Review of the Fish-out Protocol and Database for Lakes and Impoundments in the Northwest Territories and Nunavut

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2023

Canadian Technical Report of
Fisheries and Aquatic Sciences 3554

Fisheries and Oceans Canada / Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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REVIEW OF THE FISH-OUT PROTOCOL AND DATABASE FOR LAKES AND IMPOUNDMENTS IN THE NORTHWEST TERRITORIES AND NUNAVUT

by

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Cat. No. Fs97-6/3554E-PDF ISBN: 978-0-660-49334-3 ISSN 1488-5379

Correct citation for this publication:

Yee, C., Jacobs, K. B., Blanchfield, P.J. 2023. Review of the fish-out protocol and database for lakes and impoundments in the Northwest Territories and Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3554: viii + 38 p.

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Large-scale resource development projects in Canada's north often require the partial or entire destruction of inland lakes. The fish in these lakes are salvaged following a standard fish-out protocol where proponents provided data that were then compiled by Fisheries and Oceans Canada (DFO). Here we examined the fish-out data to provide an overview of the dominant fish species encountered, examine what factors might influence the efficacy of a fish-out, and test whether the protocol-described thresholds were reasonable. Of the nineteen fish-outs recorded in the database, roughly half were excluded because of missing data on lake size, habitat characteristics, and fishing effort. Fish-outs typically occurred in small lakes (~40 ha) and gillnetting was an effective method to deplete populations of Lake Trout (*Salvelinus namaycush*), Round Whitefish (*Prosopium cylindraceum*), or Arctic Char (*S. alpinus*), but less effective for removing Burbot (*Lota lota*) and smaller-bodied fishes. Our analysis indicated that a CPUE threshold of 5-10% of maximum CPUE is likely achievable for most fish-outs providing there is sufficient initial capture effort and, once reached, would be a suitable threshold to commence the final removal phase. Population estimates, determined by the depletion method (Leslie) from CPUE data, regularly underestimated fish abundance. The current protocol has limited ability to provide fish-habitat linkages and other approaches should be considered.

RÉSUMÉ

Yee, C., Jacobs, K. B., Blanchfield, P.J. 2023. Review of the fish-out protocol and database for lakes and impoundments in the Northwest Territories and Nunavut. Can. Tech. Rep. Fish. Aquat. Sci. 3554: viii + 38 p.

Les projets de développement des ressources de grande envergure dans le Nord canadien exigent souvent la destruction partielle ou totale de lacs intérieurs. Les poissons dans ces lacs sont récupérés selon un protocole normalisé qui exige que les promoteurs fournissent des données qui sont ensuite compilées par Pêches et Océans Canada. Dans le présent document, nous avons étudié les données sur la récupération des poissons afin d'obtenir un aperçu des espèces de poissons dominantes pêchées, d'examiner les facteurs pouvant influencer l'efficacité de la récupération des poissons, et de vérifier si les seuils décrits dans le protocole étaient raisonnables. Sur les dix-neuf activités de récupération enregistrées dans la base de données, environ la moitié ont été exclues en raison de données manquantes concernant la taille du lac, les caractéristiques de l'habitat et l'effort de pêche. La récupération des poissons avait généralement lieu dans de petits lacs (environ 40 ha). La pêche aux filets maillants était une méthode efficace pour réduire les populations de touladis (*Salvelinus namaycush*), de ménominis ronds (*Prosopium cylindraceum*) et d'ombles chevaliers (*Salvelinus alpinus*), mais était moins efficace pour réduire les populations de lottes (*Lota lota*) et de poissons de plus petite taille. Notre analyse a indiqué qu'un seuil des captures par unité d'effort (CPUE) équivalant à 5 à 10 % des CPUE maximales est probablement réalisable pour la plupart des activités de récupération, à condition que l'effort de capture initial soit suffisant. Une fois atteint, il s'agirait d'un seuil approprié pour commencer la phase de récupération ultime. Les estimations de la taille des populations, déterminées selon la méthode d'épuisement Leslie à partir des données de CPUE, ont régulièrement sous-estimé l'abondance des poissons. La capacité à établir des liens entre le poisson et l'habitat selon le protocole actuel est limitée et d'autres approches devraient être envisagées.

1. INTRODUCTION

Fisheries and Oceans Canada (DFO) published the "General Fish-out Protocol for Lakes and Impoundments in the Northwest Territories and Nunavut" (Tyson et al. 2011) to address the need for a standardized fish-out protocol for the permitting of a range of development activities in Canada's north. For example, to access diamond-containing kimberlite pipes, which are often located beneath lakes, new diamond mines typically require the overlying lake to be fully or partially dewatered. Expanding development activities in Canada's north is requiring fish removals from an increasing variety of waterbodies. The fish-out protocol was developed to provide standardized guidance on the removal of all fish species from the target waterbody to meet the requirements for authorization (Tyson et al. 2011).

As a condition of *Fisheries Act* s.35(3) authorizations, all fish are required to be recovered from each waterbody slated for dewatering. Dewatering an entire waterbody provides a unique opportunity to collect detailed data on the fish community and ecology of northern lakes, for which little is known compared to waterbodies in other regions of Canada. As such, the fish-out protocol provides the framework for fish-out programs that consist of three key components: (1) fish community; (2) aquatic biology/limnology; and, (3) physical habitat inventory (Tyson et al. 2011). The fish-out protocol itself focuses extensively on the fish community component of the fish-out program, describing the methodology and effort required to achieve a successful endpoint (described below). The other two components focus on lake characteristics, lower trophic levels, and habitat assessments with the goal of being able to draw linkages between fish habitat and productivity for northern lakes. The standardized approach to the removal of fish and the associated collection of data described in the protocol serves to provide data consistency among different fish-out projects and allows for better understanding fish-habitat relationships in barrenland lakes (Tyson et al. 2011).

Given the diversity in lake sizes, fish communities, and logistics in the Northwest Territories and Nunavut, DFO developed a general fish-out protocol with the expectation that a detailed site-specific plan be generated for each fish-out project (Tyson et al. 2011). The overarching goal was to have each fish-out project be consistent with the general fish-out protocol. The guiding principle of the fish-out protocol is to ensure that fish stocks in impacted waterbodies are fully utilized. All fish collected during fish-out programs are meant to be used by local communities, if possible. Under certain circumstances, the fish captured from lakes about to be dewatered may be transferred to another waterbody.

The fish community component of the fish-out protocol recommends that fish-out programs occur in two phases:1) the catch-per-unit-effort (CPUE) phase; and, 2) the final removal phase. During the CPUE phase, the physical and chemical properties of the waterbody remain unchanged from development activities. A consistent and sufficient effort of fishing is maintained throughout the CPUE phase, often targeting the dominant species in the waterbody. Captured fish are removed from the waterbody, and catches should show a declining trend during the CPUE phase. These data are to be used to estimate fish population sizes using a catch-effort relationship (Maceina et al., 1993; Tyson et al., 2011). The CPUE phase continues until a pre-determined target CPUE threshold is reached. Tyson et al. (2011) recommended that the threshold to move from the CPUE phase to the final removal phase is when no fish are caught for 24-48 hours (CPUE = 0); at which time nets are removed for 48 hours, and then redeployed, after which no fish should be caught for a further 24-48 hours. The recommendations / guidance recognized that this threshold may not be feasible in all situations. Once the CPUE threshold for the fish-out program is reached the program can transition to the final removal phase, where de-watering can occur and a complete fish census is attempted. During the final removal phase, proponents are free to use all available fishing methods and consistent fishing effort does not need to be maintained.

The protocol outlines the roles and responsibilities of the proponent for what data are to be collected (e.g. fishing effort, numbers of fish caught, species, fish size, weight, age, etc.), and provided to DFO as part of the authorization (Tyson et al. 2011). The type of information collected on fish communities is exceedingly difficult to obtain for northern lakes, and DFO has recognized the importance of cataloguing these data. Extensive early efforts were put into development of a database, based largely on manual inputting of written records from past fish-out projects (Thistle & Tonn, 2007; Tonn, 2006). Now the protocol provides examples of data sheets that the proponent is expected to complete and deliver to the DFO Fish and Fish Habitat Protection Program (FFHPP) lead for each fish-out project. Presently, DFO provides these data sheets electronically (i.e. Microsoft Excel or Access data files) to the proponent. The data collected as part of this process have been retained in an Access database, which is referred to as the "Fish-Out Database". The database has been maintained by the Arctic and Aquatic Research Division of the Ecosystem and Ocean Science Sector of the Ontario and Prairie Region of DFO located at the Freshwater Institute, Winnipeg, MB. New data are added to the database once provided to the DFO database manager, submitted by the DFO FFHPP lead dealing directly with the proponent for project permitting and conducting the fish-out program.

In the decade since the publication of the fish-out protocol, DFO FFHPP has been, and continues to be, regularly engaged in various files that require fish be removed from lakes prior to dewatering. Proponents have raised concerns regarding the time and effort required to complete the protocol, specifically the CPUE phase and the time it takes to determine an endpoint. The endpoint defined in the general fish-out protocol requires a week or more to achieve, which represents a substantial amount of time during the short ice-free season of lakes in Canada's north where most fish-outs have occurred. As a result, FFHPP has requested that DFO Science prepare and conduct a review of the "General Fish-out Protocol for Lakes and Impoundments in the Northwest Territories and Nunavut" (Tyson et al. 2011).

Our general approach is to first summarize all data currently held within the fish-out database, which contains a variety of habitat, limnological, food web and fisheries data from three different types of assessments: 1) baseline assessments; 2) fish-outs; and, 3) other types of assessments (see Methods for descriptions of these assessment types). Because the purpose of this report is to address specific concerns related to the Tyson et al. (2011) protocol that DFO endorses for fish-outs, we specifically examined the data from fish-outs only to assess the following questions:

1. Where have fish-outs occurred in the Northwest Territories and Nunavut?
2. What types of waterbodies have fish-outs occurred in, what fish communities are in these waterbodies and what fishing gear has been used for fish-outs?
3. What levels of fishing effort were used during the CPUE phase of fish-outs? Was the amount of effort sufficient to arrive at population estimates based on depletion methods for the species encountered?
4. Was the threshold to transition from the CPUE phase to the final removal phase achieved in fish-outs? If so, what effort was required? What other levels of fishing effort would be required to achieve lower thresholds (as a percentage of CPUE)?
5. How are small-bodied fish species represented in the database?
6. Are there data gaps and errors in the database?
7. Lastly, we evaluate the fish-out database in the context of its usefulness for fish-habitat linkages to support the mandate of DFO Ecosystem and Ocean Science and FFHPP.

2. METHODS

All analyses were conducted on Version2 of the fish-out database, which was last updated in June 2018 (“Dbasecopy_v2.0_4Jun2018.mdb”). This version of the database contains data ranging from 1994 to 2017. The fish-out database records fishing events as separate assessments. Multiple assessments can be conducted on a single lake across several years. Assessments are divided into three types: 1) baseline assessments; 2) fish-outs; and, 3) other types of assessments. Baseline assessments include sampling for the Aquatic Effects Monitoring Program (AEMP) and environmental baseline sampling programs. Fish-outs are assessments where proponents salvaged fish with the intent to remove all fish from the waterbody. Other assessments recorded in the fish-out database included mark-recapture studies, unidentified fish assessments, and fish transfers.

A total of 19 fish-outs were recorded in the database (*Figure 1a*). However, ten fish-out assessments were either missing lake area (A154, A21, Phaser Lake, Third Portage Lake) or were divided into cells for fish-outs (Long Lake - 3 assessments, Lac de Gras, Brandy Lake, Willy Lake) without indicating cell size. These 10 assessments were omitted from CPUE depletion analysis because effort could not be standardized. For nine of the 19 fish-outs we were able to assess effort during the CPUE phase (*Figure 1a*). For these nine fish-outs we examined the effort required to achieve four CPUE depletion thresholds representing various fractions (20%, 10%, 5% and 2.5%) of maximum CPUE, as well as the threshold of no fish caught for 48 h, as recommended in the protocol (Tyson et al. 2011). Gillnet soak time per hectare (h/ha) was used to estimate CPUE depletions during fish-outs. Gillnets were used as the unit of effort for two reasons: 1) gillnets were the dominant fishing method in all fish-outs (87.1% of fish caught); and, 2) gillnet soak time was consistently reported (99.7% of gillnets). All CPUE thresholds were calculated relative to the three-day maximum gillnet CPUE. The four CPUE thresholds were reached when the three-day average CPUE was equal to or less than the threshold. A fish-out achieved no fish caught for 48 h if no recorded gillnet captures occurred for two consecutive days.

We examined the catch data during the CPUE phase to determine the feasibility of using various percentages of maximum CPUE (20%, 10%, 5% and 2.5%) as potential thresholds to switch to the final removal phase. This analysis identifies the thresholds that previous fish-outs had achieved (i.e. 10% of maximum CPUE), and secondly, assesses whether sufficient effort was expended during the CPUE phase. To assess effort, we compared those fish-outs that achieved a given threshold (20%, 10%, 5% and 2.5% of max CPUE) to the final cumulative effort of those fish-outs that failed to achieve that threshold (i.e. achieved the previous threshold but not the current threshold). Under the assumption that proponents are selecting appropriate fishing gear for the target species, if the effort of fish-outs that achieved a given threshold is greater than the final effort of those that did not, it is likely that the threshold was not achieved because of insufficient netting effort. Conversely, if the effort of fish-outs that achieved a given threshold is less than the final effort of those that did not, it is likely that fishing effort alone did not limit the threshold from being achieved. In these cases, the threshold may not be a consistently achievable objective.

An intended goal of the CPUE phase of the fish-out is to acquire data to estimate population size of individual fish species by relating the cumulative fish removed to the decline in CPUE. To estimate abundance using CPUE depletions, the number of fish removed and fishing effort must be recorded. Fishing methods used included gill nets, angling, electrofishing, minnow traps, trap nets, and dip nets. Seven of the 19 fish-out assessments recorded the number of fish removed each day and the fishing effort (*Figure 1b)*. Within this subset of assessments gillnets, minnow traps, dip nets and electrofishing were used but only gillnet effort was consistently reported, so estimates are based on gillnet CPUE. We used the Leslie method and the Leslie-Ricker method (Maceina et al., 1993; Samarasin et al., 2014) to estimate the fish population based on fish catches during the CPUE phase and compared these estimates to the total number of fish removed from the final removal phase. The Leslie method was selected because it more closely reflected the total number of fish removed during the fish-out.

For Tail Lake, where a mark-recapture study was conducted on Lake Trout (*Salvelinus namaycush*), the population was estimated using the Schnabel method (Schnabel, 1938). The mark-recapture study was conducted during the fish-out while fish were being removed. Each day of fishing was used as a recapture period. The pre-fish-out population estimate was calculated as the recapture period estimate added to the cumulative number of Lake Trout removed prior to the recapture period.

All statistical analyses were conducted using the statistical language and software program R, version 4.0.3 (R Core Team, 2019). Population estimates were calculated using the Fisheries Stock Analysis package in R (Ogle et al., 2020).

3. RESULTS AND DISCUSSION

3.1 Database Summary

The first step in the fish-out protocol review was to assess the available data in the database. The fish-out database contains data on fish captures, fish diet composition, lower trophic level organisms (zooplankton and benthic invertebrates), water quality (Secchi depth, dissolved organic carbon, nutrients, metals, pH, etc.), and physical habitat (e.g. substrate composition). Nonetheless, the fisheries data are the most complete data set in the database and will be the focus of this report.

The fish-out database currently records fishing effort from 103 different assessments across 63 lakes. Baseline assessments (N = 79) made up the majority (76.7%) of all assessments in the database and occurred from 1994-2003 (*Figure 2*). A total of 19 fish-outs (18.4% of assessments) were recorded in the database and occurred from 1997-2017 (*Figure* 2). Of the 19 fish-outs, 4 (Two Rock, Sable, Phaser, and A21) were conducted after 2012, when modifications to the *Fisheries Act* were made (Bill C-68). The remaining 5 assessments (4.8%) were “other assessments” which included 2 mark-recapture studies, 2 unidentified assessments, and 1 fish transfer.

The assessments recorded in the database are all from lakes in the Northwest Territories and Nunavut, Canada. Few lakes in the database have complete georeferenced coordinates (many are missing UTM zones). Appendix A of Samarasin et al. (2014) was used to supplement missing location data for many of the lakes with baseline assessments. Overall, the geographical range of lakes where assessments occurred (and for which location data were available) encompassed a narrow latitudinal distribution, located as far north as N 68º 5’ 60” and as far south as N 64º 30’ 0”, but were distributed across a broader longitudinal range from W 110º 54’ 0” to W 96º 0’ 0”. A cluster of lakes where baseline and fish-out assessments were conducted is located approximately 300 km northeast of Yellowknife, NT (N 62º 27’ 23”, W 114º 22’ 26”; *Figure 3*), near the Ekati and Diavik mines.

The database showed that the majority of assessments have occurred in small lakes (median lake surface area = 29.9 ha; range = 1.3-57,200 ha; *Figure 4*). All the lakes with recorded areas are smaller than 200 ha except Lac de Gras (57,200 ha) and Long Lake (614 ha; *Figure 4*). Data on lake area were missing for 8 of the 63 lakes (*Table 1*). Additionally, some lakes (Long Lake, Willy Lake, Brand Lake, Lac de Gras) were divided into smaller cells with only a portion of the total lake area fished, but information on cell area was not always included in the database.

The number of fish caught differed between assessment types (Kruskal-Wallis: $\chi^2 = 28.24$, $p < 0.001$). More fish were caught in fish-outs (mean = 2243 ± 1015 SEM) and other assessments (mean = 1967 ± 1471 SEM) than baseline assessments (mean = 149 ± 41 SEM; Wilcoxon rank-sum test : $p < 0.05$). When the fish caught across all assessments in a lake were grouped, 34 of the 63 lakes had at least 100 fish caught. Of the remaining 29 lakes, between 90 and 50 fish were caught from 6 lakes, between 50 and 25 fish were caught from 8 lakes, and <25 fish were caught from 13 lakes.

Twelve different fish species were recorded in the database (*Table 2*). In lakes where at least 100 fish were caught, species richness varied from 1 to 8 with a mean value of 3.8 species (*Figure 5*). Based on the 34 lakes with >100 fish caught, the most prevalent species were Lake Trout, Round Whitefish (*Prosopium cylindraceum*), Burbot (*Lota lota*), and Arctic Grayling (*Thymallus arcticus*; *Figure 6)*. Lake Trout and Round Whitefish were also the dominant catches in most lakes based on the number of fish and the total biomass caught (*Figure 7*). The dominant catches by biomass and abundance were calculated for 30 lakes because data on individual fish weights and lengths were missing for four lakes.

3.2 Fish Sampling Gear Type and Selectivity Across All Assessment Types

Eight different fishing methods were used across all assessment types recorded in the fish-out database: gillnets, trap nets, angling, minnow traps, beach seines, longlines, electrofishing, and dip nets. Gillnets were the most common fishing method and were used in almost every assessment (*Figure 8*). Additionally, 85.8% of fish were caught in gillnets and 81.3% of individual fishing sets involved gillnets (*Figure 9*). All other methods were used sporadically. Trap nets were used equally across all three assessment types but only deployed in 21% of lakes (*Figure 9*). Angling was the only other fishing method used in all assessments types, but was more commonly used in “other assessments” (40% of lakes) than in baseline (17% of lakes) or fish-out (11%) assessments. Angling also accounted for a much higher proportion of catches in “other assessments” (50%) than baseline (23%) or fish-out (0%) assessments (*Figure 9*). The selectivity of angling for large-bodied Lake Trout may have been ideal for other assessments, which included fish transfers and mark-recapture studies. Minnow traps (MT) and electrofishing (EL) were used most in fish-outs, on average accounting for less than a fifth of the fish caught (mean MT = 14%, mean EL = 19%; *Figure 9*). Minnow traps were used in one baseline assessment, Peltzer Pond, and accounted for 65% of fish caught in the lake (*Figure 9*).

The efficiency of fishing methods cannot currently be compared because effort was absent from the database for most methods other than gillnets. However, the currently available information can inform the selectivity of fishing methods. Across the various assessment types, gillnet mesh sizes ranged from 0.7 cm to 16.5 cm. The method for reporting mesh sizes varied among assessments where some used multi-mesh nets identified as ranges of mesh size (e.g. 2.5 - 12.5 cm) and others used single mesh nets (e.g. 3.8 cm). Most gillnet captures were in 3.8 cm single mesh nets, accounting for 36% of fish caught. The 3.8 cm gillnets were also the most used mesh size in all assessment types accounting for 95% of nets in baseline assessments, 36% of nets in “other assessments”, and 29% of nets in fish-outs (*Figure 10*).

Generally, gillnets are selective for Lake Trout and Round Whitefish, which make up an average of 45% (N = 45) and 47% (N = 35) of captures, respectively, on a lake (*Figure 11*). Where they occurred, Lake Trout, Round Whitefish, Burbot, Arctic Grayling, Longnose Sucker (*Catostomus catostomus*), and Cisco (*Coregonus artedi)* made up at least 10% of lake-specific gillnet captures. The only species that occurred in four or more lakes and did not make up 10% of gillnet captures is Slimy Sculpin (*Cottus cognatus*). Slimy Sculpin accounted for only 1% of gillnet captures, but were the most common species in minnow traps (mean proportion of captures = 88%, N = 4) and electrofishing (mean proportion of captures = 77%, N = 3). Angling was a highly targeted fishing method, selecting for Lake Trout (mean proportion of captures = 96%, N = 11). Conversely, trap netting was the least selective fishing method, resulting in the most even distribution of species captures with mean proportions of capture ranging from 34% (Round Whitefish) to 10% (Arctic Grayling).

Fishing methods were also selective for fish size (*Figure 12*). Small fish were identified in the database as any fish <100 mm. The 100 mm threshold was based on the maximum size of sculpin in the dataset (approx. 100 mm) and to focus on species and year classes that are rarely harvested for subsistence. Very few small fish of any species were caught in gillnets with only 0.4% of fish caught in gillnets being <100 mm. The proportion of small fish caught was greater in trap nets than gillnets. Small fish made up more than 5% of captures in trap nets for Cisco (*Coregonus artedi*; mean = 27%, N = 3), Slimy Sculpin (mean = 20%, N = 5), and Round Whitefish (mean = 6%, N = 11; *Figure 12*). Both minnow traps and electrofishing had a large proportion of small Burbot (mean MT = 15%, N = 3; mean EL = 24%, N = 2) and Slimy Sculpin (mean MT = 84%, N = 4; mean EL = 77%, N = 3).

3.3 Background Information on Fish-out Projects

The database includes records from 19 different fish-out assessments on 17 different lakes (*Figure 1*). Long Lake accounts for the additional assessments; it was divided into three cells creating three assessments on a single lake. Other lakes (Lac De Gras, Brandy Lake, Willy Lake) had partial fish-outs conducted, where a single section of the lake was fished out (*Figure 3*). Nine of the 19 fish-out assessments (47%) had the size of the lake or area of the fish-out recorded (*Figure 1a*), which averaged 39.5 ha ± 13.2 SEM.

Ten fish-outs occurred before 2002, and were conducted as a single fish-out without phases. Eight fish-outs, all occurring after 2002, are structured in two phases (CPUE and final removal) as suggested in Tyson et al (2011). The only fish-out occurring after 2002 that was not conducted in two phases is A21 where a CPUE phase is the only recorded data.

The most prevalent species in fish-out lakes were Lake Trout, Burbot, and Round Whitefish (*Figure 13*), mirroring the frequency across all assessments with >100 fish caught (*Figure 6*). Lake Trout were caught in every lake except Nancy Lake where only 23 fish were caught (*Figure 13*), which is why Nancy Lake was not included in the analysis of lakes with >100 fish caught. Slimy Sculpin were more prevalent in fish-out lakes (0.35) compared to lakes with >100 fish caught (0.20). This could be attributed to the gears deployed in fish-outs where electrofishing and minnow traps were more commonly used (*Figure 8*).

All eight fishing methods recorded in the database were used in fish-outs. Up to six fishing methods were used in a single fish-out (A418), but nine lakes were only sampled with gillnets (*Figure 14)*. Gillnets were used in all fish-outs and on average caught the most fish (mean proportion of captures = 85%, *Figure 14*). Sable Lake and Airstrip Lake were exceptions where gillnets only accounted for 14% and 19% of captures. In Sable Lake, the most abundant species was Slimy Sculpin, which was better sampled using minnow traps and electrofishing than the other lakes (*Figure 14*). In Airstrip Lake, Burbot was the most captured species (71% of fish caught), and was predominantly captured using trap nets (96% of Burbot captured in Airstrip Lake).

Diet composition, zooplankton, benthic macroinvertebrates, water quality, and physical habitat have been inconsistently collected or recorded for fish-outs (*Table 3*). Physical habitat is to be recorded as a description of substrate (i.e. cobble, gravel, bedrock, etc.) when collected. It was unclear whether the habitat data were collected in a geo-referenced format that allowed temporal and spatial associations with the fish capture data from the CPUE phase of fish-outs, which would be of most use to FFHPP. Information on benthic macroinvertebrates included collection details, such as sampling method, depth, substrate, as well as the taxa collected, and wet and dry masses. Zooplankton data included collection details, such as mesh size, haul length and the taxa collected including wet and dry masses. Different water quality parameters were collected depending on the fish-out. Commonly collected measurements included pH, phosphorus (orthophosphate and total), nitrate, calcium, sulfate, total suspended solids, and alkalinity. Diet composition is a description of the taxa found in fish stomachs as well as their wet and dry weight. Fish livers and muscle samples were also taken for some fish-outs to assess fish tissue metal concentrations. Of the 17 lakes where fish-outs occurred,10 have water quality data, 9 have physical habitat data, 3 have benthic macroinvertebrates data, and 3 had zooplankton samples collected (*Table 3*). Additionally, fish stomachs contents were reported in 7 fish-outs, and metal concentrations reported for fish livers and muscle samples in 6 fish-outs (*Table 3*). Fish stomach content data was reported for 439 fish in the entire database. Only 1 of the 17 fish-outs (Third Portage Lake) had data collected in all of the categories: habitat, benthos, zooplankton, water quality and fish tissue samples of liver, muscle and stomach (*Table 3*).

3.4 Catch Per Unit Effort (CPUE) Phase of Fish-outs

The CPUE phase of fish-outs is critically important as it serves to track the overall progress of the fish removal and informs when it is appropriate to shift to the Final Removal phase. Tyson et al. (2011) recommended that the “ideal CPUE objective is achieved when no fish are captured for 24-48 hr of continuous netting, nets are removed for 48 hr, nets are then re-deployed for 24-48 hr of netting and fish are still not captured”. In reality, the complete absence of fish captures in 24-48 h of continuous netting during fish-outs was rarely achieved. Of the 9 fish-outs with effort data (see *Figure 1a*), only one of these, Airstrip Lake, achieved no fish caught in 48 h (*Table 4*). The thresholds reached (relative to maximum CPUE for a given fish-out) and the final cumulative effort achieved during the CPUE phase varied greatly among the remaining fish-out events. The final cumulative effort during the CPUE phase ranged from 27 h/ha (Panda Lake) to 789 h/ha (Sable Lake). Fish-out effort was skewed to lower values (median = 85.0 h/ha) with five assessments reporting cumulative effort at less than 100 h/ha (*Table 4*).

Seven of the 9 fish-outs with known lake area and fishing effort reached the threshold of 20% of maximum CPUE, which was the lowest threshold we examined (*Table 4*). The higher thresholds of 10%, 5% and 2.5% of maximum CPUE were achieved by progressively fewer of the fish removals (5, 4, and 3 of the fish-outs, respectively; *Table 4*). We observed large variation in the effort required to achieve a given threshold among fish-outs, such that gillnet effort alone did not entirely explain whether a fish-out reached a certain threshold (*Table 4*). For example, of the five fish-outs that did not achieve the 5% threshold, only one (Misery, 181 h/ha) had a final effort greater than the average effort estimated for the four ‘successful’ fish-outs. Generally, the cumulative effort of fish-outs that achieved a given % of maximum CPUE threshold was higher than those fish-outs that did not achieve that threshold (*Figure 15*). For example, of the four fish-outs to achieve the 5% threshold, effort ranged from 51 h/ha (Lake A418) to 204 h/ha (Airstrip Lake), with an average gillnet effort of 123 h/ha (*Table 4)*. Given that target thresholds appeared to be met more frequently when gill-netting effort was higher, the data suggest that thresholds of 20%, 10%, 5% and 2.5% of the three-day maximum CPUE were achievable for fish-outs, but insufficient netting effort occurred where target thresholds were not met.

Increasing gillnet effort does not require a longer fish-out duration (*Figure 16*). Increasing the number of gillnets deployed per day can increase the final effort without extending the duration of the CPUE phase. For example, Sable Lake averaged 23.2 h/ha per day of gillnet soak time over the CPUE phase compared to Misery Lake which averaged 4.2 h/ha per day. Even though the Misery Lake CPUE phase lasted 9 extra days (*Figure 16*), Sable Lake achieved a final effort ~4 times greater (789 h/ha vs 180 h/ha; *Table 4*).

The threshold of zero fish caught in 48 h recommended by Tyson et al. (2011) does not appear to be an achievable target. Of the three lakes that achieved 2.5% of max CPUE, only Airstrip Lake achieved no fish caught in 48 h after 204 h/ha gillnet effort. Of interest, the netting effort at Airstrip, which achieved zero fish caught in 48 h, was much lower (~2-4x) than the two fish-outs that only achieved the 2.5% threshold (Two Rock Lake, 447 h/ha; Sable Lake, 789 h/ha; *Table 4*. Although the data are limited, these findings would suggest that no fish caught after 48 h is not an ideal target, and indeed most fish-outs switched to the final removal phase without achieving this target.

Only two fish-outs (Airstrip Lake and A418) used fishing methods other than gillnets during the CPUE phase. Airstrip Lake used trap nets for fish removals whereas angling, minnow traps, electrofishing, dipnets and trap nets were used in the A418 fish-out. Anecdotally, Airstrip Lake was the only lake to achieve no fish caught for 48 h, and A418 consistently achieved thresholds with less than the mean effort of other successful assessments (*Table 4*). Fishing effort was inconsistently reported for the different fishing methods making it difficult to determine the total fishing effort expended during the CPUE phase. It is possible that multiple fishing methods during the CPUE phase may lower the total effort required to achieve thresholds.

3.5 Population Estimates from CPUE Fish-out Data

Across the seven lakes for which data on lake size and gillnet effort were available (*Figure 1b*), we made 22 separate estimates of population size using the Leslie depletion method (

18). Roughly one third (32%) of these populations did not show a significant decline in CPUE over time, and therefore population size could <u>not</u> be estimated (*Figure 17*). Fish populations that did not show significant declines in CPUE were species that were less frequently caught in gillnets, such as Burbot, and Slimy Sculpin (*Figure 17*). For these species, it is unlikely that gillnet CPUE data are an effective method to derive population estimates.

We compared abundance estimates for each population against the total number of fish removed based on combined data from the CPUE and final removal phases. Although some fish may not have been removed during the fish-out, the total number of fish removed over the entire fish-out is a reliable estimate of the minimum population size. The total number of fish removed was greater than the upper 95% confidence interval of the population estimate for 7 of the 14 populations (*Table 5; Figure 18*). For these populations, the Leslie method underestimated the minimum possible population size.

A notable exception to the low population estimates from the CPUE depletion data is Second Portage Lake where all four species removed, including Burbot, have population estimates that are consistent with the total number of fish removed (

18). Interestingly, the accuracy of the population estimates does not seem to be a result of fishing effort. The Second Portage Lake fish-out achieved a final fishing effort of 52 gillnet h/ha, much less than the two highest effort fish-outs recorded; 446 gillnet h/ha on Two Rock Lake and 789 gillnet h/ha on Sable Lake (*Table 4*). Despite high gillnetting effort, total fish removed was an underestimate in Two Rock Lake and an overestimate for Sable Lake compared to the Leslie population estimate (*Table 5*).

Tyson et al. (2011) suggests mark-recapture be incorporated into fish-outs as an optional component. Of the seven lakes where population estimates could be made using the Leslie depletion method, only Tail Lake recorded the total number of fish marked and had records of recaptures. A21, A418, Phaser Lake, and Third Portage Lake had records of fish marking but no recorded recaptures during the fish-out.

In Tail Lake, 377 Lake Trout were marked roughly three weeks (13-Jul-2011) before the fish-out started (on 5-Aug-2011). Over the fish-out, no additional Lake Trout were marked, and all fish caught were removed from the lake. Over the entire fish-out (5-Aug-2011 to 13-Sep-2011), 321 marked Lake Trout were caught leaving 56 marked Lake Trout unaccounted for at the completion of the fish-out. Using the mark-recapture data from Tail Lake, the Lake Trout population was estimated at 1718 fish [95% CI:1433, 2145]. The mark-recapture estimate is greater than the Leslie depletion estimate of 1104 fish [%95 CI; 782, 1426] and may be a more accurate estimate of the population size. Although the 95% CI of the Leslie estimate includes the actual total number of Lake Trout removed from Tail Lake (1420), there were 56 marked Lake Trout that were never recaptured, suggesting that even the total number of fish removed is an underestimation of the true Lake Trout population size.

3.6 Biological Data in the Database

The ancillary biological data reported for individual fish varies by assessment type, with biological traits more consistently reported in baseline assessments conducted on behalf of proponents (*Figure 19*). Across all assessment types, length (91.2%) and weight (62.5%) were the traits most consistently recorded for fish, with sex (28.9%) and age (12.8%) recorded less frequently. Although only 12.8% of fish have a recorded age, 15.1% of fish had an ageing structure removed. The inconsistencies between the number of ageing structures taken and the absence of ages reported are more pronounced in fish-out assessments (11%) than baseline assessments (6.8%) Additionally, 1.7% of fish with an assigned age in baseline assessments did not have a recorded ageing structure. Ageing structures were infrequently taken (9.7% of fish) during “other assessments”, presumably because fewer fish are killed in fish transfers and mark-recapture studies.

When fishes were removed during the fish-outs, collection of biological data differed between species (*Figure 19*). Biological data were commonly missing for small-bodied species like Slimy Sculpin, and Ninespine Stickleback (*Pungitius pungitius*; *Figure 19*). Additionally, commonly caught species like Burbot and Cisco, as well as small-bodied fishes rarely had ageing structures taken and no ages were recorded even when structures were removed.

An emphasis should be placed on collecting aging structures and reporting fish ages where possible. More complete age data from fish-outs would allow for better estimates of fish growth and mortality and the calibration of size-age curves for northern fish populations. Additionally, since many methods of productivity estimation are cohort-based, age data is important when estimating whole lake productivity (Hayes et al., 2007).

3.7 Current Deficiencies in the Database

A database structural flaw may be that fish caught are recorded in two different locations. The number of fish caught are recorded by: 1) set, and 2) individual fish records. A set is the record of when a specific fishing method was used and the details about the fishing event (e.g. soak time, mesh size). The fish caught by set is divided by species but does not include any of the associated individual-fish biological data like length, weight, and age, which is stored with the individual fish records. The recording of fish data in two separate tables creates inconsistencies in the database. We found that 77.3% of assessments had at least one set missing of individual fish measurements, but most sets (97.1%) have records in both tables. Most of the missing data are associated with four assessments: Phaser Lake fish-out (119 sets missing; 39% of assessment sets), Long Lake baseline (80; 74%), Fox1 baseline (48; 60%), and A21 fish-out (39; 85%). By only entering data in the individual fish records all the biological data could be preserved and a summary query of fish by set could be created in the database without having to enter any additional data.

We found incomplete data for many assessments in the database. As noted earlier, data on lake location and lake area, which are required for permitting, were often missing from the fish-out database. In addition, information about the number of fish removed from a lake, the soak-time for non-gillnet methods, and the area that was fished were often not recorded in the database (*Table 6*). Throughout our analysis, the subset of possible assessments changed because of missing data making some assessments unusable for some questions (i.e. lowering sample size). In practice, proponents are provided with a copy of the database or with datasheets to fill in throughout the fish-out, however the data were not always complete. Having mandatory fields or an software application to fill might improve the completeness of data submitted from fish-outs.

More than half the lakes fished out (9 of 17) only used gillnets during the fish-out (*Table 6*). Gillnets are selective for large-bodied fish and therefore juvenile fishes and small-bodied species may be underrepresented in these fish-outs if multi-mesh nets without fine mesh panels are not used. Likewise, benthic species such as Burbot were also poorly sampled by gillnet sampling resulting in poor CPUE depletions and unreliable population estimates. Studies targeting small-bodied fishes (e.g. cyprinids, sculpins, juveniles, etc.) rarely use gillnets and often employ sampling methods that include: beach seines, electrofishing, minnow traps, and trap nets (Darveau et al., 2012; Hards et al., 2019; McBaine et al., 2018). Incorporating multiple fishing methods into fish-outs could make catches more representative of both the community composition and size range of species.

During the preparation of this report, FFHPP expressed interest in understanding if the current fish-out database contains data useful for defining fish-habitat linkages to support the mandate of DFO Ecosystem and Ocean Science and FFHPP. In general, we found that the habitat data collected were limited, and the spatial and temporal collection of the habitat data were separate from the fish capture efforts. As such, the database does not provide an opportunity to link fish location of capture with the habitat type it was captured within. Changes to the protocol that allow for collection of habitat data during fish capture, or perhaps a different protocol, may be more beneficial if fish-habitat linkages are to be acquired from fish-out projects.

4. CONCLUSIONS AND RECOMMENDATIONS

The fish-out database forms an extremely important data repository for fish data from fish-out and other assessments conducted in Canada's north. One shortcoming of the database is that valuable lake and set meta data or other essential ancillary data were often missing. This includes fundamental information such as the location of each lake, lake area, and the number of hours that equipment was deployed (i.e. fishing effort). While additional data no doubt exist in regulatory reports and other DFO databases these are not easily cross referenced with the Fish-out data base. The Metal Mining Technical Guidance for Environment Effects Monitoring (Environment Canada 2012) requires the latitude and longitude of sampling areas in degrees, minutes and seconds; and a description of the sampling areas sufficient to identify them to be provided. In other cases the database contained incomplete data such as missing UTM zone numbers. Having a requirement for locations in degrees, minutes, and seconds would remove the question of exact lake, and set location. Likewise, when lakes are subdivided into sections (or cells) for fish-outs, reporting of the size of these cells would allow for the inclusion of these metadata for additional analyses. The absence of fundamental information from a number of fish-outs limited our sample size for the analyses in this report, and in turn limits what can be learned from these past efforts to guide future fish-out events.

The analysis of data specific to fish-out projects demonstrates that the fish-out protocol is generally followed, although the missing data and limited collection effort, in some cases, limited our ability to provide a more rigorous assessment of the protocol itself. For the fish-out data available, fishing efforts were focused on the removal of large-bodied fish species in the CPUE phase and excluded smaller bodied fishes. Generally there was limited sampling effort directed to juveniles, small-bodied fish species, and other species not easily caught by gillnets. A true understanding of the community can only be achieved by having complete data for all species of fish.

In future fish-outs, increased sampling effort should be demonstrated in two ways. Using fishing methods in addition to gillnets during the catch-per-unit-effort phase (CPUE) to catch small-bodied fishes, and fishes not easily caught in gillnets, would increase catches and improve understanding of the fish community of these lakes. Secondly, while the goal of achieving zero fish caught in 48 hours was rarely obtained, our analysis of the fish-out data demonstrated that the efficacy of the CPUE phase could generally have been improved by greater fishing effort. Experience at other locations should help dictate what a reasonable level of effort would be for each site including both time and amount of fishing equipment deployed (Environment Canada 2012). Regular consultation with a FFHPP biologist and planning for the short open water season in northern Canada could help ensure a successful CPUE campaign. Generally, when conducting environmental effects monitoring studies, a minimum of seven days of effort is recommended for each area of interest which can include a specific waterbody or for example reference and exposure areas in environmental effects monitoring studies.

Proponents have expressed concern regarding the CPUE phase of the fish-out protocol. Our analysis supports revised guidance with respect to the completion of the CPUE phase documented in the fish-out protocol. Decline in CPUE to 5% or less was generally an achievable target with sufficient fishing effort, whereas no fish capture within 48 hours was not. We recommend that reductions in CPUE to 5% of an initial 3-day maximum CPUE be considered as a threshold for progressing from the CPUE phase to the final removal phase of the fish-out protocol. This would require an estimation of desired effort and duration to ensure staffing is sufficient, based on lake size, to achieve the target threshold. Daily consultation with FFHPP during the CPUE phase is also strongly recommended as large variations in CPUE depletions achieved can occur between lakes with similar effort. Some variation because of habitat heterogeneity and prior connectivity may happen, so complete habitat information in fish-out database would be helpful for many reasons. The fish-out database provides rare insight into lakes in Canada’s north by providing complete censuses. Our review showed that while there can be data quality issues with data provided by proponents, collecting fish-out data is a worthwhile endeavor. Greater efforts could be made to ensure the data collected are more discoverable and accessible. While fish-out data can be used within DFO to refine regulatory processes, the biological data collected and ancillary lake and habitat data continue to be requested and utilized by external agencies. The DFO Access and Privacy Secretariat have provided direction that data collected from fish-outs are considered public data (A. Perreault personal communication). These data could be leveraged for greater use through proactive disclosure to data repositories such as the Government of Canada Open Data Portal for broader use.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge previous efforts by DFO staff and others to define a fish-out protocol and compile these data into the fish-out database. We thank the steering committee, comprised of Alasdair Beattie and Daniel Coombs (DFO FFHPP), Joclyn Paulic and Justin Shead (DFO Canadian Science Advice Secretariat), and Kevin Hedges and Jason Stow (DFO Ecosystem and Ocean Science), for their input and direction, as well as Susan Doka and Kevin Hedges for constructive reviews, and FFHPP for financial support.

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Table 1. Lake characteristics and the type of fisheries assessment conducted for each of the lakes recorded in the fish-out database as of 2017.

LakeID	Lake Name	Lake Area (ha)	Maximum Depth (m)	Assessment type: Baseline	Fish-out	Other
A154	A154	-	30	No	Yes	No
A21	A21	-	-	No	Yes	No
A418	A418	29.0	32	No	Yes	No
AIRST	Airstrip	19.3	3	Yes	Yes	No
BEARC	Bearclaw	8.1	10	Yes	No	No
BEART	Beartooth	4.8	14	Yes	No	No
BIGPO	Big Pond	28.2	1	Yes	No	No
BIGRE	Big Reynolds Pond	17.1	3	Yes	No	No
BRAND	Brandy	29.9	-	Yes	Yes	No
CARRI	Carrie Pond	1.3	3	Yes	No	No
COUNT	Counts	77.5	9	Yes	No	No
CUJO	Cujo	44.3	10	Yes	No	No
DESPE	Desperation Pond	7.1	6	Yes	No	No
EAGLE	Eagle	55.4	9	Yes	No	No
FAYBA	Fay Bay	46.4	12	Yes	No	No
FOX1	Fox1	43.7	29	Yes	No	No
FOX3	Fox3	26.5	7	Yes	No	No
GAZEL	Gazelle	8.9	17	Yes	No	No
GRIZZ	Grizzly	58.9	43	No	No	Yes
HORSE	Horseshoe	75.7	10	Yes	No	No
KINGP	King Pond	29.1	3	Yes	No	No
KOALA	Koala	38.0	20	No	No	Yes
KODIA	Kodiak	90.7	13	Yes	No	No
LARRY	Larry	23.4	8	Yes	No	No
LDG	Lac de Gras	57200.0*	-	Yes	No	Yes
LESLI	Leslie	61.8	13	Yes	No	No
LEWIS	Lewis	-	-	Yes	No	No
LITRE	Little Reynolds Pond	3.8	1	Yes	No	No
LITTL	Little	32.0	20	Yes	No	No
LOGAN	Logan	127.2	21	Yes	No	No
LONG	Long	614.4	32	Yes	Yes	No
MARK	Mark	5.0	7	Yes	No	No
MIKE	Mike	66.6	-	Yes	No	No
MISER	Misery	13.7	28	No	Yes	No

LakeID	Lake Name	Lake Area (ha)	Maximum Depth (m)	Baseline	Fish-out	Other
MONY	Mony	7.8	-	Yes	No	No
MOOSE	Moose	43.6	11	Yes	No	No
NANCY	Nancy	14.2	5	Yes	Yes	No
NANUQ	Nanuq	189.5	16	Yes	No	No
NEMA	Nema	77.5	9	Yes	No	No
NLESL	North Leslie	6.0	-	Yes	No	No
NMISE	North Misery	-	-	Yes	No	No
NOINL	North Inlet - Lac de Gras	-	-	No	Yes	Yes
ONEHU	One Hump	10.8	16	Yes	No	No
OSPRE	Osprey	93.8	1	Yes	No	No
PANDA	Panda	35.0	19	No	Yes	No
PELTZ	Peltzer Pond	6.8	7	Yes	No	No
PHAS	Phaser Lake	-	-	No	Yes	No
PIGEO	Pigeon Pond	-	-	Yes	No	No
POINT	Point	29.9	59	Yes	No	No
RENE	Rene	32.9	-	Yes	No	No
ROSS	Ross	54.5	14	Yes	No	No
SABLE	Sable	8.9	19	Yes	Yes	No
SECPO	Second Portage Lake	130.0	40	No	Yes	No
SLIPP	Slipper	189.5	16	Yes	No	No
TAIL	Tail	76.6	7	No	Yes	Yes
THIPO	Third Portage Lake	-	-	No	Yes	No
TWORO	Two Rock	28.6	11	Yes	Yes	No
ULU	Ulu	28.7	6	Yes	No	No
VULTU	Vulture	180.2	43	Yes	No	No
WHITE	White	57.2	8	Yes	No	No
WILLY	Willy	23.9	-	Yes	Yes	No
ZACHP	Zach Pond	1.4	8	Yes	No	No

*Lake area represents the total estimated lake area, not just the area from which fish were removed.

Table 2. Fishes recorded in the fish-out database.

Species Code	Scientific Name	Common Name
ARCH	*Salvelinus alpinus*	Arctic Char
ARGR	*Thymallus arcticus*	Arctic Grayling
BURB	*Lota lota*	Burbot
CISC	*Coregonus artedi*	Cisco
LKCH	*Couesius plumbeus*	Lake Chub
LKTR	*Salvelinus namaycush*	Lake Trout
LKWH	*Coregonus clupeaformis*	Lake Whitefish
LNSC	*Catostomus catostomus*	Longnose Sucker
NNST	*Pungitius pungitius*	Ninespine Stickleback
NRPK	*Esox lucius*	Northern Pike
RNWH	*Prosopium cylindraceum*	Round Whitefish
SLSC	*Cottus cognatus*	Slimy Sculpin

Table 3. Additional data collected during fish-out assessments. Liver and muscle samples were used to assess metal concentrations in fishes, and stomach samples were used to assess diet composition in some lakes.

Lake Name	Habitat	Benthos	Zooplankton	Water Quality	Fish Tissue Samples		
					Liver	Muscle	Stomach
A154	NO	NO	NO	NO	NO	NO	NO
A21	NO	NO	NO	NO	NO	NO	NO
A418	NO	NO	NO	YES	NO	NO	NO
Airstrip Lake	YES	NO	NO	NO	NO	NO	NO
Brandy Lake	NO	NO	NO	NO	NO	NO	NO
Long Lake	YES	NO	NO	YES	YES	YES	YES
Misery Lake	YES	NO	NO	YES	NO	NO	NO
Nancy Lake	NO	NO	NO	NO	NO	NO	NO
North Inlet - Lac de Gras	NO	NO	NO	NO	NO	NO	NO
Panda Lake	YES	NO	NO	YES	YES	YES	YES
Phaser Lake	NO	NO	NO	NO	NO	NO	NO
Sable Lake	YES	NO	NO	YES	YES	YES	YES
Second Portage Lake	YES	YES	YES	YES	YES	YES	YES
Tail Lake	YES	YES	YES	YES	NO	NO	YES
Third Portage Lake	NO	YES	YES	YES	YES	YES	YES
Two Rock Lake	YES	NO	NO	YES	YES	YES	YES
Willy Lake	YES	NO	NO	NO	NO	NO	NO

Table 4. Gillnet effort (h/ha) to achieve four CPUE thresholds during fish-outs. Percentage of Max CPUE is based on a three-day moving average of CPUE, and No Fish Caught for 48 h is based on a two-day average. Bolded values indicate when a threshold was reached (see 2. Methods). If the threshold was not reached, effort was identified as being greater than (>) the fishing effort that was applied to a specific fish-out. Average CPUE is the mean effort in fish-outs that achieved the threshold. Lakes are sorted by lake area with size increasing in order.

Lake Name	**Lake Area (ha)**	**% of Max CPUE**				**No Fish Caught for 48 h**
		20	**10**	**5**	**2.5**	
Sable Lake	8.9	**39**	**71**	**71**	**124**	>789
Misery Lake	13.7	**150**	>180	>180	>180	>180
Nancy Lake	14.2	>49	>49	>49	>49	>49
Airstrip Lake	19.3	**83**	**129**	**204**	**208**	**204**
Two Rock Lake	28.6	**54**	**81**	**166**	**313**	>446
A418	29.0	**19**	**44**	**51**	>85	>85
Panda Lake	35.0	>27	>27	>27	>27	>27
Tail Lake	76.6	**5**	**28**	>28	>28	>28
Second Portage Lake	130	**29**	>52	>52	>52	>52
Average CPUE		54	71	123	216	204
# Achieved by Assessments		7	5	4	3	1

*identifies lakes where multiple fishing methods were used

Table 5. Leslie population estimates (N) for fish-outs with known numbers of fish removals. Population estimates, with lower (LCI) and upper (UCI) 95% confidence intervals, are only shown for species where a significant (p<0.05) decline in CPUE was achieved. Total removed is the sum of both phases of the fish-out. The Within CI column indicates if the total fish removed were within 95% confidence interval .

Lake Name	Species	N	LCI	UCI	Total Removed	Within CI
A418	Lake Trout	17	9	24	31	No
	Round Whitefish	43	33	53	54	No
Phaser Lake	Round Whitefish	341	48	635	524	Yes
Sable Lake	Lake Trout	233	215	250	123	No
Second Portage Lake	Arctic Char	406	243	570	485	Yes
	Burbot	329	163	495	279	Yes
	Lake Trout	1828	1593	2064	2015	Yes
	Round Whitefish	234	172	296	294	Yes
Tail Lake	Lake Trout	1104	782	1426	1420	Yes
Third Portage Lake	Arctic Char	158	113	202	286	No
	Lake Trout	126	101	151	236	No
	Round Whitefish	107	108	130	279	No
Two Rock Lake	Lake Trout	552	507	596	748	No
	Round Whitefish	897	821	974	1659	No

Table 6. Missing data from the 17 lakes with fish-out assessments. Total fish caught (Trap) is the total fish caught in a lake based on records of fish caught in deployed fishing gears. The difference in fish is the absolute difference between the number of fish caught in a set and the individual fish records. Darker cells indicate values where records are missing or erroneous. Fewer fishing methods used are highlighted as a potentially biased sample of the fish community. Brandy, Long, and Willy lakes are highlighted as missing lake areas because they were fished out in cells and cell size was not included.

Lake Name	Area (ha)	Total Fish Caught (Trap)	Difference in Fish	Proportion of Fish Caught Removed	Number of Fishing Methods	Proportion of Traps with Soak Time
A154	NA	4035	7	0.61	4	0.02
A21	NA	284	0	0.98	2	0.00
A418	29	852	22	0.19	6	0.83
Airstrip	19.3	1005	0	0.00	2	1.00
Brandy	29.9	449	0	0.00	1	1.00
Long	614.4	17897	4	0.00	4	1.00
Misery	13.7	146	0	0.00	1	1.00
Nancy	14.1	23	0	0.00	1	1.00
North Inlet - Lac de Gras	NA	501	0	0.00	1	0.98
Panda	34.9	854	0	0.00	1	0.82
Phaser Lake	NA	1315	561	0.72	1	1.00
Sable	8.8	938	148	0.99	3	1.00
Second Portage Lake	130	3073	0	1.00	2	0.94
Tail	76.6	1435	3	1.00	1	1.00
Third Portage Lake	NA	2139	7	0.41	1	1.00
Two Rock	28.5	2684	24	0.99	4	1.00
Willy	23.8	510	0	0.00	1	1.00

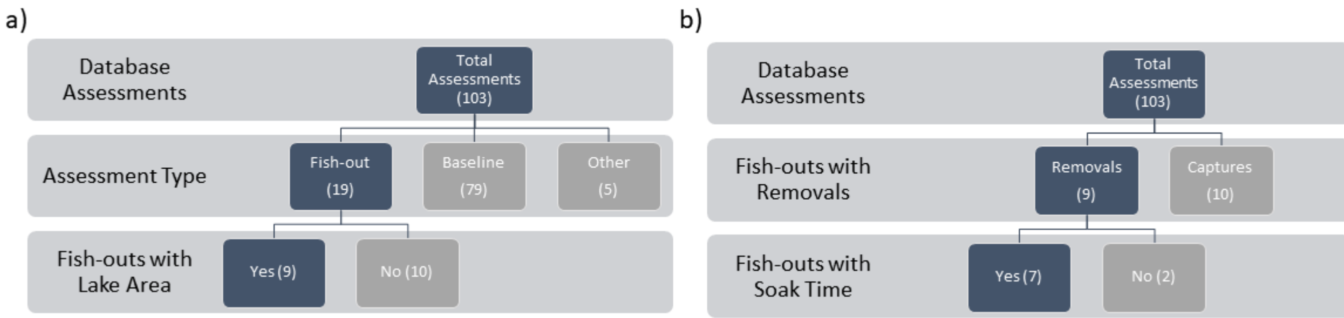

Figure 1. Breakdown of the different types of fisheries assessments recorded in the fish-out database. Dark blue boxes identify the fish-out assessments with suitable data for (a) CPUE depletion analysis, and (b) fish population estimates as recommended in the Tyson et al. (2011) protocol. In (a) "fish-outs with lake area" refer to lakes where the area fished out is known. Brandy, Long, and Willy Lake were divided into cells for fish-outs and the cell size is not identified so they were omitted from this analysis (Lake area unknown). In (b), "fish-outs with removals" refers to fish-outs where the number of fish caught, and the number of fish removed from the waterbody were recorded. Soak time refers to fish-outs where the soak times of gillnets were recorded (i.e. Two fish-outs with recorded removals did not record gillnet soak time).

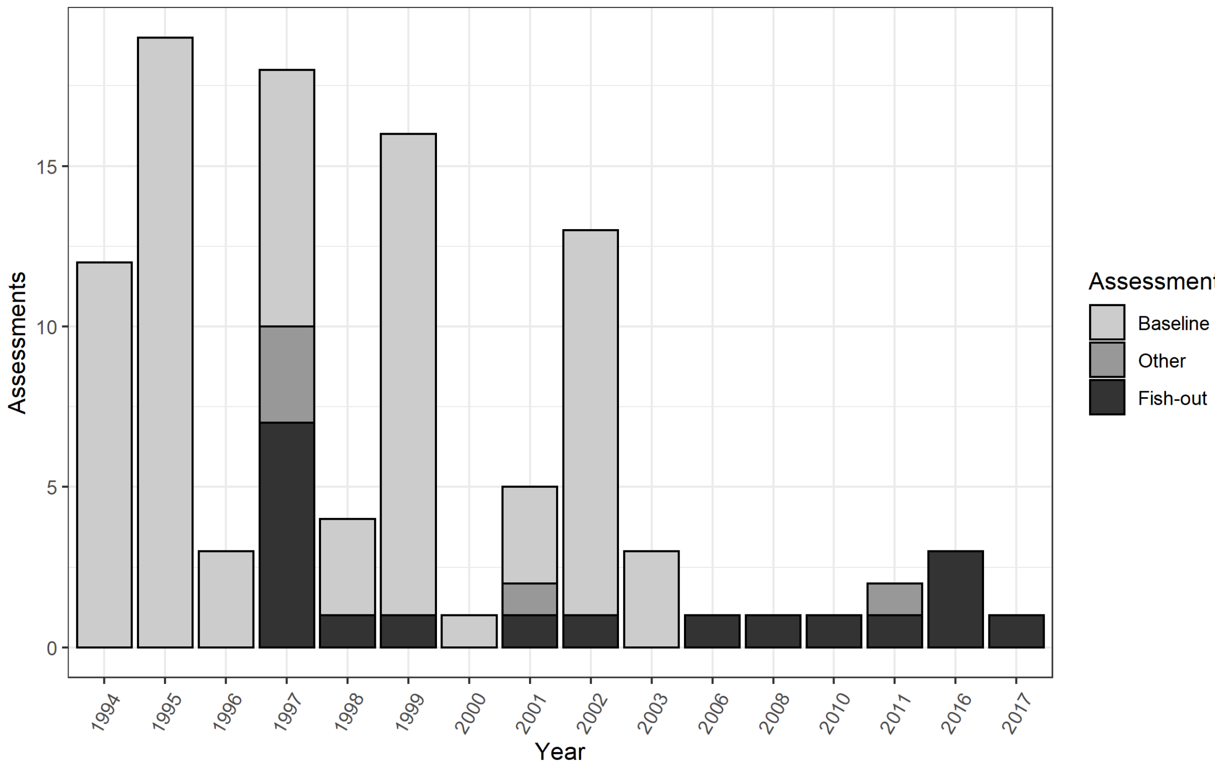

Figure 2. Number and type of fisheries assessments by year in the fish-out database. (see Methods for description of assessment types).

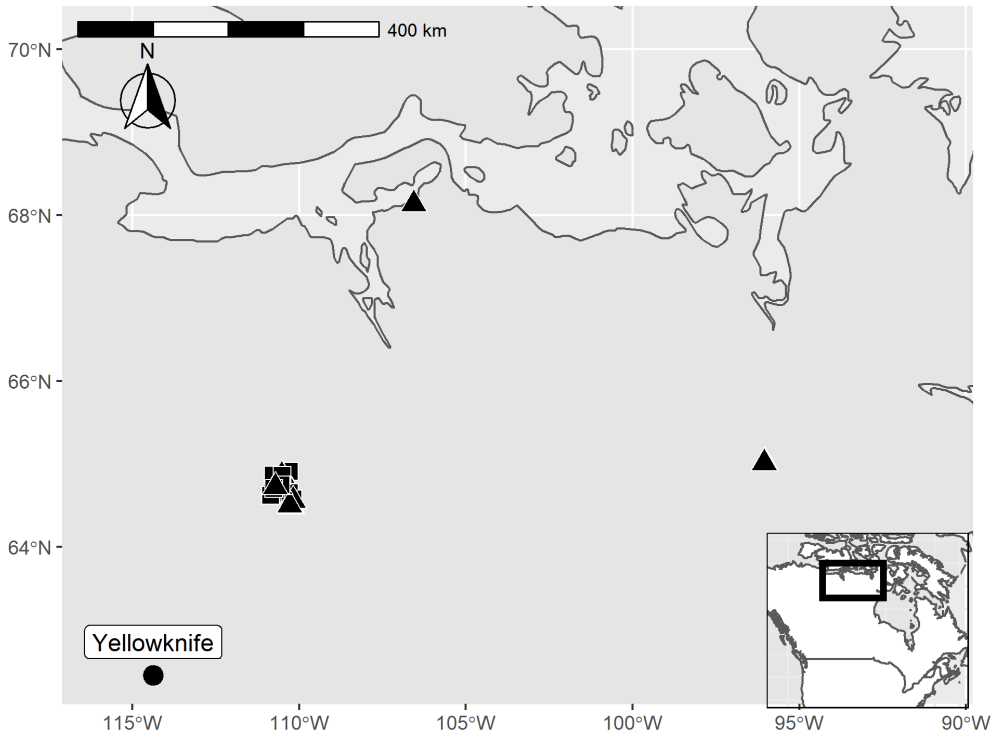

Figure 3. Locations of 32 lakes where fisheries assessments occurred. Only lakes with georeferenced coordinates, found either in the fish-out database or Appendix A of Samarasin et al. (2014), are included. Fish-outs (triangles), baseline assessments (squares), and Yellowknife, NT (circle) are shown.

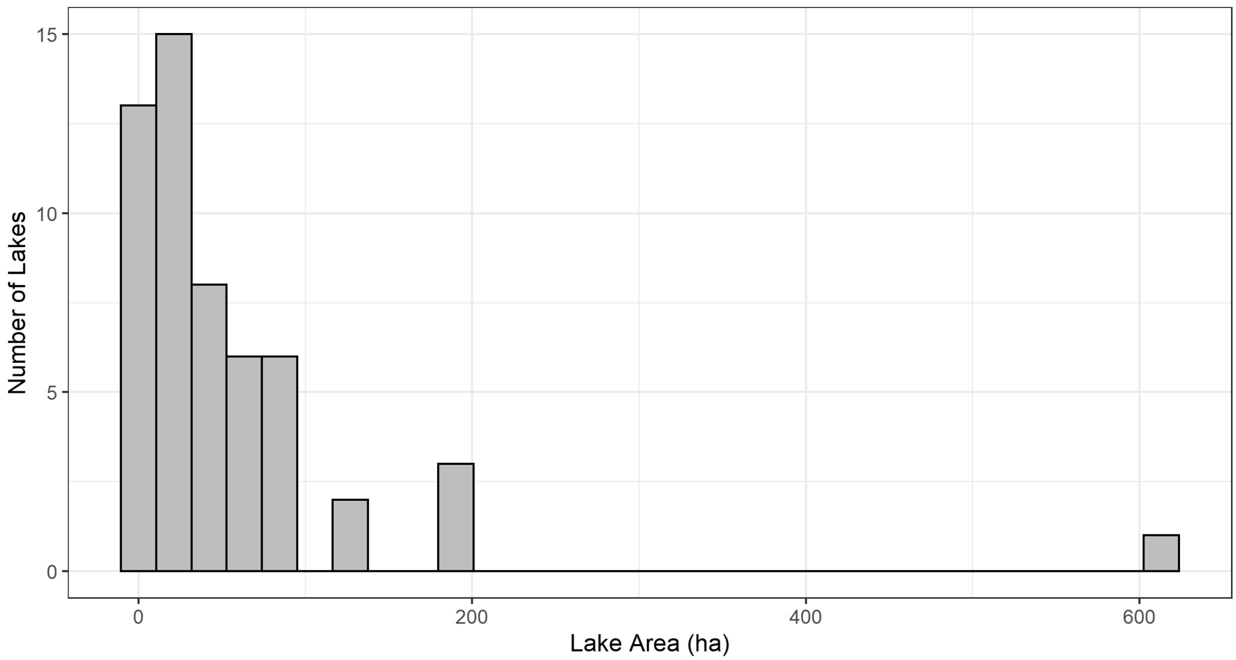

Figure 4. Surface area of lakes sampled in the fish-out database (N = 54). Lac de Gras (57,200 ha) is omitted.

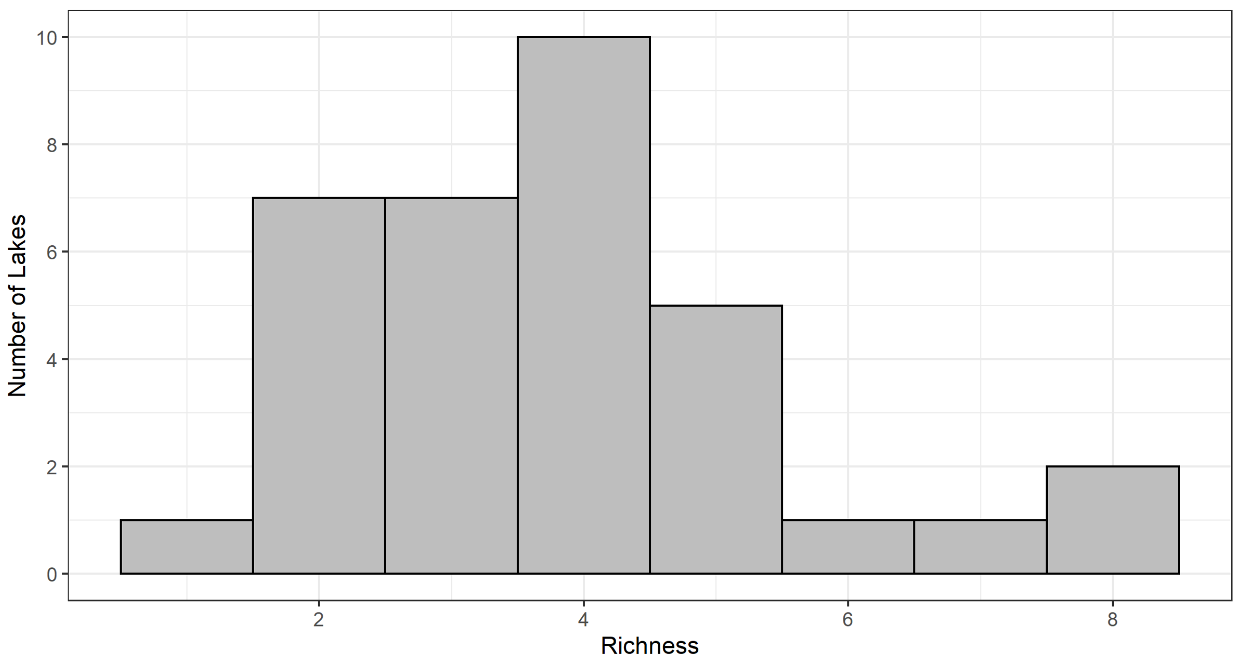

Figure 5. Species richness of the 34 lakes in the fish-out database where more than 100 fish were captured during assessments.

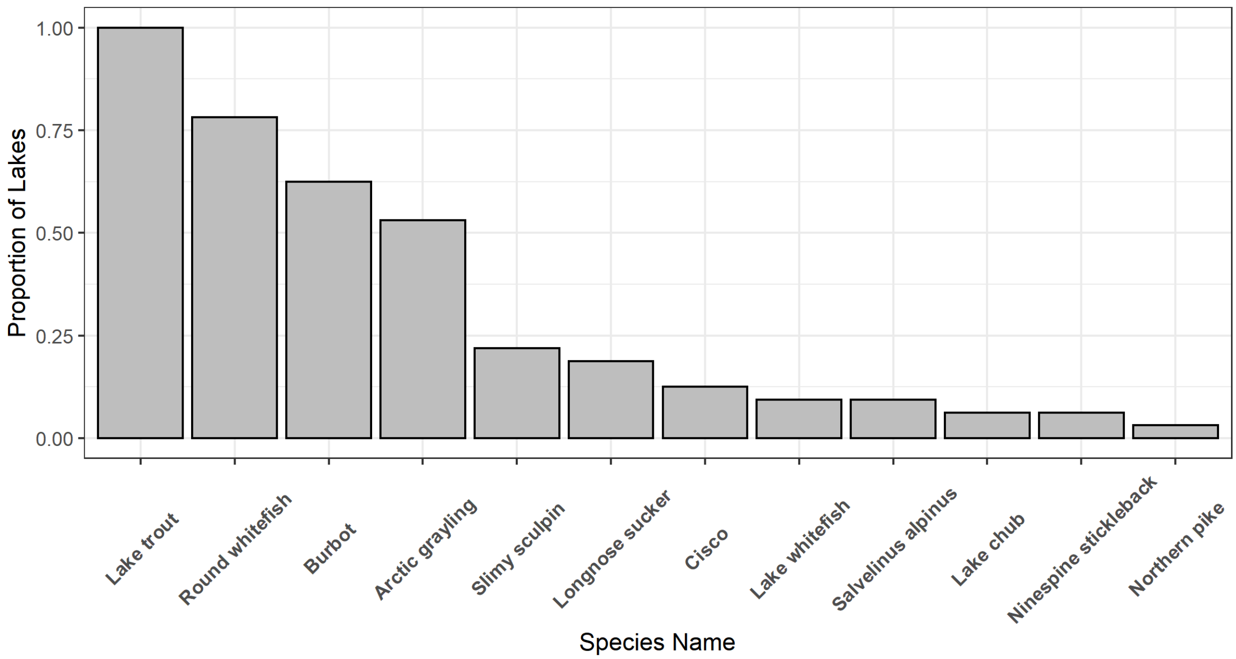

Figure 6. Prevalence of the 12 species of fish recorded in the fish-out database across lakes. Prevalence is calculated as the proportion of lakes where the species occurred. Only assessments with more than 100 fish caught (N = 34 out of 63) are included.

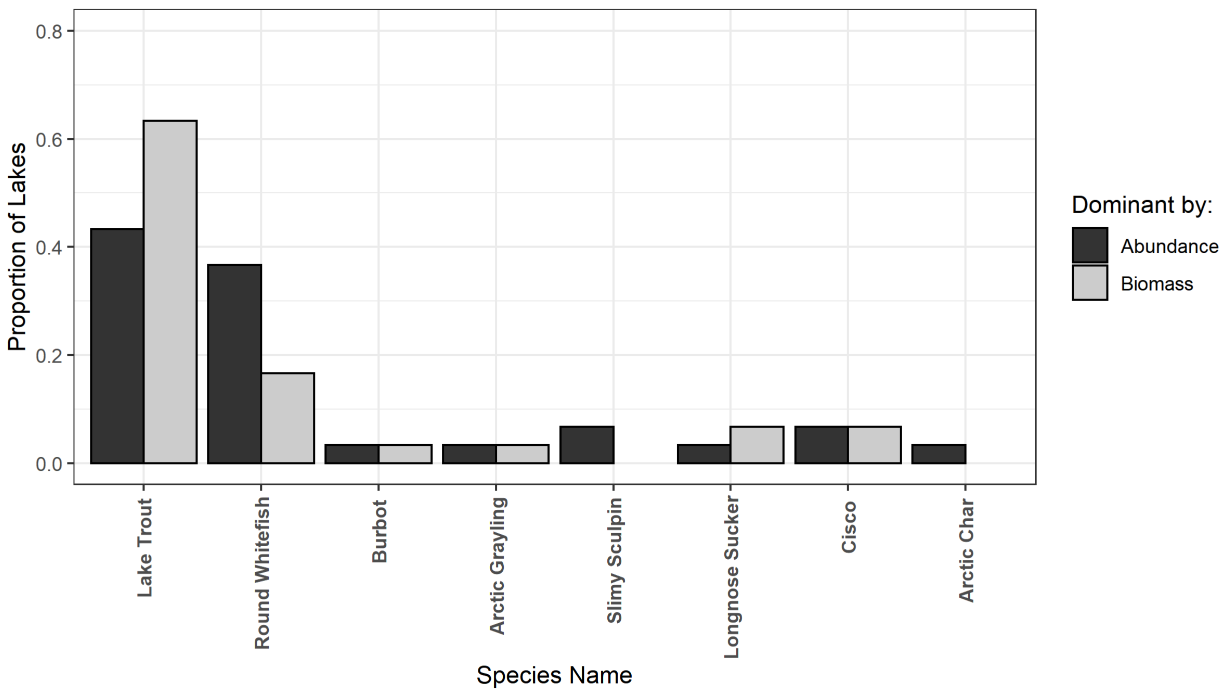

Figure 7. The most common fish species captured in assessments of northern lakes based on abundance (dark bars) and biomass (light bars). Species are sorted by their prevalence (proportion of lakes where the species occurred for lakes with more than 100 fish caught; see Figure 6). Data for 30 lakes are presented because individual fish weights are missing for four of the lakes.

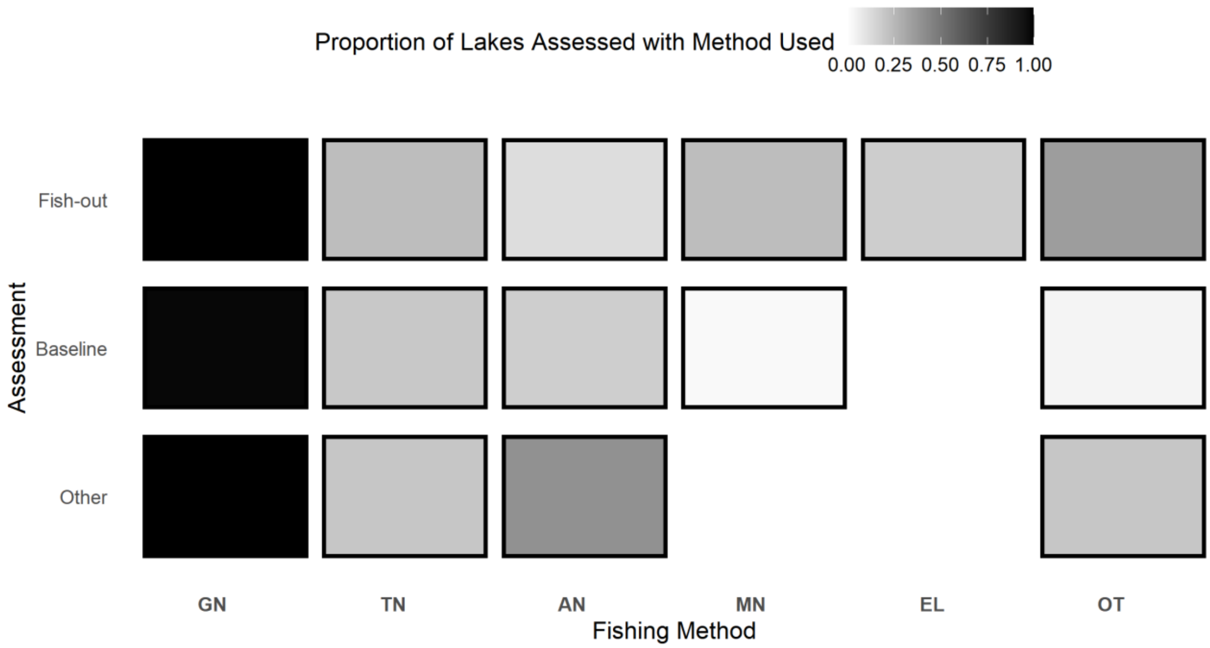

Figure 8. Proportion of lakes for each assessment type (fish-out = 17, baseline = 52, other = 5) where a fishing method was used. Fishing methods sorted by total fish caught: GN (gillnet; N = 47,189), TN (trap net; N = 5,317), AN (angling; N = 602), MN (minnow trap; N = 588), EL (electrofishing; N = 580), and OT (other; N = 714). Blank squares identify where no lakes were sampled using the fishing method for the assessment type.

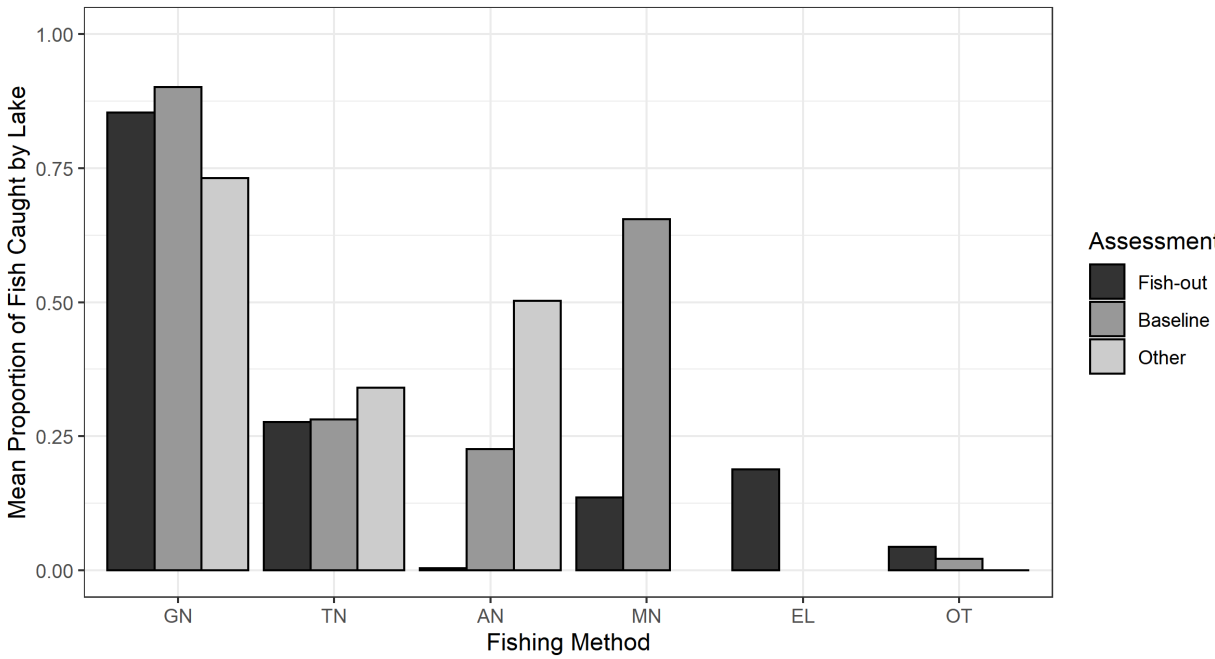

Figure 9. Mean proportion of fish caught by assessment type for the six most successful fishing methods. Only lakes where the fishing method was employed are included in the mean proportion of fish caught. Bar colour indicates the type of assessment. Fishing methods are sorted by the total fish caught: GN (gillnet; N = 47,189), TN (trap net; N = 5,317), AN (angling; N = 602), MN (minnow trap; N = 588), EL (electrofishing; N = 580), and OT (other; N = 714). OT fishing methods include beach seines, dipnets, long lines, and unknown gears.

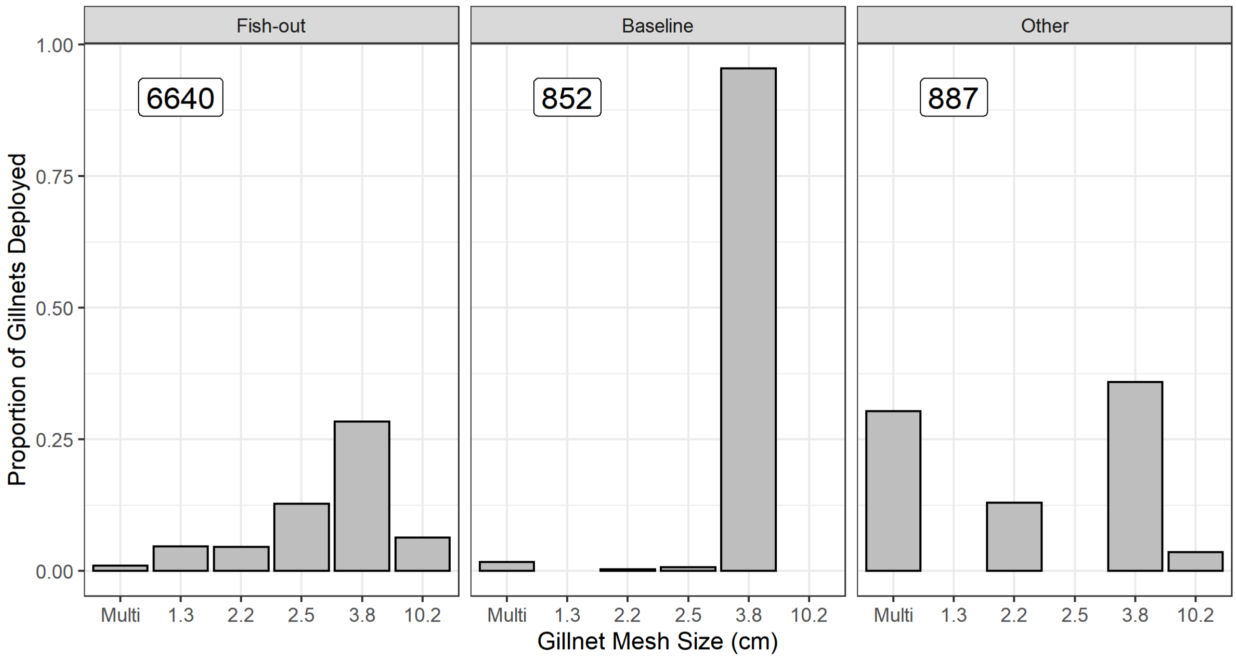

Figure 10. Mesh sizes of gillnets used by assessment type. Only mesh sizes that made up more than 0.05 of nets in at least one assessment type (baseline, fish-out, or other) are shown. "Multi" refers to nets with multiple mesh sizes, typically ranging from 2.5 cm to 12.6 cm. The total number of gillnets deployed across each assessment type is shown in the upper left corner of each plot.

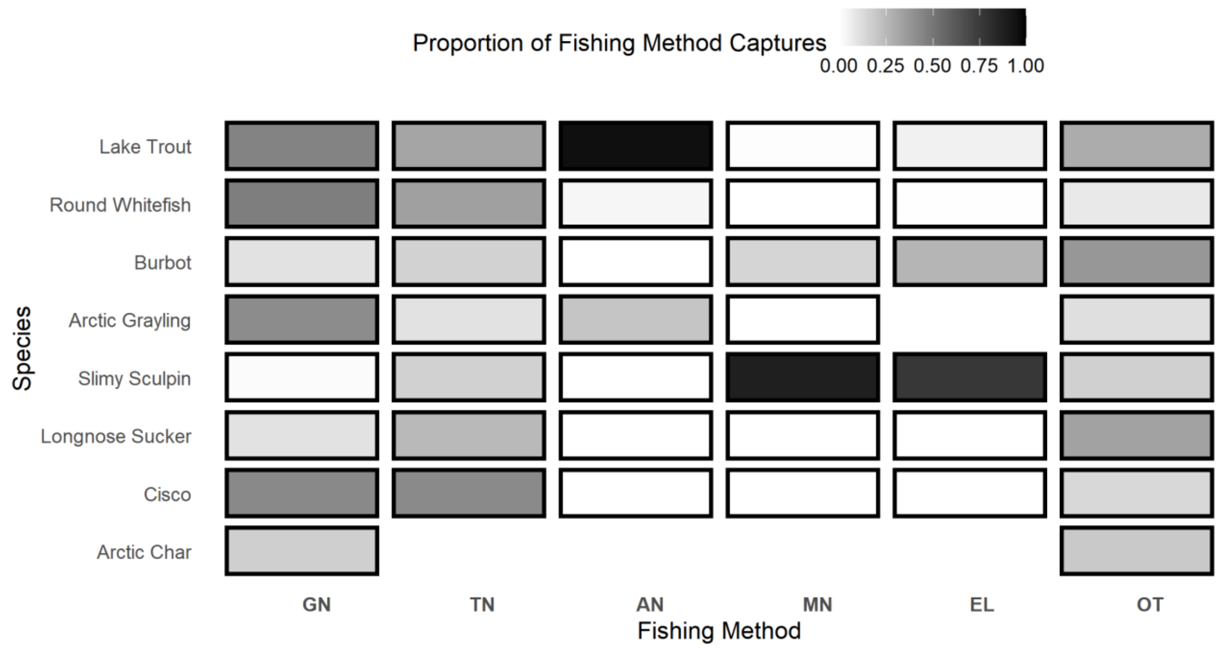

Figure 11. The mean proportion of captures by fishing method for individual fish species. Only lakes where a species was present, and the fishing method was used in the lake are included in the mean proportion of fishing method captures. Blank squares indicate that no lakes exist where the species was present, and the fishing method was used. Species and fishing methods are sorted by their prevalence in lakes. Fishing methods are sorted by the total fish caught (most of caught on the left): GN = gillnet; TN = trap net; AN = angling; MN = minnow trap; EL = electrofishing; and OT = other, including beach seines, dipnets, long lines, and unknown gears.

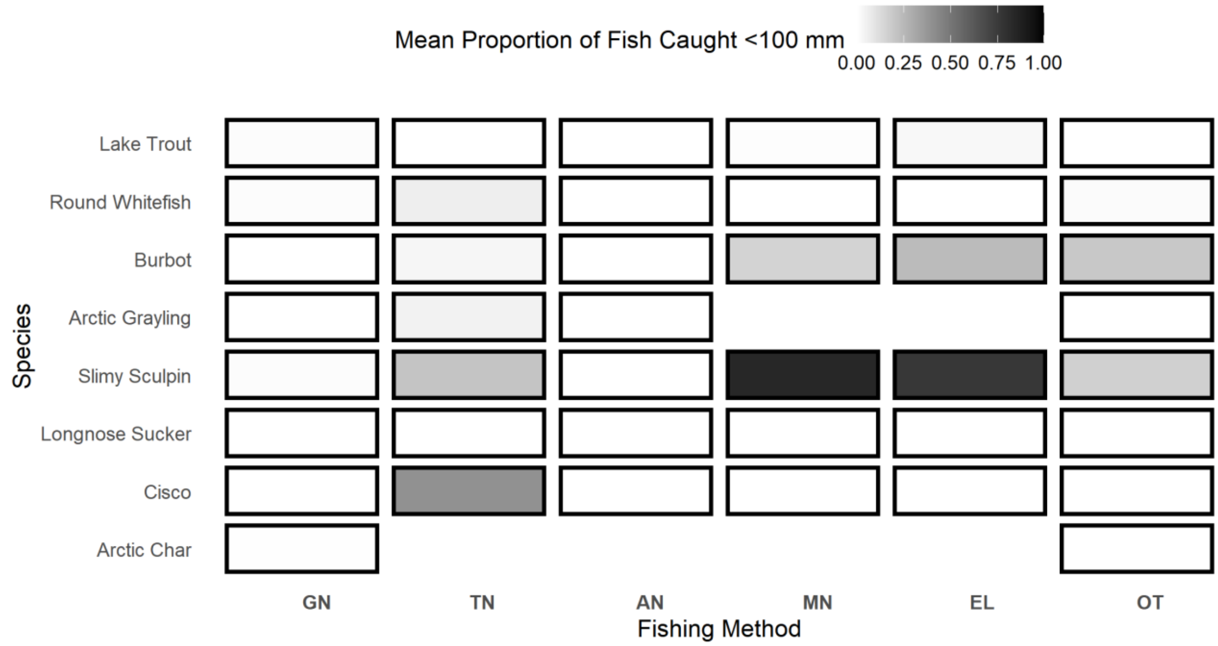

Figure 12. The proportion of fish captured <100 mm in length for a given species is categorized by fishing method. Blank squares indicate there were no lakes where the fishing method was used and the species was caught. Fishing methods are sorted by the total fish caught (most of caught on the left). Fishing methods: GN = gillnet; TN = trap net; AN = angling; MN = minnow trap; EL = electrofishing; and OT = other, including beach seines (N = 10), dipnets (N = 7), long lines (N = 38), and unknown gears (N = 68).

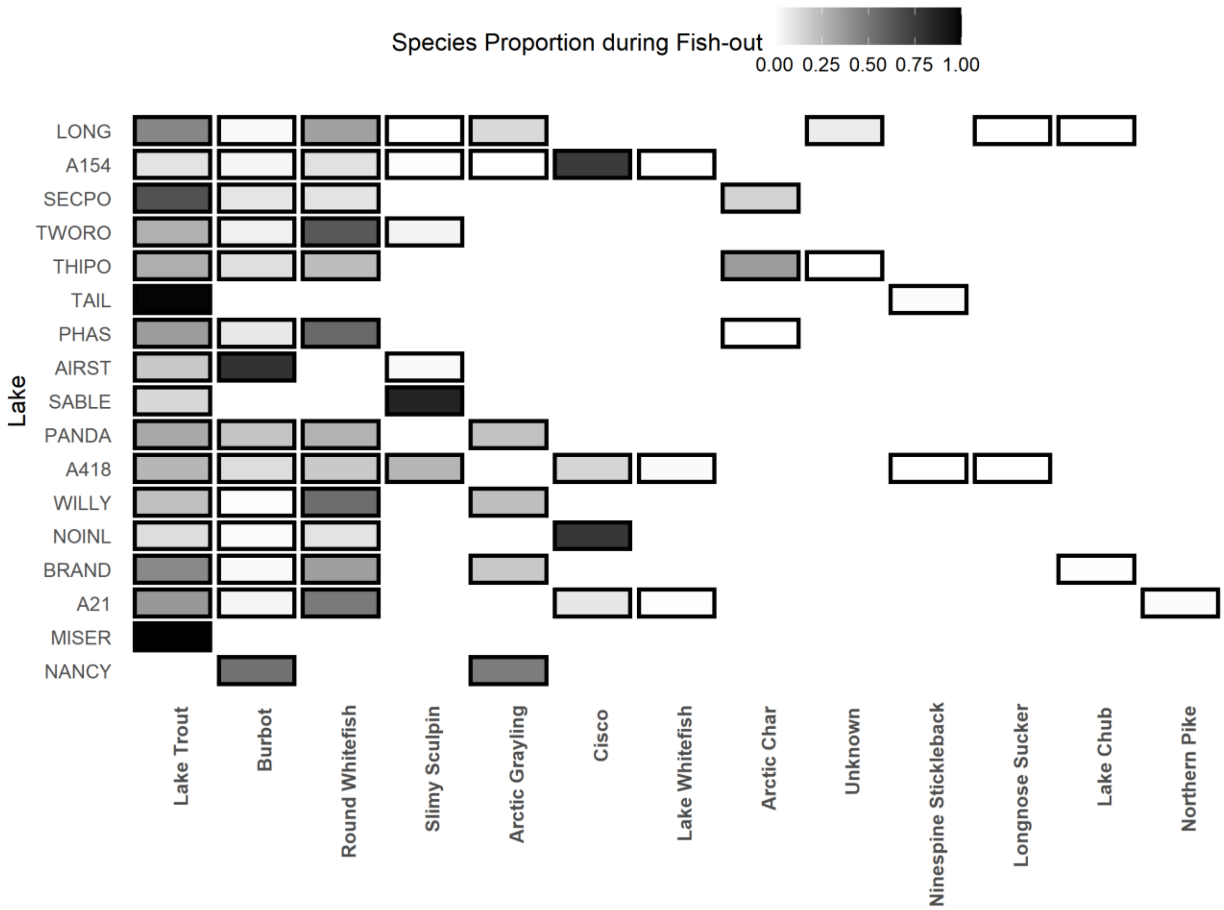

Figure 13. Fishes caught in fish-out assessments. The boxes indicate the presence or absence of a species in the lake. Species making up larger proportions of the fish caught are shown in darker colours. Lakes are sorted by the total number of fish caught during the fish-out with the largest fish-outs at the top. Fishes are sorted by their prevalence in fish-outs with the most prevalent fishes on the left. Unknown fish are records where the species could not be identified.

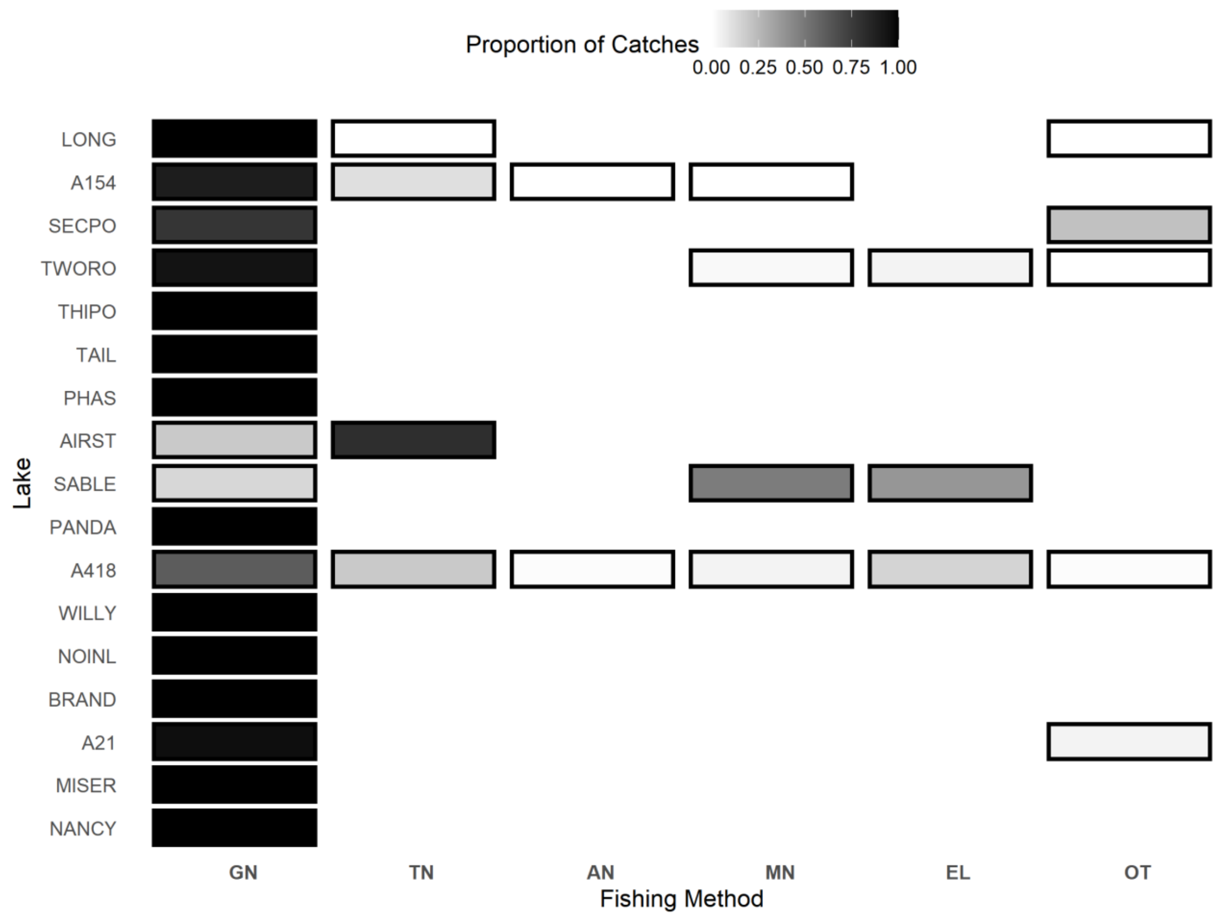

Figure 14. The proportion of fish caught during a fish-out by fishing method is shown by shading, with darker squares indicating higher proportions. Lakes are sorted by the number of fish caught with the most fish being caught in lakes at the top. Fishing methods: GN = gillnet; TN = trap net; AN = angling; MN = minnow trap; EL = electrofishing; and OT = other, including beach seines, dipnets, long lines, and unknown gears.

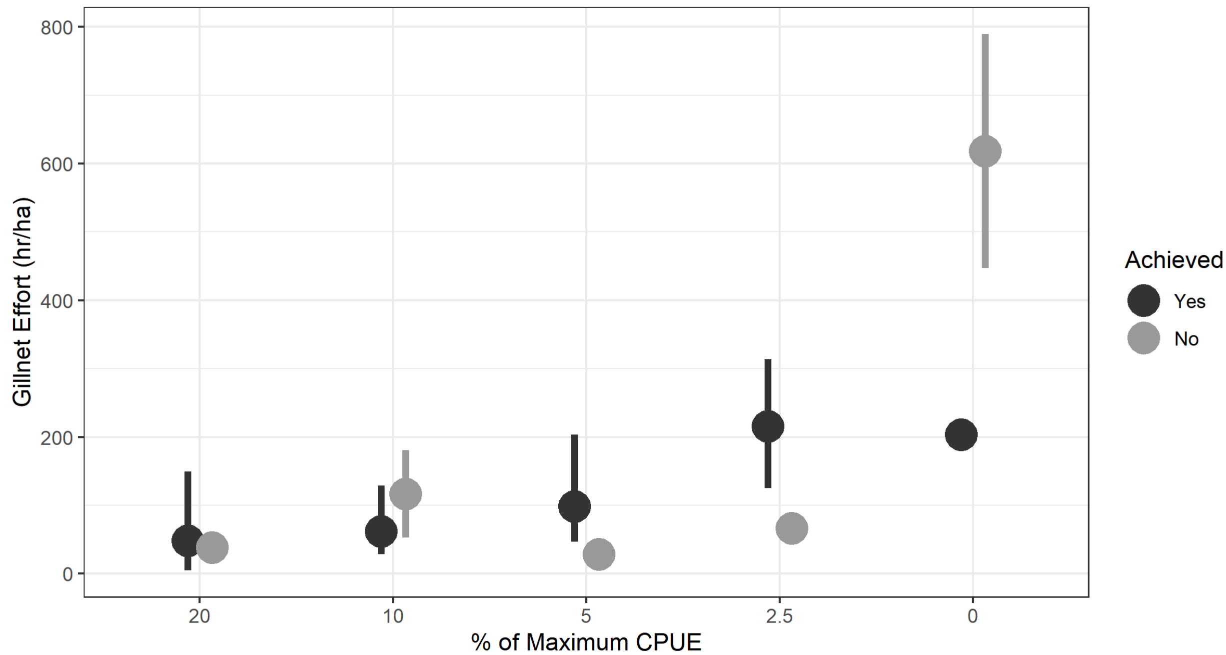

Figure 15. Gillnet effort (h/ha) required to achieve a CPUE threshold. Points identify mean effort and error bars show the total range of effort. CPUE is calculated as a three-day average for all thresholds except "0" which is no fish caught in 48 h, as recommended by Tyson et al. (2011). Fish-out effort that achieved a given threshold (black) is compared to effort for fish-outs that achieved the previous threshold but not the current (grey).

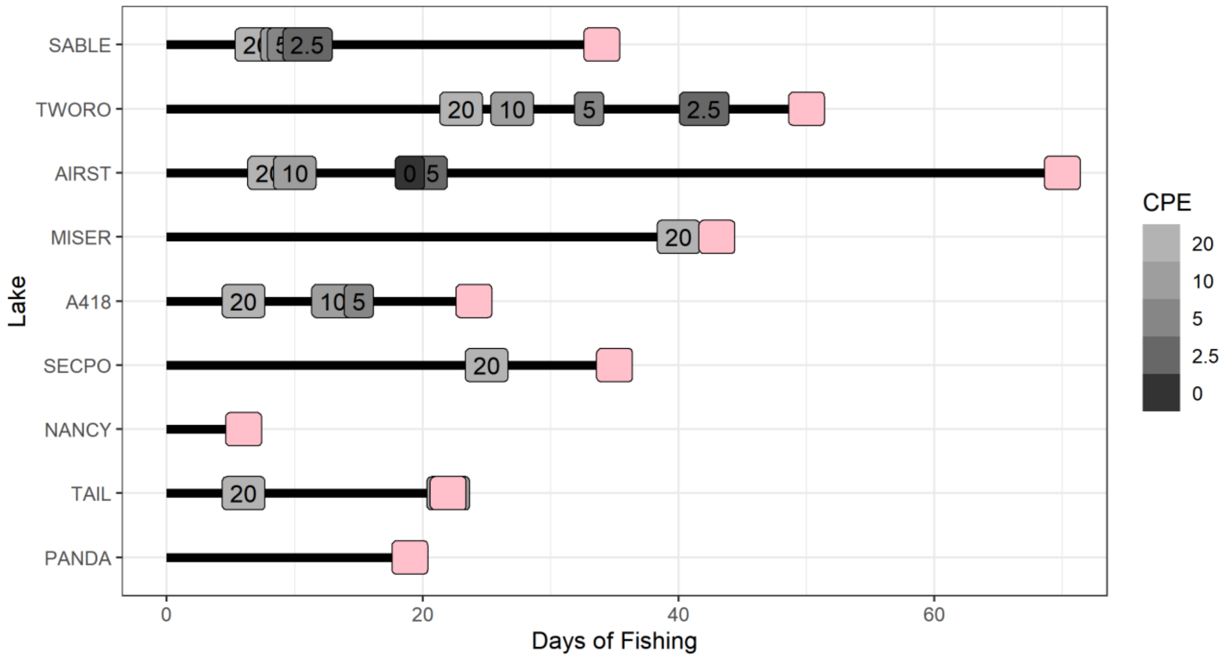

Figure 16. Duration of CPUE phase (days) to achieve a CPUE threshold. Labels in gray scale squares identify the day when a threshold was achieved. Pink boxes identify the last day of the CPUE phase. Lakes are sorted along the y-axis by the final effort (h/ha gillnet soak time) achieved with highest effort lakes at the top. Lake codes are shown in Table 1.

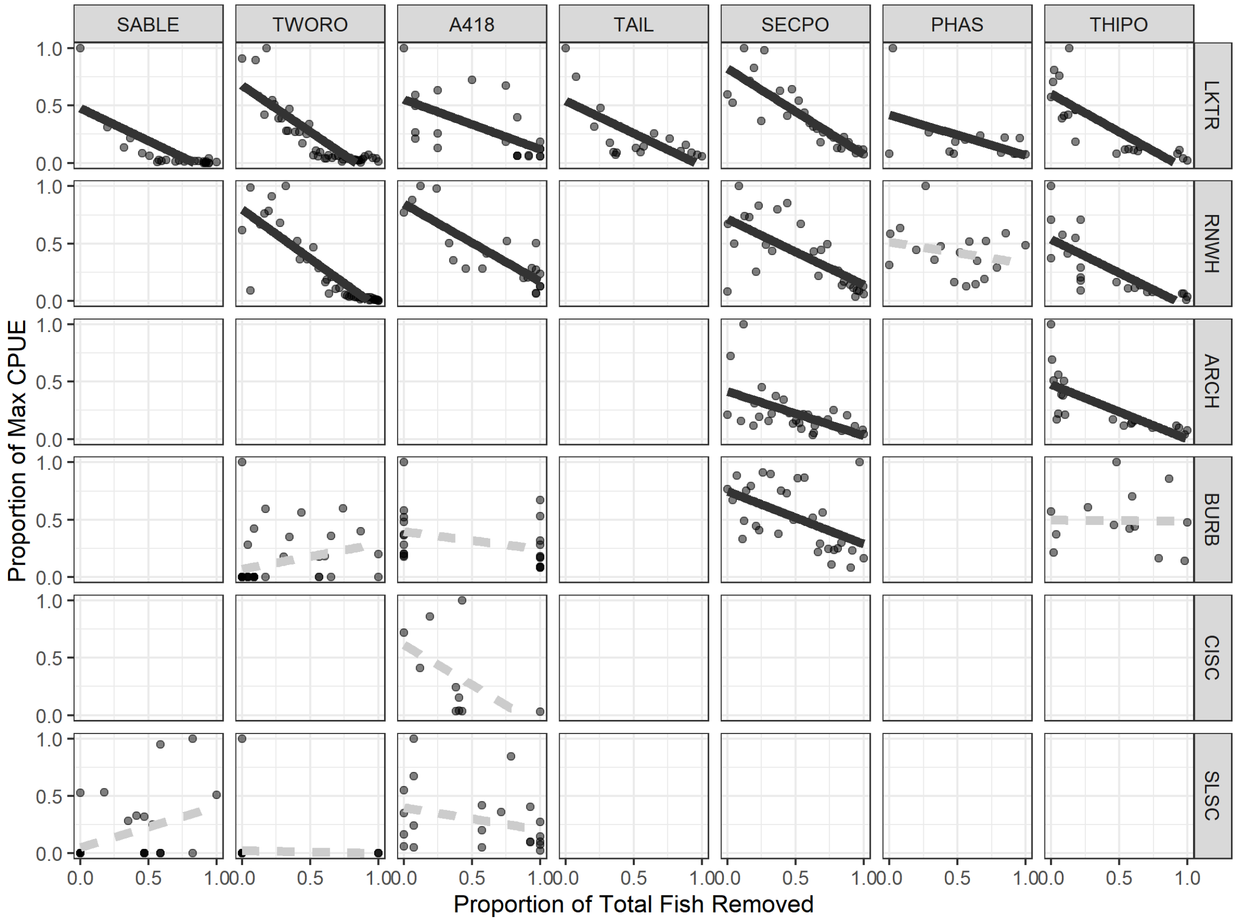

Figure 17. CPUE depletion by species during all fish-outs (N = 7) with gillnet effort data (see Figure 1b). Lakes are sorted by area with lake area increasing to the right, except Phaser Lake (PHAS) and Third Portage Lake (THIPO) which are both missing lake area. Species are sorted by the total fish removed, with the most removed species (Lake Trout - LKTR) at the top. Significant CPUE depletions (solid black lines) and non-significant depletions (dashed gray lines) are shown. Points show the proportion of maximum daily CPUE during the CPUE phase. Lake codes in Table 1 and species codes are in Table 2.

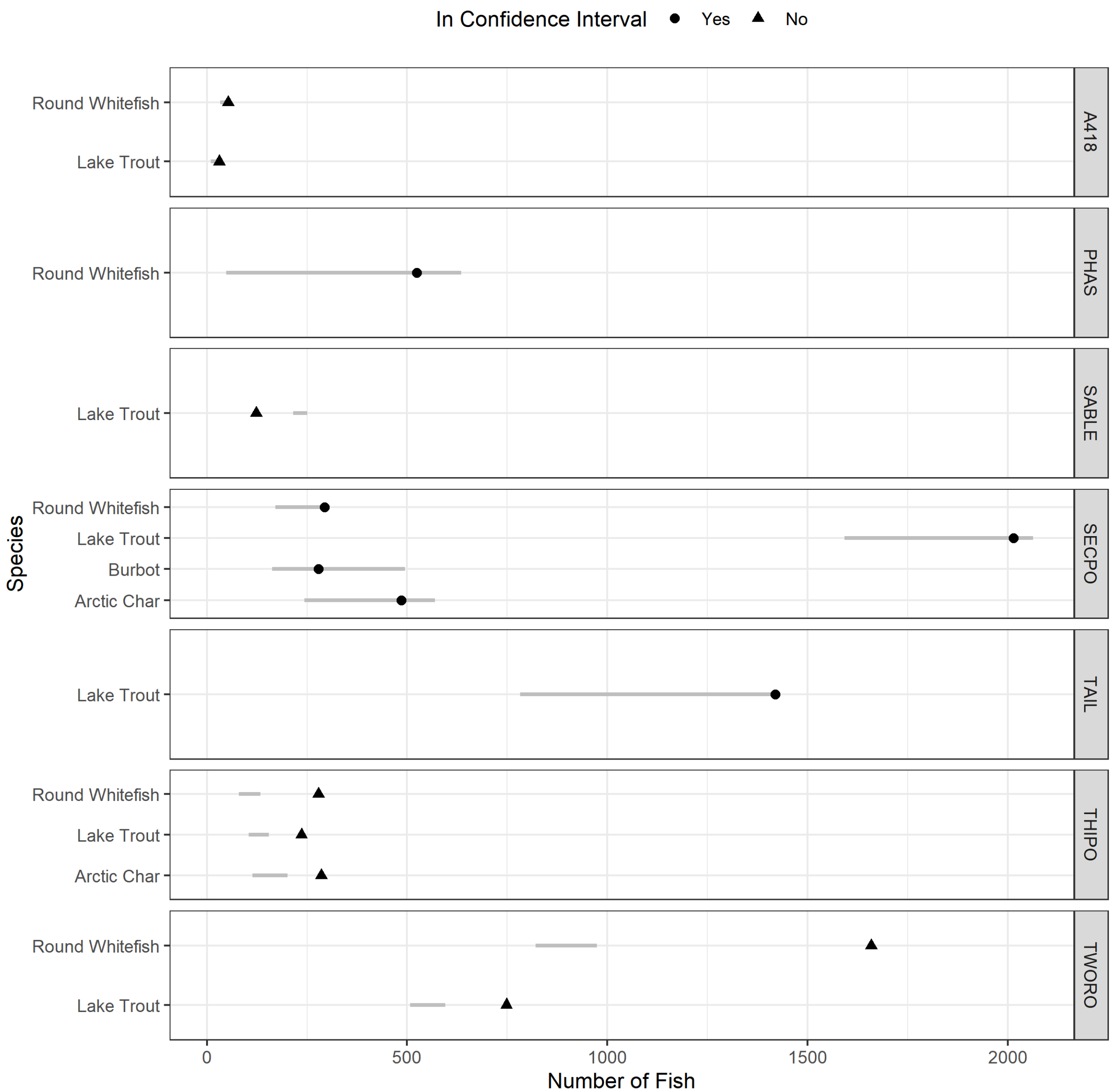

Figure 18. Comparison of Leslie population estimates to the total number of fish removed during fish-outs. Grey lines identify the 95% confidence interval for Leslie population estimates. Points show species-specific numbers of fish removed during the entire fish-out. The point shape identifies if the number of fish removed was within the 95% confidence interval (circle) or greater than the 95% confidence interval (triangle).

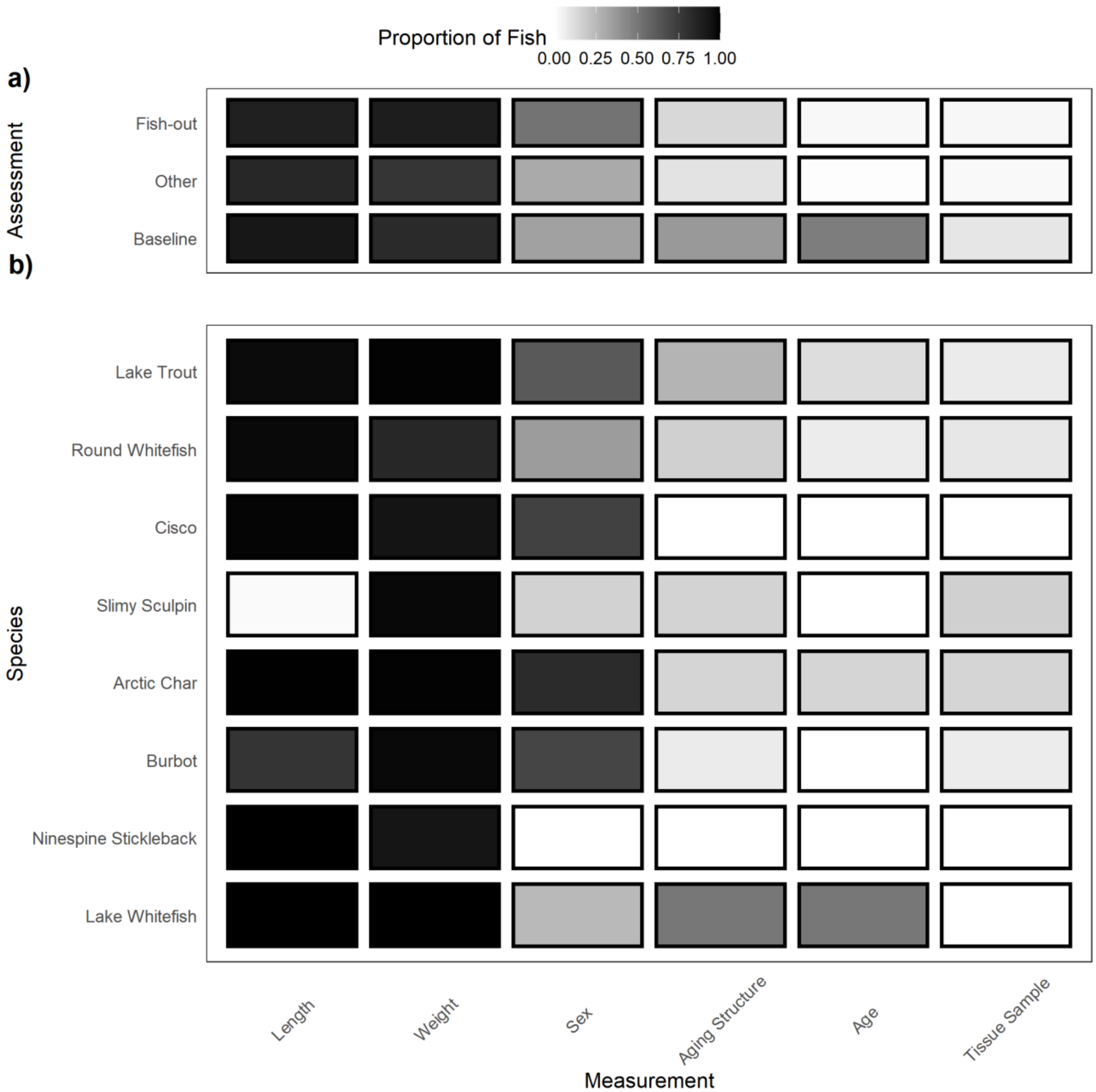

Figure 19. Completeness of fish biological data in the fish-out database grouped by a) assessment type, and b) fish species. Assessment type is ordered by the number of fish caught (Fish-out: N = 37,741; Other: N = 9,835; Baseline: N = 6,051), with the proportion of fish caught shown within each assessment type. The proportion of individual fish species captured during fish-outs are ranked by the most abundant at the top and least abundant fish at the bottom.