Assessment of Lake Trout Populations Within the Inuvialuit Settlement Region of Northwest Territories and Yukon, 2014-2015

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ABSTRACT

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Fish are an important subsistence resource to residents of the Inuvialuit Settlement Region (ISR). While many lakes and rivers exist in the ISR, access can be seasonally limited due to changes on the landscape (i.e., winter snow and ice cover vs. summer open water). Due to these limitations, waterbodies within the ISR are used at various times of year. To allow for year-round access via ground travel between Inuvik and Tuktoyaktuk, the Inuvik-Tuktoyaktuk Highway (ITH) was constructed. This highway has also created the opportunity for year-round access to many lakes and rivers in close proximity to the road, creating the potential for increased fishing pressure. One species that is highly sought after in the region is Lake Trout (*Salvelinus namaycush*). Lake Trout are a long-lived and late-maturing species that reside in cold, low-productivity lakes and are vulnerable to overharvest. To better understand Lake Trout ecology within the region and collect baseline data prior to the ITH completion, we sampled six lakes believed to hold Lake Trout within the ISR. To accomplish this, we set short-set experimental gill nets along the shoreline to describe species composition, key biological metrics, catch rates, and to collect tissue samples for additional projects. In addition, lake bathymetry and water properties were assessed at all locations. Key findings from the study indicate that 1) Lake Trout spawn at the end of August and into early September, 2) spawning typically occurs on the leeward side of lakes (i.e., south to southeastern end for this region) on cobble shoals, 3) during spawning, Lake Trout aggregate in high numbers on spawning shoals, and 4) Lake Trout were found in all but Parsons Lake. Moving forward with management of fisheries along the ITH, local management agencies should recognize that Lake Trout aggregate in large numbers during spawning and are highly vulnerable to nets and angling during late summer. If overharvest becomes a concern, management action should be taken to protect this locally important resource.

RÉSUMÉ

Kissinger, B.C., Mochnacz, N., Day, W., Chapelsky, A.J., and Reist, J.D. 2019. Assessment of Lake Trout populations within the Inuvialuit Settlement Region of Northwest Territories and Yukon, 2014-2015. Can. Manuscr. Rep. Fish. Aquat. Sci. 3181: vi + 34 p.

Le poisson est une ressource de subsistance importante pour les résidents de la région désignée des Inuvialuit (RDI). Bien qu'il existe de nombreux lacs et rivières dans la RDI, l'accès peut être limité de façon saisonnière en raison des changements dans le paysage (c.-à-d. la couverture de neige et de glace en hiver par rapport à l'eau libre en été). En raison de ces limites, les plans d'eau au sein de la RDI sont utilisés à diverses périodes de l'année. Afin de permettre un accès toute l'année par voie terrestre entre Inuvik et Tuktoyaktuk, on a construit la route reliant Inuvik et Tuktoyaktuk. Cette route a également créé une possibilité d'accès toute l'année à de nombreux lacs et rivières situés à proximité, ce qui pourrait accroître la pression de la pêche. Une espèce très recherchée dans la région est le touladi (*Salvelinus namaycush*). Le touladi est une espèce longévive et à maturation tardive qui vit dans des lacs froids et à faible productivité, et qui est vulnérable à la surexploitation. Afin de mieux comprendre l'écologie du touladi dans la région et de recueillir des données de référence avant l'achèvement de la route reliant Inuvik et Tuktoyaktuk, nous avons échantillonné six lacs qui devraient contenir le touladi dans la RDI. Pour ce faire, nous avons mis en place des filets maillants expérimentaux à courte distance le long du littoral pour décrire la composition des espèces, les principales mesures biologiques, les taux de prise et pour recueillir des échantillons de tissus en vue de projets supplémentaires. De plus, la bathymétrie des lacs et les propriétés aquatiques ont été évaluées à tous les emplacements. Les principales conclusions de l'étude indiquent que 1) le frai du touladi a lieu à la fin d'août et au début de septembre; 2) le frai a généralement lieu du côté sous le vent des lacs (c.-à-d. du sud au sud-est pour cette région) sur des hauts-fonds de galets; 3) pendant le frai, on a observé des concentrations élevées de touladi dans les hauts-fonds de frai; 4) le touladi se trouvait dans tous les lacs sauf dans le lac Parsons. En ce qui concerne la gestion des pêches le long de la route reliant Inuvik et Tuktoyaktuk, les organismes de gestion locaux devraient reconnaître que le touladi se regroupe en grand nombre pendant le frai et qu'il est très vulnérable aux filets et à la pêche à la ligne à la fin de l'été. Si la surexploitation devient une préoccupation, des mesures de gestion devraient être prises pour protéger cette ressource importante à l'échelle locale.

INTRODUCTION

Lake Trout (*Salvelinus namaycush*) are widely distributed within North America, occurring in every province and territory of Canada and in northern regions of the USA (Scott and Crossman 1973). Lake Trout are predominantly found in cold, freshwater, pelagic systems, though some populations use rivers for part of their life cycle (Scott and Crossman 1973). Lake Trout are typically considered extremely stenohaline especially when compared to others within Salmonidae (Hiroi and McCormick 2007) and are seldom observed in salinities > 1 practical salinity unit (psu; Swanson et al. 2010).

Within the Inuvialuit Settlement Region (ISR) of northern Canada, Lake Trout are highly sought after as a subsistence fish, particularly during the early spring months by ice fisherman on the Husky Lakes, Northwest Territories (NWT; Hart 2011). Substantial time is spent by local anglers pursuing Lake Trout on Husky Lakes, and numerous camps and cabins have been built along their shorelines (Hart 2011). Prior to opening the Inuvik-Tuktoyaktuk Highway (ITH) in 2017, access by ground was only possible by snowmobile when conditions permitted as the lakes are located ~43 km northeast of Inuvik and 23 km east of Tuktoyaktuk (Hart 2011). Following completion of the ITH, improved road vehicle access will facilitate easier year-round use and potential for increased fishing pressure on lakes within close proximity to communities, including Husky Lakes.

Husky Lakes, also known as Eskimo Lakes and Imaryuk in Inuvialuktun, meaning “big water, or lots of water; (salt) water that is not good for drinking” (Hart 2011), are a series of five interconnected lake basins draining approximately 150 km northeast into the Beaufort Sea. The presence of both fresh and marine water inputs into the lakes creates a salinity gradient transitioning from ~1 psu in the southern-most basin to 17 psu in the northern-most basin (Roux et al. 2014). Because of the salinity gradient, fish species composition varies among basins, transitioning from common freshwater species in the southern basin to marine species in the northern basin (Roux et al. 2014, 2016). The observation of Lake Trout within this brackish-water environment by Indigenous fishers has raised scientific interest as the presence of Lake Trout in brackish water is extremely rare (Swanson et al. 2010). Research into Lake Trout life history indicates a substantial proportion (86 %) of the Husky Lakes population completes its entire life within the brackish water of Husky Lakes, termed a brackish-water resident life history (Kissinger et al. 2016). To date, this is the only known population of brackish-water resident Lake Trout. Two additional life histories were also documented, including semi-anadromous, a Lake Trout that hatches in freshwater and migrates to brackish-water at some point in life, and freshwater resident, a Lake Trout that completes an entire life cycle in freshwater (Kissinger et al. 2016). The presence of the semi-anadromous life history is relatively rare in Lake Trout and has only been documented in select regions of the Arctic (Swanson et al. 2010). Documentation of a semi-anadromous life history also indicates that there is connectivity and movement between Husky Lakes and connected freshwater lakes. Research by Kissinger et al. (2016) and Roux et al. (2016) has focussed on only a few locations and to date little is known about other lakes within the region, specifically those along the ITH. Available data on fish within this region relies heavily on traditional knowledge and is focused on historic areas of easy access and high use, typically for subsistence purposes (Hart 2011).

Due to the importance of Lake Trout to local people for food, the uniqueness of the brackish-water resident life history type within this species, the observations of migrations between connected lakes (semi-anadromous life history), and increased access to this region from the construction of the ITH, there is a need for better understanding of Lake Trout ecology within the ISR with a focus on lakes near the ITH. Specific objectives under this overarching goal include: 1) understanding where Lake Trout occur, 2) what types of lakes (abiotic and biotic environment) support Lake Trout, 3) characterize and identify ecologically significant habitat (i.e., spawning locations), 4) further describe Lake Trout movement and connectivity within the Husky Lakes, 5) examine Lake Trout genetic structure, and 6) determine how and why Lake Trout complete entire life cycles in the brackish water of Husky Lakes.

This report will focus primarily on how data was collected, lake-specific information, and general trends observed (objectives 1–3). More detailed analysis of samples collected in Husky Lakes (objectives 4–6) are described in Kissinger et al. (2016, 2018, 2019) and will be discussed below.

MATERIALS AND METHODS

In total, 6 lakes (Yukon 105, Wolf, Parsons, Noell, Jimmy, and Sitidgi) were sampled within the ISR (Figure 1). These lakes were selected based on past surveys and local knowledge suggesting that Lake Trout may be present and to describe Lake Trout ecology across a range of lake sizes. Lakes were sampled in 2014 and 2015 during the fall season (August to September). This time period was selected to coincide with Lake Trout spawning in an attempt to identify spawning locations, key features where spawning occurs, and to aid in collecting minimum sample sizes for assessments of growth, genetics, and life history. To conduct these surveys, a crew of 2 to 4 individuals were flown via helicopter to each lake to establish a camp, sample fish, complete vertical water profiles, and conduct bathymetric surveys. Sampling was conducted out of a 14 ft inflatable boat (Zodiac) with a 9.9 hp motor on all lakes except Yukon Lake 105 where an inflatable raft (self-propelled, Intex Mariner 3) was used. Both vessels were equipped with a depth sounder (Model Lowrance HDS7) for depth measurements used for creating bathymetric maps. All sampling locations were documented with a Garmin handheld GPS (Model Garmin GPSMAP® 64st).

FISH CAPTURE

Standardized nearshore index netting surveys were conducted using benthic experimental gill nets that were 60 m in length and 1.8 m high. Each net consisted of six 10 m panels of 25, 38, 64, 89, 114, and 127 mm monofilament mesh. Following methods similar to those of Roux et al. (2014), nets were set close to shore in waters > 1.8 m to ensure full net deployment. Nets were anchored to shore with a lead and deployed perpendicular from shore. When possible, nets were spaced a minimum of 1 km apart along the perimeter of the lake to sample a variety of near-shore habitats. In addition, nets were set opportunistically at random offshore locations throughout the lake to sample fish occupying deeper waters. The total number of nets set in each lake was primarily determined by time, weather limitations, and collection of minimum Lake Trout biological samples. In addition, hook and line angling was conducted to supplement Lake Trout sample collections. All captured fish were identified to species, weighed (g), measured (fork and total length, mm), and a genetic sample was taken (adipose fin clip). The fin clip also acted as a secondary mark to ensure released fish were not recaptured and counted more than once. For a subset of fish consisting of any accidental mortalities and lethal samples up to the permit limitation (25 or less for Lake Trout and 50 or less for all other species, adhering to DFO Licenses to Fish for Scientific Purposes S-14-15-3004 and S-15-16- 3007), full dissections to assess diet, sex, and maturity were conducted and additional tissues samples were taken including white muscle and otoliths for future analysis. Additionally, a photograph of the left side of all Lake Trout was taken for future morphometric analysis.

ABIOTIC MEASURES

Water chemistry was assessed at anchored locations using a portable YSI meter to measure vertical water parameter profiles recorded every meter from the surface (0 m) to the lake bottom. Dissolved oxygen (mg/l), pH, temperature (°C), and salinity (psu) were assessed in each lake at multiple points with a minimum of one measurement taken near the deepest location. Bathymetric mapping was conducted using a depth sounder (Model Lowrance HDS7) and maps were made using Dr. Depth software (version 5.1). Data collected for bathymetric map were made from transect grids with 500 m spacing to ensure complete coverage of the lakes when weather permitted.

RESULTS

YUKON LAKE 105

Access and Abiotic Measures

Yukon Lake 105 was accessed via helicopter by a crew of two departing out of Inuvik (one crew member was from Aklavik). Camp consisted of small tents and was located on the south side of the lake opposite the outflow (Figure 2). Yukon Lake 105 is 13.4 ha with a 2 km perimeter and a maximum depth of 15 m (Table 1; Appendix 1). Water properties were measured at seven locations throughout the lake and inlet streams. Vertical profiles taken within the lake were similar and indicate that it was not stratified at the time of sampling with temperature transitioning from 10.8 °C on the surface to 9.4 °C at the bottom (Figure 3a). Salinity (mean = 0.1 psu), pH (mean = 7.7) and dissolved oxygen (DO, mean = 10.6 mg/l) also were not stratified following a similar pattern as temperature (Figure 3a). Assessment of the inlet indicated temperatures were much lower than in the lake (3.8 °C) and may be a product of snow or permafrost melt. DO was also slightly elevated at the inlet (11.4 mg/l) which is likely influenced by a small waterfall present and a greater capacity to hold oxygen at colder temperatures.

Netting

Gillnets were set in 19 locations between August 19th and 22nd, 2014 for a total of 35.1 hours and an average set time of 1.8 hours per net and location (± 0.17 hours SE; Figure 2). Surface water temperatures ranged between 9° C and 11° C. In total, 79 fish were caught with gill nets representing two species, Lake Trout (n = 22) and Least Cisco (*Coregonus sardinella*, n = 57) (Table 2). Catch per unit effort (CPUE) for all fish caught was 3.7 fish/net hour (± 0.8 SE) and ranged from 0 to 10 fish/net hour (Table 2). Mean Lake Trout CPUE was 1.3 fish/net hour (± 0.4) and ranged from 0 to 6 fish/net hour. In addition to gillnetting, 43 fish were captured through angling – 26 Lake Trout and 17 Arctic Grayling (*Thymallus arcticus*, Table 2).

Arctic Grayling

Arctic Grayling were sampled only via angling and occurred near shore in shallow waters and in the inlet and outlet of the lake. Arctic Grayling were caught and visually observed above the lake in an inlet stream and below the lake in an outlet stream for approximately 200 m in each direction, at which time the stream gradient became very steep and likely limited fish migration. Arctic Grayling average fork length was 277 mm (± 5 mm SE) and ranged from 205 to 315 mm (Figure 4). While catch rates were not calculated for Arctic Grayling, fish were readily captured using small spinners at most locations around the lake with slightly higher catches at the inlet and outlet to the lake.

Least Cisco

Least Cisco were only captured in gillnets but represented the highest species relative abundance sampled (n = 57). Least Cisco were 201 mm (± 6 mm SE) fork length on average and ranged in size between 120 and 300 mm fork length (Figure 5).

Lake Trout

Lake Trout were on average 404 mm (± 12 mm SE) fork length and ranged from 190–580 mm (Figure 6a). Lake Trout from this lake had the smallest average fork length of any lake sampled within this study. Larger, deeper bodied Lake Trout were more commonly found in deep sets at the centre of the lake (~14 m depth). Based on this observation in multiple net sets, it appears there may be segregation of habitats by size or potentially by morphology as fish shape and size differed (Figure 7). Lake Trout were captured throughout the lake and did not congregate in any one location. In addition, a total of three Lake Trout were recaptured (which were not included in any calculations), suggesting the Lake Trout population is not large within this lake.

WOLF LAKE

Access and Abiotic Measures

Wolf Lake was accessed via helicopter by a crew of three from Inuvik. Camp consisted of multiple small tents and was located on the peninsula to allow for easier access to different regions of the lake (Figure 8). Wolf Lake is 1,300 ha with a 24.6 km perimeter and a maximum depth of 40 m (Table 1; Appendix 2). Water properties were measured at one location in Wolf Lake (Figure 8). The vertical profile of the lake indicates that it was not thermally stratified at the time of sampling, transitioning from 11.7 °C on the surface to 11.0 °C at the bottom (Figure 3b). Salinity (mean = 0.1 psu), pH (mean = 8.0) and DO (mean = 10.7 mg/l) were also not stratified, following a similar pattern as temperature (Figure 3b). Assessment of lake bathymetry indicates that there is a deep trough in the north basin that extends along the eastern side of the lake (Appendix 2). Here the bottom drops to 40 m along a channel oriented in a northwesterly to southeasterly direction. Due to thick aquatic vegetation in the southern basin we could not assess depth throughout the entire basin, however, depth in this portion of the lake is likely < 1 m (Appendix 2).

Netting

Gillnets were set in 35 locations between August 28th and 30th, 2014 for a total of 43 hours and an average set time of 1.2 hours (± 0.1 hours SE; Figure 8). Surface water temperatures at net locations were 11.7 °C. In total, 39 fish were caught with gill nets representing four species, Lake Trout (n = 13), Northern Pike (*Esox lucius,* n = 16), Broad Whitefish (*Coregonus nasus*, n = 9) and Least Cisco (n = 1) (Table 2). Mean CPUE for all species was 1.0 fish/net hour (± 0.2 SE) and ranged from 0 to 6 fish/net hour (Table 2). Mean Lake Trout CPUE was 0.2 fish/net hour (± 0.1 SE) and ranges from 0 to 2 fish/net hour. In addition to gill netting, 37 fish were captured through angling – 29 Lake Trout and eight Northern Pike (Table 2).

Broad Whitefish

Broad Whitefish mean length was 394 mm (± 28 mm SE) and ranged in size from 340 mm to 620 mm. The outlet to the lake had little to no flow at the time of sampling, thus it appears that these fish may be seasonally or completely landlocked potentially representing a lake resident life history which is uncommon for this species (Scott and Crossman 1973).

Lake Trout

Lake Trout average fork length was 523 mm (± 6.9) and ranged from 430–683 mm (Figure 6b). High numbers of Lake Trout were captured in the southeast corner of Wolf Lake. The majority of Lake Trout sampled from this region were males and all fish were mature and expelling gametes. Based on the high number of mature fish, it appears this region of the lake is likely used for spawning and may explain why catch rates were lower in other regions of the lake.

Northern Pike

Northern Pike average fork length was 557 mm (± 9 mm SE) and ranged from 429–649 mm (Figure 9a). The southern lobe of Wolf Lake was heavily weeded and likely provides good habitat for Northern Pike (Scott and Crossman 1973). This region was not heavily sampled because the density of submerged aquatic vegetation made setting and retrieving nets difficult.

JIMMY LAKE

Access and Abiotic Measures

Jimmy Lake was accessed via helicopter by a crew of three from Inuvik. Camp was established on the north side of the small island located in the centre of the lake and consisted of multiple small tents (Figure 10). Jimmy Lake is 1,152 ha with a 28.5 km perimeter; maximum depth was not taken due to equipment malfunctions (the lake is at least 15 m deep based on vertical water profiles; Table 1). The northern basin appeared to be the deepest basin based on manual depth measures taken during net sets. Water properties were measured at two locations in Jimmy Lake. Water profiles indicate that the lake was not stratified at the time of sampling with temperature transitioning from 11.5 °C on the surface to 11.4 °C at the bottom (Figure 3c). Salinity (mean = 0.03 psu), pH (mean = 7.2) and DO (mean = 9.9 mg/l) were not stratified either following a similar pattern as temperature (Figure 3c).

Netting

Gill nets were set in 18 locations between September 1st and 3rd, 2014 for a total of 21.7 hours and an average set time of 1.2 hours (± 0.1 hours SE; Figure 10). Surface water temperatures at net locations were 11.4 °C. In total, 87 fish were caught with gill nets representing five species, Lake Trout (n = 23), Northern Pike (n = 18), Broad Whitefish (n = 2), Lake Whitefish (*Coregonus clupeaformis*, n = 42) and Longnose Sucker (*Catostomus catostomus* n = 2) (Table 2). Mean CPUE for all species was 4.2 fish/net hour (± 1.3 SE) and ranged from 0 to 25 fish/net hour (Table 2). Mean Lake Trout CPUE was 1.3 fish/net hour (± 0.9 SE) and ranged from 0 to 17 fish/net hour. In addition to gill netting, 17 fish were captured through angling, consisting of 14 Lake Trout and three Northern Pike (Table 2).

Lake Trout

Lake Trout average fork length was 590 mm (± 5.2 mm SE) and ranged from 550–735 mm (Figure 6c). High numbers of Lake Trout were captured at a small shoal in the eastern arm of Jimmy Lake. The majority of Lake Trout sampled from this region were males and all fish were mature and ripe. Based on the high number of mature fish, it appears this region of the lake is likely used for spawning. In addition, both Lake Trout and Lake Whitefish had fertilized eggs in their stomach contents, indicating some spawning had already occurred by the time of the survey.

Lake Whitefish

Lake Whitefish average fork length was 498 mm (± 9.2 mm SE) and ranged from 359–640 mm (Figure 11a). High numbers of Lake Whitefish were captured at a small shoal in the eastern arm of Jimmy Lake where Lake Trout appeared to be spawning. The presence of Lake Trout eggs in the stomach of the Lake Whitefish suggest high numbers of Lake Whitefish may be linked to foraging on Lake Trout eggs.

Northern Pike

Northern Pike average fork length was 559 mm (± 30 mm SE) and ranged from 176–760 mm (Figure 9b). The southern arm of Jimmy Lake was shallower than the rest of the lake and had regions of thick aquatic vegetation where Northern Pike were captured in higher numbers by both gill nets and angling.

SITIDGI LAKE

Access and Abiotic Measures

Sitidgi Lake was accessed via helicopter by a crew of three from Inuvik. The crew stayed at a Parks Canada cabin located at the northeastern end of the lake (Figure 12). Sitidgi Lake is 28,653 ha with an 80.0 km perimeter and a maximum depth of 37.5 m (Table 1; Figure 12). Water properties were measured at one location in Sitidgi Lake. The vertical profile indicates that the lake was stratified with temperature transitioning from 11.0 °C on the surface to 7.3 °C at the bottom (Figure 3d). Temperature transitioned at ~20 m depth which is relatively deep for most lakes in this area but was similar to historical measurements (Roux et al. 2014). Salinity (mean = 0.1 psu), pH (mean = 7.3) and DO (mean = 10.2 mg/l) were not stratified (Appendix 3). The lake has one deep basin in the north eastern side that drops to 37.5 m, otherwise the lake is relatively shallow (Appendix 3).

Netting

Gill nets were set in 20 locations between August 27th and 30th, 2015 for a total of 22.6 hours and an average set time of 1.1 hours (± 0.1 hours SE; Figure 12). Sampling conditions were extremely poor and limited the ability to set nets throughout the lake due to high winds and rain. Surface water temperatures at net locations were 11.0 °C. In total, 74 fish were caught with gill nets representing five species, Lake Trout (n = 31), Northern Pike (n = 12), Broad Whitefish (n = 1), Lake Whitefish (n = 29) and Round Whitefish (*Prosopium cylindraceum,* n = 1) (Table 2). Mean CPUE for all species was 4.0 fish/net hour (± 0.7 SE) and ranged from 0 to 16 fish/net hour (Table 2). Mean Lake Trout CPUE was 1.5 fish/net hour (± 0.9 SE) and ranged from 0 to 17 fish/net hour. In addition to gill netting, 41 Lake Trout were captured via hook and line (Table 2).

Lake Trout

Lake Trout average fork length was 580 mm (± 5.2 mm SE) and ranged from 442–855 mm (Figure 6d). Capture rates in gill nets were fairly even throughout the locations sampled. Most of the Lake Trout captured through hook and line angling occurred on the western edge of the deep basin at the north eastern end of the lake (Appendix 3).

Lake Whitefish

Lake Whitefish average fork length was 384 mm (± 14.4 mm SE) and ranged from 259–509 mm (Figure 11b). An external parasite (*Coregonicola orientalis*) was observed on one Lake Whitefish and was the only one documented throughout the program, though other Lake Whitefish from Sitidgi Lake had round external scarring which may have been caused by this parasite. *Coregonicola orientalis* is found on anadromous Lake Whitefish (Stewart and Bernier 1999), suggesting that these fish may have travelled to the Husky Lakes estuary.

Northern Pike

Northern Pike average fork length was 568 mm (± 16.4 mm SE) and ranged from 482–700 mm (Figure 9c). The low number of Northern Pike in comparison to other lakes was likely because netting focused on the northeastern basin which did not have ideal Northern Pike habitat (depths up to 37.5 m). Sampling was restricted to this area due to poor weather conditions during the survey.

PARSONS LAKE

Access and Abiotic Measures

Parsons Lake was accessed via helicopter by a crew of three from Inuvik. The crew stayed in tents located on the southern peninsula; the southeastern basin was very weedy thus future locations for camps are recommended for different locations to allow for easier access by boat (Figure 13). Parsons Lake is 6,310 ha with a 54.2 km perimeter and a maximum depth of 7 m (Table 1). Water properties were measured at two locations in Parsons Lake (Figure 3e). A representative vertical profile of the lake at its deepest location indicates that the lake was not stratified at the time of sampling with temperature transitioning from 5.6 °C on the surface to 5.9 °C at the bottom (Figure 3e). Salinity (mean = 0.1 psu) and pH (mean = 7.3) remained relatively constant from the surface to the bottom but did change slightly in the last 1.5 m (Figure 3e). DO transitioned from 12.4 mg/l on the surface to 0.8 mg/l at the bottom, dropping quickly within 1.5 m from the bottom (Figure 3e). The second water profile mirrored the findings of the first but was assessed in shallower water (3.5 m). Subtle decreases in pH and large drops in DO often signify high levels of decomposition which may be caused by the high levels of vegetation in this lake. This lake was the shallowest lake assessed (maximum depth 7 m) and may explain why Lake Trout were not documented. In addition, the lake was almost 5 °C colder than Sitidgi Lake even though it was sampled within 3 days. Lower temperatures are likely a product of cold weather, high winds and large volumes of rain that had occurred over the previous week in combination with the smaller volume and shallower depths of Parsons Lake.

Parsons Lake is connected to multiple lakes including Husky Lakes. We were able to access a connected lake to the west which was heavily vegetated (location, 68.934330°, -133.838907°). The outflow to Husky Lakes could not be navigated due to numerous shallow locations, but fish may be able to pass through it at the higher flows during the spring freshet.

Netting

Gill nets were set in 26 locations between September 2nd and 4th, 2015 for a total of 22.7 hours and an average set time of 0.9 hours (± 0.1 hours SE; Figure 13). Surface water temperatures at net locations were between 5.1 and 6.3 °C. In total, 89 fish were caught with gill nets representing four species: Northern Pike (n = 44), Lake Whitefish (n = 33), Least Cisco (n = 11) and Burbot (*Lota lota*, n = 1) (Table 2). Mean CPUE for all species was 4.1 fish/net hour (± 0.8 SE) and ranged from 0 to 16 fish/net hour (Table 2). Mean Northern Pike CPUE was 2.2 fish/net hour (± 0.6 SE) and ranged from 0 to 13 fish/net hour. Mean Lake Whitefish CPUE was 1.6 fish/net hour (± 0.3 SE) and ranged from 0 to 5 fish/net hour. No Lake Trout were captured at this lake via netting or angling.

Lake Whitefish

Lake Whitefish average fork length was 421 mm (± 9.9 mm SE) and ranged from 248–480 mm (Figure 11c). Lake Whitefish were fairly evenly distributed throughout the lake except in the south basin where shallow depths and high volumes of aquatic vegetation were documented.

Northern Pike

Northern Pike average fork length was 561 mm (± 17 mm SE) and ranged from 375–910 mm (Figure 9d). The large vegetated bays and numerous tributaries that feed into smaller vegetated lakes, are ideal Northern Pike habitat and likely bolstered catches.

NOELL LAKE

Access and Abiotic Measures

Noell Lake was accessed via helicopter by a crew of four from Inuvik. The crew stayed with permission at a community member's cabin on the north end of the lake near the outlet (Figure 14). Noell Lake is 2,988 ha with a 21.5 km perimeter, maximum depth was 12 m (Table 1; Figure 14). Water properties were measured at two locations in Noell Lake (Figure 14). Vertical water profiles of the lake indicate that the lake was not stratified at the time of sampling with temperature transitioning from 7.3 °C on the surface to 7.5 °C at the bottom (Figure 3f). Salinity (< 0.1 psu), pH (mean = 6.9) and dissolved oxygen (mean = 11.6) remained relatively constant from the surface to bottom (Figure 3f). The lake has two deep basins, one at the northeast end and one at the west end (Appendix 4). There is a large shoal at the southern end of the lake (~ 0.8

km^2) that rises up to just under 1 m depth. Little submerged aquatic vegetation was observed within the lake at the time of sampling.

Netting

Gill nets were set in 18 locations between September 7th and 9th, 2015 for a total of 12.1 hours and an average set time of 0.7 hours (± 0.1 hours SE; Figure 14). Surface water temperatures at net locations were 7.3 °C. In total, 117 fish were caught with gill nets representing five species: Lake Trout (n = 32), Lake Whitefish (n = 58), Least Cisco (n = 22), Northern Pike (n = 4) and Round Whitefish (n = 1) (Table 2). Mean CPUE for all species was 11. 6 fish/net hour (± 4.3 SE) and ranged from 0 to 83 fish/net hour (Table 2). High catches of Lake Whitefish occurred near a small inflow at the southeastern end of the lake. Mean Lake Trout CPUE was 1.7 fish/net hour (± 1.3 SE) and ranged from 0 to 12 fish/net hour. High catch rates were documented on a shoal at the southern end of the lake ~ 1 km offshore. Here catch rates were high for both gill nets and hook and line angling. Mean Lake Whitefish CPUE was 5.6 fish/net hour (± 3 SE) and ranged from 0 to 58 fish/net hour. An additional 13 Lake Trout were caught via hook and line angling; only genetics samples were taken from these fish (Table 2).

Lake Trout

Lake Trout average fork length was 574 mm (± 8.6 mm SE) and ranged from 499–690 mm (Figure 6e). High Lake Trout catches of mature fish on a shoal ~ 1.5 km (68.518888°, -133.577932°) offshore suggest that this is likely a spawning location. This shoal was relatively large in comparison to the lake's size covering approximately 65 ha, but the vast majority of fish were found on the northern side facing the prevailing wind. Based on little structure in the lake and low catches at other netting locations, it appears that this may be their primary spawning location. Similar to Jimmy and Wolf lakes, the spawning shoal is located at the southern end of the lake allowing for ~ 4.5 km of fetch to the prevailing wind out of the northwest. Underwater camera footage of the shoal shows that there is large cobble substrate present with little sediment which is ideal Lake Trout spawning habitat.

Lake Whitefish

Lake Whitefish average fork length was 469 mm (± 5.5 mm SE) and ranged from 337–609 mm (Figure 11d). Large numbers of mature Lake Whitefish congregating at an inflow to the lake at the southeastern end may indicate staging prior to spawning at this location or upstream in one of the connected lakes.

DISCUSSION

We successfully conducted six surveys of fish-bearing lakes within the ISR. Lakes ranged from 13.4 ha (Yukon Lake 105) to 28,653 ha (Sitidgi Lake) in surface area and 7 m (Parsons Lake) to 40 m (Wolf Lake) in maximum depth. Lake Trout were captured in five of the six lakes. In Parsons Lake, Lake Trout were not captured; therefore, if present, the density of this species is presumably low, given the rigorous sampling effort geared towards Lake Trout. We also documented locations of high Lake Trout aggregations associated with spawning events occurring near the end of August and into early September. In addition, we collected biological samples that have been used in multiple studies further investigating Lake Trout ecology in the region.

LAKE TROUT SPAWNING

Lake Trout were gravid and aggregating on spawning shoals at all locations except in Parsons Lake (no Lake Trout were captured) and Yukon Lake 105. It appears Lake Trout spawn in this region between the last week of August and the first week of September, based on the capture of ripe males and females during our sampling campaign. This is further supported by the observation of Lake Trout and Lake Whitefish with Lake Trout eggs in their stomachs in Jimmy Lake on September 3rd. In Jimmy, Noell, and Wolf lakes, Lake Trout aggregate at high densities on clean, rocky shoals at the southeastern ends of the lakes. The prevailing northwest wind in this region provides clean well-oxygenated cobble substrate ideal for spawning on the leeward side of these basins (Muir et al. 2012). Since Yukon Lake 105 is nestled in a mountain valley and was relatively small, spawning areas might be less defined as the prevailing wind was less consistent, therefore large aggregations may not occur in any one area of the lake. A lack of defined spawning shoals has been documented elsewhere in the NWT by Callaghan et al. (2016). They observed lake-wide spawning and described it as a likely product of unpredictable wind patterns, potential interstitial water flow, and large amounts of high-quality spawning habitat spread over the lake areas. A similar statement could be made for Yukon Lake 105 as the substrate in nearly all regions was cobble except for the inflow and outflow areas of the lake. Models using wind direction, fetch and lake depth accurately predict Lake Trout spawning locations in many lakes, especially when the direction of prevailing winds is relatively constant (Flavelle et al. 2002). These models find that spawning areas often occur in the same locations within lakes, as we predominately found – i.e., leeward side relative to the prevailing wind where shallow shoals and points rise up from the lake bottom (Flavelle et al. 2002). Since Lake Trout are highly prized by local harvesters, caution should be taken to protect these ecologically significant habitats.

ABIOTIC ENVIRONMENT

Of the six lakes surveyed, there was a wide range in lake depths and sizes where Lake Trout were found. While it is common to find Lake Trout in large, deep, oligotrophic lakes like Sitidgi Lake (Gunn et al. 2004), the observation of Lake Trout in Yukon Lake 105 was very interesting as it is a small (13.4 ha) and relatively shallow lake (< 13.0 m). In the southern extent of the range of Lake Trout, their absence in shallow small lakes is primarily due to their inability to tolerate warm temperatures which is more of an issue in low volume lakes (Evans 2007). Since the lakes sampled here are at the northern extent of the northwestern distribution of this species, summer water temperatures likely do not get as high, providing a thermal range which allows for survival in lakes with smaller volumes and shallower depths. Additionally, the river flowing into Yukon Lake 105 was much colder than the lake and likely had permafrost melt or groundwater inputs which would help maintain colder temperatures. Many texts show Lake Trout distribution extending through the Yukon North Slope region (e.g., McPhail and Lindsey 1970; Scott and Crossman 1973; Coad and Reist 2018 (coastal)) but, to the best of our knowledge, there are no capture records of Lake Trout within this area except for our records at Yukon Lake 105. The nearest recorded capture of a Lake Trout was at Shingle Point, approximately 76 km away (Loewen et al. 2013) which is 140 m lower in elevation with about 20 km of wet tundra between Yukon Lake 105 and the nearest connected water (i.e., Beaufort Sea). The capture event at Shingle Point likely represents a straying individual rather than an established population of Lake Trout, as capture of Lake Trout in this region of the Beaufort Sea is extremely rare. The closest documented Lake Trout populations are those within the Mackenzie Delta as described in Sawatzky et al. (2007). It is important to note that Sawatzky et al. (2007) did not include records from the Yukon Territory in their reporting, but we could not find any other literature referencing Lake Trout capture closer to Yukon Lake 105. Thus, it is possible that this population represents a relict surviving in this lake from the last major glaciation (~ 10,000 years ago). It is also impressive that the ecosystem balance within this small lake among Lake Trout, Arctic Grayling, Least Cisco and Ninespine Stickleback, *Pungitius pungitius* (observed but not captured during this work) has been maintained for this period with likely no other fish immigration for thousands of years.

BIOTIC ENVIRONMENT

Comparison of catches from each lake suggest that CPUE was highest in Noell Lake and lowest in Wolf Lake. Differences observed among lakes in CPUE are potentially biased as net locations were not completely random (i.e., some nets were set in deep locations) and netting occurred during the spawning period for numerous fall-spawning species including ecologically dominant species such as Lake Trout and Lake Whitefish. Sampling during spawning periods increases variability in captures (e.g., 0 to 58 Lake Whitefish/net hour in Noell Lake), due to spatial aggregations of adults at spawning locations and netting is often biased to adults. In Noell Lake, high total CPUE was likely due to fewer net sets for longer durations (n = 18, for 12.1 hours). If comparison of CPUE is the goal of future assessments, consideration of other standard protocols is recommended (e.g., Summer Profundal Index Netting (SPIN), Sandstrom and Lester 2009 or Broad-scale Monitoring (BsM), Sandstrom et al. 2013), but caution must be taken as many of the lakes did not show signs of thermal stratification, suggesting that common standards like SPIN, which rely on annual thermal stratification may not be appropriate. Assessment of CPUE in the surveys documented herein was primarily an attempt to identify high aggregations of Lake Trout associated with spawning.

Assessment of species richness (S) indicates that Noell, Jimmy, and Sitidgi lakes had equal numbers of species captured (S = 5), though a past assessment on Sitidgi Lake indicated that at least 8 species are present (Roux et al. 2014). Fewer species captured in Sitidgi Lake during the present study could be a product of fewer net sets (20 vs. 55) and an inability to sample the entire lake due to weather limitations. Higher species richness in these three lakes is likely a product of the lakes larger surface area and depths providing a greater range of habitat types. In addition, all three lakes are connected to Husky Lakes which has a high species richness (S = 17; Roux et al. 2014) and movements among these lakes by some species have been documented (Kissinger et al. 2016).

ADDITIONAL ASSESSMENTS OF LAKE TROUT ECOLOGY

In addition to the data reported within this study, samples were also collected through a local Lake Trout monitoring program on Husky Lakes. In combination with the present sample collection, Roux et al. (2014) and the local Lake Trout monitoring program, samples have been assessed for fish movement and life history (Kissinger et al. 2016), genetic structure (Kissinger et al. 2018), and growth rates and longevities (Kissinger et al. 2019). These additional studies have shown that multiple Lake Trout life history types are observed throughout these lakes (inferred from otolith microchemistry) including freshwater resident (all lakes in the present study), semi-anadromous (Jimmy, Sitidgi, and Husky lakes), and brackish-water residents (Husky Lakes) (Kissinger et al. 2016, 2018). Based on these findings, the occurrence of a semi-anadromous Lake Trout life history in Jimmy, Sitidgi, and Husky lakes expands the known distribution of this life history type for Lake Trout to the western from the central mainland Arctic (Swanson et al. 2010). The Husky Lakes brackish-water resident Lake Trout life history type represents the only known occurrence of this type (Kissinger et al. 2016), however, sampling for Lake Trout in brackish waters is limited within the Canadian Arctic, thus more populations may exist. The inference of movements from otolith microchemistry among Sitidgi Lake, Jimmy Lake and Husky Lakes based on the presence of semi-anadromous Lake Trout and *Coregonicola orientalis* parasites on Lake Whitefish demonstrates connectivity between fresh and marine influenced environments (Kissinger et al. 2016, 2018). While more migratory species like Lake Whitefish and Broad Whitefish have yet to be assessed for movement patterns through otolith microchemistry, we would predict even higher proportions of semi-anadromous life history types would be observed as these species are more well known to migrate long distances and use brackish-water environments (Scott and Crossman 1973). The presence of migratory fish in these lakes highlights the need to ensure connectivity is maintained among these locations, as this attribute appears to occur in a substantial proportion of these populations (i.e., 44% of Lake Trout assessed from Sitidgi Lake) (Kissinger et al. 2018). While inferred movement patterns were assessed in Lake Trout, additional life histories and morphometry were not. The observation of different Lake Trout sizes and body shapes in Yukon Lake 105 (Figure 7) suggests that additional morphological differences could exist within this lake increasing the intraspecific ecological diversity observed within this region. Similar morphological diversity is not uncommon but is typically documented in larger ecosystems (e.g., Lake Trout in Great Bear Lake; Chavarie et al. 2013) where greater diversity in forage items and habitat types exist.

Assessment of Lake Trout genetics among lakes sampled in the region found that there were high levels of genetic differentiation among all lakes, even those such as Jimmy, Noell, Sitidgi, and the Husky Lakes that are connected (Kissinger et al. 2018). High genetic structure is likely linked to segregation of spawning habitat among lakes due to physical barriers (e.g., landlocked Yukon Lake 105) and spawning site fidelity in other lakes (Kissinger et al. 2018). This suggests that even when semi-anadromous Lake Trout migrate to Husky Lakes, presumably for foraging, they return to their natal lake to spawn (Kissinger et al. 2018). Based on the assessment of life history type and genetics, the highest proportion of semi-anadromous Lake Trout is found in Sitidgi Lake (44%) and appears to be the source of nearly all semi-anadromous Lake Trout captured in Husky Lakes and Jimmy Lake (Kissinger et al. 2018). Allelic richness varied among lakes with Husky Lakes having the highest and Yukon Lake 105 the lowest; 15.0 vs. 1.9 alleles per loci on average, respectively (Kissinger et al. 2018). Low allelic richness in Yukon Lake 105 suggests the population has been isolated for a long time, and is likely a product of its location and isolation from nearby Lake Trout populations as discussed above. In addition, the Husky Lakes brackish-water resident life history type was genetically differentiated from both populations and life history types in all other lakes, suggesting this life history is likely locally adapted to the brackish water of Husky Lakes.

Assessment of growth and longevity from Lake Trout populations within the Husky Lakes drainage basin found that Lake Trout can live to be 51 years (mean age from Husky Lakes sample = 21.8 years) and have higher growth rates in the brackish waters of Husky Lakes (Kissinger et al. 2019). Benefits to growth are likely linked to higher levels of resources (prey items) within Husky Lakes, as significantly higher catch rates were observed when compared to connected freshwater lakes (Roux et al. 2014). In addition, species diversity is higher in Husky Lakes than in connected lakes (Roux et al. 2014) and changes in species presence appear to be linked to the salinity gradient observed (Roux et al. 2016). At the interface between freshwater and marine habitats, Lake Trout and other freshwater species can occupy areas with lower salinity levels (1–17 psu) than those with full-strength saltwater (~ 33 psu), and prey upon marine species not found in fresh water, and upon higher densities of fish overall (mean = 61.8, range 2–253 fish/net hour).

CONCLUSION

Here we expand the current information on species presence, basic biological metrics, and Arctic freshwater ecology within the ISR, while providing samples for more in-depth assessment of Lake Trout ecology in follow-on analyses. Key findings from the present study indicated that 1) Lake Trout spawn in this region at the end of August and into early September, 2) spawning typically occurs on the leeward side of lakes (i.e., south to southeastern margins) on cobble shoals, 3) during spawning Lake Trout aggregate in high numbers on spawning shoals, and 4) Lake Trout are found in all locations sampled except Parsons Lake. Moving forward with management of fisheries along the ITH, local management agencies should recognize that Lake Trout aggregate in large numbers during spawning and are highly vulnerable to nets and angling. If overharvest becomes a conservation concern, catch restrictions during the spawning period should be considered (e.g., fishing closures or gear restrictions during the spawning period). This assessment represents only a small number of lakes within the ITH corridor, and therefore additional work should be conducted to collect baseline data to enable monitoring these populations. Doing so will improve our ability to conserve existing fisheries for future generations, despite increased angler accessibility to these lakes through improved access and impacts associated with the ITH.

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TABLES

Table 1. Physical properties of lakes assessed throughout the Inuvialuit Settlement Region, YK and NWT 2014 and 2015. Lake surface area and perimeter were determined using ArcGIS mapping tools and maximum (max) depth was obtained using set transects and a depth sounder.

	YK 105	Wolf	Jimmy	Sitidgi**	Parsons	Noell***
Surface area (ha)	13	13,00	1,152	28,653	6,310	2,988
Perimeter (km)	2	24.6	28.5	80	54.2	21.5
Max depth (m)	12.2	40	*15	37.5	7	12

* a large portion of the southern basin was not assessed so a deeper location may exist.

** Max depth from Roux et al. 2014.

*** Max depth from Paquette-Struger 2011.

Tables 2. Total fish catch from gill netting and hook and line angling at lakes sampled in the Inuvialuit Settlement Region, NWT and YK, 2014 and 2015. Catch per unit effort (CPUE) is calculated based only on the gill net capture and is represented as fish/net hour ± SE.

Lake	Arctic Grayling	Broad Whitefish	Burbot	Lake Trout	Lake Whitefish	Least Cisco	Longnose Sucker	Northern Pike	Round Whitefish	CPUE	SE
YK											
105	26	0	0	39	0	57	0	0	0	3.7	0.8
Wolf	0	9	0	42	0	1	0	24	0	1	0.2
Jimmy	0	2	0	37	42	0	2	21	0	4.2	1.3
Sitidgi	0	1	0	72	29	0	0	12	1	4	0.7
Parsons	0	0	1	0	33	11	0	44	0	4.1	0.8
Noell	0	0	0	31	58	22	0	4	1	11.6	4.3

FIGURES

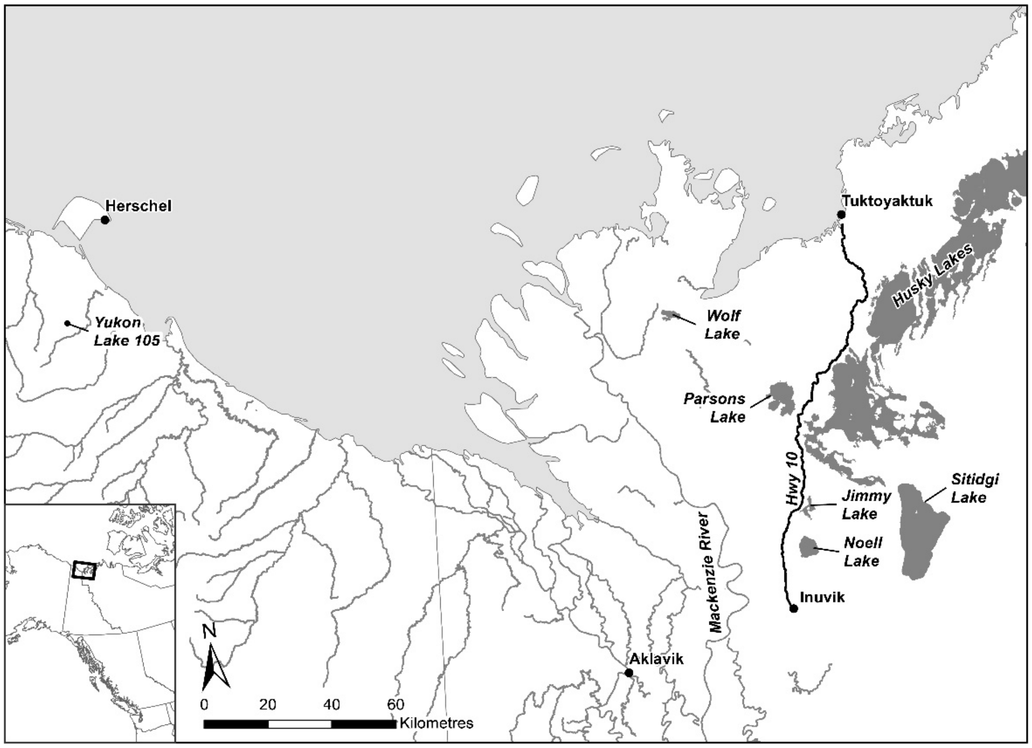


Figure 1. Lakes sampled throughout the Inuvialuit Settlement Region (ISR), 2014 and 2015.

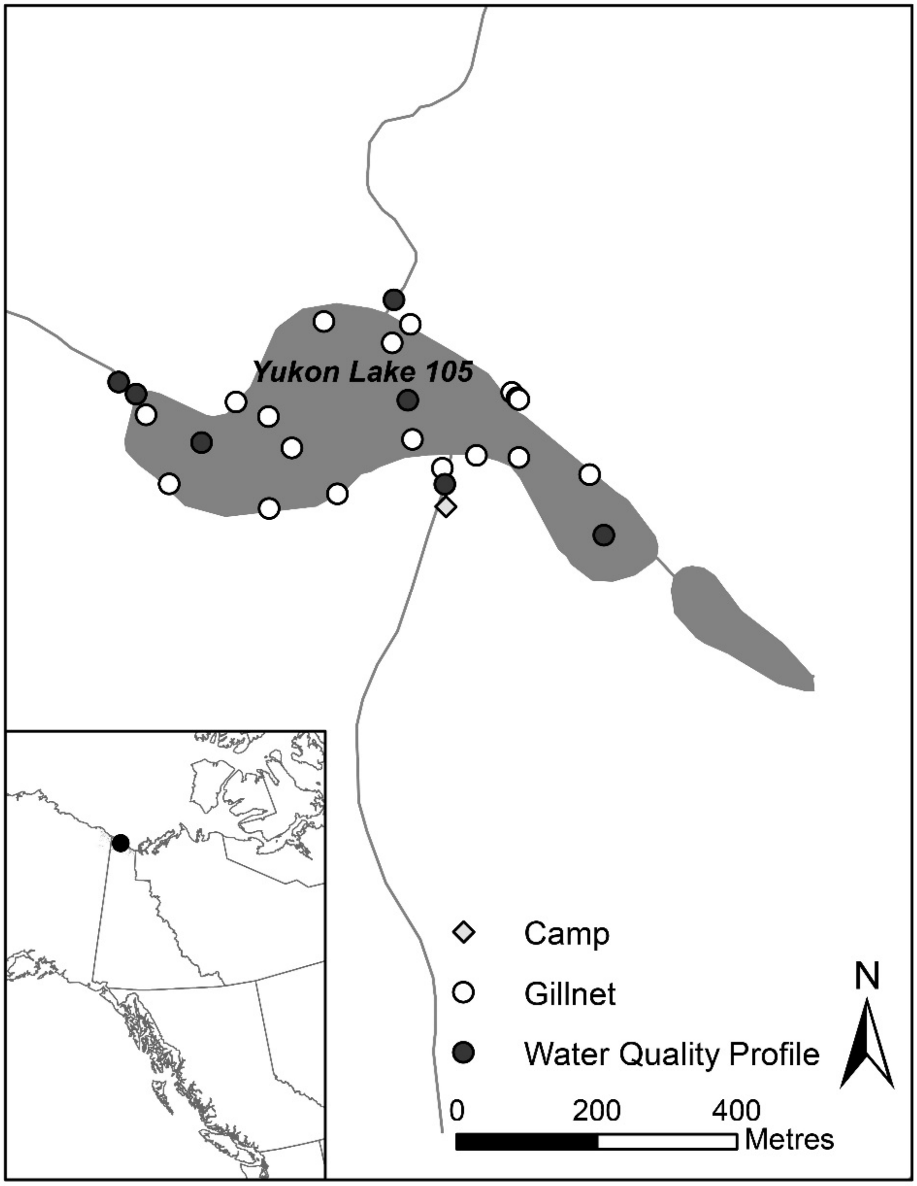


Figure 2. Gillnet locations (hollow points) and water sampling locations (filled points) at Yukon Lake 105, YK 2014.

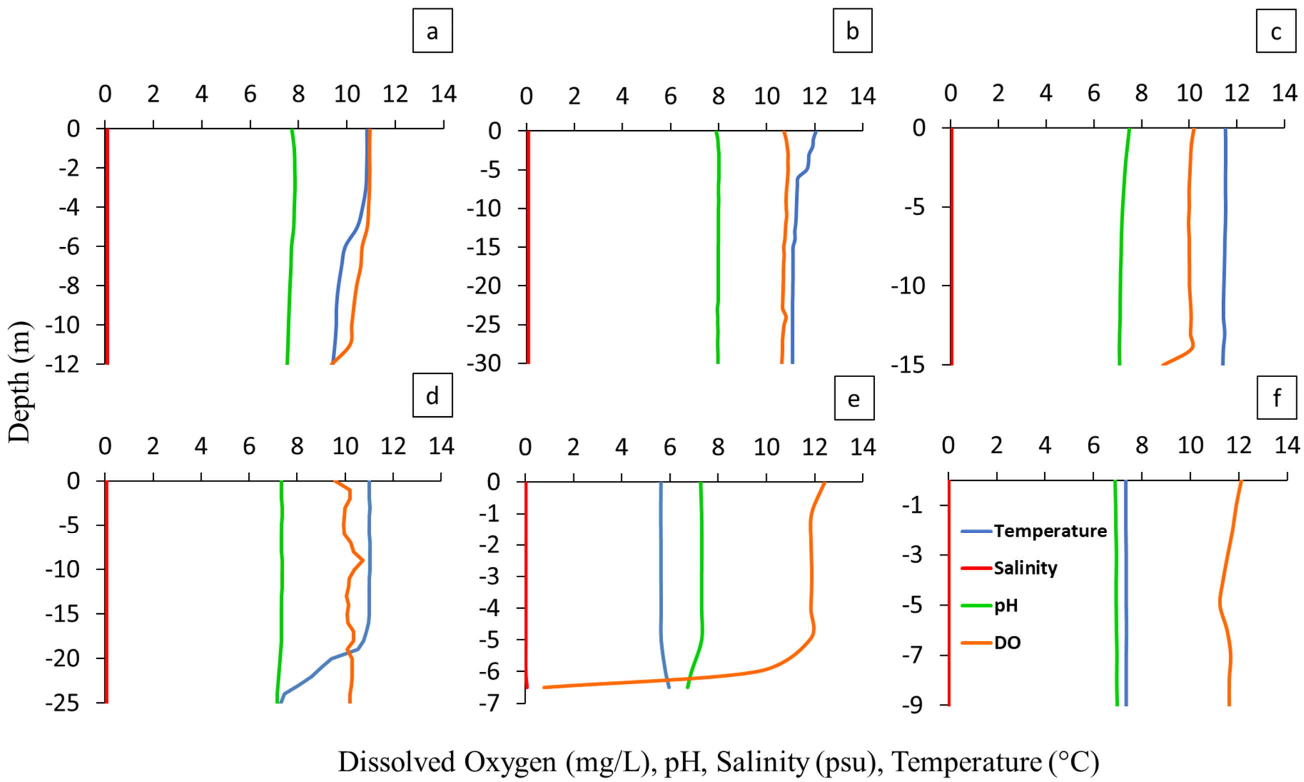


Figure 3. Water properties from a representative vertical profile at, a) Yukon Lake 105, YK, b) Wolf Lake, NWT, c) Jimmy Lake, NWT, d) Sitidgi Lake, NWT, e) Parsons Lake, NWT, and f) Noell Lake, NWT.

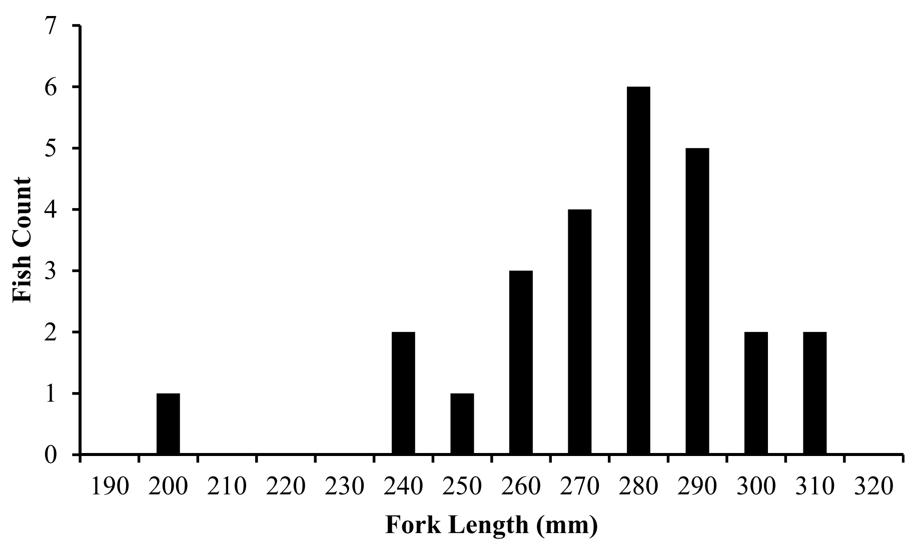


Figure 4. Fork length distribution of Arctic Grayling captured via hook and line angling in Yukon Lake 105, YK 2014. Lengths are enumerated into 10 mm bins.

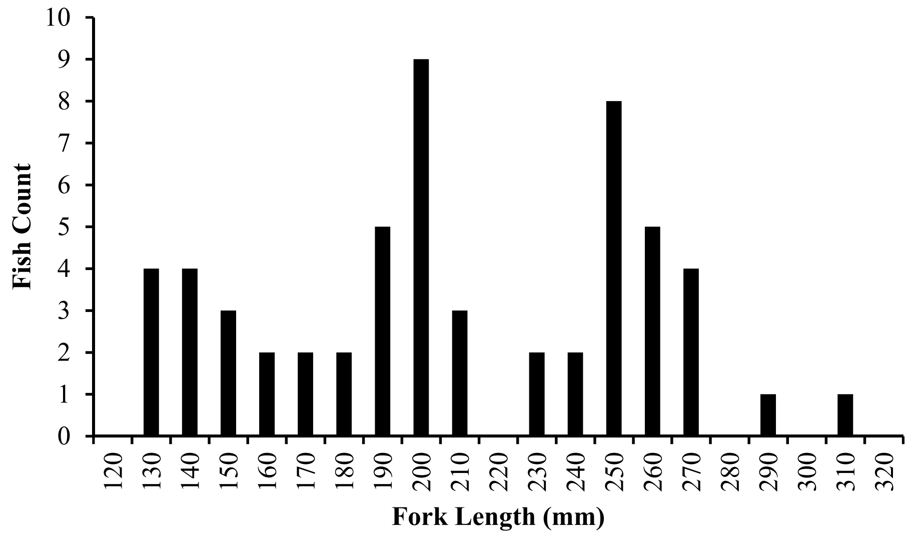


Figure 5. Fork length distribution of Least Cisco captured via gillnetting in Yukon Lake 105, YK 2014. Lengths are enumerated into 10 mm bins.

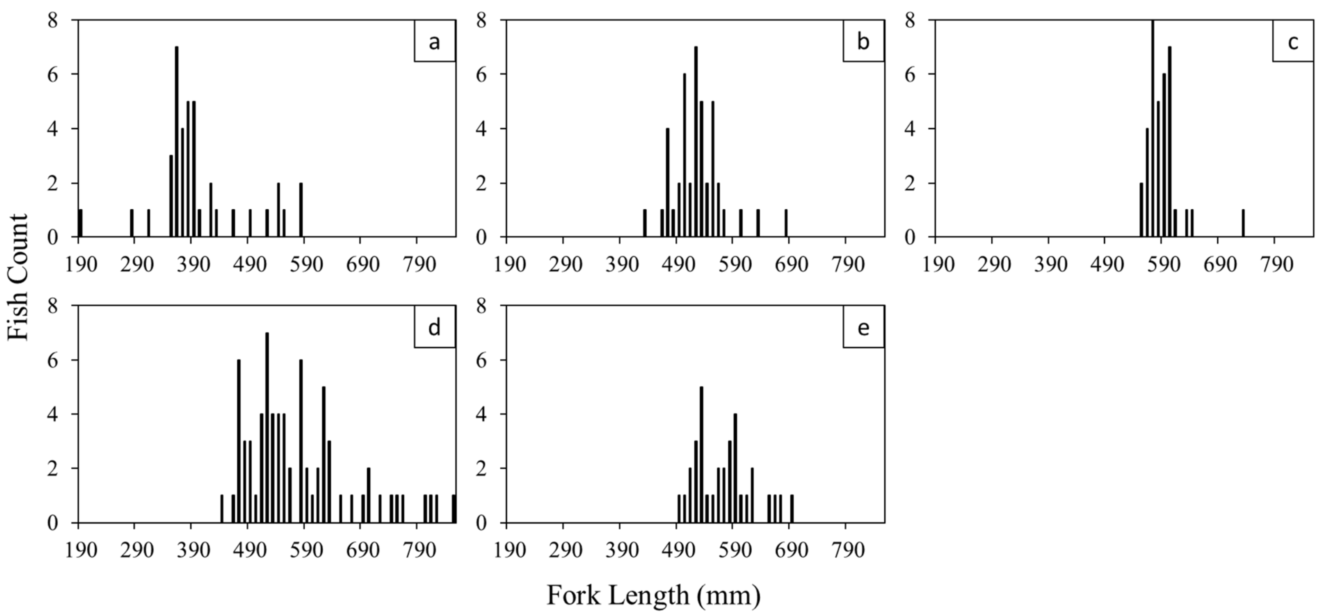


Figure 6. Fork length distribution of Lake Trout captured in a) Yukon Lake 105, YK b) Wolf Lake, NWT, c) Jimmy Lake, NWT, d) Sitidgi Lake, NWT, and e) Noell Lake, NWT. Fork lengths are enumerated in 10 mm bins.

Figure 7. Two Lake Trout captured in Yukon Lake 105, YK 2014: a) representative picture of Lake Trout caught in the deepest depth strata in the lake via gillnet, b) representative picture of a Lake Trout typically caught near shore in shallow net sets or by hook and line.

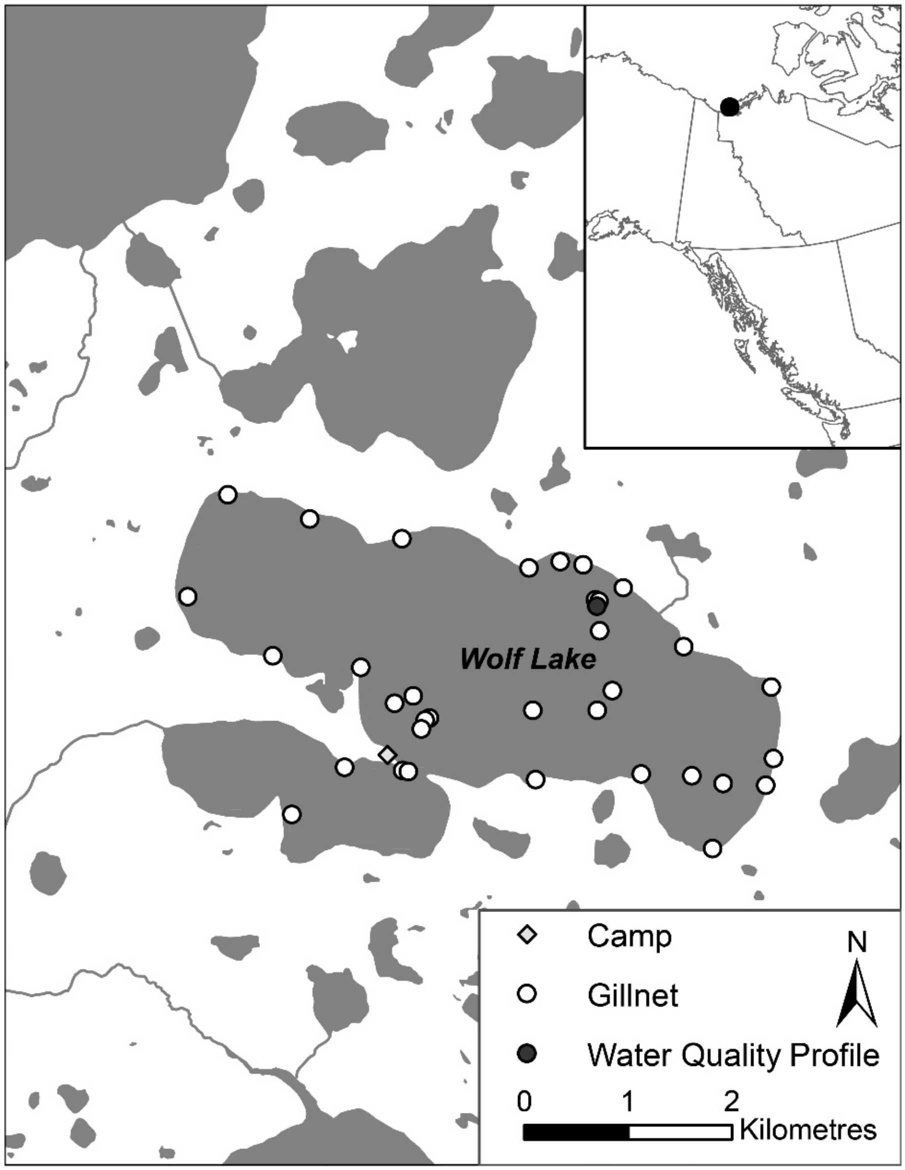


Figure 8. Gillnet locations (hollow points) and water sampling locations (filled points) at Wolf Lake, NWT 2014.

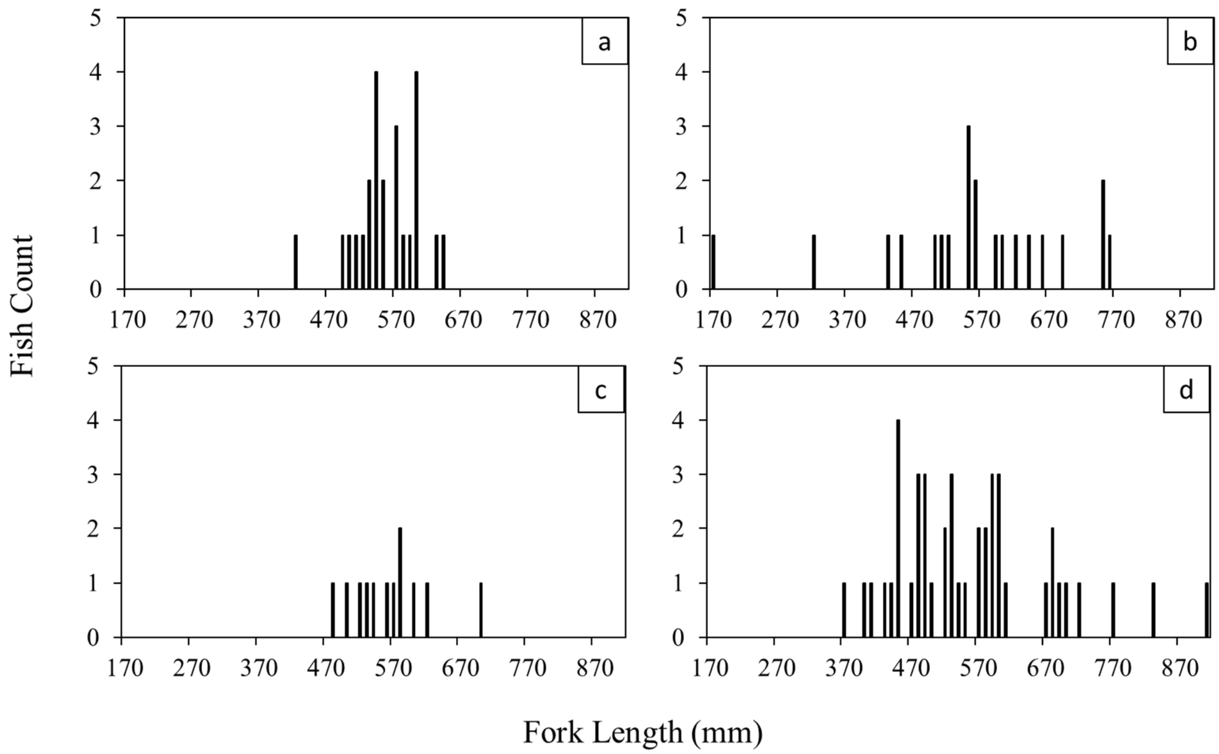


Figure 9. Fork length distribution of Northern Pike captured in a) Wolf Lake, NWT, b) Jimmy Lake, NWT, c) Sitidgi Lake, NWT, and d) Parsons Lake, NWT. Fork lengths are enumerated in 10 mm bins.

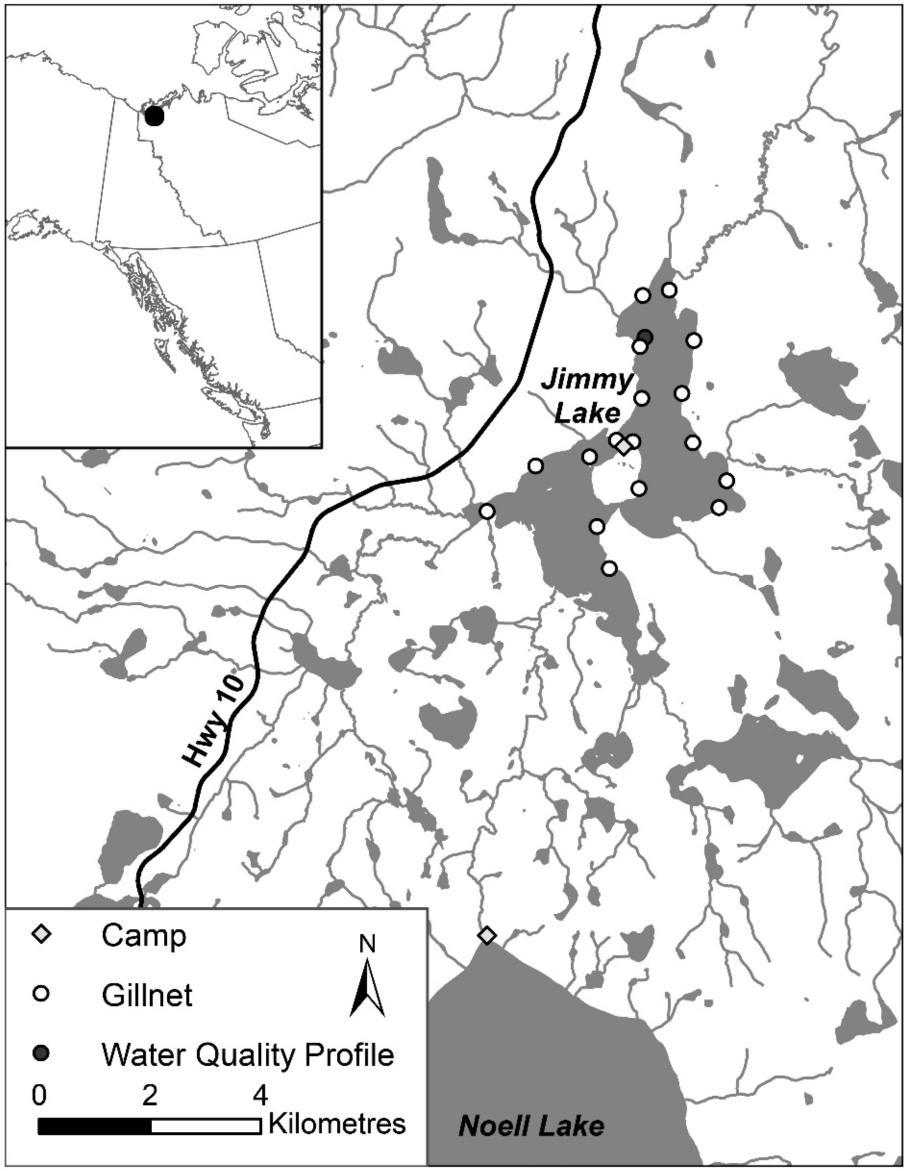


Figure 10. Gillnet locations (hollow points) and water sampling locations (filled points) at Jimmy Lake, NWT 2014.

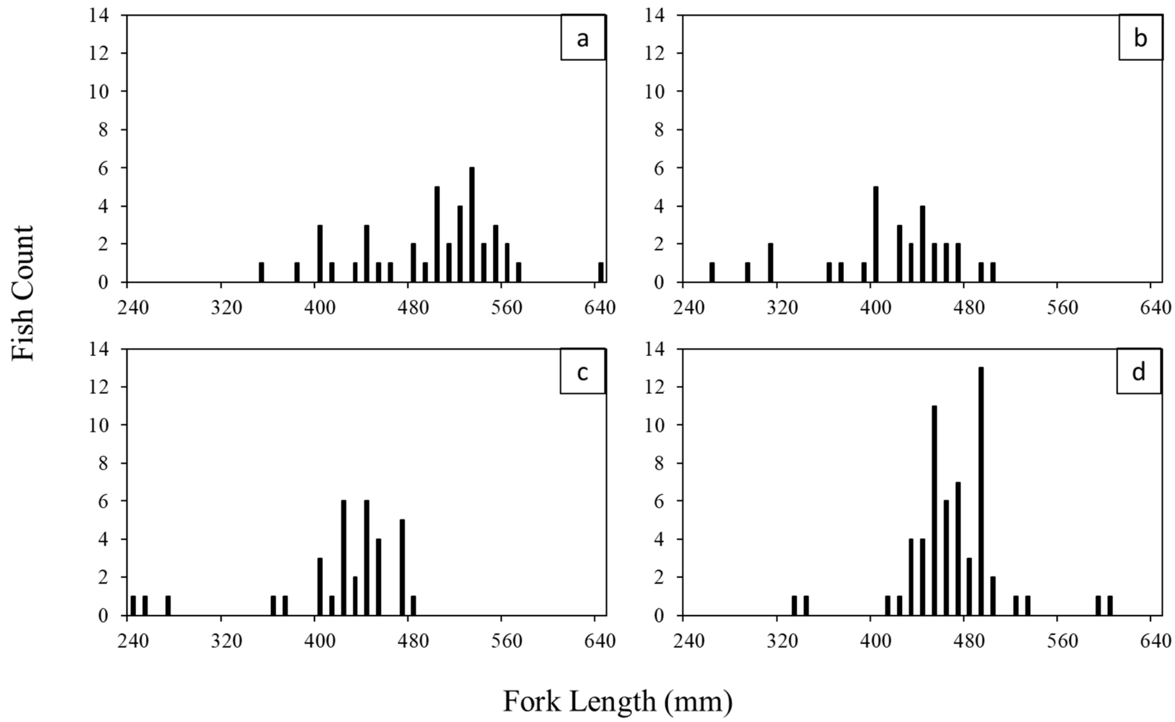


Figure 11. Fork length distribution of Lake Whitefish captured in a) Jimmy Lake, NWT b), Sitidgi Lake, NWT, c) Parsons Lake, NWT and d) Noell Lake, NWT. Fork lengths are enumerated in 10 mm bins.

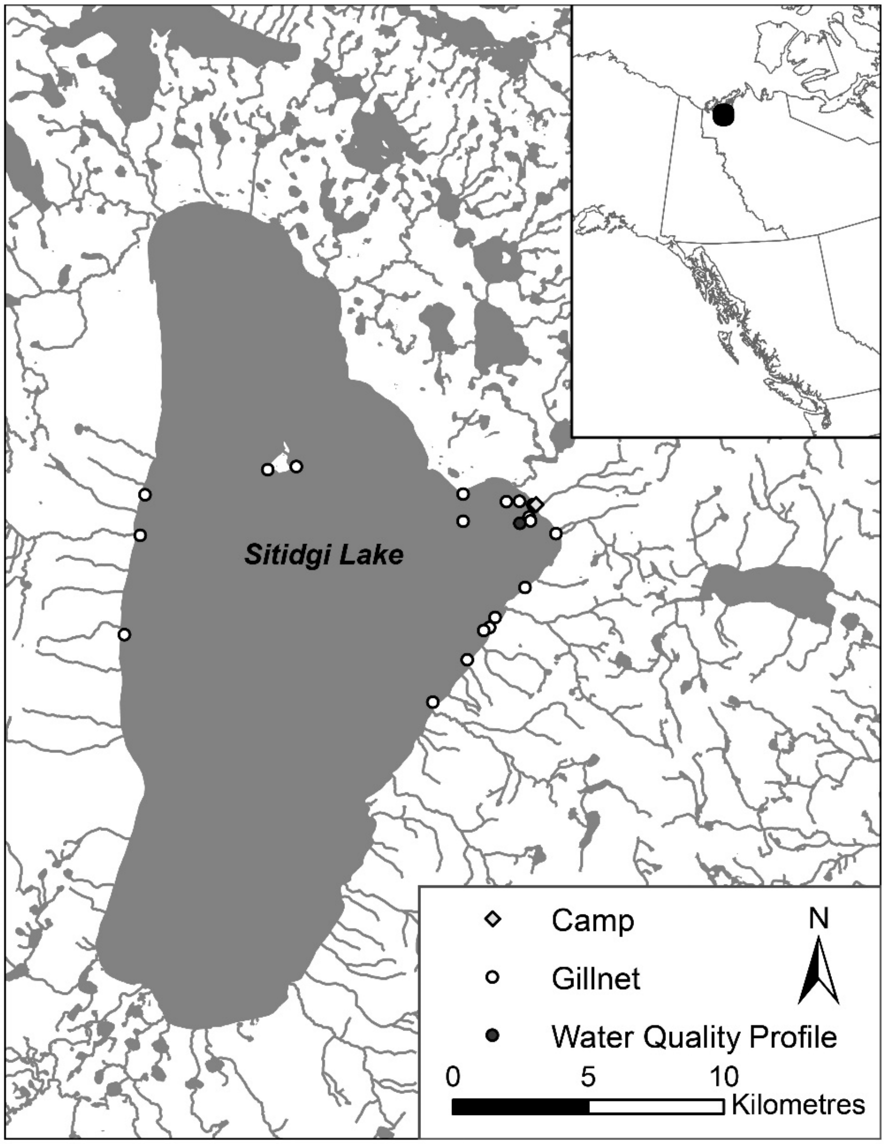


Figure 12. Gillnet locations (hollow points) and water sampling locations (filled points) at Sitidgi Lake, NWT 2015.

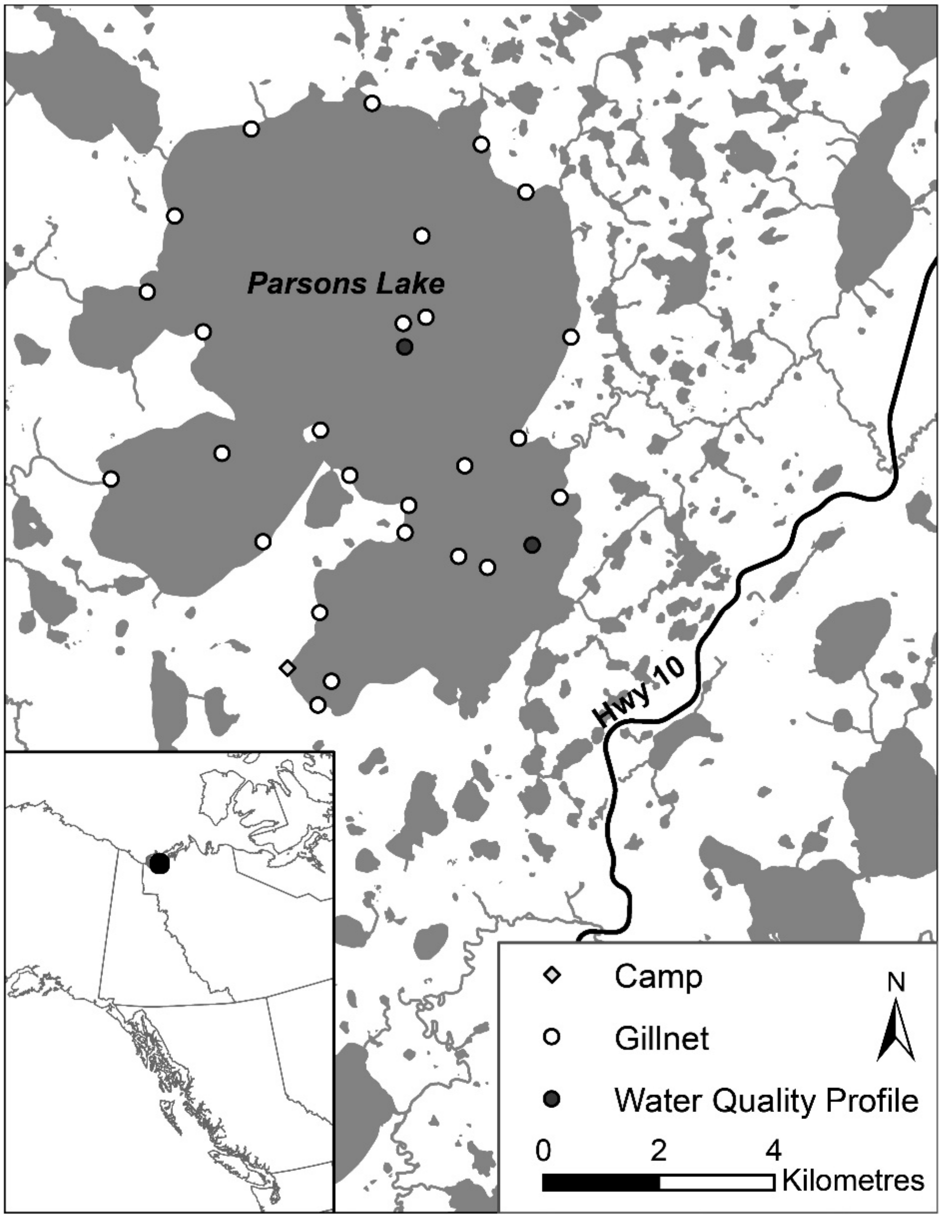


Figure 13. Gillnet locations (hollow points) and water sampling locations (filled points) Parsons Lake, NWT 2015.

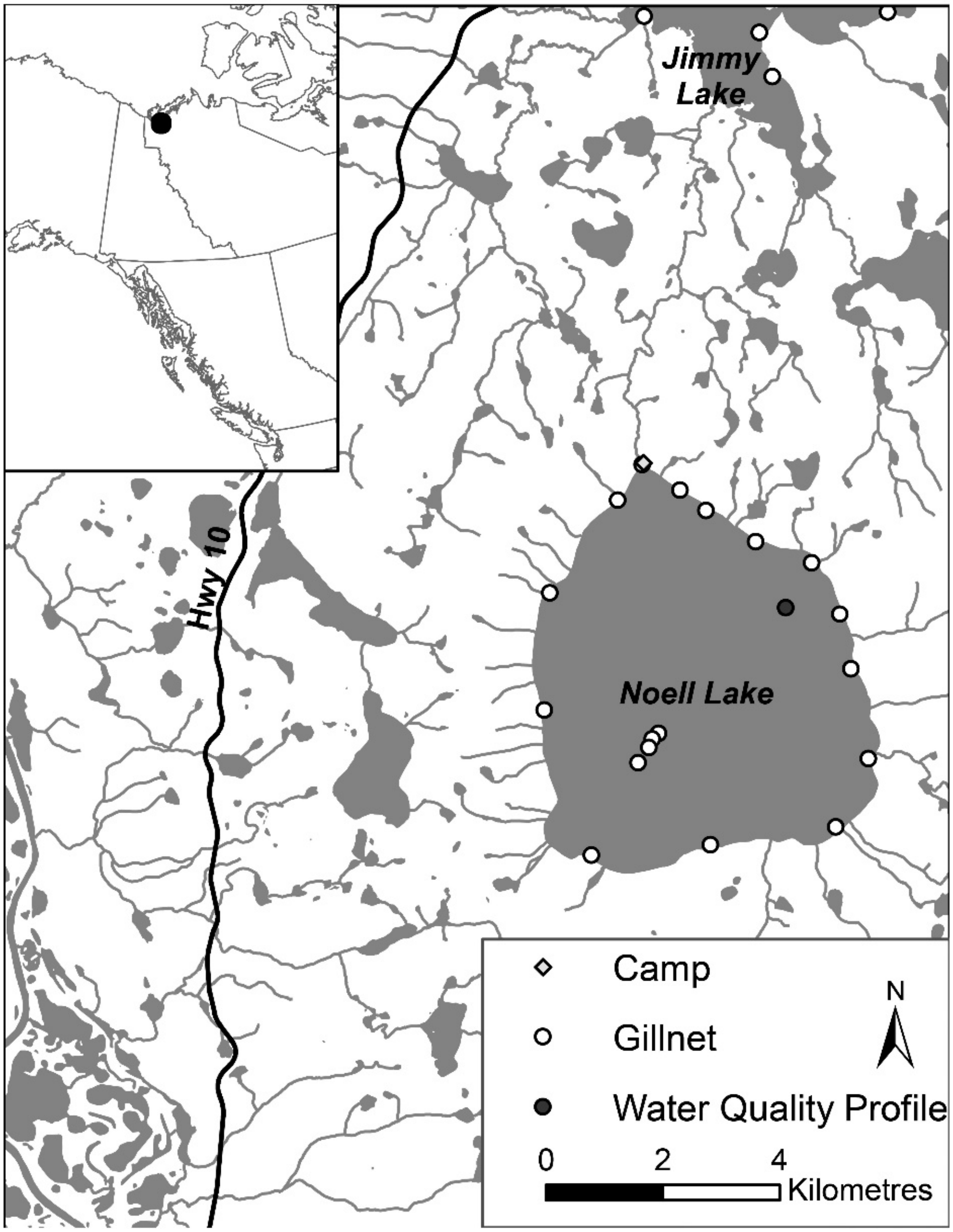
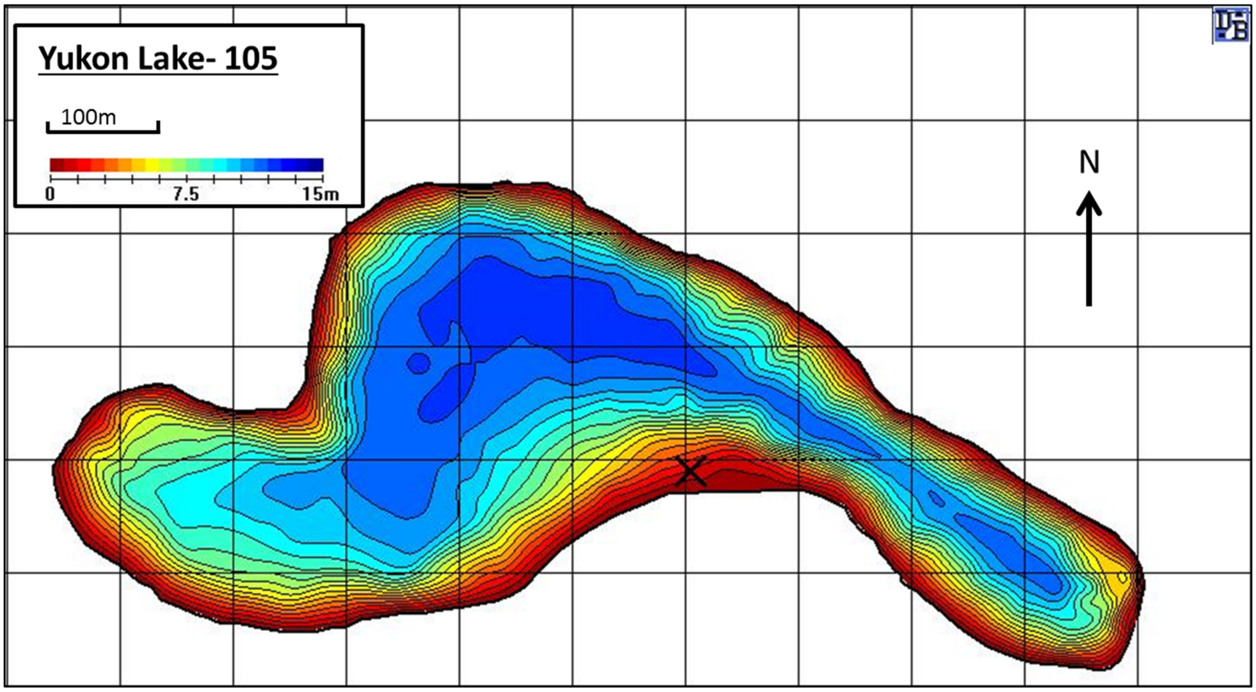


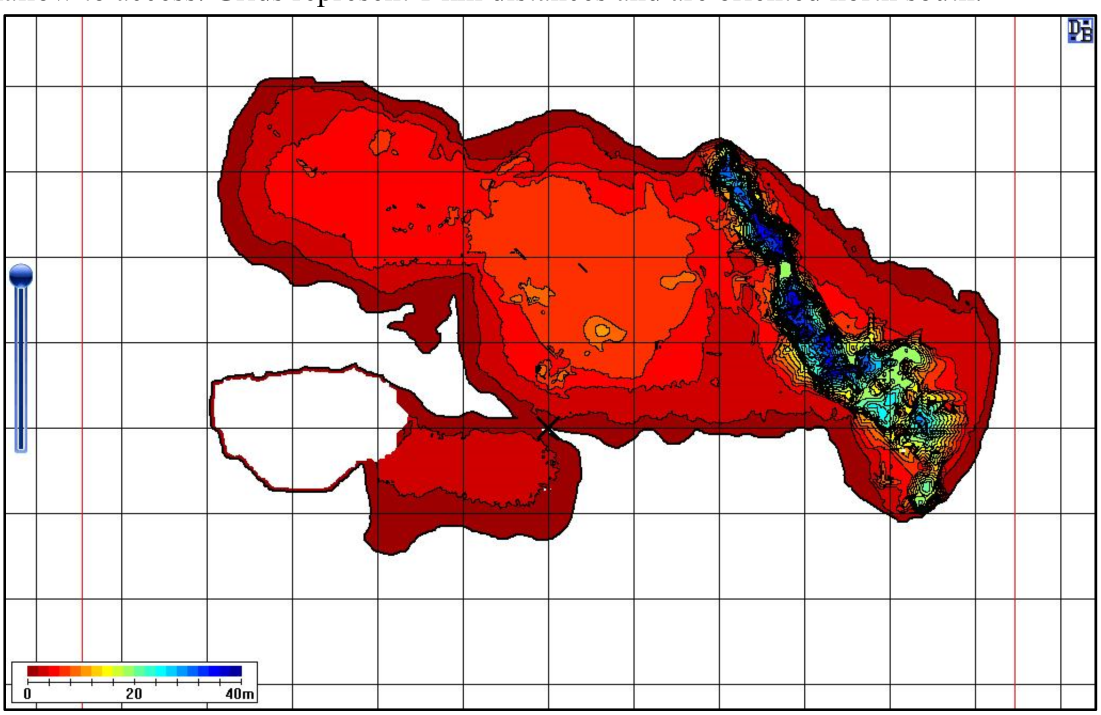
Figure 14. Gillnet locations (hollow points) and water sampling locations (filled points) Noell Lake, NWT 2015.

APPENDICES

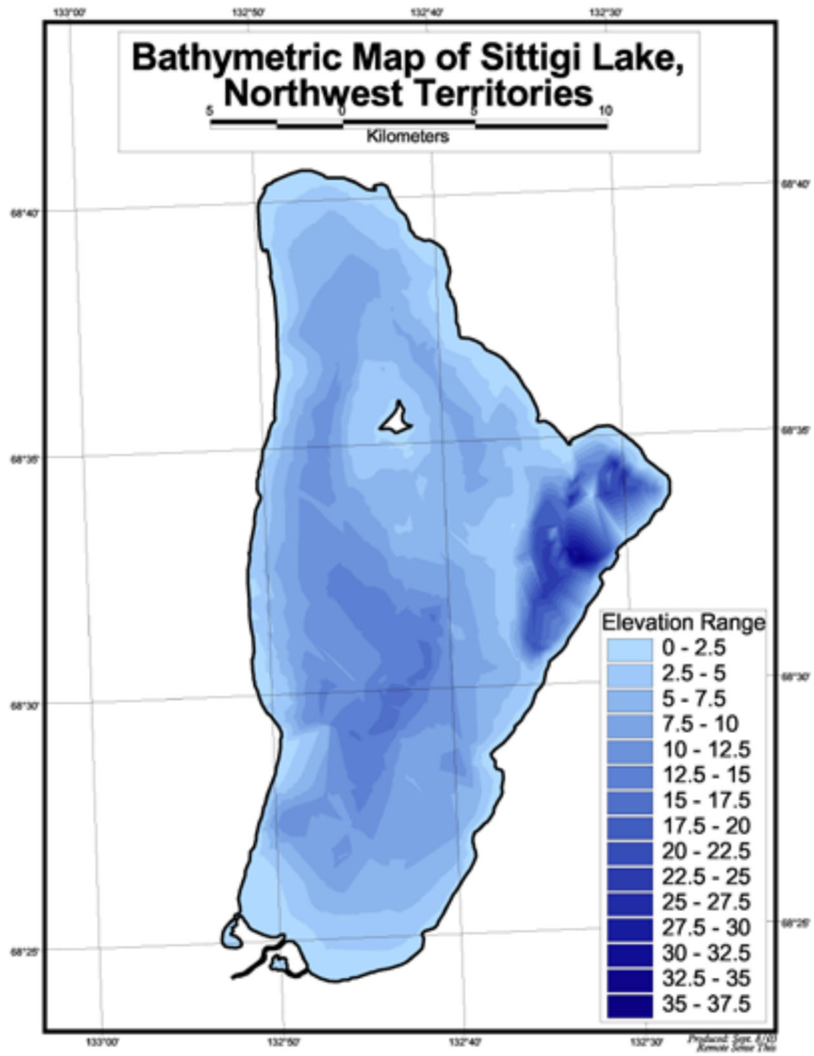
Appendix 1. Yukon Lake 105 bathymetric map created using Dr. Depth software 2014, NT. Grids represent 100 m distances.



Appendix 2. Wolf Lake bathymetric map created using Dr. Depth software 2014, NT. The white region within the lake lacks data to interpolate depths but is believed to be < 1 m as the area was too shallow to access. Grids represent 1 km distances and are oriented north south.



Appendix 3. Sitidgi Lake bathymetric map from Roux et al. (2014). Depth measurements are in metres.



Appendix 4. Noell Lake bathymetric map from Paquette-Struger (2011). Measurements are in meters.