is unreliable for distinguishing larval Lake Whitefish and Cisco and will generate misidentifications (George et al. 2018). A combination of visual and genetic methods is often preferred for identifying larval coregonines depending on study purpose and scope (Overdyk et al. 2016).

Photographs of Lake Whitefish from Opeongo Lake are provided below in Figure 1.

Lake Whitefish (unknown form) from Opeongo Lake preserved at the ROM (182 mm SL). Photo credit: M. Burridge.

Lake Whitefish (unknown form) from Opeongo Lake preserved at the ROM (200 mm SL). Photo credit: M. Burridge.

Lake Whitefish (unknown form) from Opeongo Lake, fish length not provided. Photo credit: C. Dewar.

Lake Whitefish (large-bodied form) from Opeongo Lake, fish length not provided. Photo credit: D. Smith.

Figure 1. Photographs of Lake Whitefish from Opeongo Lake in Ontario.

Species biology

Lake Whitefish populations across North America (and coregonines in general) exhibit remarkable variation of physical characters and uniqueness in life history (e.g., diet), which has occasionally led to unresolved taxonomic issues (Mee et al. 2015). Such morphological differentiation includes populations from hydrologically disconnected waterbodies (allopatric) and extends to intra-lake (sympatric) settings where distinguishable and reproductively isolated forms co-occur (Bernard 2006). Such intra-lake populations have been referred to as “sympatric pairs” or more commonly “species pairs” (Rogers 2008). A minimum of 19 lakes across Canada are currently known to contain Lake Whitefish species pairs, including Opeongo Lake and nearby Big Trout Lake (Mee et al. 2015; Ridgway et al. 2017). The mechanism(s) driving sympatry of these species pairs has been attributed to (1) post-glacial colonization of a waterbody by Lake Whitefish from different source populations, and (2) local (in-situ) adaptions derived from evolutionary processes including adaptive radiation and/or genetic drift (Bernard 2006; Bernatchez et al. 2010; Mee et al. 2015; Ridgway pers. comm. 2023).

Kennedy (1943) performed the first morphometric analysis of the two forms of Lake Whitefish in Opeongo Lake which revealed several key differences, as summarized in Table 1 below. Until recently, evidence for reproductive isolation between the two forms was indirect (Mee et al. 2015) and inferred based on the physical differences outlined in Table 1. More recent (unpublished) genetic work has confirmed that the two forms have speciated in-situ (i.e., within Opeongo Lake) and shows evidence of limited interbreeding in the past (C. Wilson pers. comm. 2023). Therefore, occupation of Opeongo Lake by Lake Whitefish does not reflect a “double invasion” of different lineages, as is the case for nearby Big Trout Lake (M. Ridgway pers. comm. 2023). Within-population genetic diversity of the large-bodied form of Lake Whitefish in Opeongo Lake appears to be low but shows high differentiation from populations in

Lake Ontario (Bay of Quinte and Chaumont Bay) and Lake Simcoe (Bernard et al. 2009).

Table 1. Morphological and biological differences between the large- and small-bodied forms of Lake Whitefish in Opeongo Lake as reported by Kennedy (1943).

Morphological Attribute	Large-bodied Form	Small-bodied Form
Mean standard length (SL; mm)	251	126
Mean number of gill rakers (± SD)	27.7 (± 1.1)	25.4 (± 0.14)
Mean number of lateral line scales	83.3	77.3
Age of sexual maturity (years)	4 to 7 (as early as 3)	2
Maximum age (years)	14	5

Despite Kennedy’s study published 80 years ago, there are remaining uncertainties related to age and growth patterns of the two forms, which complicate their differentiation. There is limited comparative data for the two forms as many historical and more recent sampling efforts in Opeongo Lake did not assign the appropriate form to captured Lake Whitefish (M. Ridgway pers. comm. 2023), though in some cases age structures (i.e., otoliths) are still available for modern assessment (A. Challice pers. comm. 2023). Other morphological differences detected historically by Kennedy (1943) such as eye diameter, head length and caudal peduncle length were not statistically significant and have not yet been subject to modern study (M. Ridgway pers. comm. 2023).

The morphometric and age data reported by Kennedy can be compared with unpublished MNRF datasets from the 1980s and 2010s (i.e., 2010, 2018, and 2019). The unpublished MNRF data revealed a maximum age of 34 years (1980s) and 24 years (2010s) for large-bodied individuals; small-bodied individuals showed maximum ages of 26 years (1980s) and eight years (2010s). The reported maximum ages between the three datasets (i.e., Kennedy 1943, MNRF 1980s, MNRF 2010s) range between 14 and 34 (20 year difference) for the large-bodied form and between 5 and 26 (21 year difference) for the small-bodied form. The unpublished MNRF datasets also differ in mean FL, which were reported as 332.4 mm (1980s) and 301 mm (2010s) for large-bodied individuals, and 226.7 mm (1980s) and 145 mm (2010s) for small-bodied individuals (Kennedy reported SL rather than FL). Overall, Kennedy (1943) reported the lowest values for age and length, while the 1980’s MNRF data contains the greatest values. The 2010’s MNRF dataset (Table 2) represents the most recent and reliable source of information used to distinguish the two forms, though further sampling is ongoing (M. Ridgway pers. comm. 2023).

Table 2. Morphological and biological differences between the large- and small-bodied forms of Lake Whitefish in Opeongo Lake based on unpublished MNRF data from the 2010s (as reported in Colm and Drake 2022).

Morphological Attribute	Large-bodied Form	Small-bodied Form
Mean fork length of mature individuals (FL; mm)	301	145
Maximum fork length of mature individuals (FL; mm)	519	176
Maximum age (years)	24	8

While Kennedy (1943) likely underestimated the ages of older/reproductive individuals by using scales (as compared to otoliths recorded by MNRF; M. Ridgway pers. comm. 2023), the discrepancies in maximum reported ages within the unpublished MNRF datasets are not understood and were subject to recent scientific debate (DFO 2022). Gillnetting surveys are planned for 2024 to further clarify the morphological and physiological boundaries between the two forms and determine whether additional characters are useful in assigning an individual to form, such as gill raker density (i.e., number of gill rakers per length of gill arch; M. Ridgway pers. comm. 2023).

Lake Whitefish are benthivorous (i.e., feed on benthic or bottom-dwelling prey) and associated with cold, oligotrophic lakes. Given the variability in Lake Whitefish life history strategies (e.g., life cycle, diet) across its range in response to localized biophysical conditions (e.g., food availability, competition intensity, lake morphometrics), the following biological description centres primarily on what is currently known about Lake Whitefish in Opeongo Lake. Information from other populations (i.e., in Ontario or elsewhere) is drawn upon primarily to minimize knowledge gaps. Apart from the above-noted physical differences and age at maturation, limited information exists upon which to differentiate key life history attributes between the large- and small-bodied forms. As such, the description that follows in Table 2 and the proceeding text largely treats both populations concurrently.

Table 3. Life stages of Lake Whitefish (adapted and simplified from Colm and Drake 2022).

Life Stage	Function	General Timeframe	Habitat Feature(s)
Adult spawning to hatch	Spawning	Late October to November	Nearshore areas with rocky shoals
	Egg development	Late October to April	Nearshore areas with rocky shoals

Life Stage	Function	General Timeframe	Habitat Feature(s)
	Hatch	Late April through May (commencing the first few days following ice out)	Nearshore areas with rocky shoals
Larval (up to approximately 6 weeks after hatch)	Nursery; feeding	May to June	Nearshore areas with rocky shoals
Age 0 (approximately 50 mm, or at the onset of diet shift)	Feeding	All year	Unknown
Juvenile/Sub-adult (age 1 to onset of maturity; age three to five for large-bodied form and age two for small-bodied form)	Feeding	All year	Cold, deep water (hypolimnion) with access to pelagic and benthic invertebrates
Adult	Feeding	All year	Cold, deep water (hypolimnion) with access to pelagic and benthic invertebrates

Lake Whitefish occupies a narrow thermal envelope and is intolerant of warmer water. The optimal thermal niche for Lake Whitefish has been reported to be between 10 and 14 °C (Christie and Regier 1988). General avoidance of temperatures greater than 10 °C during thermal stratification has been documented in northwestern Ontario (Rodrigues et al. 2022), although Lake Whitefish in Opeongo Lake were found to have a high probability of detection up to 13.6 °C (Challice et al. 2019). Cucin and Faber (1985) failed to capture larval Lake Whitefish in Opeongo Lake where surface waters exceeded 12 °C. Water temperature drives both habitat selection and diel vertical movements (Gorsky et al. 2012).

Lake Whitefish spawn in Opeongo Lake from late October to late November when water temperatures decline to 4 to 7 °C (Ihssen et al. 1981), with activity peaking between November 8 and 15 (Cucin and Faber 1985). The onset of initial and peak spawning may average later in recent years given climate change, but more recent data are lacking. Low water temperatures and extensive ice cover are considered a requirement for proper Lake Whitefish egg development (Colm and Drake 2022). Lab reared Lake Whitefish eggs have been shown to hatch successfully when developing in water temperatures ranging from 0.5 to 10 °C, with hatching unsuccessful at both higher and lower temperatures (Price 1940).

Eggs are randomly broadcast over shoals (i.e., shallow rocky areas) and rock ledges primarily consisting of cobble-sized rock with interstitial spaces (i.e., voids or crevices between the rocks), which protect the incubating eggs from displacement and/or predation (Ihssen et al. 1981; Cucin and Faber 1985; Scott and Crossman 1998). The mean diameter of Lake Whitefish eggs collected in Lake Michigan (near Elk Rapids) and Lake Ontario (Chaumont Bay) was 3.21 mm (SD=0.20, n=99), and can be reliably differentiated from Cisco (which has smaller eggs) based on the species-separating size threshold of 2.88 mm (Paufve et al. 2020). Egg hatching occurs in late April to May (Cucin and Faber 1985).

Larval Lake Whitefish in Opeongo Lake have been captured via tow netting within three to five days of ice-break (Cucin and Faber 1985). A study from Chaumont Bay (eastern Lake Ontario) from 2004 to 2006 found that larval Lake Whitefish fed overwhelmingly (81.4%) on copepods (mainly cyclopoids) – small crustaceans within the class Copepoda – and to a lesser extent water fleas within the superorder Cladocera (mainly daphnids) and chironomids (Johnson et al. 2009). Nearshore seining surveys indicated that larvae descended from the water column to the lake bottom at night (Johnson et al. 2009).

Analysis of the stomach contents of 280 Lake Whitefish in Opeongo Lake during the summer of 1963 (i.e., between mid-May and late-August) revealed a seasonally variable diet reliant upon benthic crustaceans, insect larvae and mollusks (Sandercock 1964). In the latter half of May, Lake Whitefish fed almost exclusively on mayfly (Ephemeroptera) nymphs, comprising 95.3 percent of stomach contents by volume. By June and July, a broader array of mostly bottom-dwelling organisms was consumed including crustaceans such as Cladocera (e.g., *Sida crystallina*, *Ophryoxus gracilis*, *Eurycercus lamellatus*, *Latona setifera*), Copepoda (*Cyclops* sp.) and seed shrimp (Ostracoda), along with non-biting midges (Chironomidae), freshwater molluscs (e.g., *Amnicola limosa*, *Pisidium* sp.), and water mites. By August, Cladocera (particularly *S. crystallina*), copepods, dipterans (particularly Chironomidae), water mites and freshwater molluscs (particularly *Pisidium* sp.) were taken in greatest abundance. Yellow Perch (*Perca flavescens*) comprised 47.4 percent of the diet by volume in early August but was not otherwise consumed during the study period. Large- and small-bodied forms were not differentiated during this study but (based on published SLs ranging between 160 to 450 mm) most were probably large-bodied (Colm and Drake 2022). Lake Whitefish in Opeongo Lake are also preyed upon by predatory fish including Burbot (*Lota lota*; Hackney 1973; Kennedy 1943) and Lake Trout (*Salvelinus namaycush*; Kennedy 1943; Martin and Fry 1973).

1.3 Distribution, abundance and population trends

The landscapes of Algonquin Provincial Park (PP) were released from glacial ice (and thus available for colonization by fish) between approximately 13,800 to 13,000 years ago, following sufficient northward retreat of the Laurentide ice sheet (Ridgway et al. 2017). Lake Whitefish is speculated to have entered watersheds emanating from the Algonquin highlands (i.e., in the area to become Opeongo Lake) soon after glacial retreat, as the distribution of Lake Whitefish spans many lakes in Algonquin PP (74 in total) which vary in elevation and watershed position (Ridgway et al. 2017). Additional colonization events by Lake Whitefish may have occurred in northern Algonquin PP between 13,000 to 12,000 years ago when proglacial Lake Algonquin discharged eastward through a series of successively lower outlets, but these watersheds are more northward and topographically below Opeongo Lake (and thus were not hydrologically connected to the Algonquin highlands). Previous genetic study suggested that all Lake Whitefish populations in Algonquin PP (and Ontario more broadly) originated from the Mississippian refuge (Bernatchez and Dodson 1991); however, more recent (unpublished) genetic evidence suggests that Lake Whitefish are represented by multiple lineages in the park which emanated from separate glacial refuges (M. Ridgway pers. comm. 2023).

The Opeongo Lake large- and small-bodied forms of Lake Whitefish are found only in Opeongo Lake, Algonquin PP. The two co-occurring forms are referred to as “populations” by COSEWIC (2018) and COSSARO (2020), and also represent separate “Designatable Units” (DUs) as defined by Fisheries and Oceans Canada (DFO) (Colm and Drake 2022). Opeongo Lake (known colloquially as “Lake Opeongo”) is a coldwater, oligotrophic lake consisting of four discrete basins (South Arm, North Arm, East Arm and Annie Bay) separated by shallow narrows (Martin and Fry 1973). Opeongo is believed to derive from the Algonkian phrase “Ope au wingauk” or “sandy at the narrows”, likely reflecting the conditions separating the North and East Arms (Shaw 1998). Opeongo Lake extends approximately 14 kilometres (km) north to south and 12 km east to west, with a surface area of 5,154.2 hectares (ha), a maximum depth of 49.4 metres (m) and an average depth of 13.7 m (MNRF 2023b). Approximately 23.3 percent of Opeongo Lake exceeds 20 m in depth while 48.3 percent is less than 10 m in depth (including the entirety of Sproule Bay) (Challice et al. 2019). Water levels in Opeongo Lake are controlled by a fixed-crest weir dam (“Opeongo Lake Dam”) at the Annie Bay outlet to the Opeongo River (Colm and Drake 2022; OPG and MNR 2018).

The spatial configuration and topographic relief of the Opeongo Lake watershed is illustrated below in Figure 2, highlighting the extent and character of surrounding lands which convey water to the lake. Historical and current records of Lake Whitefish (not differentiated by form) in Opeongo Lake are shown below in Figure 3. Records for several years between 1936 and 1971 represent specimens deposited at the ROM (M. Burridge pers. comm. 2023) while the remaining data were provided by MNRF (T. Middel pers. comm. 2023). Records representing various years between 1981 and 1995 are also available but lack spatial attribution and are thus omitted from Figure 3.

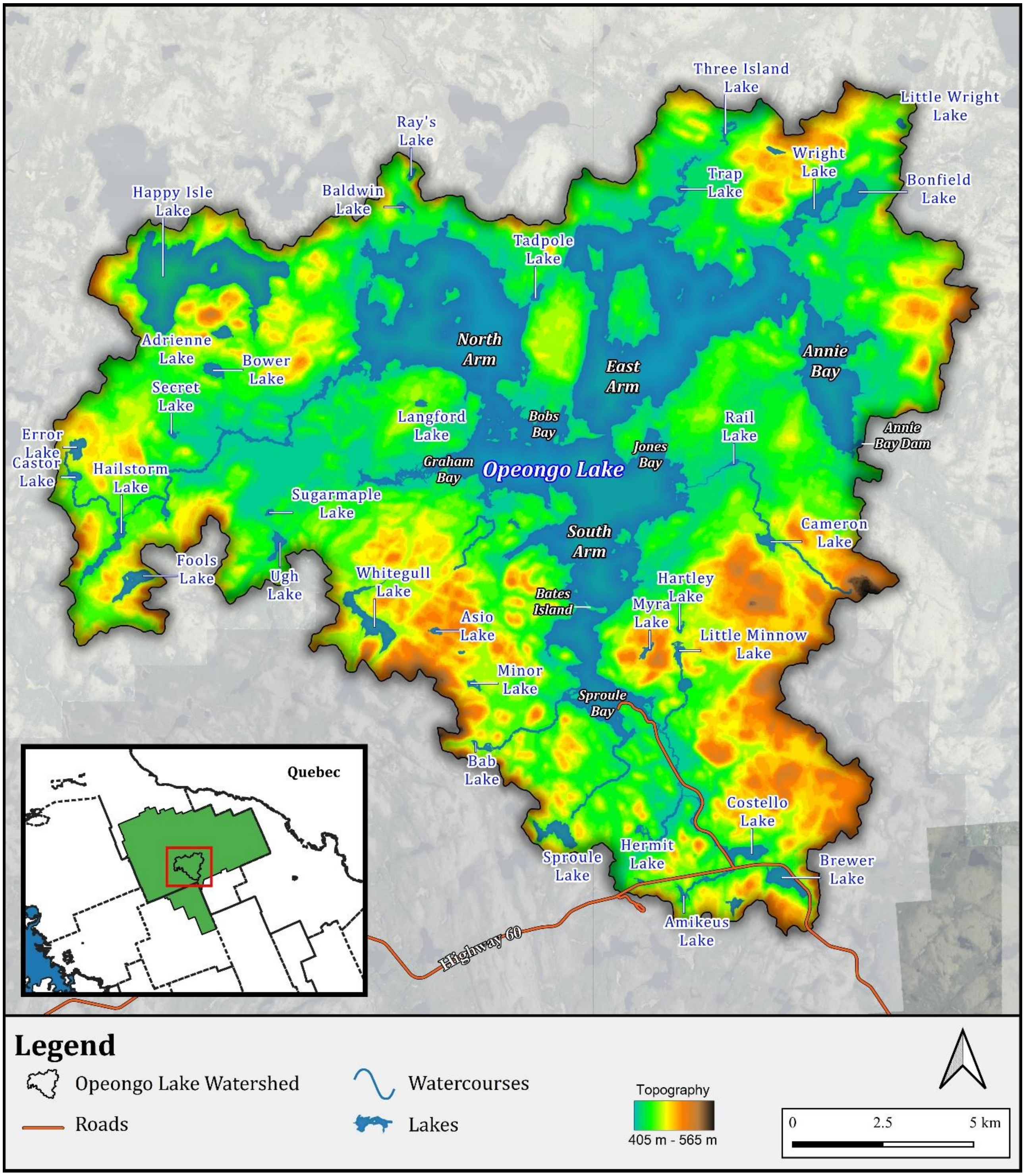

Figure 2. Physiography of the Opeongo Lake watershed.

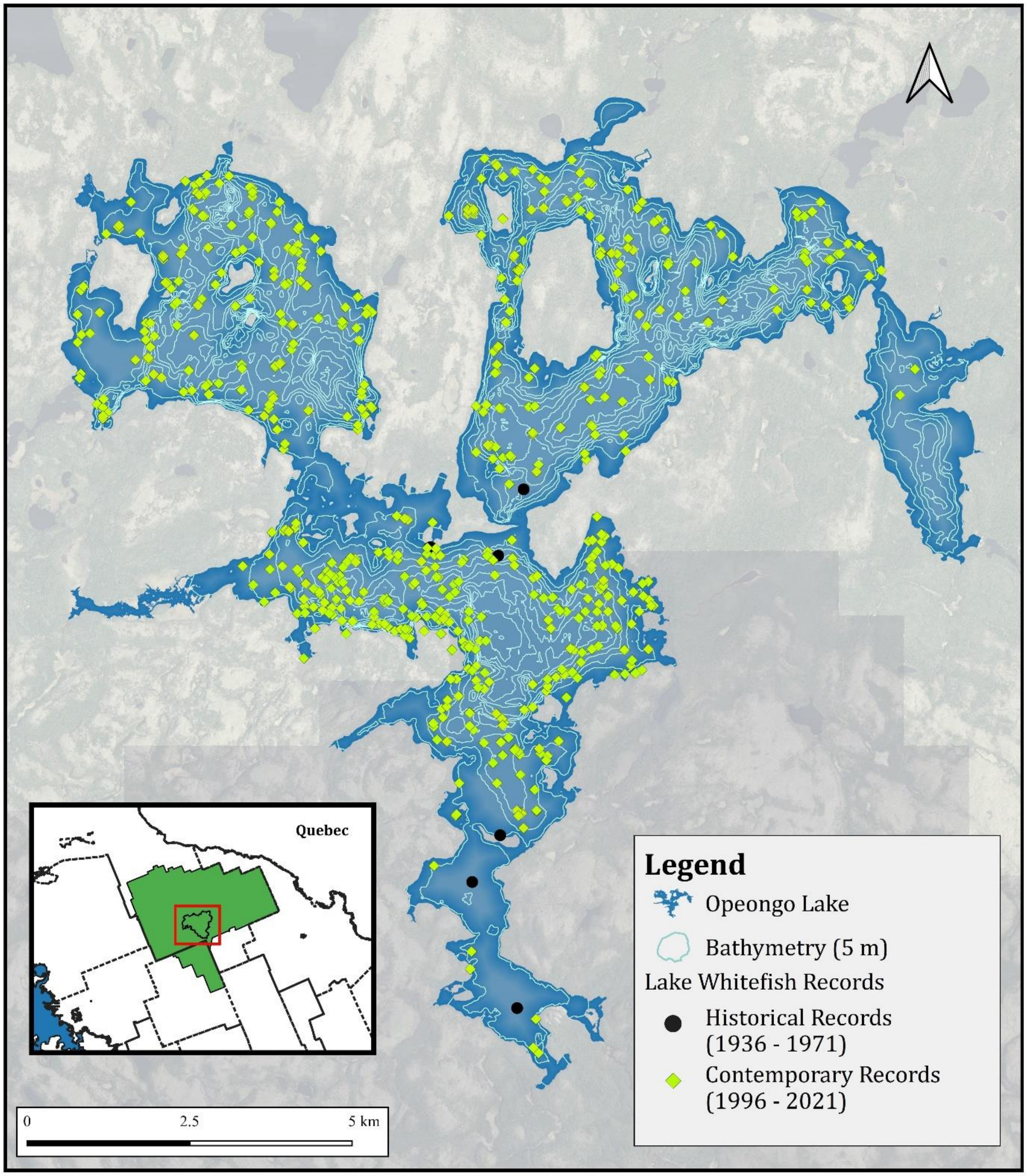

Figure 3. Historical and current records of Lake Whitefish (large- and small-bodied populations) in Opeongo Lake.

Lake Whitefish has historically been captured throughout Opeongo Lake in each of the four arms, though the occurrence map in Figure 3 reveals patterns reflecting summer concentration in the North, East, and South (i.e., north of Bates Island) arms. Limited records from shallower bays (e.g., Annie Bay, Sproule Bay) likely reflect unsuitable oxythermal habitat. Shallower areas (i.e., less than 10 m) and connected creeks (e.g., Hailstorm Creek) may be occupied by Lake Whitefish outside of thermal stratification (M. Ridgway pers. comm. 2023). The distribution of habitats occupied by Lake Whitefish in Opeongo Lake during winter (i.e., when the lake is well-mixed) is unknown (M. Ridgway pers. comm. 2023).

Based on (unpublished) MNRF datasets from 2010 and 2019, Colm and Drake (2022) report two separate lake-wide abundance estimates for the large-bodied form of Lake Whitefish in Opeongo Lake of 11,378 (95% CI, 6,509 to 18,712) and 22,792 (95% CI, 10,437 to 54,415), respectively. For both the 2010 and 2019 datasets, sampling made use of large-mesh gillnets in which most individuals captured were mature and greater than 190 mm FL (thus representing the large-bodied form). Surveys targeting the small-bodied form in 2018 using small-mesh gillnets captured 23 small-bodied individuals (i.e., mature and < 180 mm FL) and 50 large-bodied individuals (Colm and Drake 2022). The small-bodied form evades capture by large-mesh gillnets and thus has not been well-sampled historically (M. Ridgway pers. comm. 2023).

Recent modeling suggests that the supply of available habitat in Opeongo Lake exceeds that required by the estimated minimum viable population (MVP), and that current population estimates exceed the MVP (Fung et al. 2022). Notwithstanding this, current population size, structure, and trends of Lake Whitefish in Opeongo Lake (both forms) are not known with certainty.

1.4 Habitat needs

The habitat needs of Lake Whitefish in Opeongo Lake are differentiated below based on life-stage as described in Table 3.

Spawning habitat

Areas selected for spawning by Lake Whitefish in Opeongo Lake are predominantly concentrated along exposed shorelines and points, including islands (Cucin and Faber 1985). Spawning habitat is typified by substrates consisting of gravel, rocky shoals or granite boulders and broken rocks (Cucin and Faber 1985). Spawning is assumed to occur in nearshore areas up to 50 m offshore and at depths of less than 8 m (Colm and Drake 2022), though this is based on published reports of spawning in lakes across Canada (per Scott and Crossman 1998). Historical descriptions of known Lake Whitefish spawning areas in Opeongo Lake indicate that they are found within 10 to 50 m from shore and at depths ranging between 3 to 5 m (Cucin and Faber 1985). Nearshore sampling efforts in Opeongo Lake have shown that Lake Whitefish use spawning grounds where surface water temperatures reach 4 to 7 °C during peak spawning activity (Ihssen et al. 1981).

Lake Whitefish spawning areas are assumed to overlap with those of Lake Trout, though few have been confirmed to date and Lake Whitefish may be less particular than Lake Trout (M. Ridgway pers. comm. 2023). Twenty-two Lake Trout spawning shoals are known in the North, South and East arms (T. Middel pers. comm. 2023). Suspected Lake Whitefish spawning areas occur most frequently in the East Arm, and areas are also known from the South Arm (Martin and Fry 1973).

Whitaker and Wood (2020) describe spawning habitat in Maine as consisting of areas with deeply lain coarse substrates of multiple size classes, which create interstitial spaces (crevices) for egg cover. Currents passing through the interstitial spaces wash them free of fine sediments; thus, aspects of shoreline morphometry such as fetch (maximum length of open water traveled by wind), aspect (orientation to the direction of prevailing winds and storms) and exposure (presence or absence of sheltering features such as islands) affect spawning habitat quality. Less optimal Lake Whitefish spawning habitat was found where the depth of substrate was shallower; however, these areas still contained diverse substrate particle sizes to provide egg cover (Whitaker and Wood 2020). A requirement for optimal Lake Whitefish spawning habitat is the presence of either strong currents or wave action to reduce sediment deposition on eggs (Whitaker and Wood 2020). Cucin and Faber (1985) identify the importance of rocky crevices for protecting eggs throughout the duration of development.

Key characteristics of suitable and/or optimal spawning habitat for Lake Whitefish in Opeongo Lake are unknown (M. Ridgway pers. comm. 2023; T. Middel pers. comm. 2023). Variables such as substrate type, substrate size and structure, water depths, distance from shore, and degree of wave energy likely influence spawning habitat quality in Opeongo Lake.

Larval habitat

Lake Whitefish eggs develop over winter during a four-to-six-month period in Opeongo Lake. Once hatched, larvae begin swimming immediately and move upward in the water column above spawning areas (Cucin and Faber 1985). Larvae appear to remain around their spawning grounds for approximately six weeks before dispersing to deeper waters (Ihssen et al. 1981). Triggers for dispersal may include prey availability, surface currents, avoidance of predators or innate behavioural factors (Cucin and Faber 1985). It has been speculated that larvae transition away from surface waters towards the colder lake bottom in Opeongo Lake in June (Cucin and Faber 1985).

Age 0 (approximately 50 mm) habitat

The habitat needs of age 0 (approximately 50 mm) Lake Whitefish in Opeongo Lake are largely unknown. It is possible that their tendency to specialize in a single type of prey (Pothoven et al. 2014; Pothoven and Olds 2020) may influence habitat selection.

Juvenile habitat

The habitat needs of juvenile and sub-adult (i.e., age 1 to onset of maturity) Lake Whitefish in Opeongo Lake are unknown, although juveniles have been captured alongside adults during sampling, suggesting some degree of overlap in habitat use (Kennedy 1943).

Adult habitat

Available information suggests that habitat use by adults of both forms in Opeongo Lake generally overlaps throughout the summer months, with occupancy concentrated in deep water (hypolimnion). Kennedy (1943) observed that large- and small-bodied Lake Whitefish occupy similar water depths from early spring (May) through early fall (September); however, a difference in vertical distribution (depth occupancy) was detected throughout August. Sampling efforts in August revealed that large-bodied individuals typically congregated in warmer (15 °C), shallower (9.1 m, 30 ft) water, whereas small-bodied fish were found in cooler (9 °C), deeper (15.2 m, 50 ft) areas, though the results may have been influenced by two locations with exceptionally high catches (Kennedy 1943). Notwithstanding this, small-mesh gillnet surveys by MNRF in mid-August 2018 captured both forms in the same nets (Colm and Drake 2022), suggesting that each may be benthic (M. Ridgway pers. comm. 2023). Further study is needed to ascertain the extent and seasonality of niche overlap versus habitat partitioning amongst the two forms.

The summer oxythermal envelope (i.e., portion of the waterbody remaining rich in oxygen and of a suitable temperature) used by most (i.e., probability of occupancy > 50%) Lake Whitefish in Opeongo Lake (forms not differentiated) in 2003, 2009 and 2010 encompassed a temperature range of 7.6 to 20.0 °C at depths between approximately 6 to 32 m (Challice et al. 2019). Greater Lake Whitefish occupancy (i.e., probability of occupancy > 75%) was found in temperatures ranging from 7.7 to 13.6 °C at depths between approximately 10 and 29 m (Challice et al. 2019). Based on these findings and the results of acoustic substrate mapping of the lake bottom, Challice et al. (2019) found that Lake Whitefish in Opeongo Lake predominantly occupy areas where the thermocline meets the substrate during thermal stratification. Lake Whitefish in Opeongo Lake did not make significant vertical movements between water depths throughout the day but appeared to be more active during morning hours than afternoons, which may reflect foraging behaviours which optimize capture of zooplankton prey (Challice et al. 2019).

Passive acoustic telemetry of Lake Whitefish in northwestern Ontario (Lake 658 from the Experimental Lakes Area) found that individuals were mainly found in a narrow temperature band of 5.3 to 7.9 °C during stratification, and that fish avoided temperatures greater than 10 °C even where they became exposed to hypoxic conditions in the hypolimnion (DO < 2 mg/L; Rodrigues et al. 2022). The authors speculated that Lake Whitefish may be making brief foraging forays into the hypoxic hypolimnion to capture hypoxia-tolerant benthic prey including non-biting midges (Chironomidae) and phantom midges (*Chaeoborus* spp.).

1.5 Limiting factors

It is generally believed that there are no confirmed limiting factors which pose a meaningful risk to the maintenance of self-sustaining populations of Lake Whitefish (both forms) in Opeongo Lake at this time (M. Ridgway pers. comm. 2023; N. Mandrak pers. comm. 2023; T. Middel pers. comm. 2023). Suitable spawning habitat appears to be widespread throughout the East Arm and North Arm (and portions of the South Arm), though this requires verification. Similarly, there is no evidence of a dissolved oxygen (DO) limitation in Opeongo Lake (generally considered to be < 7 mg/L in the hypolimnion of lakes on the Precambrian Shield; MOE et al. 2010). Challice et al. (2019) found DO to be greater than 7 mg/L at all depths measured, while unpublished MNRF data (reported in Colm and Drake 2022) revealed DO levels generally above 8.5 mg/L at locations where Lake Whitefish (large-bodied form) were captured in 2010 and 2019.

The presence of nonindigenous predatory fish in Opeongo Lake including Cisco and Smallmouth Bass (*Micropterus dolomieu*) would constitute a limiting factor if evidence suggested they were adversely affecting the survival, growth, or recruitment of Lake Whitefish. Cisco was purposefully introduced to Opeongo Lake in 1940, then introduced again in 1948 using stock from Mary Lake in Huntsville (Cucin and Faber 1985). By the early 1950s, Cisco were documented in the stomachs of Lake Trout, confirming establishment (Martin and Fry 1973). Introducing Cisco to any waterbody containing a small-bodied form of Lake Whitefish (which occupies a similar trophic niche) is predicted to produce negative effects to Lake Whitefish due to competitive exclusion driven by an overlap in required resources (Pigeon et al. 1997; Trudel et al. 2001). It is further hypothesized that zooplankton biomass may not be sufficient to support both fishes (Trudel et al. 2001). Establishment of Cisco in Opeongo Lake preceded the intensive study of Lake Whitefish diet by Sandercock (1964) by at least ten years, so any effect of introducing Cisco on the historical diet of Lake Whitefish (if any) cannot be known. Both forms of Lake Whitefish have persisted since the establishment of Cisco approximately 70 years ago, suggesting these coregonines are using different prey items (and that a cisco-related limitation is unlikely).

Smallmouth Bass was introduced to several lakes in Algonquin PP (including Opeongo Lake in 1928) through park stocking programs beginning in 1899 and spanning well into the 20th century (Martin and Fry 1973; Mitchell et al. 2017). Although Smallmouth Bass introductions increase recreational angling opportunities, they may result in a loss of species diversity, particularly of smaller-bodied native fish (Findlay et al. 2000). Similar to Cisco, there is a lack of baseline information to confidently assess the impacts (if any) of introducing Smallmouth Bass on Lake Whitefish, and an equal lack of evidence implying that said introduction has resulted in a biological limitation for either form. A historical analysis of Smallmouth Bass stomach contents did not reveal any Lake Whitefish eggs (Martin and Fry 1973).

Possible limiting factors for Lake Whitefish in Opeongo Lake as reported by Colm and Drake (2022; see also references therein) and synthesized herein are offered below, which are primarily based on inferences from empirical studies of Lake Whitefish in other areas. Upon further study, it may be determined that certain factors noted below are indeed limiting, but only under restricted conditions (e.g., when compounded by other factors).

- **Poor recruitment due to egg predation by predatory fish** could affect population viability for one or both forms (at least when other stressors are prevalent). The intensity of species-specific predation on Lake Whitefish eggs in Opeongo Lake is unknown.
- **Competition with Cisco (for pelagic prey) and Round Whitefish (for benthic prey)** may limit Lake Whitefish abundance; however, current evidence suggests that both Lake Whitefish forms are benthic (M. Ridgway pers. comm. 2023) and (if so) each would have co-occurred with Round Whitefish for centuries (or perhaps much longer).
- **Effects caused by genetic structure** (e.g., drift, inbreeding depression, founder effects) could increase population vulnerability. Although this has been observed of Lake Whitefish populations in other isolated waterbodies throughout Algonquin PP and elsewhere, it is speculative for populations in Opeongo Lake.

1.6 Threats to survival and recovery

Opeongo Lake is situated within a protected area (Algonquin PP) managed for the purposes of maintaining natural and cultural landscapes and supporting low-intensity recreational opportunities (Ontario Parks 1998). Maintenance of ecological integrity is also the first priority for all planning and management of Ontario’s provincial parks per the Provincial Parks and Conservation Reserves Act (2006). As a result, Lake Whitefish in Opeongo Lake are not considered vulnerable to habitat deterioration resulting from threats that emerge from human settlement and/or natural resource exploitation, such as riparian vegetation clearing (Martin and Fry 1973; T. Middel pers. comm. 2023). In particular, there is a minimum 120 m zone surrounding Opeongo Lake as described in the 2013 amendment to the Algonquin Park Management Plan, in which forest harvesting and intensive recreational activities are prohibited (Ontario Parks 2013, P. Gelok pers. comm. 2023).

The primary threats to the survival and recovery of Lake Whitefish in Opeongo Lake (listed in order of severity) include:

- accidental introduction of invasive aquatic invertebrates, particularly Spiny Water Flea (*Bythotrephes longimanus*) which is not currently present in Opeongo Lake
- accidental or purposeful introduction of nonindigenous/predatory fish, particularly Rainbow Smelt (*Osmerus mordax*) and Northern Pike (*Esox lucius*) which are not currently found in Opeongo Lake
- human-induced climate change, which may reduce habitat quantity, increase egg mortality, reduce prey availability, and increase the incidence of harmful algal blooms
- incidental angler by-catch, the likelihood and intensity of which is low

Introduction of invasive aquatic invertebrates

Invasive zooplankton

Spiny Water Flea is an invasive species of zooplankton that has spread rapidly throughout the Great Lakes basin, leading to significant reductions of pelagic zooplankton diversity in large and small waterbodies alike. Following introduction into Lake Ontario via contaminated ship ballast, Spiny Water Flea has invaded approximately 150 lakes from southcentral to northwestern Ontario (Yan et al. 2011). The discovery of exoskeletal remains in lake sediment cores found in Three Mile Lake (Township of Muskoka Lakes) suggests that Spiny Water Flea was present in Ontario prior to 1650, predating the earliest recorded observations of the species in North America by nearly three centuries (DeWeese et al. 2021). Angling is likely the primary vector of Spiny Water Flea invasion, wherein individuals and propagules are transported to new water bodies via fishing gear (e.g. fishing lines), boats, trailers and live wells (Yan et al. 2011; MAISRC 2023). To combat the threat of aquatic invasive species, an amendment was made in 2022 to the Ontario *Invasive Species Act* (2015) to regulate the overland movement of watercraft (and watercraft equipment) as carriers of invasive species. The likelihood of natural dispersal to downstream waterbodies via river/stream connections is generally considered low and/or limited to lakes close-by (Gertzen and Leung 2011).

Spiny Water Flea shows a preference for inhabiting the epilimnion of deep, cold lakes and tends to avoid the hypolimnion (Yan et al. 2001). It can reduce food supply for fish by directly impacting crustacean zooplankton diversity and abundance, or cause indirect impacts by pushing zooplankton to deeper and colder waters and/or altering zooplankton growth rates (Yan et al. 2001, 2011). There is currently no means of eradicating an established population of Spiny Water Flea, although a recent study by Martin et al. (2023) found that predation of Spiny Water Flea by Cisco in Vilas County, Wisconsin, played a direct role in Spiny Water Flea density declines.

A study in Harp Lake (northeast of Huntsville, Ontario) found that the invasion of Spiny Water Flea led to an overall decline in crustacean zooplankton richness and size structure (Yan et al. 2001). In this instance, while Cisco was present in the lake, no evidence was found to suggest that Cisco predation played any role in Spiny Water Flea declines. Instead, Spiny Water Fleas in Harp Lake adapted by seeking refuge from predation, occupying warmer, dark portions of the lake above the hypolimnion (Yan et al. 2001). These findings by Yang et al. (2001) suggest that Spiny Water Flea responses to predation may be variable across waterbodies.

The COSEWIC Assessment and Update Status Report on Lake Whitefish in Lake Simcoe (COSEWIC 2005) indicated a lack of evidence linking Spiny Water Flea to reduced growth or survival of hatchery-reared Lake Whitefish (which prey heavily on Spiny Water Flea), but that the effect on juveniles (i.e., less than six months of age) was unknown. Notwithstanding this, Lake Simcoe presents a different context than Opeongo Lake as it does not possess a Lake Whitefish species pair. Reid et al. (2017) detailed the collapse of a Lake Whitefish species pair (i.e., “normal-bodied” and small-bodied) in Como Lake (northwest of Sudbury, Ontario) due to the introduction of Spiny Water Flea around 2011. The species pair was replaced by a single large-bodied form, which is deeper-bodied and possesses significant differences in morphology from the normal- and small-bodied forms. It was hypothesized that the introduction of Spiny Water Flea led to drastic changes in trophic niches which previously maintained the species pair, causing Lake Whitefish to shift their diet from smaller prey items (such as native zooplankton) towards the larger and more abundant Spiny Water Flea (Reid et al. 2017).

Spiny Water Flea is present in many major waterbodies surrounding Algonquin PP (EDDMapS 2023). In 2022, Spiny Water Flea was first detected in the northwestern region of Algonquin PP in three lakes (North Tea Lake, Manitou Lake, Kioshkokwi Lake) forming part of the Upper Amable du Fond River watershed (J. Hoare pers. comm. 2023; P. Gelok pers. comm. 2023). It has been suggested that Spiny Water Flea poses the greatest risk to the long-term survival of the Lake Whitefish species pair in Opeongo Lake (A. Drake pers. comm. 2023; J. Colm pers. comm. 2023; N. Mandrak pers. comm. 2023; T. Middel pers. comm. 2023).

Fishhook Water Flea (*Cercopagis pengoi*) is another invasive zooplankton which invaded Lake Ontario in July 1998 (Jacobs and MacIsaac 2007). Unlike Spiny Water Flea, Fishhook Water Flea has not (yet) expanded into inland waterbodies in southern or central Ontario but poses similar risks to the composition, richness and abundance of native zooplankton should this species ever become established in Opeongo Lake.

Invasive bivalves

Zebra Mussels (*Dreissena polymorpha*) were introduced to the Great Lakes in 1988 and have rapidly colonized lake and river bottoms, rocks, and aquatic vegetation (DFO

2013; Pollux et al. 2010). Although Zebra Mussel generally occupies water depths of around four to seven metres, some populations occupy deeper waters (DFO 2013; Pollux et al. 2010). Quagga Mussel (*D. begensis*) was introduced to North America through contaminated ballast water and is generally limited to deep water habitats within the southern Laurentian Great Lakes (DFO 2013). Quagga Mussel also occupies a broad range of substrates in rivers and lakes, including cobble, gravel, and fine sediments (Patterson et al. 2005). Dispersal of both Zebra Mussel and Quagga Mussel larvae may occur through various pathways, including contaminated watercrafts or by passive drift (Orlova et al. 2005). In shallower waters, Quagga Mussel has replaced Zebra Mussel in many areas of the Great Lakes basin through competitive exclusion (Wilson et al. 2006). Zebra Mussel and Quagga Mussel are not known from Opeongo Lake (EDDMapS 2023).

The introduction of dreissenid mussels (i.e., mussels belonging to the family Dreissenidae) to a waterbody can significantly alter native invertebrate assemblages and nutrient dynamics. Both Quagga Mussel and Zebra Mussel are known to feed extensively on zooplankton and planktonic algae, often leading to significant changes in ecosystem structure and functions across trophic levels (see DFO 2013 and references therein). Similar to Spiny Water Flea, no evidence of direct impacts to the growth or survival of Lake Whitefish in Lake Simcoe was expected following Zebra Mussel colonization (COSEWIC 2005); however, Cunningham and Dunlop (in press) found a significant decline in Lake Whitefish larval density based on historical (1976-1986) and contemporary (2017-2019) data. Dreissenid mussel presence was associated with reduced larval densities, and dreissenid establishment was considered a potential contributing factor to slower growth and reduced survival of Lake Whitefish as a result of changes in zooplankton biomass and composition. It is also possible that decreases in nutrient inputs to Lake Simcoe following the implementation of the Lake Simcoe Phosphorus Reduction Strategy (2010) may have influenced zooplankton biomass in conjunction with the presence of dreissenid mussels. Lake Simcoe does not contain a Lake Whitefish species pair, but given these findings the impacts to Lake Whitefish in Opeongo Lake would likely be significant should dreissenid mussels ever become established.

Low calcium availability and low pH levels in lakes on the Precambrian Shield are known to limit dreissenid establishment (Hincks and Mackie 1997; N. Mandrak pers. comm. 2023; T. Middel pers. comm. 2023); therefore, the likelihood of impact to Lake Whitefish in Opeongo Lake is significantly lower for dreissenids than Spiny Water Flea.

Introduction of nonindigenous and predatory fish

Rainbow Smelt

Unlike Cisco and Smallmouth Bass, Rainbow Smelt is not currently established in Opeongo Lake. Introduction of Rainbow Smelt to Opeongo Lake poses a known risk to Lake Whitefish as introductions elsewhere in Ontario (e.g., Fairy Lake and Mary Lake near Huntsville) have been implicated in Lake Whitefish population decline, at least in combination with introductions of other nonindigenous game fish (MNR 2009).

Rainbow Smelt larvae may compete with larval Lake Whitefish for resources, while adult Rainbow Smelt are known to feed on Lake Whitefish larvae (Evans and Loftus 1987). A study conducted in Twelve Mile Lake (north of Minden, Ontario) observed larval Lake Whitefish in the stomach contents of most (93%) captured Rainbow Smelt, with a daily average of 8.4 larvae predated per smelt (Loftus and Hulsmann 2011). The authors suggested that Lake Whitefish recruitment failure in Twelve Mile Lake was due to Rainbow Smelt predation. Another study conducted in Lake Simcoe supports these results, finding that the abundance of Lake Whitefish decreased as Rainbow Smelt numbers increased (Evans and Waring 2011). Similar Lake Whitefish population declines following the introduction of Rainbow Smelt have been documented in Maine (Wood 2016).

While Rainbow Smelt are not a permitted baitfish per the Ontario Recreational Fishing Regulations Summary (MNRF 2023a), the species is currently present in the Amable du Fond River watershed (e.g., North Tea Lake, Manitou Lake, Kioshkokwi Lake) and Petawawa watershed (e.g., Tim Lake, Rosebary Lake, Catfish Lake) in the northern and northwestern regions of Algonquin PP (Ridgway et al. 2018). Rainbow Smelt are not currently known from the Upper Madawaska drainage (EDDMapS 2023). Additional lakes in the Petawawa River watershed are accessible and predicted to be invaded by Rainbow Smelt in the future (Ridgway et al. 2018).

Northern Pike

Northern Pike is not native to Algonquin PP (Ridgway and Middel 2020) and was first discovered in the Opeongo River inside the park’s southeastern boundary in the 1980s (Strickland 2000). It was then found upstream of the Booth Lake dam (a barrier to fish passage) in 1994, suggesting that more than one individual was purposely transferred via human intervention, and by 1999 four Northern Pike were captured during sampling immediately downstream of the Opeongo Lake dam (Strickland 2000). The dam was specifically designed to prevent the passage of fish, and although fishing within 300 m downstream of the dam and transporting live sport fish overland is prohibited (MNRF 2023a), it is possible that Northern Pike will eventually gain access to Opeongo Lake, posing a significant risk to Lake Whitefish survival.

Studies examining the influence of Northern Pike introductions on the morphology of the closely related European Whitefish (*C. lavaretus*) in Sweden found that pike initiate a “morphological response” (i.e., altered physiology and physical attributes) in whitefish. This response is speculated to result from avoidance of predation (Enbom 2013). Trudel et al. (2011) hypothesize that predation of large-bodied Lake Whitefish by Northern Pike is likely as they tend to select larger prey items.

Human-induced climate change

The effects of human-induced climate change on coldwater species such as Lake Whitefish directly stem from (i) increasing water temperature and (ii) changes in winter ice cover, which in turn indirectly alter habitat use, habitat quality and overall survival. Clear evidence of climate change influencing the aquatic ecosystems of Algonquin PP is revealed by long-term datasets (Ridgway et al. 2018; Ridgway and Middel 2020). Ice-out dates on Opeongo Lake have been recorded since 1964 and exhibit a relatively consistent trend, averaging approximately ten days earlier today (The Friends of Algonquin Park 2022). Ice-out on Opeongo Lake in 2021 occurred on April 10 (the third earliest date recorded), while ice-out in 2022 occurred on April 25 (more consistent with the long-term trend line).

Although projected climate warming is expected to impact smaller lakes more significantly than larger lakes, Opeongo Lake exhibits a large surface area and is comprised of four smaller lake basins. Opeongo Lake may therefore respond to climate change similarly to a series of smaller, interconnected lakes (N. Mandrak pers. comm. 2023).

As described below, climate change threatens Lake Whitefish in Opeongo Lake via multiple pathways, although further study (and time) is required to gauge the true effect.

Reduction in suitable oxythermal habitat

Lake Whitefish require sufficient levels of DO, which can be influenced by changes in temperature (Gorsky et al. 2012). Unusually warm spring water temperatures may trigger early onset of thermal stratification, increasing the amount of time in which the hypolimnion is physically isolated from the atmosphere (which would otherwise replenish DO levels). This effect ultimately results in a decline in hypolimnetic DO and increases the likelihood (and longevity) of hypoxia and/or anoxia in a given year.

Suitable water temperature and DO collectively create an oxythermal habitat envelope for Lake Whitefish (and other coldwater fish). Projected climate warming is expected to decrease the volume and spatial extent of optimal and/or suitable oxythermal habitat conditions (Gorsky et al. 2012; Ridgway et al. 2018; Ridgway and Middel 2020), thereby reducing the quantity and/or quality of Lake Whitefish habitat in Opeongo Lake.

Increased egg mortality

Spawning and egg development in Lake Whitefish are linked to water temperature, with successful egg development occurring between 0.5 and 10 °C (Gorsky et al. 2012; Price 1940). Projected warming may delay the onset of initial and peak spawning by Lake Whitefish, decreasing the time available for egg development. Reductions in ice-cover may also expose developing eggs to greater wave intensity during storm events (particularly in late fall and/or early spring), causing damage or displacement. The incidence of egg mortality was related to the timing of ice cover during a study of Lake Whitefish in Lake Michigan (Grand Traverse Bay), with early onset of ice cover associated with the highest rates of egg survival (Freeberg et al. 1990).

Changes in prey availability

Lake Whitefish emerge in Opeongo Lake within days of ice-out (Cucin and Faber 1985). Any changes to ice-out timing may reduce zooplankton prey availability for larval Lake Whitefish, unless prey are also able to shift life history strategies (Freeberg et al. 1990; Gorsky et al. 2012).

Increased incidence of harmful algal blooms

Increases in air and water temperature may in turn increase the likelihood of blue-green algae (i.e., cyanobacterial) blooms in Algonquin PP waterbodies, which are also known as harmful algal blooms (HABs). HABs may cause stress and/or ultimate mortality of Lake Whitefish due to a sudden decrease of oxygen (i.e., hypoxia) as excess algae die and subsequent decomposition consumes available oxygen (Ridgway and Middel 2020). Local effects of HABs may also include the creation of discreet dead zones which have low to no oxygen, a reduction in sunlight penetration below the water's surface, or a reduction in the ability of fish to forage due to algae limiting their field of view (EPA 2023). Local effects may differ across the lake based on morphometrics within each basin (e.g., water depth, surface area, shape).

A cyanobacterial bloom in nearby (and oligotrophic) Dickson Lake has been linked to a series of conditions beginning with late ice-out and early thermal stratification (resulting in incomplete spring mixing), triggering an early onset of hypolimnetic anoxia and increased internal nutrient loading, coupled with elevated summer temperatures and low wind speeds (Favot et al. 2019). The authors of this widely-reported study eliminated the possibility that increased nutrient levels from the broader watershed and/or changes in zooplankton grazing pressure drove the cyanobacterial bloom, and implicated climate change as an "ultimate driver and proximate cause". The well-publicized cyanobacterial bloom in Dickson Lake does not appear to have adversely affected the long-term viability of either Lake Trout or Brook Trout (*Salvelinus fontinalis*), whose populations quickly recovered (M. Ridgway pers. comm. 2023). The potential implications for Lake Whitefish are unknown but presumed to be similar.

Incidental by-catch

Angling effort in Opeongo Lake greatly exceeds that of all other lakes in Algonquin PP, with anglers primarily targeting Lake Trout and Smallmouth Bass (Mitchell et al. 2020). MNRF creel data from Opeongo Lake indicates that an average of 8.6 Lake Whitefish were caught per year by anglers between 2005 and 2019, with an average harvest per year of 5.9 (T. Middel pers. comm. 2023). Estimated rod hours targeting Lake Whitefish within that period averaged only 30.5 hours per year, with several years (2013, 2014, 2018, 2019) representing no angling effort whatsoever. Overall angling effort targeting Lake Whitefish has been negligible historically when compared to other fishes in Opeongo Lake and throughout Algonquin PP (T. Middel pers. comm. 2023).

Angling for Lake Whitefish in Opeongo Lake was prohibited in 2022 (MNRF 2022) following provincial listing of the large- and small-bodied forms as Threatened. Given historically low angling effort and low harvest rates per year prior to prohibition, incidental by-catch likely poses a minor threat and has the greatest likelihood of occurrence when anglers target Lake Trout (which occupies similar though often deeper portions of the lake) rather than Smallmouth Bass or other littoral species (which generally feed in nearshore areas).

1.7 Knowledge gaps

Despite historical and recent research interest, there are several gaps in current knowledge that would benefit from further research and assessment to inform recovery efforts and future habitat protections. These knowledge gaps are detailed below and include:

- key physical attributes of the large- and small-bodied forms
- population abundance, structure, and trends
- genetic isolation of forms
- ontogenetic and seasonal variation in habitat use
- spawning habitat
- larval survival, diet, and dispersal
- trophic niche

Key physical attributes of the large- and small-bodied forms

From the early 1980s until about 2017, research studies focusing on Lake Whitefish in Opeongo Lake (e.g., Ihssen et al. 1981; Challice et al. 2019) along with MNRF fish monitoring programs did not always distinguish between the large- and small-bodied forms (T. Middel pers. comm. 2023). Records of Lake Whitefish from this time period generally represent large-bodied individuals due to biases introduced through sampling methodologies (i.e., small-bodied forms are not typically captured in standard large-mesh gillnets; M. Ridgway pers. comm. 2023). A large historical dataset in which the forms were distinguished is available from Kennedy (1943), though certain metrics reported (e.g., maximum age) differ from more recent (unpublished) MNRF data.

While there is no scientific debate as to the presence of two physically, physiologically, and genetically distinguishable forms of Lake Whitefish in Opeongo Lake (M. Ridgway pers. comm. 2023), a modern systematic study of their physical characteristics (with a focus on key differences) is lacking. It is further unknown whether the large- and small-bodied forms can be differentiated at the larval stage, either through visual inspection or genetic methods.

Population abundance, structure, and trends

Long-term monitoring of fish populations in lakes throughout Algonquin PP is undertaken using North American standard (NA1) large-mesh gillnets (T. Middel pers. comm. 2023), which are 24.8 m long by 1.8 m high, and consist of eight panels (each 3.1 m long) with mesh sizes ranging from 38 to 127 mm (i.e., 38, 51, 64, 76, 89, 102, 114, and 127 mm; Sandstrom et al. 2013). The monitoring program in Algonquin PP involves sampling at five-year intervals and represents a modified-version of the provincial Broad-scale Monitoring (BsM) program, given shorter-duration net sets (i.e., two-hour rather than overnight; T. Middel pers. comm. 2023). Sampling data from the modified-BsM protocol is available from 2013 and 2019, with additional data deriving from Summer Profundal Index Netting (SPIN) sampling completed in 2009 and 2010. Population estimates have been developed for the large-bodied form (as reported in Colm and Drake 2022) based on this sampling data.

The small-bodied form of Lake Whitefish in Opeongo Lake is not typically captured by large-mesh gillnets (M. Ridgway pers. comm. 2023). An Ontario-standard (ON2) small-mesh gillnet is required to survey the small-bodied form, which is 12.5 m long by 1.8 m high, and consists of five panels (each 2.5 m long) with mesh sizes ranging from 13 to 38 mm (i.e., 13, 19, 25, 32, and 38 mm; Sandstrom et al. 2013). In addition to capturing the small-bodied form, small-mesh gillnets will also capture smaller individuals of the large-bodied form.

Modern surveys targeting Lake Whitefish specifically (rather than the pelagic and benthic fish community generally) are needed to support rigorous population abundance estimates and guide future management. Targeted surveys for the large-bodied form with standard large-mesh gillnets occurred in 2021, while small-mesh gillnet surveys targeting the small-bodied form occurred in 2018 (T. Middel pers. comm. 2023). The small-bodied form has not been afforded a population estimate due to lack of sufficient data, and population trends are not available for either form at this time (Fung et al. 2022). Current information related to population abundance, structure, and trends for both forms is limited or lacking, and thus represents a knowledge gap.

Genetic isolation of forms

Recent genetic work has shown that the large- and small-bodied forms of Lake Whitefish in Opeongo Lake are allopatric (i.e., arose in-situ, rather than arriving from separate colonization events) and show evidence of limited interbreeding in the past (C. Wilson pers. comm. 2023). Notwithstanding this, additional studies are needed to determine whether speciation of the two forms is irreversible or if coalescence between the two forms may result from future changes in habitat (or other factors). Ontogenetic and seasonal variation in habitat use

Lake Whitefish habitat is known to vary across life stages and seasons. Spawning and larval habitat are relatively well understood; however, ontogenetic shifts in diet and prey specialization are known to occur in age 0 and juvenile Lake Whitefish (Pothoven et al. 2014; Pothoven and Olds 2020), suggesting the possibility of differences in habitat use across age classes. Additionally, the timing of certain life processes (e.g., egg development) is poorly understood given the unique challenges associated with documenting year-round habitat use (e.g., beneath ice cover). While Lake Whitefish are known to spawn in rivers (Wood 2016), occupation of creeks which are hydrologically connected to Opeongo Lake (e.g., Costello Creek, Hailstorm Creek) is unknown. Variation in habitat use for all Lake Whitefish age classes in Opeongo Lake (and connected watercourses), and the seasonality of habitat use patterns, represents a knowledge gap.

Spawning habitat

Little is known about the physical characteristics of Lake Whitefish spawning habitat in Opeongo Lake (M. Ridgway pers. comm. 2023; T. Middel pers. comm. 2023). Lake Whitefish are assumed to spawn in the same areas as Lake Trout, for which 22 spawning shoals have been identified (T. Middel pers. comm 2023). Nevertheless, the extent to which Lake Whitefish spawning habitat coincides with areas used by Lake Trout is unknown, and it is further thought that Lake Whitefish spawning habitat may be less spatially restricted (M. Ridgway pers. comm. 2023). The extent to which fine-scale physical attributes such as (among others) substrate type, substrate size and structure, water depths, distance from shore, and fetch control spawning habitat quality in Opeongo Lake remains a key knowledge gap.

Larval survival, diet, and dispersal

Apart from previous work by Cucin and Faber (1985), limited survey effort has focused on understanding the spatial distribution and growth patterns of larval Lake Whitefish in Opeongo Lake. The diet of larval Lake Whitefish in Opeongo Lake is unknown, and there is no baseline data upon which to assess annual and long-term trends in larval survival, diet, and dispersal.

Trophic niche

Lake Whitefish species pairs in Canada have often evolved in waterbodies where Cisco are absent. In such cases, one Lake Whitefish form (the larger or “normal” form) occupies the typical benthivore (bottom-feeding) foraging niche while the other (the smaller or “dwarf” form) adopts a pelagic/limnetic (open-water) life strategy and feeds on plankton (Bernatchez 2004), effectively acting as a “Cisco mimic” (Ridgway and Middel 2020). This pattern of habitat partitioning has arisen independently in several lakes including Como Lake northwest of Sudbury (Vuorinen et al. 1993) and Big Trout Lake in Algonquin PP (Ridgway and Middel 2020). Other unusual instances of trophic specialization in Lake Whitefish have arisen elsewhere. Lake La Muir in Algonquin PP possesses only the pelagic/limnetic form of Lake Whitefish and lacks a benthic form entirely despite the availability of deep water with sufficient DO (Ridgway and Middel 2020).

At this time, evidence of habitat partitioning between the large- and small-bodied forms in Opeongo Lake is limited. Kennedy (1943) found that the large-bodied form occupied shallower water (10 m) than the small-bodied form (15 m) in August, but otherwise did not find differences in vertical distribution during the remaining survey period (May to September). It has been speculated that the large-bodied form could co-exist alongside the introduced Cisco in shallower waters (i.e., occupy a pelagic niche) given its larger size and thus greater ability to compete for plankton (J. Colm pers. comm. 2023). Notwithstanding this, gillnets set in the pelagic zone of Opeongo Lake typically only capture Cisco (M. Ridgway pers. comm. 2023). Current sampling data seems to suggest that both forms are benthic (M. Ridgway pers. comm. 2023), though the mechanisms which maintain niche partitioning are unknown. There is a need to confirm diet and overall trophic niche for both the large- and small-bodied forms individually.

1.8 Recovery actions completed or underway

Studies of Lake Whitefish in Opeongo Lake began nearly a century ago when Kennedy (1943) captured large- and small-bodied morphotypes during sampling with gillnets and fyke nets deployed in the late 1930s. Since Kennedy's seminal study, researchers operating out of the Harkness Laboratory of Fisheries Research have made further and significant contributions to our understanding of Lake Whitefish life history (primarily the large-bodied form) in Opeongo Lake. Ihssen et al. (1981) explored variation in ecology and morphology of Lake Whitefish populations across Ontario (including Opeongo Lake), while Cucin and Faber (1985) considered reproduction and early life history. Later, Carl and McGuiness (2006) compared the Lake Whitefish community structure in Opeongo Lake to those of nine other lakes across southcentral Ontario. Most recently, Challice et al. (2019) used depth stratified gillnet sampling to reveal and model habitat associations.

Angling for Lake Whitefish (either form) in Opeongo Lake was prohibited in 2022 following provincial listing as Threatened (MNRF 2022). While angling pressure for Lake Whitefish in Opeongo Lake has been low to negligible over the previous decade (T. Middel pers. comm. 2023), the prohibition on angling for Lake Whitefish is a statutory requirement under section 9 of the ESA and provided clarity to anglers and park visitors that the species (both forms) could no longer be targeted.

Also in 2022, a pamphlet introducing anglers and park visitors to the large- and small-bodied populations of Lake Whitefish was prepared and distributed by park staff at the fish check station at the Opeongo Lake Access Point (T. Middel pers. comm. 2023). Recent articles in *The Raven* (LeGros 2022; published by the Friends of Algonquin Park) and the creel bulletin (N. Lacombe pers. comm. 2023) served to introduce a wide audience to the uniqueness of Lake Whitefish in Opeongo Lake.

Surveys targeting Lake Whitefish in Opeongo Lake undertaken by MNRF staff occurred in 2018 (small-bodied) and 2021 (large-bodied). A more comprehensive sampling program for the small-bodied form is planned for 2024, with preliminary surveys to occur in 2023 (M. Ridgway pers. comm. 2023).

Additionally, the Algonquin Provincial Park Management Plan (1998) guides day-to-day management and development activities within Algonquin PP as well as informing stewardship policies and wildlife management decisions. The management plan also includes direction regarding species at risk within the park. Per the management plan, provincially vulnerable species, Threatened, and Endangered species will be prioritized in management decisions to ensure their protection, which includes encouraging further studies of species at risk within the park, such as Opeongo Lake Whitefish.

2.0 Recovery

2.1 Recommended recovery goal

The recommended long-term recovery goal for Lake Whitefish (large- and small-bodied populations) in Opeongo Lake is to maintain self-sustaining populations of both forms.

2.2 Recommended protection and recovery objectives

The recommended protection and recovery objectives for Lake Whitefish (Opeongo Lake large- and small-bodied populations) are:

1. Minimize risk of introducing aquatic invasive and predatory species.
2. Refine population abundance estimates and project trends.
3. Clarify patterns in habitat occupancy for all life stages to inform habitat protection.
4. Clarify trophic niche and diet to inform recovery efforts.
5. Monitor key water quality parameters to inform recovery efforts.
6. Promote awareness of large- and small-bodied Lake Whitefish in Opeongo Lake and threats facing them.

2.3 Recommended approaches to recovery

Table 4. Recommended approaches to recovery of the Opeongo Lake large- and small-bodied populations of Lake Whitefish in Ontario.

Objective 1: Minimize risk of introducing aquatic invasive and predatory species.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Short-term	Management	**1.1** Install boat and gear washing stations at Opeongo Lake access points. • Prepare an operations plan to support management and maintenance by park staff. • Consider feasibility of multiple stations (e.g., access point, Opeongo Road). • Consider operating as inspection stations.	Threats: • Introduction of invasive aquatic invertebrates
Critical	Ongoing	Management	**1.2** Manage motorboat and angling activity. • Limit boat horsepower. • Consider the feasibility of further restrictions on boating and angling to reduce risk of aquatic invasive species introduction.	Threats: • Introduction of invasive aquatic invertebrates • Incidental by-catch
Necessary	Short-term	Management	**1.3** Prepare an invasive species rapid response framework. • Assess feasibility and effectiveness of post-introduction management options to limit impacts of aquatic invasive species.	Threats: • Introduction of invasive aquatic invertebrates • Introduction of nonindigenous/ predatory fish

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Beneficial	Short-term	Management	**1.4** Install signage at the Opeongo Lake boat launch and Annie Bay dam to support aquatic invasive species prevention efforts. • Inform anglers and visitors about the risks of aquatic species introductions and best management practices (e.g., drying gear between lakes, not moving live sportfish overland).	Threats: • Introduction of invasive aquatic invertebrates
Beneficial	Short-term	Management	**1.5** Position park staff at access points (i.e., vehicular and portage) particularly during peak times. • Bring gear cleaning supplies and describe best management practices (e.g., drying gear between lakes).	Threats: • Introduction of invasive aquatic invertebrates

1062 Objective 2: Refine population abundance estimates and project trends.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Ongoing	Inventory, Monitoring and Assessment	**2.1** Establish and deliver a long-term monitoring program. • Program design should consider study goals, sampling timing, gear type, gillnet set duration, interval, etc. • Program should establish baseline data and provide reliable inputs to population estimates (abundance, genetics, structure and trends), to determine whether the population is self-sustaining.	Knowledge gaps: • Key physical attributes of the large- and small-bodied forms • Population abundance, structure and trends • Genetic isolation of forms • Ontogenetic and seasonal variation in habitat use • Trophic niche

Objective 3: Clarify patterns in habitat occupancy for all life stages to inform habitat protection.

Relative priority	**Relative timeframe**	**Recovery theme**	**Approach to recovery**	**Threats or knowledge gaps addressed**
Necessary	Short-term	Inventory, Monitoring and Assessment	**3.1** Locate, delineate and characterize spawning areas for Lake Whitefish (both forms). • Undertake annual surveys during the spawning season (November) involving (i) passive acoustic telemetry and/or (ii) opportunistic gillnetting in suitable spawning habitat. • Characterize the physical attributes (e.g., depth to substrate, substrate size classes, structure, distance from shore, fetch) of confirmed spawning areas, and compare with other areas which lack spawning activity. • Produce spawning habitat mapping (internal to MNRF/Ontario Parks) to advance management goals and inform habitat protection.	Knowledge gaps: • Spawning habitat
Necessary	Short-term	Inventory, Monitoring and Assessment	**3.2** Clarify larval habitat use. • Conduct larval surveys in nearshore (seine) and offshore (tows) areas. • Determine timing of emergence, growth and dispersal. • Link larval surveys with known spawning areas to clarify hatching success, productivity, and functional value of different spawning areas.	Knowledge gaps: • Larval survival, diet and dispersal

Relative priority	**Relative timeframe**	**Recovery theme**	**Approach to recovery**	**Threats or knowledge gaps addressed**
Necessary	Short-term	Monitoring and Assessment	**3.3** Clarify seasonal habitat use for adults. • Assess movement and occupancy patterns throughout the year through a combination of (1) passive acoustic telemetry and (2) gillnetting in specific habitats and time-periods. • Confirm whether hydrologically connected watercourses (e.g., Costello Creek, Hailstorm Creek) provide important habitat (e.g., for spawning) and/or seasonal habitat (e.g., when the lake is well-mixed). • Determine the functional value, spatial distribution, and importance of different habitat types to inform habitat protection.	Knowledge gaps: • Ontogenetic and seasonal variation in habitat use

1066 Objective 4: Clarify trophic niche and diet to inform recovery efforts.

Relative priority	**Relative timeframe**	**Recovery theme**	**Approach to recovery**	**Threats or knowledge gaps addressed**
Beneficial	Short-term	Monitoring and Assessment, Research	**4.1** Clarify diet and trophic niche for adults to inform recovery efforts. • Conduct isotopic analysis to reveal differences (if any) in trophic niche between the large- and small-bodied forms. • Conduct stomach contents analysis to complement the isotopic analysis.	Knowledge gaps: • Trophic niche
Beneficial	Short-term	Monitoring and Assessment, Research	**4.2** Clarify diet for larvae to inform recovery efforts. • Conduct isotopic analysis on larvae. • Conduct stomach contents analysis to complement the isotopic analysis. • Sample zooplankton during larval surveys to confirm prey availability.	Knowledge gaps: • Larval diet and dispersal

Objective 5: Monitor key water quality parameters to inform recovery efforts.

Relative priority	**Relative timeframe**	**Recovery theme**	**Approach to recovery**	**Threats or knowledge gaps addressed**
Beneficial	Ongoing	Monitoring and Assessment, Research	**5.1** Prepare and implement an ongoing water quality monitoring program to inform recovery efforts. • Monitoring program could be implemented concurrently with targeted Lake Whitefish surveys. • Monitor key chemical parameters including (at a minimum) DO, temperature, calcium, and pH at stratified depths. • Continue ice-out monitoring.	Threats: • Human-induced climate change Knowledge gaps: • Ontogenetic and seasonal variation in habitat use

Objective 6: Promote awareness of large- and small-bodied Lake Whitefish in Opeongo Lake and threats facing them.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Ongoing	Education and Outreach	**6.1** Disseminate information to park staff and visitors. • Install educational signage at the Opeongo Lake Access Point (#11). • Create and disseminate educational materials (e.g., pamphlets) and deliver lectures/workshops at the Visitors Centre, Opeongo Lake Access Point (#11) and other strategic areas. • Build on pre-existing exhibit at the Visitors Centre to incorporate Lake Whitefish information.	Threats: • Introduction of invasive aquatic invertebrates • Introduction of nonindigenous/predatory fish • Incidental by-catch

Narrative to support approaches to recovery

The recommended long term recovery goal for Lake Whitefish in Opeongo Lake emphasizes the need to maintain a “self-sustaining” population of both forms. The recovery goal does not reference increasing the size of either population (through habitat enhancement, etc.) as there is currently no evidence suggesting that this would contribute meaningfully to recovery efforts and/or be justified in terms of resource expenditure. Implementation of the monitoring program and other recovery approaches outlined herein may reveal that certain strategic enhancement efforts (e.g., improvement or creation of spawning habitat) would be beneficial or even necessary, but data which support such a conclusion is lacking at this time.

Wherever possible, all recommended survey, sampling/monitoring and research efforts should distinguish between the large- and small-bodied forms. This is not explicitly stated in the recovery objectives and approaches (for brevity) but is implied. For example, fish sampled during spawning surveys (via strategic gillnetting) should be differentiated at each discrete sampling area (if possible) to determine whether the timing and/or location of spawning habitats overlap between the two forms. This will assist with identifying reproductive barriers, which may be prezygotic (i.e., arising prior to reproduction) or postzygotic (i.e., arising after zygote formation and hampering embryo development). Additionally, research program design should strive to minimize mortality (to the extent possible). Instances of unavoidable mortality will allow for additional morphometric and genetic study of the two forms. All research activities must employ gear which has been sterilized to avoid the risk of aquatic invasive species introductions.

Minimize threats associated with the introduction of aquatic invasive and predatory species

The introduction of aquatic invasive species (AIS) and nonindigenous predatory fish poses a severe risk to both forms of Lake Whitefish in Opeongo Lake. Collapse of the Lake Whitefish species pair in Como Lake (and replacement with a single, larger species) offers an instructive and disconcerting lesson on how quickly trophic effects can reverberate through a lake ecosystem following the introduction of Spiny Water Flea (Reid et al. 2017). Invasive zooplankton such as Spiny Water Flea, Fishhook Water Flea and others have the greatest likelihood of transfer to Opeongo Lake via watercraft and/or gear associated with anglers having recently visited an invaded waterbody. Predatory fishes whose historical range fell beyond the boundaries of Algonquin PP now occur in close proximity to Opeongo Lake: Northern Pike gained access to Tip Up Lake below the Opeongo Lake dam nearly three decades ago, while Rainbow Smelt occurs in at least six lakes extending across the northern region of the park.

There are many angling restrictions in Opeongo Lake which seek to limit the risk of introduction and transfer of AIS, including prohibitions on using live bait and fishing within 300 m downstream of the Opeongo River dam (MNRF 2023a). Still, Opeongo Lake is particularly susceptible to introductions of AIS and predatory fish given vehicular access from Highway 60, intense angling and visitor interest, and permissibility of motorboats with no horsepower limits (Ridgway et al. 2018). On a busy summer day, 100 boats may be launched from the Opeongo Lake Access Point (N. Lacombe pers. comm. 2023).

AIS risk mitigation on Opeongo Lake benefits from the fact that only a single boat and parking access point is available to visitors. Installation of a mandatory boat and gear washing station(s), with an accompanying operations plan to support management by park staff, is considered a critical, short-term recovery activity. Despite this, there are significant implementation challenges associated with the management of such stations by park staff given the sheer volume of boats, timing (e.g., boats may be launched as early as 5:00 a.m.), contaminated fishing gear, and enforcement (P. Gelok pers. comm. 2023). To partly address these issues, boat and gear wash stations could be established in multiple locations; for example, at both the Opeongo Lake Access Point and on Opeongo Road in a suitable location north of Highway 60. Effectiveness would likely be improved if the wash stations were treated as inspection stations, which would require additional commitment and resources from park staff.

Given the likelihood and severity of Spiny Water Flea establishment, and due to the aforementioned challenges with wash stations, there is a need to consider more effective measures to control motorboats and alter angling activity on Opeongo Lake to reduce the likelihood of Spiny Water Flea establishment. Establishing reasonable horsepower limits could be implemented swiftly to reduce traffic on the lake and would lessen the risk of invasive invertebrate introductions to some degree (Ridgway et al. 2018).

An invasive species rapid response framework specific to Algonquin PP should be developed to guide efforts following detection of an introduced AIS or predatory fish, which balances the feasibility and effectiveness of various response options (e.g., eradication, containment, control). Although eradication may not be feasible, other management options – such as containment or control – may reduce impacts and spread of AIS. Similar frameworks from other jurisdictions may serve as a guide, including the Invasive Species Early Detection and Rapid Response Plan for British Columbia (IMISWG 2014).

Installation of signage at portage access points would emphasize the risks of AIS to Opeongo Lake to visitors, and reinforce best management practices (e.g., cleaning and/or drying gear before use in another waterbody, watercraft cleaning). Park staff should also be stationed at the Opeongo Lake Access Point and portages with cleaning supplies and educational materials outlining best management practices for reducing the spread of invasive zooplankton.

Refine population abundance estimates and project trends

Much of what is known about Lake Whitefish in Opeongo Lake has emerged from research efforts over the past several decades (e.g., Challice et al. 2019; Cucin and Faber 1985; Ihssen et al. 1981; Kennedy 1943) and sampling efforts by MNRF staff since 2009 (e.g., SPIN and modified-BsM surveys). There are limitations with existing datasets, including that most do not distinguish between the large- and small-bodied forms. The small-bodied form in Opeongo Lake is not effectively captured by large-mesh gillnets (M. Ridgway pers. comm. 2023), suggesting that most published and unpublished data pertains only to the large-bodied form. Further, current population estimates of the large-bodied form are based on sampling data focused on the fish community generally (rather than Lake Whitefish specifically) and are insufficient to model population trajectories (Fung et al. 2022).

Additional sampling is needed at routine intervals to (i) verify and/or refine previous population estimates of the large-bodied form, (ii) develop a defensible population estimate of the small-bodied form and (iii) project trends for both forms. Given the high incidence of Lake Whitefish mortality during gillnetting (i.e., approximately 95%, M. Ridgway pers. comm. 2023), the regularity of monitoring should be selected in a way that minimizes impact. Unavoidable mortality does offer copious samples upon which modern morphometric and genetic analysis can be performed. Most individuals cannot be assigned to form without dissection (M. Ridgway pers. comm. 2023), which allows for analysis of age structures and confirmation of reproductive status. If a methodology facilitating visual identification of live specimens could be developed (i.e., supported by growth curves and/or discovery of additional and reliable physical differences) this could assist with minimizing mortality (and permit acoustic telemetry of the small-bodied form).

Clarify patterns in habitat occupancy for all life stages

Many aspects of Lake Whitefish biology and life history are understood generally across its distribution; however, the uniqueness of the large- and small-bodied forms in Opeongo Lake suggests that extrapolation from other populations (in Ontario or elsewhere) may not be appropriate. Lake Whitefish spawning locations in Opeongo Lake are assumed to overlap with those of Lake Trout, but few are known with certainty, nor have any been treated to modern study (T. Middel pers. comm. 2023; M. Ridgway pers. comm. 2023). Other key attributes of life history which are essential for informing management and conservation – such as seasonal/winter habitat use, potential occupation of connected creeks (outside of thermal stratification) and timing of larval dispersal – are based on limited empirical study dating back several decades or are inferred from Lake Whitefish populations elsewhere.

Developing a better understanding of habitat use within Opeongo Lake across forms, age classes, and seasons will inform future management and protection. Critical to this endeavour is the identification, delineation and characterization of all spawning areas, allowing for differentiation and comparisons with areas where spawning activity has not been documented. Such efforts may also clarify the functional value of different spawning areas and their relative productivity, particularly when considered in tandem with the results of offshore (ichthyoplankton tows) and nearshore (seine netting) larval sampling.

A multi-disciplinary team from DFO, MNRF, and several Ontario universities recently installed acoustic receiver arrays (InnovaSea) in Smoke Lake, Canoe Lake, and Tea Lake to assess fish movement patterns (M. Ridgway et al. 2021). These lakes are considerably smaller than Opeongo Lake, and if all 149 receivers were relocated to

Opeongo Lake they would only sufficiently cover the South Arm (M. Ridgway pers. comm. 2023). Despite the obvious challenges and costs associated with installing a receiver array in Opeongo Lake (or in a particular basin), the resulting data would significantly advance knowledge of seasonal habitat use and movement patterns over a multi-year timeframe. The acoustic data would be comparable with the results of strategic gillnetting (e.g., in potential spawning habitat during November, in connected streams) to offer a more fulsome picture of Lake Whitefish habitat use (for both forms) over time and throughout the lake.

Clarify trophic niche and diet

Previous work by Sandercock (1964) and unpublished data collected by the MNRF in the 1980s revealed much of what is known about Lake Whitefish diet in Opeongo Lake through stomach contents analysis. Modern studies should combine stomach contents analysis and isotopic analysis using stable isotopes to clarify the predominant prey items for Lake Whitefish during all life stages. Further analysis of diet (coupled with the results of regular sampling and acoustic telemetry) is intended to resolve longstanding ambiguity regarding trophic niche, particularly whether the large- and small-bodied forms occupy a pelagic/limnetic and/or benthic position.

Monitor key water quality parameters

There are several pathways through which the indirect effects of climate change could adversely affect the quantity or quality of habitat for Lake Whitefish in Opeongo Lake. This includes reducing the availability of suitable oxythermal habitat (i.e., with sufficient DO and appropriate temperature), increasing egg failure (through changes in ice cover), altering prey composition and availability, and increasing the incidence of HABs. A routine monitoring program should be prepared and implemented wherein chemical parameters which are known to (or may) affect Lake Whitefish growth and survival (directly or indirectly) are analyzed, such as DO, temperature, calcium, and pH. Annual monitoring of ice-out dates must also continue.

Promote awareness

Opeongo Lake is easily accessible to park visitors from Highway 60 and offers a centralized launching point for backcountry camping throughout the park. Ease of access facilitates intense interest from anglers, campers, and other visitors, furthered by the permissibility of (and lack of horsepower restrictions on) motorboats. Awareness and outreach initiatives such as installing educational signage at the Opeongo Lake Access Point focused on the uniqueness and importance of Lake Whitefish (and the adverse effects of AIS) would be highly visible to many visitors. There is further opportunity to develop educational materials for dissemination at other strategic locations (e.g., permit offices), discuss threats and ongoing research in published form (e.g., additional publications in *The Raven*) and produce displays for exhibition at the Visitors Centre.

2.4 Area for consideration in developing a habitat regulation

Under the ESA, a recovery strategy must include a recommendation to the Minister of the Environment, Conservation and Parks on the area that should be considered if a habitat regulation is developed. A habitat regulation is a legal instrument that prescribes an area that will be protected as the habitat of the species. The recommendation provided below by the author will be one of many sources considered by the Minister, including information that may become newly available following the completion of the recovery strategy should a habitat regulation be developed for this species.

Lake Whitefish have been documented in all four basins of Opeongo Lake (see Figure 3), though summer habitat use (i.e., following stratification) is restricted to areas with suitable thermal characteristics (i.e., hypolimnion). Occupation of connected creek systems including Costello Creek and Hailstorm Creek is possible (particularly when the lake is well mixed) but not known. Spawning shoals have not been systematically documented but may roughly coincide with those used by Lake Trout. Considerable monitoring and research efforts are needed (and recommended herein) to clarify the spatial distribution of Lake Whitefish (both forms) in Opeongo Lake across seasons and life stages.

It is well established that upland/terrestrial riparian zones adjacent to waterbodies provide indirect (and sometimes critically important) habitat for certain species (or life stages) of freshwater fish. Alternatively, benthivores which occupy a profundal niche in lake-environments are less functionally reliant upon riparian condition or changes in riparian function (Caskenette et al. 2021; Richardson et al. 2010). As a coldwater fish that is largely restricted to deep waters (at least during summer), the persistence of both forms of Lake Whitefish in Opeongo Lake is likely insensitive to riparian conditions (T. Middel pers. comm. 2023, J. Colm pers. comm. 2023, A. Drake pers. comm. 2023, N. Mandrak pers. comm. 2023, M. Ridgway pers. comm. 2023). Thus, the riparian zone surrounding Opeongo Lake does not appear to constitute “habitat” as defined in the ESA.

Given significant knowledge gaps in life history and habitat occupation – both for Lake Whitefish generally and the large- and small bodied forms individually – and Opeongo Lake’s location within a protected area, a habitat regulation may not be required at this time. Should a habitat regulation be developed in the future, it is recommended to include all portions of Opeongo Lake consisting of rocky shoals 10 to 50 m offshore with depths ranging from 3 to 5 m (i.e., suitable spawning and nursery habitat) and deep water areas with water depths ranging from 6 to 32 m (i.e., suitable feeding habitat for juveniles and adults). Further refinement of this habitat recommendation may be possible once more information pertaining to habitat occupancy is revealed through future survey and sampling efforts.

Glossary

Adaptive radiation: process in which organisms diversify rapidly from an ancestral species into a multitude of new forms, particularly when a change in the environment makes new resources available, alters biotic interactions or opens new environmental niches.

Adipose fin: A soft, fleshy fin located behind the dorsal fin and just forward of the caudal fin, found in fish of certain families, believed to have some sensory function.

Allopatric: A group of organisms which are geographically isolated.

Annulus (pl. Annuli): Annual markings (rings) produced on fish scales in response to seasonal growth patterns.

Benthivore: Fish that prey on shellfish, crustaceans and other small invertebrates that dwell on the lake bottom or seafloor.

Caudal: Referring to the posterior or tail.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC): The committee established under section 14 of the Species at Risk Act that is responsible for assessing and classifying species at risk in Canada.

Committee on the Status of Species at Risk in Ontario (COSSARO): The committee established under section 3 of the *Endangered Species Act, 2007* that is responsible for assessing and classifying species at risk in Ontario.

Conservation status rank: A rank assigned to a species or ecological community that primarily conveys the degree of rarity of the species or community at the global (G), national (N) or subnational (S) level. These ranks, termed G-rank, N-rank and S-rank, are not legal designations. Ranks are determined by NatureServe and, in the case of Ontario’s S-rank, by Ontario’s Natural Heritage Information Centre. The conservation status of a species or ecosystem is designated by a number from 1 to 5, preceded by the letter G, N or S reflecting the appropriate geographic scale of the assessment. The numbers mean the following:

1 = critically imperiled
2 = imperiled
3 = vulnerable
4 = apparently secure
5 = secure
NR = not yet ranked

Cycloid: Thin, rounded scales which overlap.

Diel vertical movement: Also known as diurnal vertical migration. Pattern of movement typical of certain aquatic organisms, involving changes in occupied water depth across a 24-hour period.

Dorsal: Referring or related to the back or upper side of an organism’s body.

Endangered Species Act, 2007 (ESA): The provincial legislation that provides protection to species at risk in Ontario.

Epilimnetic (Epilimnion): Referring to the surface layer in a body of water.

Fork length: A fish’s body length measured from the tip of its snout to the fork of the tail.

Founder effects: Reduced genetic diversity in a population, arising from descendance from a small number of colonizing ancestors.

Genetic drift: Changes in the gene pool of a small population owing to random chance events.

Gill rakers: Bony or cartilaginous projections from the gill arch which serve to sieve and retain food particles.

Hypolimnion: Deeper and colder layer in a thermally stratified body of water.

Interstitial space: Open areas or cavities between particles of substrate.

Limnetic: Referring to (living in) an open body of water.

Melanophore: Specialized cells filled with the dark pigment melanin.

Morphotype: Group of different types of individuals of the same species.

Nuptial tubercles: Raised structures made of keratin typically shed after breeding.

Oligotrophic: Lake or water body with relatively low productivity as a result of poor nutrient supply.

Ontogenetic: of or relating to the origin and development of individual organisms.

Oxythermal: Referring to both oxygen and temperature collectively.

Pelagic: Referring to open water.

Pelvic axillary process: A small, triangular projection at the upper end of the base of the pelvic fin.

Postzygotic (reproductive barrier): Arising after zygote formation and hampering embryo development.

Prezygotic (reproductive barrier): Arising prior to reproduction.

Propagule (pl. Propagules): A structure which may give rise to a new individual organism.

Rod hours: Number of hours spent by an angler targeting a particular species.

Species at Risk Act (SARA): The federal legislation that provides protection to species at risk in Canada. This Act establishes Schedule 1 as the legal list of wildlife species at risk. Schedules 2 and 3 contain lists of species that at the time the Act came into force needed to be reassessed. After species on Schedule 2 and 3 are reassessed and found to be at risk, they undergo the SARA listing process to be included in Schedule 1.

Species at Risk in Ontario (SARO) List: The regulation made under section 7 of the *Endangered Species Act, 2007* that provides the official status classification of species at risk in Ontario. This list was first published in 2004 as a policy and became a regulation in 2008 (Ontario Regulation 230/08).

Standard length: A fish’s body length from the tip of its nose to the end of its last vertebrae.

Thermocline: Transition layer between warmer, less dense water at the surface and cooler, denser water below; a product of lake stratification in summer.

Thermal stratification: Settling of colder water below warmer water in a waterbody, producing layers with distinct thermal characteristics.

Trophic Niche: The unique position an organism occupies in a food web.

List of abbreviations

AIS: Aquatic Invasive Species
CI: Confidence Interval
COSEWIC: Committee on the Status of Endangered Wildlife in Canada
COSSARO: Committee on the Status of Species at Risk in Ontario
CWS: Canadian Wildlife Service
DO: Dissolved Oxygen
DU: Designatable Unit
DFO: Fisheries and Oceans Canada
ESA: Ontario’s *Endangered Species Act, 2007*
FL: Fork Length
HAB: Harmful Algal Bloom
ISBN: International Standard Book Number
MECP: Ministry of the Environment, Conservation and Parks
MNRF: Ministry of Natural Resources and Forestry

MVP: Minimum Viable Population
PP: Provincial Park
ROM: Royal Ontario Museum
SARA: Canada's *Species at Risk Act*
SARO List: Species at Risk in Ontario List
SD: Standard Deviation
SL: Standard Length

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