Wahleach Project Water Use Plan

Wahleach Reservoir Fertilization Program

Implementation Year 18

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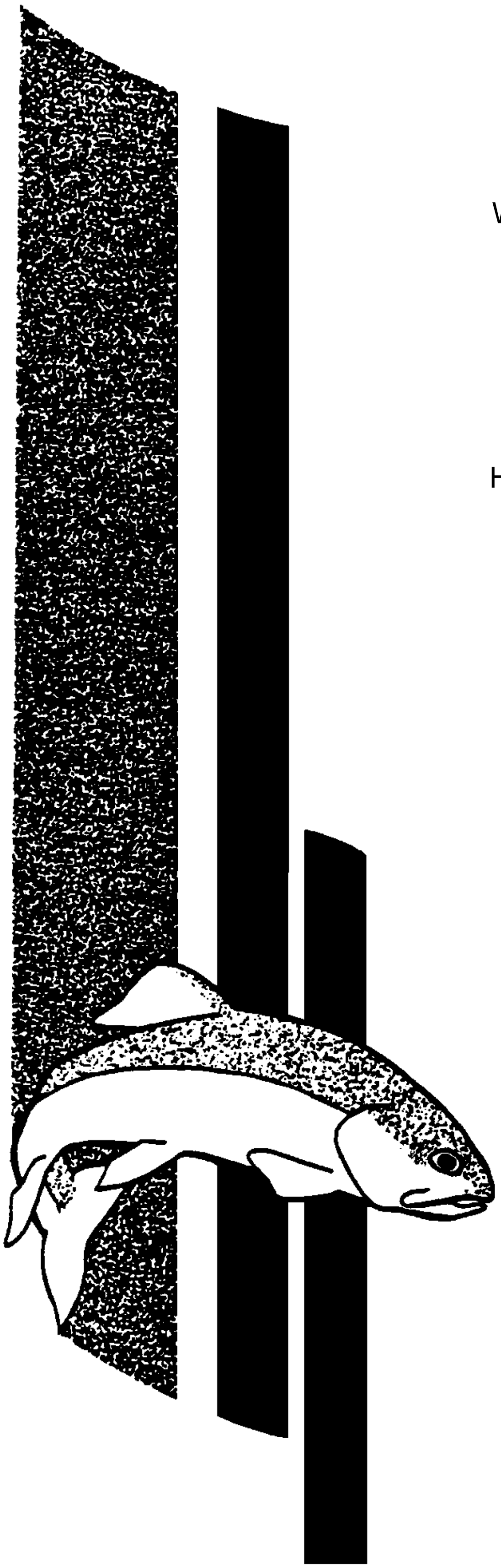

WAHLEACH RESERVOIR NUTRIENT RESTORATION PROJECT REPORT, 2022

by

H.E. Vainionpaa, J.A. Sarchuk, D. Johner, T. Weir, and
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Province of British Columbia
Ministry of Water, Land and Resource Stewardship
Aquatic Ecosystems Branch

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Executive Summary

The restoration of the Wahleach Reservoir Kokanee population continued in 2022 based on a strategy of nutrient addition in combination with biomanipulation of the food web via stocking of sterile Cutthroat Trout. Physical, chemical and biological parameters were monitored to assess the ecosystem's response to treatments and to adaptively manage the program. This document is a summary data report for the 2022 monitoring year.

In 2022, Wahleach Reservoir was characterized as ultra-oligotrophic using nutrient concentrations and as oligotrophic to mesotrophic using Secchi depths. Patterns and concentrations of nitrogen and phosphorus in the epilimnion were consistent with the seasonal growth of phytoplankton and suggested a rapid uptake and assimilation of useable forms of these nutrients by phytoplankton. The phytoplankton community was predominantly made up of blue-green algae (class *Cyanophyceae*) and flagellates (class *Chryso*- & *Cryptophyceae*). Edible species were dominant throughout the season, while abundance of inedible species was lower and more commonly seen during the spring and fall. In August in the south basin, a large bloom of the edible blue-green algae *Merismopedia* occurred (present as cells). Blooms of blue-green algae are common in Wahleach during the summer and have not been observed to negatively impact higher trophic levels. The seasonal mean phytoplankton abundance was 18,396 cells·mL^{-1} (SD = 44,475), while biovolume was 0.35 $mm^3 \cdot L^{-1}$ (SD = 0.22). At the secondary trophic level, *Daphnia* densities averaged 2.2 individuals·L^{-1} and biomass averaged 57.3 µg·L^{-1}; *Daphnia* accounted for 33% of the total zooplankton density and 74% of the total biomass. Both abundance and biomass of other cladocerans was strong early in the season. It is important to stress that the results observed provide a "snapshot" of the plankton community at a given point in time and ultimately reflect a combination of factors that increase or decrease the abundance of the community such as flushing, sinking and grazing.

Project monitoring data show that nutrient addition has had a positive bottom-up effect on lower trophic levels, and subsequently on the Kokanee population. Once considered extirpated, Kokanee are now a self-sustaining population in the reservoir. Total catch during the nearshore gillnet sampling in 2022 was 214 fish. The majority of the catch were Kokanee at 48%, followed by Rainbow Trout at 30% and Cutthroat Trout at 22%. Cutthroat Trout catch included ages 2+ to age 5+ fish, with a mean length of 334 ± 73 mm (range 242 to 525 mm). Threespine Stickleback abundance based on hydroacoustic estimates was low at 13,982 individuals, suggesting predation by stocked sterile Cutthroat Trout has had the intended impact on the population density and in turn reduced competition for zooplankton resources. In 2022, the adult Kokanee (age ≥1+) population was ~42,000 individuals, which was higher than the time series mean of ~33,000 individuals (2015-2022), while Kokanee fry (age 0) had a 2022 mean of ~30,000 individuals which was lower than the time series mean of ~62,000 individuals. The escapement estimate for Kokanee was a record high of 25,758 spawners, which was significantly higher than the long-term mean of 8,482 (2006-2022; data on file).

Overall, data from Wahleach Reservoir have demonstrated that seasonal nutrient additions have positive ecological effects, particularly for the pelagic food web. Seasonal *in situ* data are required to adaptively manage nutrient additions and inform restoration actions to ensure that desired outcomes are achieved.

Table of Contents

List of Figures

List of Tables

List of Appendices

1. Introduction

The Wahleach Reservoir Nutrient Restoration Project was originally developed as part of a fisheries management strategy focused primarily on the restoration of Kokanee (*Oncorhynchus nerka*). Hirst (1991) suggested Wahleach Reservoir's close proximity to the heavily populated Lower Mainland, the recently improved road access, and the camping facilities provided by BC Hydro created ideal conditions for a fisheries restoration project. The first phase of restoration was initiated in 1993, at a time when the recreational fishery on Wahleach Reservoir had collapsed; Rainbow Trout (*O. mykiss*) were <20 cm and in poor condition, and Kokanee abundance was very low. By 1995 the Kokanee population was considered extirpated (Perrin, 1996). The collapse of Wahleach Reservoir fish populations coincided with multiple stressors; foremost was low and declining nutrient availability and subsequent declines in phytoplankton and zooplankton productivity – a pattern typical of ageing reservoirs (Ney, 1996; Schallenberg, 1993). Resource limitations were exacerbated by an illegal introduction of Threespine Stickleback (*Gasterosteus aculeatus*) into the reservoir, which are known to utilize the same food sources as Kokanee (Scott and Crossman, 1973). Recognizing the value of restoring the fish populations in Wahleach Reservoir, the Province of British Columbia (the Province) and BC Hydro embarked on a multi-year restoration project that combined a bottom-up treatment of nutrient addition with a top-down treatment of fish stocking. This was the first nutrient addition project in BC coupled with a direct food web manipulation treatment.

Generally, the goal of the Wahleach Reservoir Nutrient Restoration Project is to restore and maintain recreational fish populations. The nutrient addition treatment was meant to increase nitrogen and phosphorus concentrations to optimize food resources for higher trophic levels. It is well established that nutrient additions can compensate for the loss in productivity resulting from dam construction and operation (Ashley et al., 1997; Stockner and Shortreed, 1985) by increasing production of phytoplankton and, in turn, zooplankton. Specifically, nutrient additions were intended to promote growth of edible phytoplankton, so that carbon was efficiently transferred through the food web to zooplankton species such as *Daphnia* spp., which are a key forage item for planktivorous fish like Kokanee (Perrin and Stables, 2000, 2001; Thompson, 1999). By increasing resource availability, nutrient additions play a critical role in increasing planktivorous fish populations. The fish stocking treatment had two purposes: the first was to re-establish the extirpated Kokanee population through short-term supplementation, and the second was to manipulate the food web through the addition of a sterile predator fish species. In some systems, competition between Kokanee and other fish species counteracted the positive effects of nutrient additions (Hyatt and Stockner, 1985). Top-down control of competitor fish species would ensure that increased productivity from nutrient additions would have the intended effects on the Kokanee population. Sterile Cutthroat Trout (*O. clarkii clarkii*), a known piscivore, were introduced to decrease the Threespine Stickleback population and associated forage pressure on *Daphnia* to free up resources for Kokanee.

The Wahleach Reservoir Nutrient Restoration Project consisted of three phases: baseline data collection completed in 1993 and 1994, nutrient addition treatments and monitoring from 1995 onward, and fish stocking treatments (sterile Cutthroat Trout) completed in 1997 onward. Kokanee were stocked from 1997 to 2004 (with the exception of 2001) to re-establish the population. Program monitoring includes collection of physical and chemical limnology data, as well as phytoplankton and zooplankton data. Additionally, the fish population is monitored through gillnetting, creel, hydroacoustic, and Kokanee spawner surveys.

Project funding was provided by BC Hydro in 1993 through to 2002 for the initial delivery of the program. While the Water Use Plan (WUP) was in development, limited funding for the 2003 and 2004 seasons was provided to the Province for purchase of fertilizer. In 2005, BC Hydro adopted a WUP to balance water use and stakeholder interests in the watershed. Among other requirements, the WUP introduced reservoir operating constraints and a commitment to the Wahleach Reservoir Nutrient Restoration Project (WAHWORKS-2) until 2014 (BC Hydro, 2004) when the WUP Order was to be reviewed. The objective of the restoration project as stated in the WUP Terms of Reference (TOR) was to restore and maintain the reservoir's Kokanee population (BC Hydro, 2005, 2006). Various monitoring programs have been completed using an adaptive management approach to assess whether restoration actions have been effective; these programs were generally outlined in the original TOR and in subsequent revisions and addendums (BC Hydro, 2005, 2006, 2008, 2010). Although the last year of the WUP was scheduled for 2014, the Province and BC Hydro agreed to continue the project until completion of the WUP Order Review. As such, an addendum to the TOR was submitted to the Comptroller of Water Rights to continue the project for 2015, 2016, 2017 (BC Hydro, 2015). Due to further delays in the WUP Order Review process, a three-year Memorandum of Understanding was signed by BC Hydro and the Province for 2018-2020 and then again for 2021-2023. The WUP Order Review is currently in progress at the time of this report publication.

This summary report presents data from the 2022 monitoring season.

2. Study Area

Wahleach Reservoir, locally known as Jones Lake, is located at 49°13'N, 121°36'W, approximately 100 km east of Vancouver, British Columbia (Figure 1). It is bordered on the west by Four Brothers Mountain and on the south by Cheam Ridge. The Wahleach watershed encompasses the traditional territory of the following Indigenous Nations: Chawathil, Cheam, Kwaw-Kwaw-Apilt, Leq'a:mel, Peters, Popkum, Seabird Island, Shxw'ow'hamel, Skawahlook, Skwah, Soowahlie, Sto:lo Nation, Sto:lo Tribal Council, and Union Bar. It has a drainage area of 88 km^2 with elevations in the basin ranging from 640 m to 2,300 m.

The reservoir was created for hydroelectric power generation in 1952 with the construction of an earth fill dam at the original lake's outlet stream. Wahleach Reservoir has a surface area of 490 ha, volume of 66 million m^3, maximum depth of 29 m and mean depth of 13.4 m. The maximum water surface elevation is 641.6 m (equal to the elevation of the crest of the dam), and the minimum operating elevation is constrained at 628 m (BC Hydro, 2004). Inflow into the reservoir is largely uncontrolled occurring via the tributaries of upper Jones Creek, Flat Creek and several unnamed streams. One of the main tributaries situated at the north end of the reservoir near the dam is Boulder Creek. Boulder Creek has been modified with a berm and diversion channel to divert flow from its natural channel, which originally flowed into lower Jones Creek below the dam, into the reservoir. Flows are also diverted back into the original Boulder Creek channel to meet flow requirements in lower Jones Creek downstream of the dam. At the dam, discharge can be controlled through a water release siphon to lower Jones Creek when the reservoir surface elevation is above 637 m; the dam spillway is ungated and will freely spill when water levels are above the crest elevation. Discharge is also controlled via a power intake and tunnel on the west side of the reservoir that is released into the Fraser River in the Herrling Island Side Channel. Wahleach Reservoir is dimictic with two seasons of complete mixing within the water column (spring and fall), and two seasons of thermal stratification (summer and winter). Ice cover generally occurs from December through March. Fish species in Wahleach Reservoir include: Kokanee, Rainbow Trout, sterile Cutthroat Trout and Threespine Stickleback.

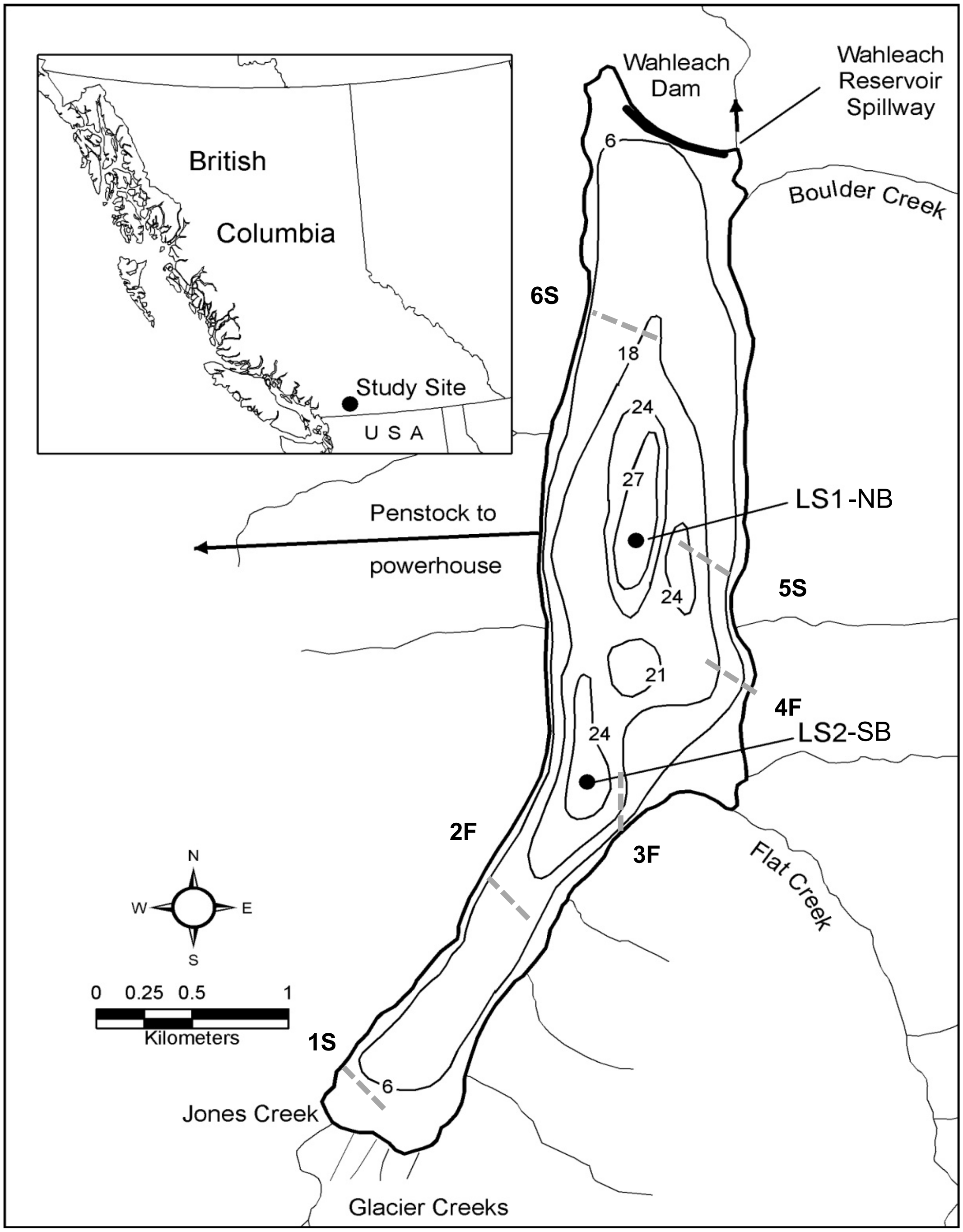

Figure 1. Map of Wahleach Reservoir, BC, including sampling locations. LS2-SB and LS1-NB are limnological sample locations and 1S, 2F, 3F, 4F, 5S, and 6S are gillnetting locations, with S=sinking net and F=floating net. Bathymetric contour depths (m) represent the reservoir at full pool.

3. Methodology

All figures and analyses contained in this report were completed using R version 3.6.1 (R Core Team, 2019). Supporting R packages included doBy and tidyverse. The reported long-term mean values were calculated for the duration of the Wahleach Reservoir Nutrient Restoration Project from 1993-2022. Values used in a comparative context represent baseline conditions from 1993-1994, and nutrient restoration conditions from 1995-2022. Summary statistics were reported as means ± standard deviations. Methods were consistent with those reported in Sarchuk et al. (2019).

3.1 Restoration Treatments

3.1.1 Nutrient Additions

Agricultural grade liquid ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight) were added on a weekly basis to Wahleach Reservoir from the second week of June (after thermal stratification) for a period of up to twenty weeks, or until stratification in the reservoir had broken down. The ammonium polyphosphate and urea-ammonium nitrate were blended on-site immediately prior to dispensing. Ratios of fertilizer blends, timing of the additions, and total amounts added to the reservoir were adjusted seasonally to mimic natural spring phosphorus loadings, compensate for biological uptake of dissolved inorganic nitrogen, and maintain optimal nitrogen to phosphorus concentrations for growth of edible phytoplankton. Perrin et al. (2006) recommended annual phosphorus loading rates for Wahleach Reservoir to target approximately 200 mg $P \cdot m^{-2}$ to improve the production of *Daphnia*; however, for several consecutive years actual loads were reduced to less than half the planned value due to in-season modifications. Despite this reduction in phosphorous loading rates, no negative effects on *Daphnia* growth were observed (Sarchuk et al., 2019). Therefore, beginning in 2016, planned phosphorus loading rates were reduced to approximately half this rate to manage dissolved inorganic nitrogen concentrations and growth of undesirable phytoplankton species. Nitrogen was added concurrently with the aim to keep epilimnetic concentrations above 20 $\mu g \cdot L^{-1}$ (the concentration considered limiting to phytoplankton growth; Wetzel, 2001), and to maintain suitable nitrogen to phosphorus ratios. Fertilizer additions during 2022 included nitrogen-only applications from weeks 5 to 7 in an effort to prevent nitrogen limitation (Figure 2).

Nutrient addition programs in British Columbia (i.e., Arrow Lakes, Kootenay Lake, Alouette Reservoir and Wahleach Reservoir) are adaptively managed based on the results of comprehensive monitoring programs delivered in concert with nutrient applications. In-season modifications are made based on *in situ* conditions of the system (e.g., Secchi disc transparencies, littoral algal accumulation, weather forecast) and informed by the results of the limnological monitoring program. While reservoir productivity is largely governed by nutrient loading, climate also strongly influences the ecosystem response. Actual nutrient loading rates in 2022 were generally consistent with the planned loading strategy, except for weeks 1 and 6 which were missed due to low reservoir levels and logistical challenges, respectively (Figure 2, Table 1). Overall, weekly areal loading rates for phosphorus were greatest at the start of the season with a maximum of 8.2 mg $P \cdot m^{-2}$, with a total of 59.5 mg $P \cdot m^{-2}$ for the season. Nitrogen loading increased rapidly during the first five weeks of the season with a maximum of 108.0 mg $N \cdot m^{-2}$ (Figure 2). Total nitrogen loading for the season from both the ammonium polyphosphate and urea-ammonium nitrate was 807.7 mg $N \cdot m^{-2}$. The weekly molar nitrogen to phosphorus ratio peaked at 33.5 during the latter half of the season when both phosphorus and nitrogen loading rates were being ramped down (Figure 2).

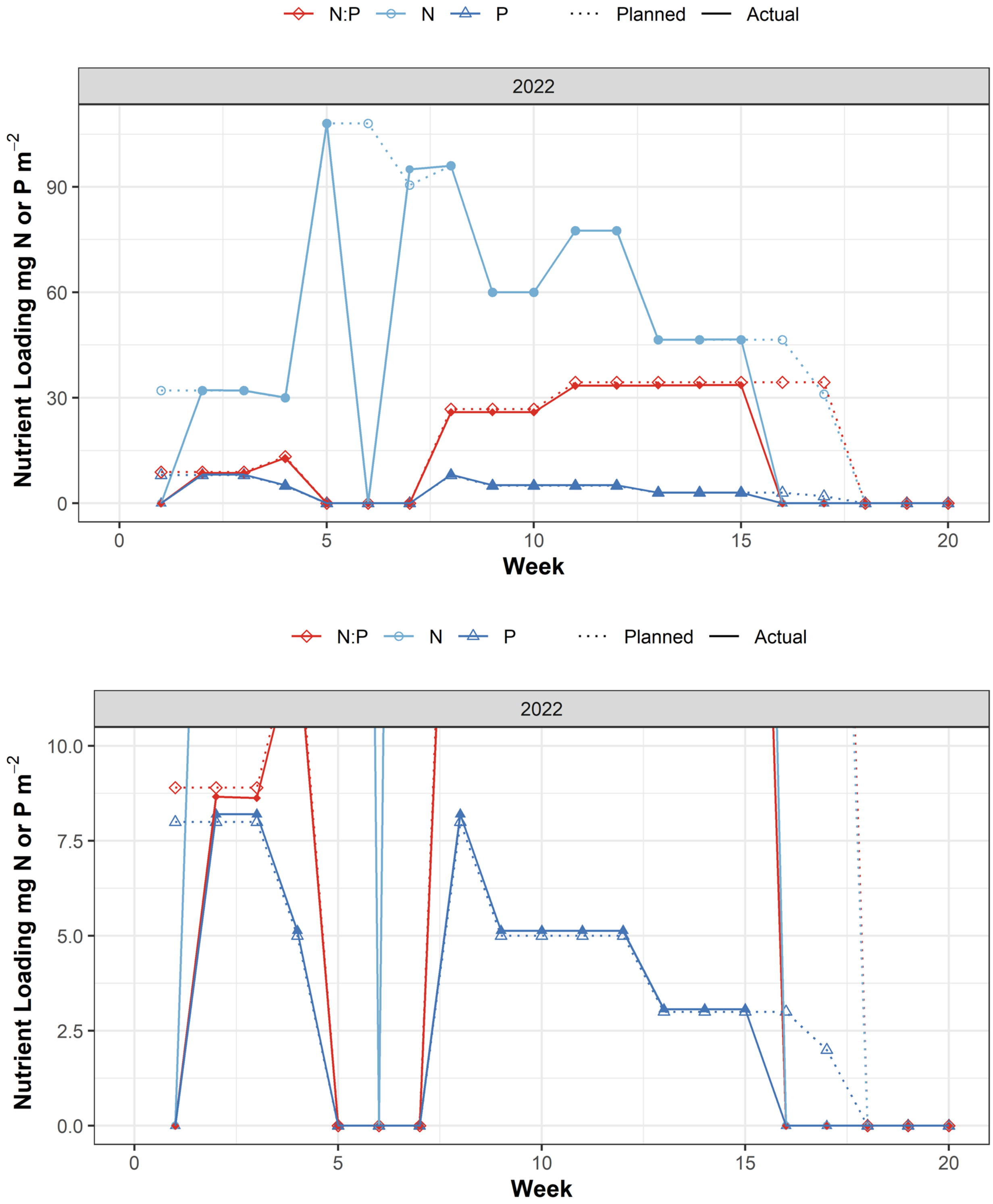

Figure 2. Upper figure shows seasonal planned and actual nutrient additions for Wahleach Reservoir, including areal nitrogen and phosphorus loading as well as molar N:P ratios, 2022; planned values are represented by hollow points and dashed line, while actual values are represented by solid points and solid line. Lower figure is zoomed in to better show phosphorus loading values.

Table 1. Annual nutrient additions by weight and areal loading, 2022, Wahleach Reservoir, BC.

Year	Date Range	Fertilizer		Total Phosphorus		Total Nitrogen	
		10-34-0	28-0-0				
		t	t	Kg	$mg \cdot m^{-2}$	Kg	$mg \cdot m^{-2}$
2022	15-Jun to 14-Sep	1.60	10.97	545	59.5	3,231	808

3.1.2 Fish Stocking

Stocking of (sterile) triploid Cutthroat Trout was continued to maintain top-down pressure on the Threespine Stickleback population. In 2022, a total of 2,000 triploid Cutthroat Trout (average weight 92.86 g) were stocked into the reservoir. Stocking decisions are evaluated annually based on the previous year's monitoring results; specifically, indicators include the condition and growth of Cutthroat Trout captured during the fall gillnetting program, as well as hydroacoustic population estimates.

3.2 Monitoring

3.2.1 Hydrometrics and Reservoir Operations

Data were provided by BC Hydro. Discharge values in this report refer to generation discharge (i.e., discharge from a downstream project after passing through the penstock). Analysis methods followed Sarchuk et al. (2019).

3.2.2 Climate

Air temperature and precipitation data were provided by BC Hydro. Analysis methods followed Sarchuk et al. (2019).

3.2.2.1 Stream Temperature

Stream temperatures were measured in the three main tributaries to Wahleach: Boulder, Flat, and Jones Creeks. Onset Tidbit® temperature data loggers set to record a temperature measurement hourly, or in some instances, four times per day (midnight, 6 am, 12 pm, and 6 pm) were installed at two locations in each of the tributaries (one "upper" section and one "lower" section). For the 2022 season, temperature data were downloaded from Jones and Flat Creeks on August 24 and again on October 19. Boulder Creek temperature loggers had unfortunately washed out from the previous year due to fall/winter storms and so data were provided by BC Hydro.

3.2.3 Physical and Chemical Limnology

Two sites were sampled monthly from May to November: one in the north at LS1 (EMS ID#E219070; also known as the north basin) and one in the south at LS2 (EMS ID#E219074; also known as the south basin; Figure 1). All physical and chemical limnology data, as well as phytoplankton and zooplankton data were collected from these locations. Parameters measured included water temperature and dissolved oxygen profiles, Secchi disc transparencies and water chemistry (i.e., dissolved and total nutrient concentrations). Discrete water chemistry samples were collected at 1 m (epilimnion) and 20 m (hypolimnion) and a depth-integrated sample of the epilimnion was also collected. All reported values, unless explicitly defined, were from the 1 m epilimnetic samples. All water quality data is available on the BC government

Environmental Monitoring System website (https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/environmental-monitoring-system). Water chemistry samples were analyzed by ALS Laboratory in Burnaby, BC. Samples below detection limits were assigned a value equal to one half of the detection limit for analyses. For additional field sampling and analysis methods refer to Sarchuk et al. (2019).

Chlorophyll *a* samples were collected from the epilimnion and sent to ALS for analysis. Analysis by ALS was conducted using procedures modified from EPA Method 445.0 (Arar and Collins, 1997). Chlorophyll *a* was determined by a routine acetone extraction followed with analysis by fluorometry using the non-acidification procedure.

3.2.4 Phytoplankton

Depth-integrated samples of the epilimnion were collected monthly from May to November. Phytoplankton samples were analyzed by taxa for abundance, biovolume and edibility. Edibility refers to whether the phytoplankton species and/or form was considered edible to zooplankton; edibility was categorically defined as inedible, edible, or both ("both" refers to instances where edible and inedible forms of the same species were found in a single sample; in these cases, edible and inedible fractions were not determined quantitatively). In earlier reports, phytoplankton analysis was conducted by John Stockner, Eco-Logic Ltd. Starting in 2019, analyses were performed by Darren Brandt, Advanced Eco-Solutions. For additional field sampling and analysis methods, refer to Vainionpaa et al. (2021).

3.2.5 Zooplankton

Zooplankton sampling (duplicate 0-20 m vertical hauls) was conducted monthly from May to November using a Wisconsin plankton net with 150 μm mesh. Samples were analyzed by taxa for density, biomass and fecundity. Values are reported based on taxonomic groups: *Daphnia* spp. (suborder *Cladocera*), other species belonging to the order *Cladocera*, and species belonging to the subclass *Copepoda.* For additional field sampling and analysis methods, refer to Sarchuk et al. (2019).

3.2.6 Fish Populations

Fish populations were assessed by gillnet, minnow trap, hydroacoustic, and spawner surveys. For simplification, abbreviated fish species names are used in tables and graphs: Kokanee (KO), Rainbow Trout (RB), Cutthroat Trout (CT), and Threespine Stickleback (TSB).

3.2.6.1 Gillnet and Minnow Trap Surveys

Nearshore gillnet sites are shown on Figure 1, with exact coordinates for 2022 gillnet and minnow trap stations in Table 2. Although exact coordinates may vary slightly from year to year, the general locations of sampling sites have remained consistent.

Table 2. Locations of nearshore gillnet (S=sinking net and F=floating net) and minnow trap stations, 2022, Wahleach Reservoir, BC.

Gear	Station	Latitude	Longitude	Station	Latitude	Longitude
GN	1S	49°12.460 N	121°38.147 W	4F	49°13.470 N	121°36.275 W
GN	2F	49°13.207 N	121°37.182 W	5S	49°14.275 N	121°36.265 W
GN	3F	49°13.048 N	121°36.708 W	6S	49°14.465 N	121°36.942 W
MT	1M	49°13.985 N	121°37.123 W	4M	49°13.317 N	121°37.140 W
MT	2M	49°13.762 N	121°37.145 W	5M	49°12.218 N	121°37.948 W
MT	3M	49°13.418 N	121°37.137 W	6M	49°12.202 N	121°37.928 W

Standardized annual nearshore gillnet sampling was completed from October 25 to 26, 2022, after Kokanee spawners had moved out of the reservoir. Each station was set with one Resources Information Standards Committee (RISC) seven panel gillnet (measuring a total of 106.4 m long by 2.4 m deep) with mesh sizes of 25 mm, 89 mm, 51 mm, 76 mm, 38 mm, 64 mm, and 32 mm (i.e., 1", 3.5", 2", 3", 1.5", 2.5", 1.25"). In 2014, the provincial standard net composition changed to include a panel of 32 mm (1.25") mesh to better sample fish in the age-1 size range. All fish captured in the 32 mm mesh panel were recorded separately, so annual comparisons can be made throughout the length of the monitoring data set.

Minnow traps were set to target Threespine Stickleback. In 2022, six minnow traps baited with salmon roe were set on the bottom of the reservoir in 1 to 3 m of water at standard littoral habitat stations (Table 2). For additional field sampling and analysis methods, refer to Sarchuk et al. (2019).

3.2.6.2 Kokanee Spawner Surveys

Kokanee spawner escapement in three index streams – Boulder Creek, Flat Creek, and Jones Creek – was estimated using standardized visual surveys. Surveys were conducted weekly on index streams from September 8 to October 26, 2022. For additional field sampling and analysis methods, refer to Sarchuk et al. (2019). Additional stream sections were surveyed on September 21, 2022, beyond the original established sections of Jones Creek and Flat Creek. Approximately 500 m of upstream habitat was surveyed on Flat Creek, while several side tributaries were explored on Jones Creek, including the Glacier Creeks. Additional survey sections were excluded from the Kokanee escapement to be comparable to previous years data.

Four wildlife cameras were installed in 2022, two in Flat Creek and two in Jones Creek. Camera locations were chosen based on likelihood of encountering wildlife (e.g., nearby game trails, tracks, predated/scavenged Kokanee carcasses). SD cards were changed weekly.

3.2.6.3 Hydroacoustic Surveys

A hydroacoustic survey was completed in the summer within one week of the new moon along eleven standardized transects (Figure 3, Table 3) using a Simrad EK60 120 kHz split beam system. Survey conditions for 2022 are shown in Table 3. Additional details on field and analysis methods can be found in Sarchuk et al. (2019).

Table 3. Summary of equipment and conditions for hydroacoustic surveys, 2022, Wahleach Reservoir, BC.

Year	Survey Date	Sounder	Reservoir Elevation[1] (m)	Avg Transect Start/End Depth (m)
2022	July 28	EK60	640.45	8

1. Maximum elevation of 641.6 m (equivalent to the spillway crest elevation)

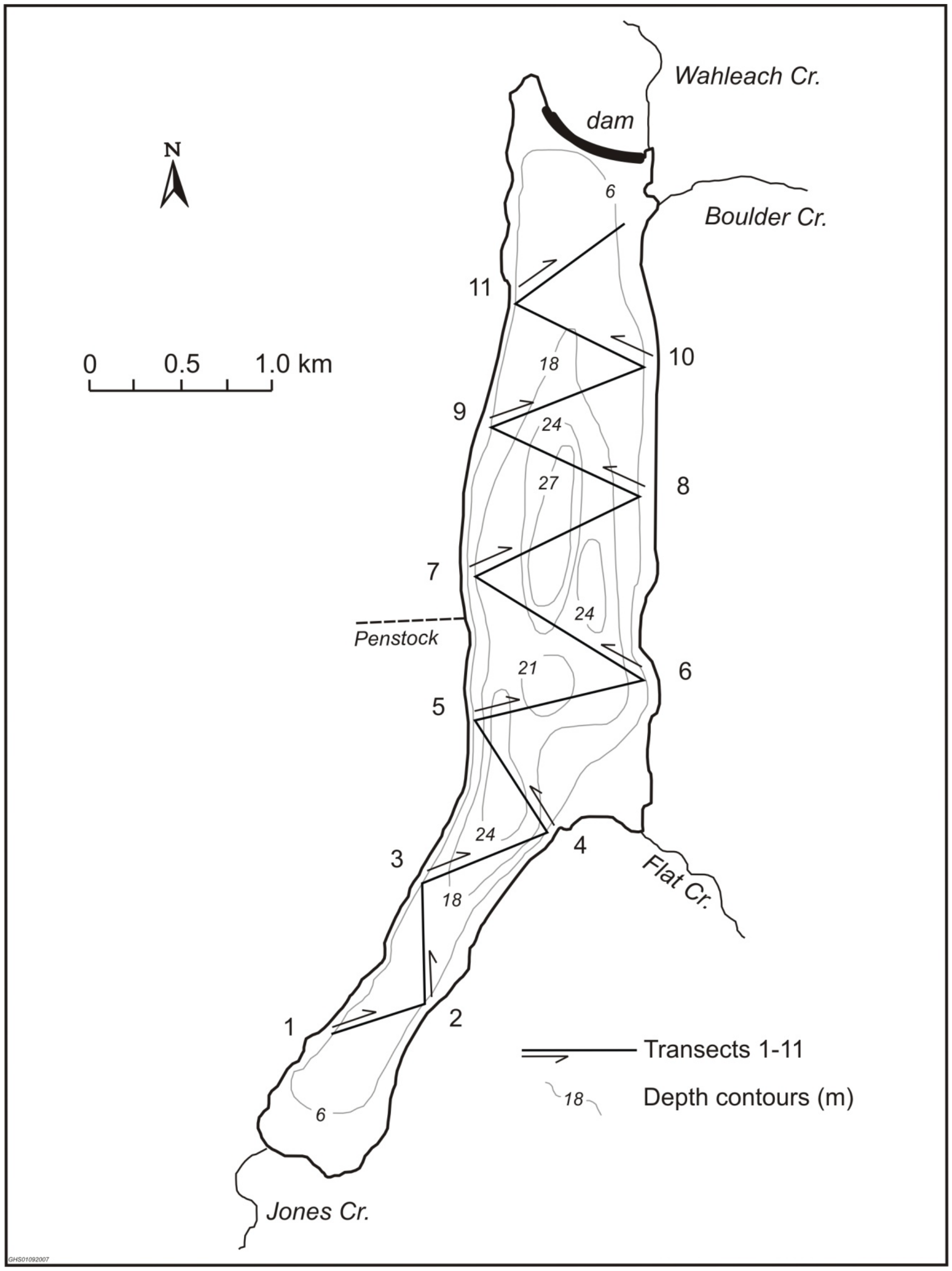

Figure 3. Locations of standardized hydroacoustic transects, Wahleach Reservoir, BC.

3.2.6.4 Population and Biomass

Data were analyzed using Sonar 5 post-processing software (version 606.16; Balk and Lindem, 2019), from -70 dB to -24 dB, a target size range expected to include all fish within the reservoir. Data were analyzed from the surface to reservoir bottom while applying a 0-2 m surface exclusion layer. Evaluation of the acoustic target distribution identified -66 dB as the minimum range of the fish size distribution. These data were separated into two components by visual identification of the inflection point where the more abundant small fish met the remainder of the distribution of larger fish; in 2022 the inflection point was -47 dB (Table 4). The small fish component (-66 to -48 dB) included age 0 Kokanee (fry) and Threespine Stickleback while the larger size group (≥ -49 dB) represented age ≥1+ Kokanee, as well as lesser numbers of Cutthroat Trout and Rainbow Trout. Acoustic data were then partitioned by depth to further differentiate between species and refine the Kokanee population estimates. Depth stratification of acoustic data assumed that targets distributed where water temperatures were <17˚C and dissolved oxygen concentrations >5 $mg \cdot L^{-1}$ were primarily Kokanee, as supported by results of previous pelagic gillnetting and directed trawling (Sarchuk et al., 2019). In 2022, the depth range that met these criteria was 4-30 m.

A method for setting the minimum acoustic thresholds was developed for the acoustic datasets for Kinbasket and Revelstoke Reservoirs. The purpose of this method was to reduce the impact of low-end noise (i.e., non-Kokanee targets) encroaching on the Kokanee acoustic target distribution. This noise reduction method, described by Sebastian and Weir (2015) has also been applied to Wahleach acoustic data to partition out the majority of smaller target noise (likely Threespine Stickleback) in order to refine abundance estimates for Kokanee. This was first completed for Wahleach in 2021 and was further refined in 2022 and applied to the long-term dataset (2015-2022). Smaller noise targets trimmed from the acoustic distribution were combined with the estimate of small targets above the Kokanee layer to estimate the total Threespine Stickleback population. Table 4 summarizes the depth and size criteria applied to produce Kokanee specific population estimates.

Table 4. Summary of analysis parameters for hydroacoustic data, 2015-2022, Wahleach Reservoir, BC.

Year	Groups	Analysis Depth Range (m)	Age 0 KO dB Thresholds	Age ≥1+ KO dB Thresholds
2015	Kokanee	10-30	-58 to -47	≥ -46
2016	Kokanee	6-30	-56 to -47	≥ -46
2017	Kokanee	6-30	-58 to -49	≥ -48
2018	Kokanee	6-30	-59 to -49	≥ -48
2019	Kokanee	6-30	-56 to -47	≥ -46
2020	Kokanee	6-30	-55 to -47	≥ -46
2021	Kokanee	4-30	-59 to -50	≥ -49
2022	Kokanee	4-30	-56 to -48	≥ -47

Kokanee populations were estimated with confidence intervals using a stochastic simulation approach (a Monte Carlo method). Simulations were done in R (R Core Team, 2022), producing estimates for Kokanee fry and for older Kokanee within the reservoir.

Kokanee biomass estimates, initially presented by Sarchuk et al. (2019), were based on an approach developed specifically for Wahleach Reservoir and varied from methodology used by the Province for other lakes and reservoirs, primarily due to the smaller size of Wahleach and the mixed species assemblage (data on file). With newly refined acoustic estimates for Kokanee, the methodology for estimating biomass specific to Kokanee has also been refined. First, target strengths were converted to fork length equivalents using an empirical relation between acoustic target strength (TS) and fish fork length (FL; cm) developed for Kokanee by Bray et al. (2018) for 120 kHz split beam downward looking hydroacoustic data:

$$TS = 23.909 \times \log10(FL) - 68.216$$

The weight was then estimated for each TS/FL increment based on the length-weight relationship from Wahleach Kokanee caught from 2014-2017 (n=195, R^2=0.99):

$$WT\ (g) = 0.00748\ (FL)^{3.13973}$$

Data for 2014-2017 were chosen as they provided reasonable sample sizes of both trawl (age 0) and gillnet (age ≥1+) caught fish. Next, for each survey, abundance 1 decibel (dB) bins were converted to biomass by multiplying by the corresponding mean weight. Biomass estimates by 1 dB size increments were then summed over the full range of Kokanee sizes to estimate the total Kokanee biomass. The lower thresholds are described in Table 4, and the uppermost threshold used to partition Kokanee from larger Rainbow Trout and Cutthroat Trout was determined based on survey timing, spawner size, and evaluation of the acoustic size frequency plots. The biomass estimates have only been re-calculated back to 2015, the remaining years will be presented in future reporting.

4. Results

4.1 Hydrometrics and Reservoir Operations

4.1.1 Inflow

Mean daily inflow into Wahleach Reservoir during 2022 was 5.3 ± 4.2 $m^3 \cdot s^{-1}$ (range 0 to 22.9 m^3 s^{-1}), which was lower than the long-term mean of 6.2 ± 5.6 $m^3 \cdot s^{-1}$ (range 0 to 101.3 $m^3 \cdot s^{-1}$). During the nutrient addition period (June to September, inclusive), mean daily inflow was 7.0 ± 5.4 $m^3 \cdot s^{-1}$ (range 1.6 to 22.9 $m^3 \cdot s^{-1}$) which was higher than the long-term mean of 6.3 ± 4.6 $m^3 \cdot s^{-1}$ (range 0 to 42.0 $m^3 \cdot s^{-1}$). Peak inflow occurred in the late spring during a particularly wet June. Typical high flows were also observed during the fall and winter storm season (Figure 4).

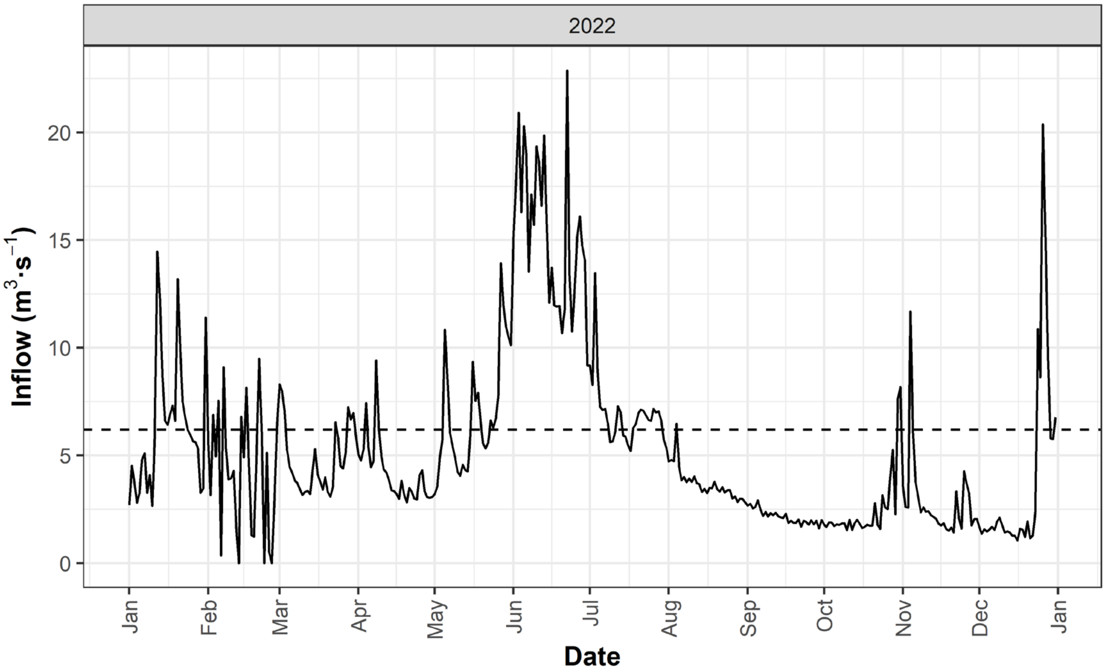

Figure 4. Daily inflow ($m^3 \cdot s^{-1}$), 2022, Wahleach Reservoir, BC. Dashed line is the long-term mean from 1993-2022 for daily inflows.

4.1.2 Discharge

Mean daily generation discharge (herein referred to as discharge) from Wahleach Reservoir in 2022 was 5.9 ± 4.2 $m^3 \cdot s^{-1}$ (range 0 to 12.9 $m^3 \cdot s^{-1}$), which was slightly lower than the long-term mean of 6.2 ± 4.9 $m^3 \cdot s^{-1}$ (range 0 to 78.9 $m^3 \cdot s^{-1}$). During the nutrient addition period, mean daily discharge was 5.2 ± 3.4 $m^3 \cdot s^{-1}$ (range 0 to 12.8 $m^3 \cdot s^{-1}$), which was similar to the long-term mean of 5.3 ± 4.4 $m^3 \cdot s^{-1}$ (range 0 to 28.1 $m^3 \cdot s^{-1}$). Figure 5 shows the annual pattern in discharge, which was highly variable. Discharge in 2022 was the greatest during high inflow periods associated with fall and winter storms. High discharge was also observed during the wet spring, and again in July following a late freshet. No discharge occurred for most of March.

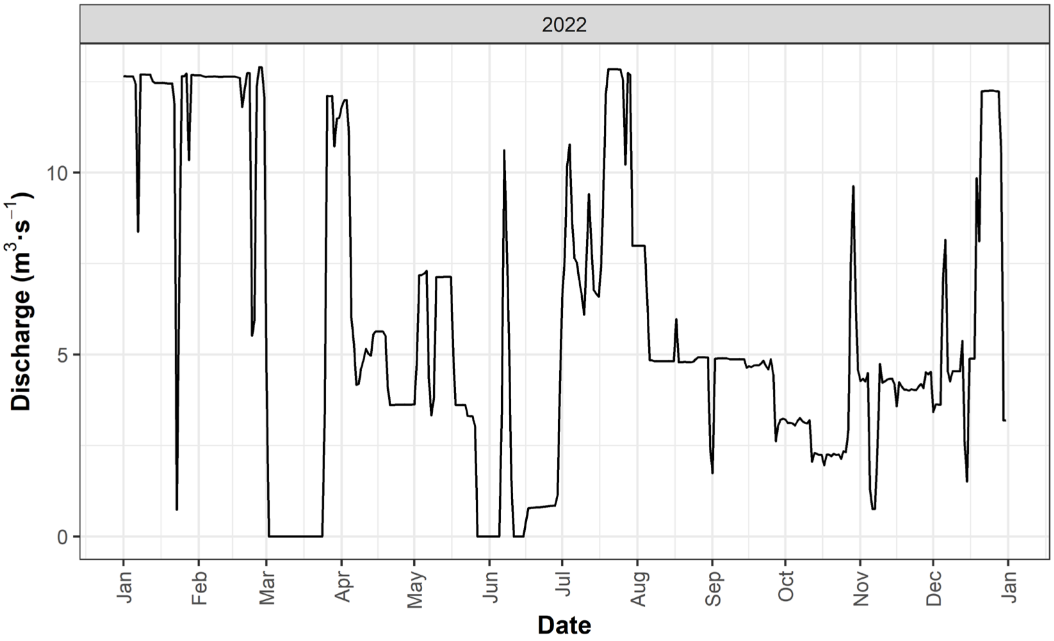

Figure 5. Daily discharge ($m^3 \cdot s^{-1}$), 2022, Wahleach Reservoir, BC.

4.1.3 Reservoir Elevation

Typically, the minimum reservoir elevation is observed during the early spring, the reservoir is recharged during the annual spring freshet, reaching its maximum water elevation during June or July (which corresponds with the onset of nutrient additions), and then the reservoir is slowly drawn down until April or May the following year. Surface water elevations are generally stable throughout the nutrient addition season. In 2022, the minimum elevation was observed in late February. After this, reservoir levels rose slightly but remained relatively low until June, at which point they rapidly increased until reaching peak elevation in early July. The drawdown was 11.2 m in 2022, which was less than the long-term (1993-2022) mean of 12.1 m (Figure 6). Throughout the year, the reservoir remained above the minimum standard operating level of 628 m.

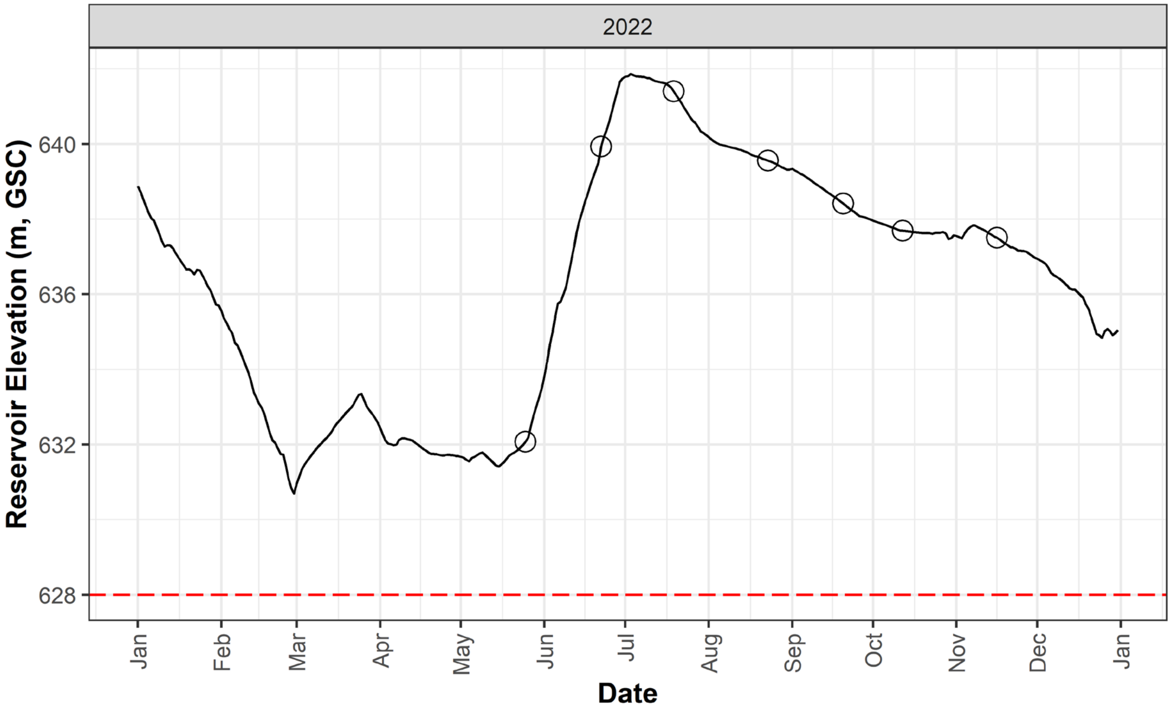

Figure 6. Daily reservoir surface elevation (m, Geodetic Survey of Canada), 2022, Wahleach Reservoir, BC. Open circles represent limnology sampling dates. The red dashed line represents minimum operating level of 628 m.

4.2 Climate

4.2.1 Air Temperature

Seasonal air temperatures in 2022 were highest in July and August, with peak temperatures occurring in July, while lowest temperatures were observed in December (Figure 7). Overall, the mean daily temperature in 2022 (7.2 ± 8.2°C, range -22.1 to 33.7°C) was similar to the long-term mean (7.1 ± 6.8°C, range -22.5 to 37.8°C). During the nutrient addition period (June through September), mean daily temperature was 16.0 ± 4.1°C (range 4.9 to 33.7°C), which was higher than the long-term mean (14.3 ± 3.9°C, range 0.8 to 37.8 °C).

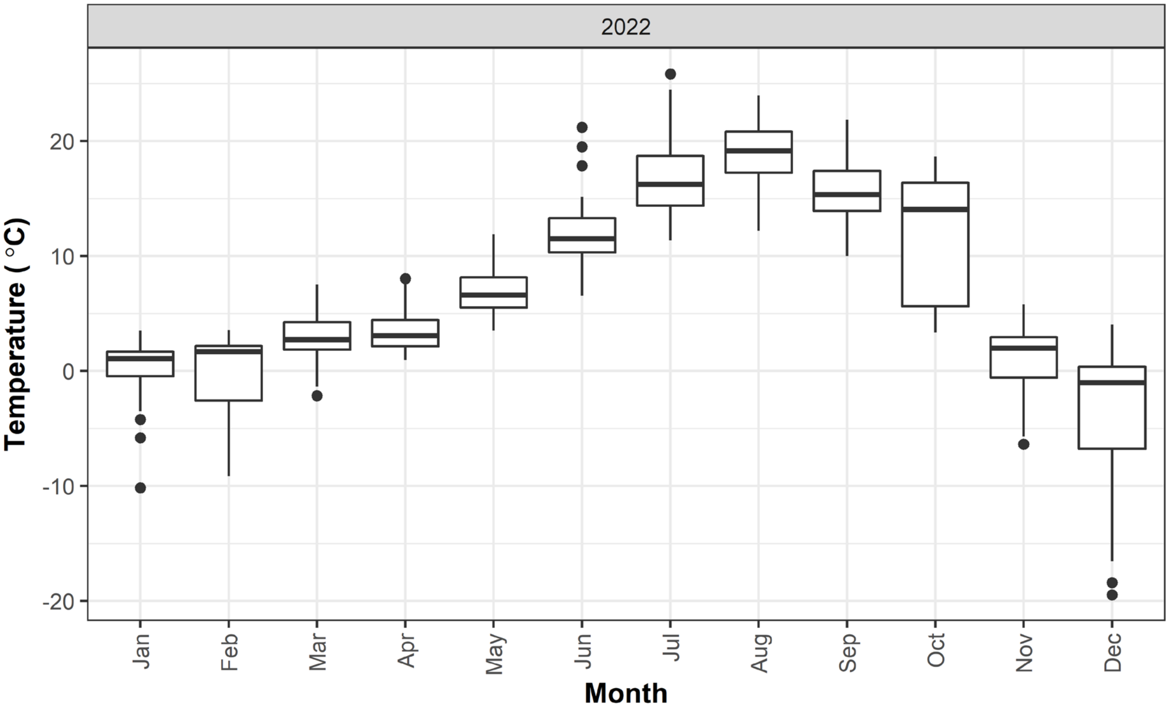

Figure 7. Boxplot of daily mean air temperatures (°C) for each month, 2022, Wahleach Reservoir, BC. Black dots represent outliers.

4.2.2 Precipitation

The seasonal precipitation pattern generally followed the inverse trend of air temperature; precipitation was low in the summer months and high in the fall and winter months (Figure 8). Precipitation in 2022 was also high during the spring months, particularly in June. In 2022, mean daily (6 ± 10 mm, range 0 to 57 mm) precipitation was slightly lower than the long-term mean (7 ± 13 mm, range 0 to 152 mm). Mean monthly precipitation was 172 ± 91 mm (range 16 to 289 mm), which was lower than the long-term mean of 217 ± 125 mm (range 2 to 806 mm). A total of 2,061 mm of precipitation fell in 2022, which was the lowest total precipitation on record and subsequently lower than the long-term mean of 2,607 ± 297 mm (range 2,061 to 3,124 mm). During the 2022 nutrient addition period (June through September), the daily and monthly means for precipitation were 3 ± 6 mm (0 to 40 mm) and 85 ± 98 mm (16 to 231 mm), respectively, which were lower than the long-term means of 4 ± 9 mm (0 to 114 mm), and 122 ± 77 mm (2 to 335 mm), respectively. Total seasonal precipitation during the nutrient addition period in 2022 was 341 mm, which was also lower than the long-term mean (487 ± 123 mm, range 202 to 746 mm).

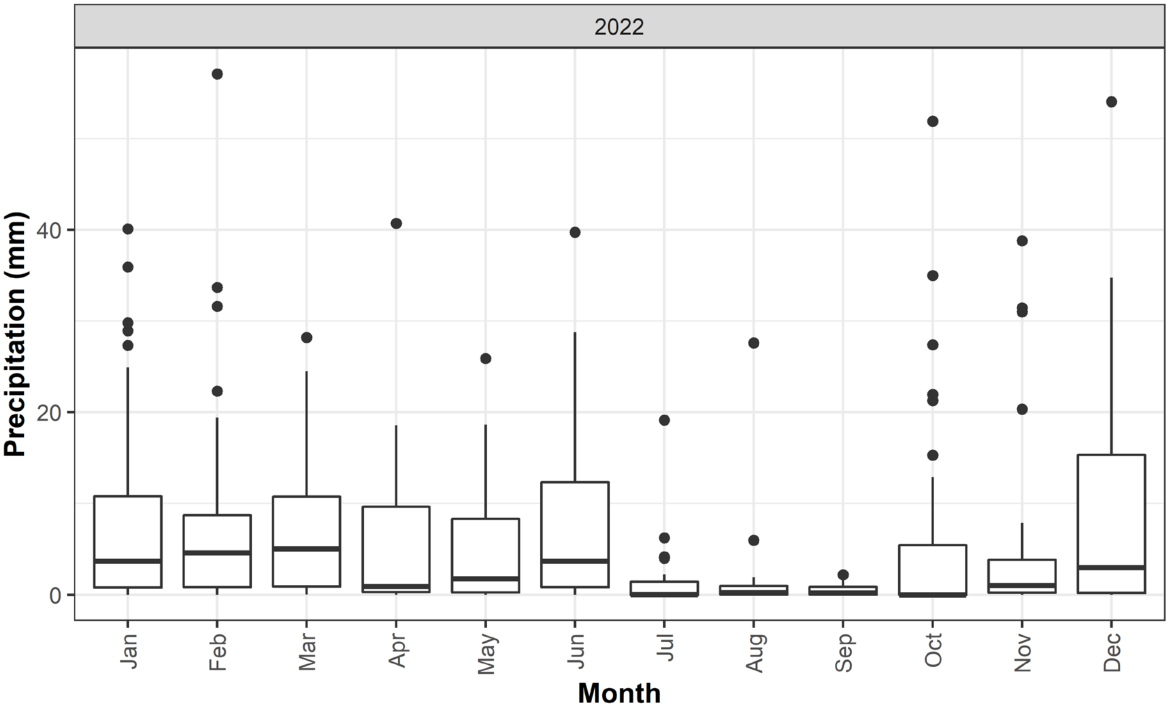

Figure 8. Boxplot of daily total precipitation (mm) for each month, 2022, Wahleach Reservoir, BC. Black dots represent outliers.

4.2.3 Stream Temperature

Mean daily water temperature in Jones Creek in 2022 was 4.7°C ± 0.5°C (January to October) and ranged from a maximum of 6.9°C in July to a low of 3.9°C in May and June. (Figure 9 shows daily average water temperatures). In Flat Creek, mean daily water temperature was 5.5°C ± 2.5°C (January to October) and ranged from a maximum of 12.0°C in July to a low of just above 0°C in January and February, when the surface likely froze. Boulder Creek data loggers had unfortunately washed out from the previous year and so data were provided by BC Hydro. Boulder Creek had a mean daily water temperature of 5.7°C ± 3.9°C (January to October) and ranged from a maximum of 14.8°C in July, to a low of 0°C in January and February, when the surface was likely frozen.

Water temperature data in Boulder, Flat, and Jones Creeks are reflective of their different habitat characteristics (Figure 9). Boulder Creek has very little tree canopy and subsequently has the highest water temperatures with more pronounced fluctuations, whereas Jones Creek has a high amount of terrestrial canopy and complexity resulting in lower and more stable water temperatures. Flat Creek is intermediary.

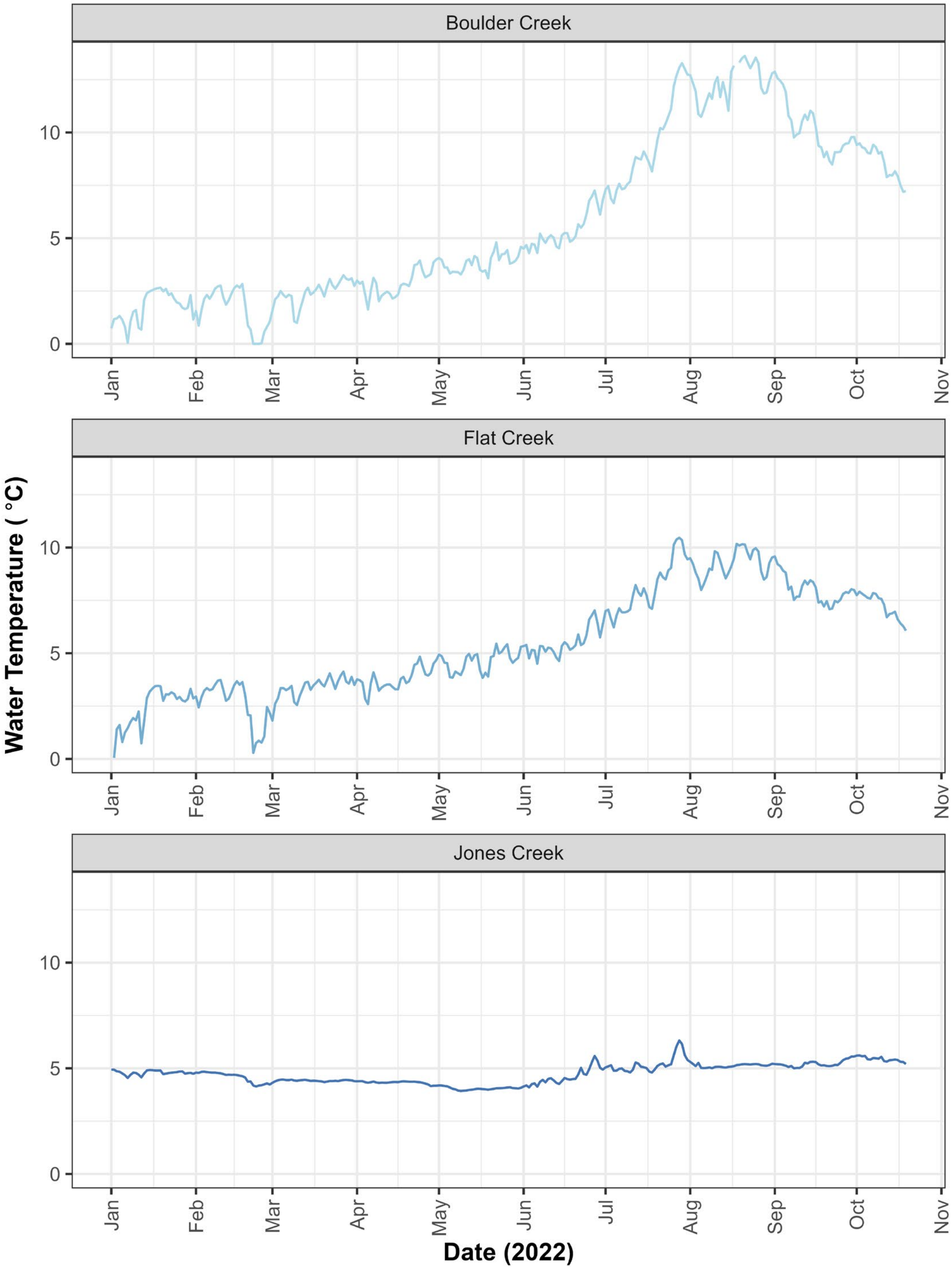

Figure 9. Daily average water temperatures (°C) in Boulder, Flat, and Jones Creek, 2022, Wahleach Reservoir, BC.

4.3 Physical and Chemical Limnology

Wahleach Reservoir exhibits a seasonal pattern of thermal stratification typical of higher elevation temperate systems (Wetzel, 2001), as shown in Figure 10. In 2022 a thermocline began to develop in June, strong thermal stratification was observed from July through to September, and then stratification began to weaken in October. Generally, the water column is well-mixed (isothermal) in the spring (May) and fall (October); however, in 2022 it was still isothermal in the north basin in June and in the fall did not become isothermal until November. In 2022, the thermocline ranged between 3 and 12 m (Figure 10). Water temperatures were similar between the north basin and the south basin with a combined mean temperature of 11.0 ± 3.8°C (range 6.7 to 22.2°C) for the upper 20 m of the water column. No instances of water temperatures at or above 25°C were observed, which is the lethal temperature for most resident salmonids (Ford et al., 1995).

Mean dissolved oxygen concentration in 2022 for both basins combined was 9.8 ± 1.2 mg·L^{-1} (range 6.4 to 11.8 mg·L^{-1}) for the upper 20 m of the water column. Federal guidelines for dissolved oxygen in cold water lakes for salmonid early life stages and other life stages are 9.5 mg·L^{-1} and 6.5 mg·L^{-1}, respectively (CCME, 1999). Throughout the growing season dissolved oxygen concentrations in the hypolimnion remained above 6.5 mg·L^{-1}, with the exception of October which dipped only slightly below 6.5 mg·L^{-1} in both basins at 20 m depth (Figure 10).

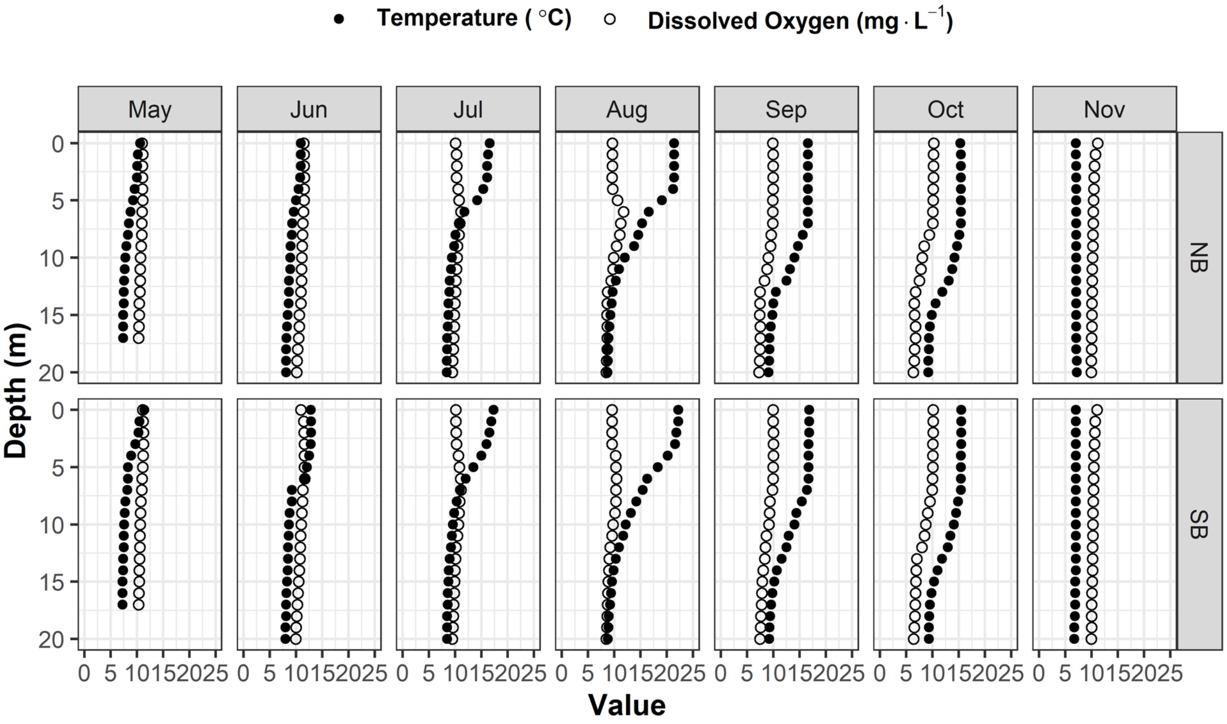

Figure 10. Water temperature (°C) and dissolved oxygen (mg·L^{-1}) profiles at the north basin (NB-LS1) and south basin (SB-LS2) limnology sampling stations May to November, 2022, Wahleach Reservoir, BC.

The pH in Wahleach Reservoir, as taken from 1-m water samples, was neutral with a mean of 7.2 ± 0.2 (range 6.9 to 7.3; Figure 11), which was similar to baseline pH levels (7.1 ± 0.3, range 6.6 to 7.8). Alkalinity is the buffering capacity of water to resist changes in pH and involves the inorganic carbon components present in most freshwater (Wetzel, 2001). Alkalinity in Wahleach Reservoir ranged between 8.5 and 11.4 mg $CaCO_3 \cdot L^{-1}$ with a mean of 10.0 ± 1.0 mg $CaCO_3 \cdot L^{-1}$ in 2022 (Figure 12). This was lower than alkalinity measured in 1993 (13.8 ± 2.4 mg $CaCO_3 \cdot L^{-1}$, range 11.7 to 16.5 mg $CaCO_3 \cdot L^{-1}$), though it should be noted that the 1993 alkalinity samples were collected later in the season and only in the north basin. Alkalinity values of less than 10 are considered to have high chemical sensitivity to acidic inputs, while values between 10-20 are considered moderately sensitive (Swain, 1987).

Secchi disk transparencies during 2022 averaged 5.3 ± 1.4 m (range 3.4 to 7.8 m) and were generally similar between the two basins (Figure 13). This year's average was shallower compared to the 1994 baseline average of 7.0 ± 0.4 m (range 6.2 to 7.6 m).

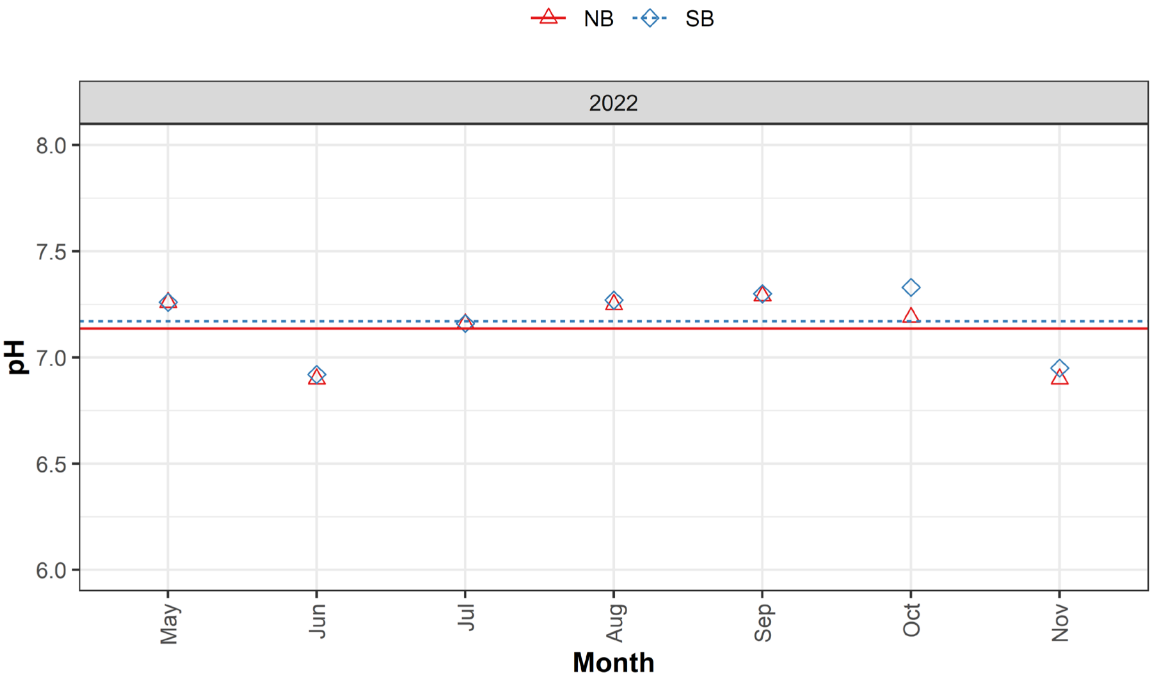

Figure 11. pH values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

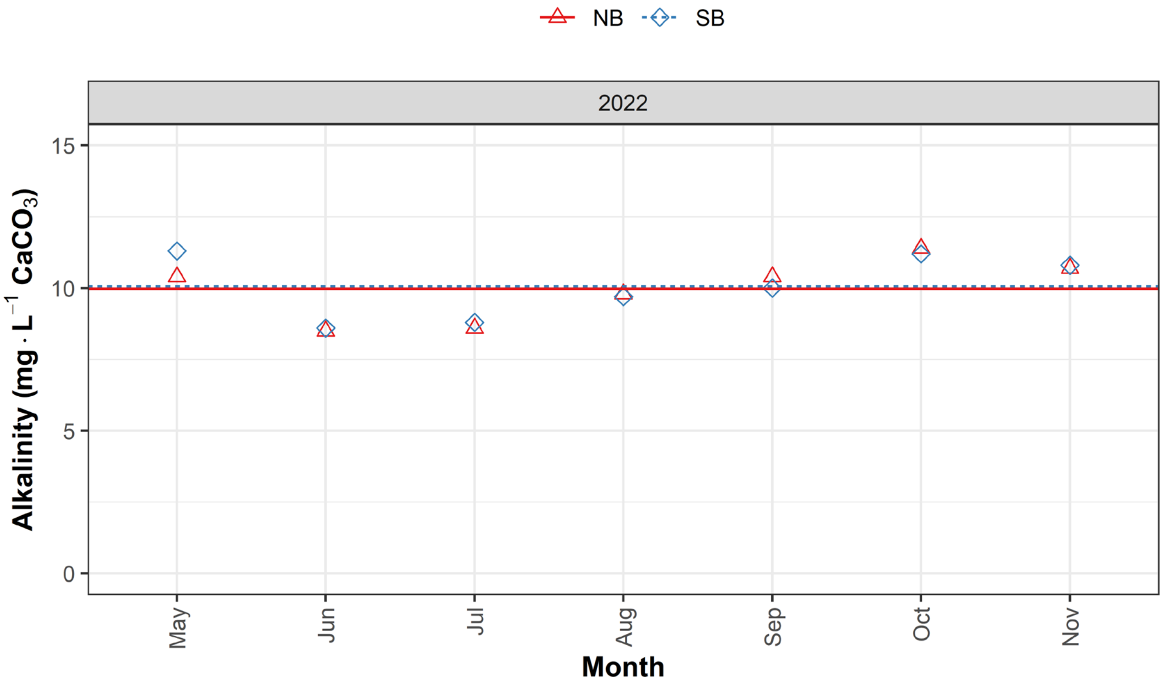

Figure 12. Alkalinity (mg $CaCO_3 \cdot L^{-1}$) values from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC. Horizontal bars represent seasonal mean for each station.

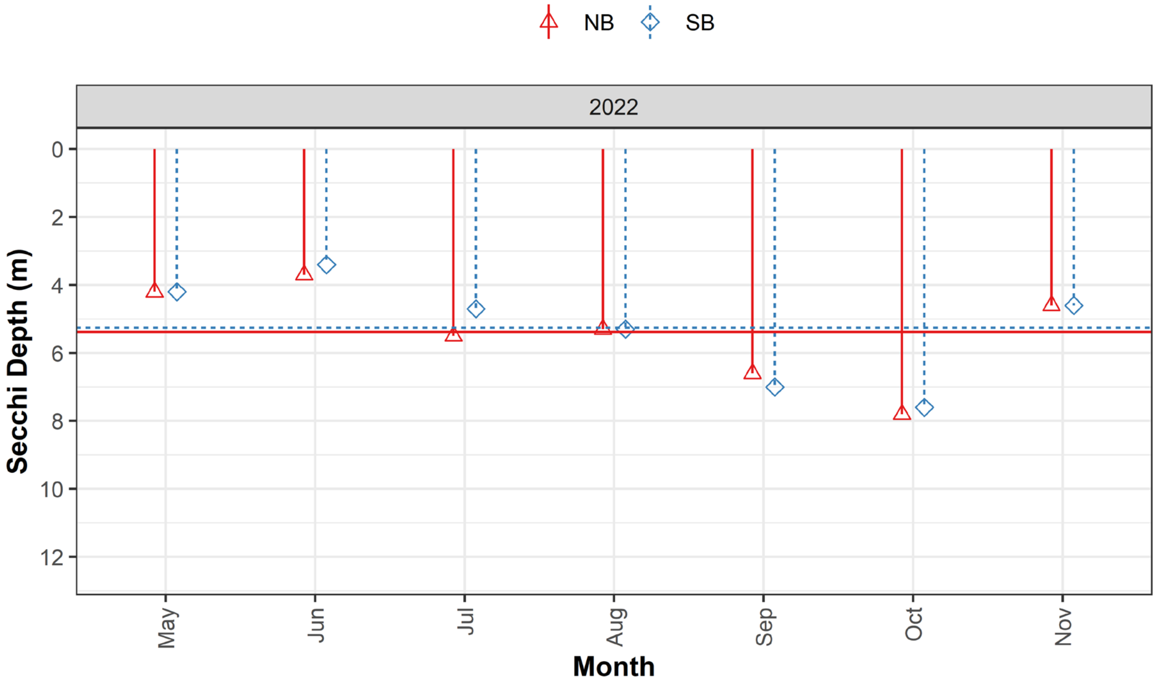

Figure 13. Secchi depths (m) at the north basin (NB) and south basin (SB) limnology sampling stations May to November 2022, Wahleach Reservoir, BC. Horizontal bars represent seasonal means for each station.

Vollenweider (1968) found total phosphorus (TP) concentrations below 5 µg·L^{-1} were indicative of ultra-oligotrophic productivity, while TP concentrations between 5-10 µg·L^{-1} were indicative of oligotrophic productivity. In 2022, TP values ranged from 2.6 to 6.0 µg·L^{-1} with a seasonal mean of 4.3 ± 1.0 µg·L^{-1} indicating phosphorus concentrations remained in the ultra-oligotrophic productivity range (Figure 14). Prior to nutrient restoration, seasonal mean epilimnetic TP was 4.3 ± 2.0 µg·L^{-1} and ranged from 2.9 to 12.0 µg·L^{-1}, which was representative of ultra-oligotrophic productivity nearing oligotrophic productivity.

Soluble reactive phosphorous (SRP), a measurement of low-level orthophosphate, is the form of phosphorous readily available to phytoplankton. In 2022, SRP values ranged from below detection limits of <1 µg·L^{-1} to 1.1 µg·L^{-1} with a seasonal mean of 0.6 ± 0.2 µg·L^{-1} (Figure 15); most values were below detection limits. This suggests rapid uptake and assimilation of useable phosphorus by phytoplankton. The SRP concentration during the baseline era was 1.1 ± 0.3 µg·L^{-1} with a range of 1 to 2 µg·L^{-1}.

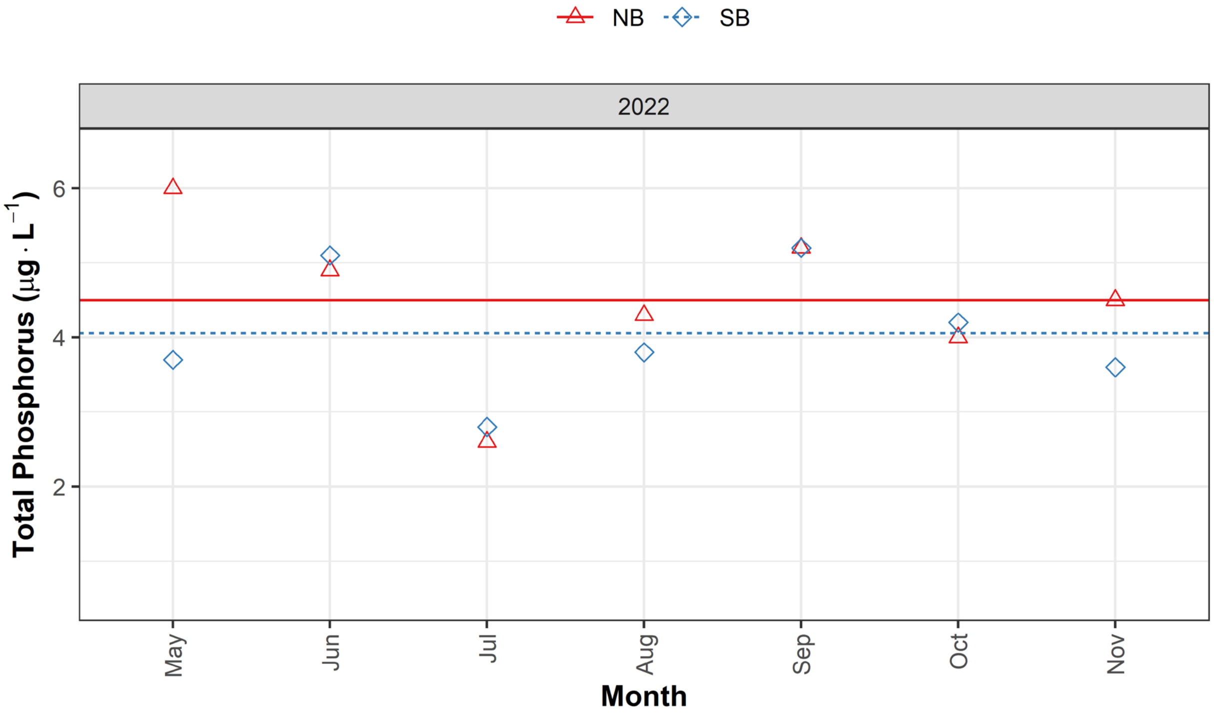

Figure 14. Total phosphorus concentration (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC.

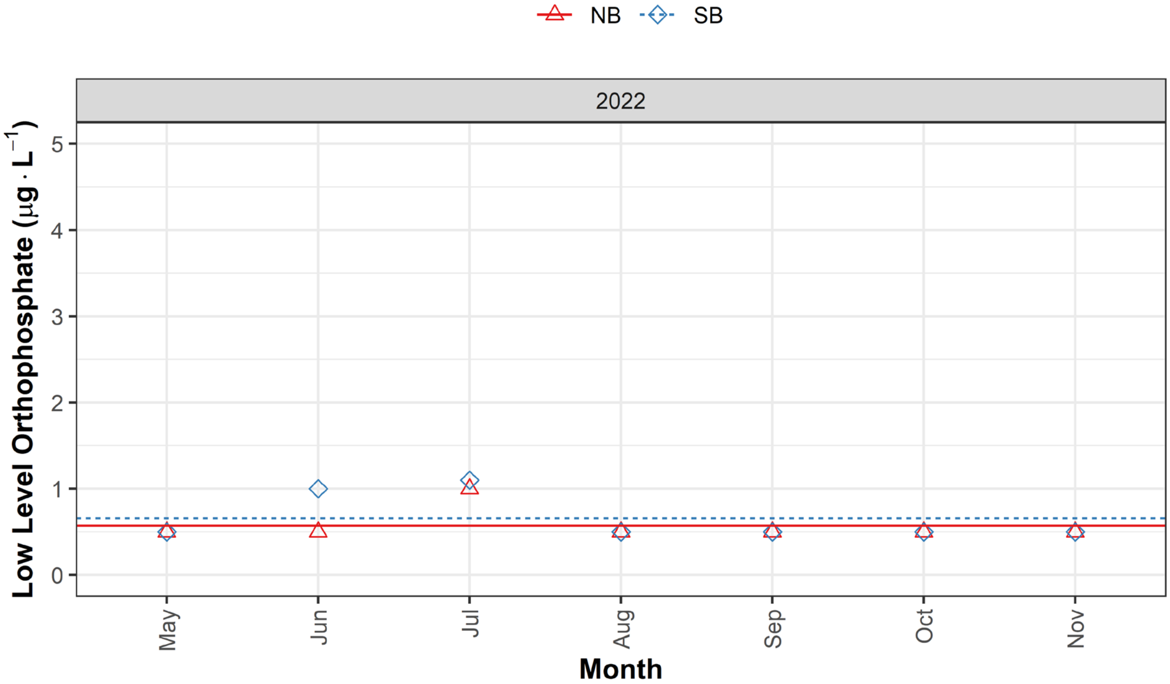

Figure 15. Low level orthophosphate concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC.

Total nitrogen (TN) represents dissolved inorganic forms of nitrogen (i.e., nitrate, nitrite and ammonia) and particulate forms of nitrogen (mainly organic). Typically, epilimnetic TN concentrations are slightly higher in spring, and gradually decrease through the summer and fall. This pattern coincides with the seasonal growth and utilization of dissolved nitrogen by phytoplankton in the reservoir's epilimnion. In 2022, TN was highest in early spring and followed a slight decreasing trend through to October, before increasing again in November (Figure 16). The mean TN concentration in 2022 was 123 ± 35 µg·L^{-1} (range 88 to 190 µg·L^{-1}), which was higher than the baseline of 107 ± 47 µg·L^{-1} (range 9 to 220 µg·L^{-1}; Figure 16).

Nitrate and nitrite-N (NO_3+NO_2-N) are important forms of dissolved nitrogen supporting algal growth (Wetzel 2001). In 2022, the highest concentrations of NO_3+NO_2 were observed during spring when the reservoir was completely mixed, NO_3+NO_2 decreased throughout the summer and into October before rising again in November. In August and September NO_3+NO_2 concentrations dipped below the level considered limiting for phytoplankton growth (<20 µg·L^{-1}), while in October NO_3+NO_2 concentrations were below detection limits (<3.2 µg·L^{-1}) — a pattern suggestive of strong biological utilization of NO_3+NO_2, occurring after the cessation of nutrient additions in September. The seasonal mean NO_3+NO_2 concentration in 2022 was 36 ± 38 µg·L^{-1} (range 1.6 to 114 µg·L^{-1}; Figure 17), which was lower than baseline conditions of 66 ± 69 µg·L^{-1} (range 0.9 to 426 µg·L^{-1}).

The total nitrogen to total phosphorus ratio (TN:TP) is useful in determining the limiting nutrient. Ratios above 50 suggest phosphorus limitation while ratios below 20 suggest nitrogen limitation (Guildford and Hecky, 2000). In 2022, TN:TP stayed within these bounds for the duration of the season, ranging between 21 to 46 with a mean of 29 ± 7 (Figure 18). The TN:TP in 2022 had a smaller range, but similar mean compared to baseline years, when TN:TP ranged between 3 to 67 with a mean of 27 ± 14.

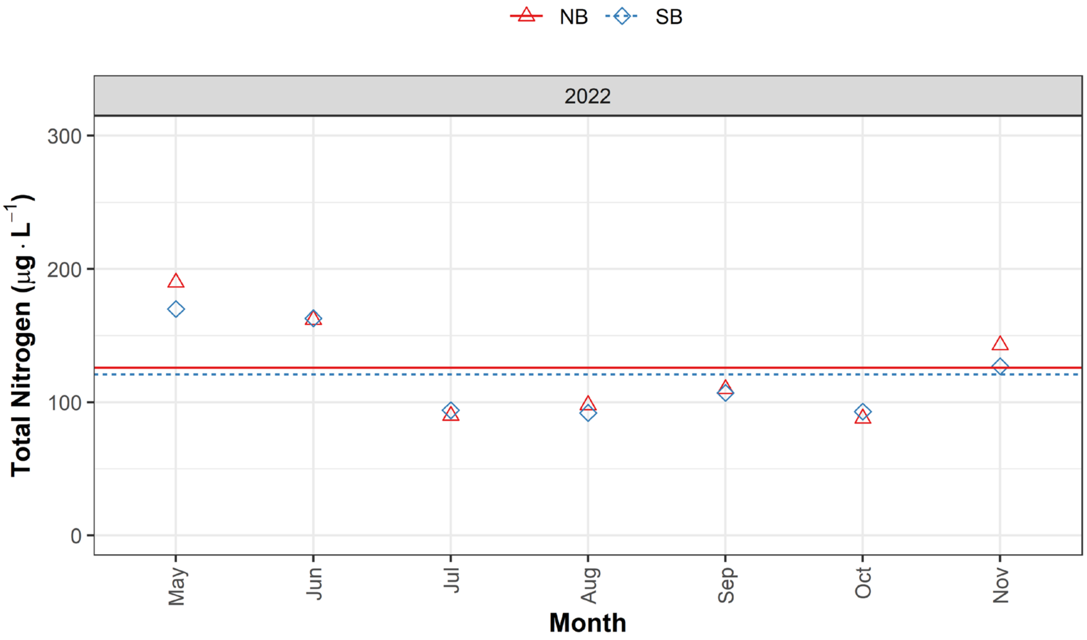

Figure 16. Total nitrogen concentrations (µg·L^{-1}) from 1 m water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC; horizontal lines represent seasonal means for each station.

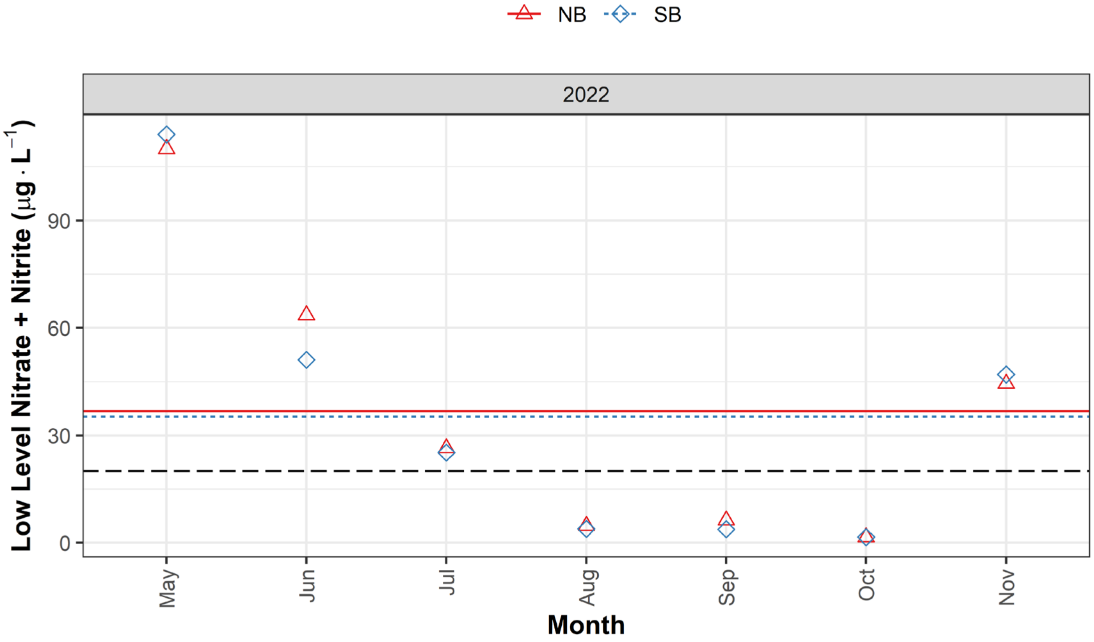

Figure 17. Low level nitrate + nitrite nitrogen concentrations (µg·L^{-1}) from 1 m discrete water chemistry samples at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC; black dashed line at 20 µg·L^{-1} represents the limiting concentration for phytoplankton growth.

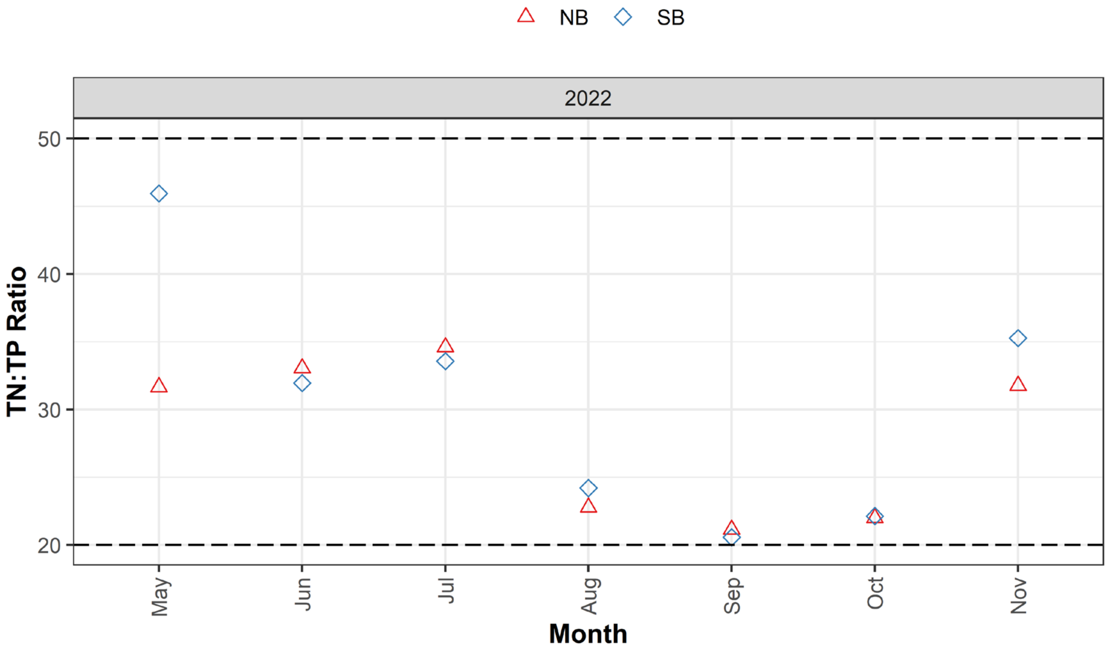

Figure 18. Total nitrogen (TN) to total phosphorus (TP) ratios based on 1 m water chemistry samples from the north basin (NB) and the south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC. Points above dashed line at 50 were likely in a state of P limitation, while points below dashed line at 20 were likely in a state of N limitation (Guildford and Hecky 2000).

4.4 Phytoplankton

A total of 41 phytoplankton species were detected in Wahleach Reservoir during 2022 (Appendix A), which was higher than the 1994 baseline year, when 38 phytoplankton species were detected. Mean phytoplankton abundance in 2022 was 18,396 ± 44,475 cells·mL^{-1} (range 3,634 to 172,617 cells·mL^{-1}), which was higher than the 1994 baseline year abundance of 8,793 ± 4,929 cells·mL^{-1} (4,632 to 20,093 cells·mL^{-1}). Abundance in 2022 was driven largely by growth of blue-green algae (class *Cyanophyceae*) during the summer months and to a lesser extent flagellates (class *Chryso*- & *Cryptophyceae*) during the spring and fall (Figure 19). In August in the south basin, a large bloom of the edible blue-green algae *Merismopedia* occurred (present as cells). It is common for Wahleach Reservoir, like many other coastal and sub-alpine lakes in BC, to move into low or limiting nitrogen conditions during peak growing season (Stockner, 1981; Stockner and Shortreed, 1985). Under these conditions, growth of nitrogen-fixing cyanophytes (e.g., *Aphanothece*, *Merismopedia*) are favoured; negative impacts to the fish population have not been observed. The phytoplankton community consisted of edible species and forms found throughout the season (16,095 ± 43,755 cells·mL^{-1}; range 1,146 to 167,763 cells·mL^{-1}; Figure 20). Inedible fractions (2,413 ± 1,402 cells·mL^{-1}; range 610 to 4,854 cells·mL^{-1}) were more prominent in the spring and fall, particularly in the north basin.

Phytoplankton biovolume in 2022 was 0.35 ± 0.22 mm^{3}·L^{-1} (range 0.12 to 0.87 mm^{3}·L^{-1}) which was lower than observed during baseline years (0.88 ± 0.51 mm^{3}·L^{-1}; range 0.20 to 1.90 mm^{3}·L^{-1}), but comparable to the last several years (0.38 mm^{3}·L^{-1} in 2021 and 0.34 mm^{3}·L^{-1} in 2020, data on file). Biovolume comparisons to earlier years, including baseline, are difficult due to the laboratory switch (slight differences in taxonomic identification and calculations; D. Brandt, personal communication, December 23, 2021). Early in the season, biovolume was largely driven by chlorophytes (class *Chlorophyceae*), and to a lesser extent flagellates and dinoflagellates (class *Dinophyceae*). In August in the south basin, biovolume was dominated by blue-green algae due to the bloom of *Merismopedia* mentioned above, while the north basin had a balance of chlorophytes, flagellates, dinoflagellates, and blue-green algae. September had increased biovolume of diatoms (class *Bacillariophyceae*) in both basins, while the fall was primarily flagellates and dinoflagellates (Figure 21). Edible species were dominant throughout the season (Figure 22). Edible biovolume (0.26 ± 0.19 mm^{3}·L^{-1}; range 0.09 to 0.83 mm^{3}·L^{-1}) was predominantly driven by flagellates and dinoflagellates, while inedible biovolume (0.04 ± 0.05 mm^{3}·L^{-1}; range 0.002 to 0.17 mm^{3}·L^{-1}) was largely a result of diatom growth in September.

It is important to stress that the values measured, and species composition observed provide a “snapshot” of the phytoplankton community at a given point in time. This snapshot does not reflect the instantaneous growth of particular species or size classes, and ultimately it reflects a combination of factors that increase or decrease the abundance of the community such as flushing, sinking and variable zooplankton grazing.

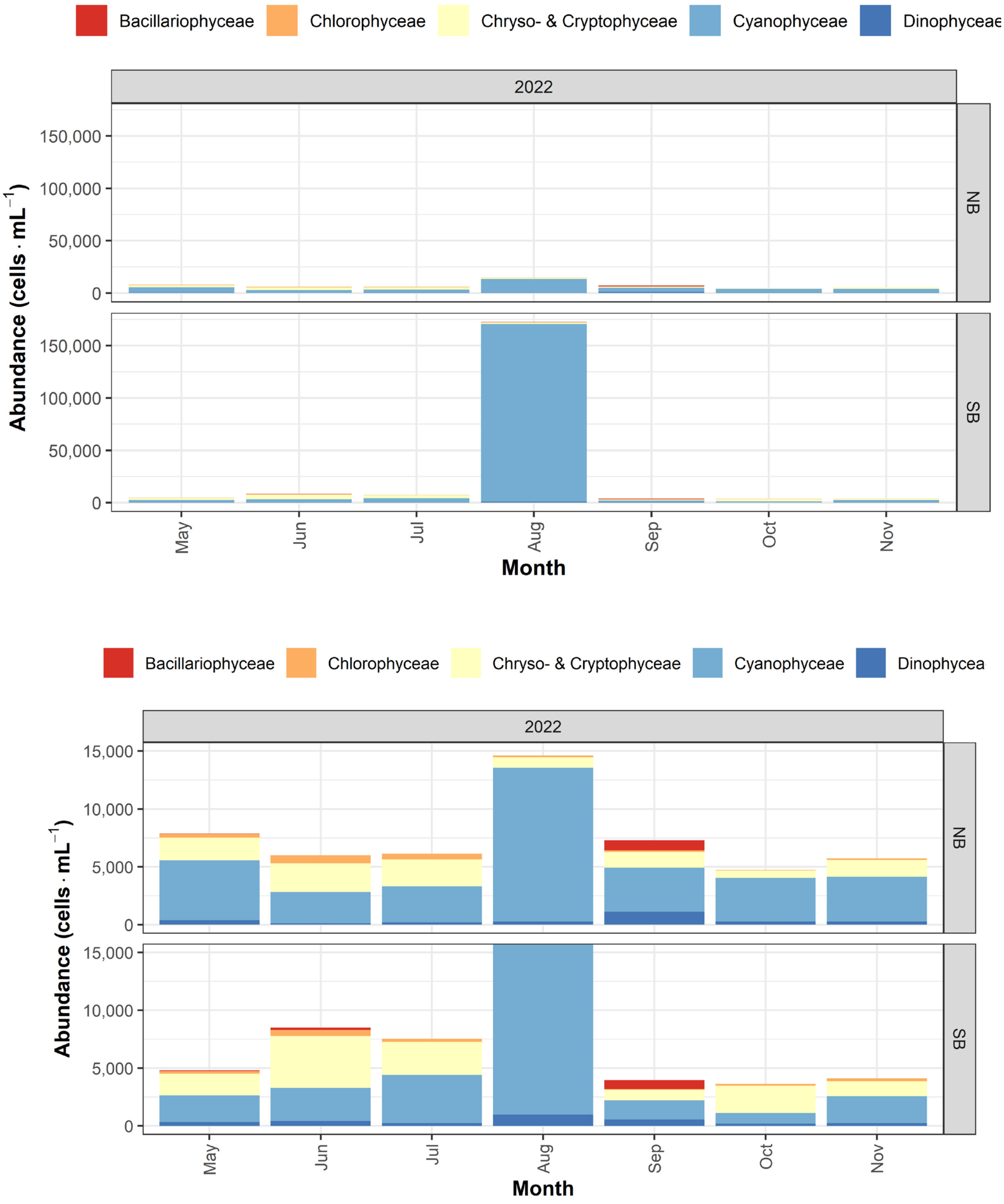

Figure 19. Seasonal phytoplankton abundance (cells·mL^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir BC. Upper figure captures the SB August bloom while the lower figure is zoomed in to better illustrate the other months.

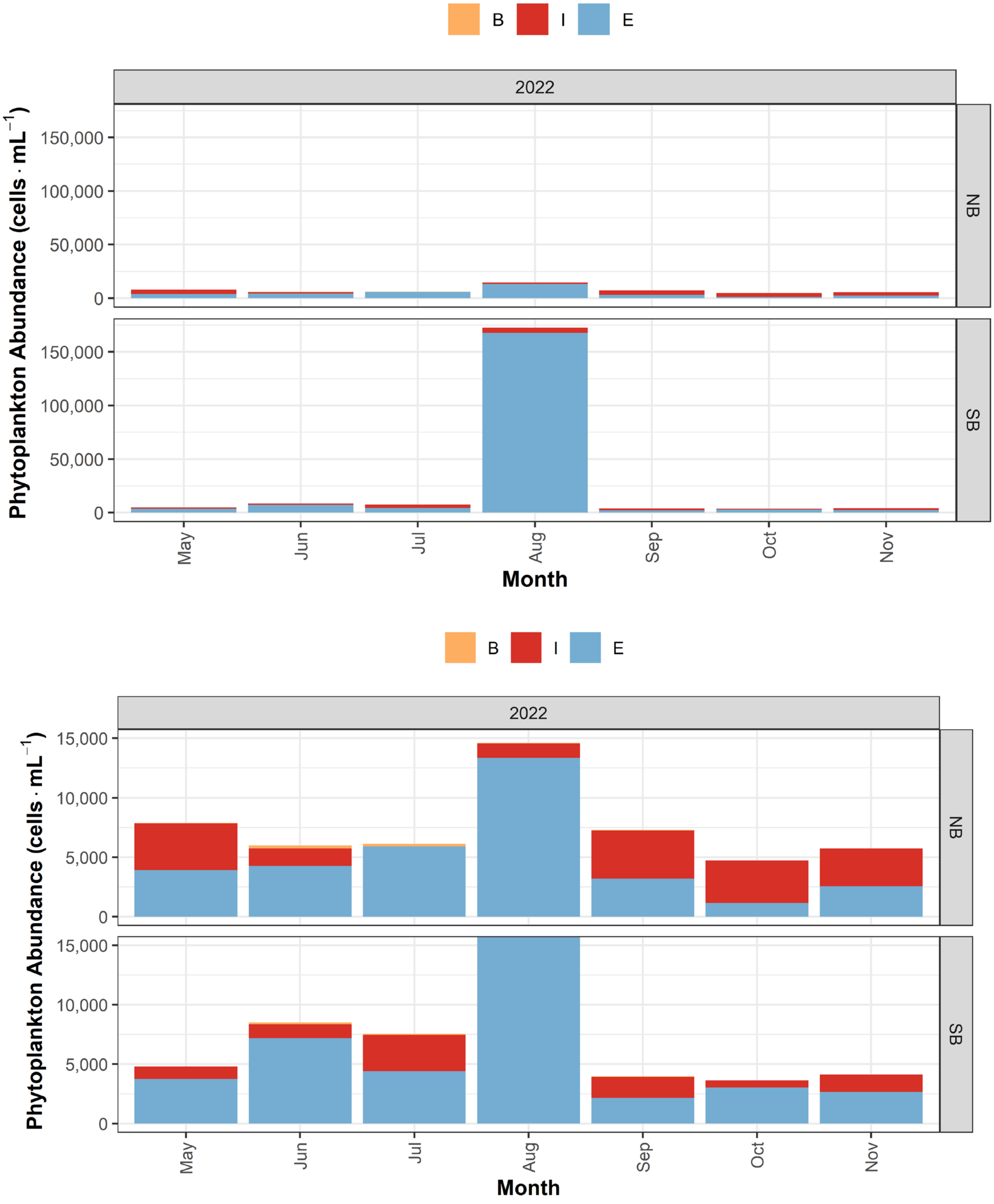

Figure 20. Seasonal phytoplankton abundance (cells·mL^{-1}) by edibility (E=edible, I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to November 2022, Wahleach Reservoir, BC. Upper figure captures the SB August bloom while the lower figure is zoomed in to better illustrate the other months.

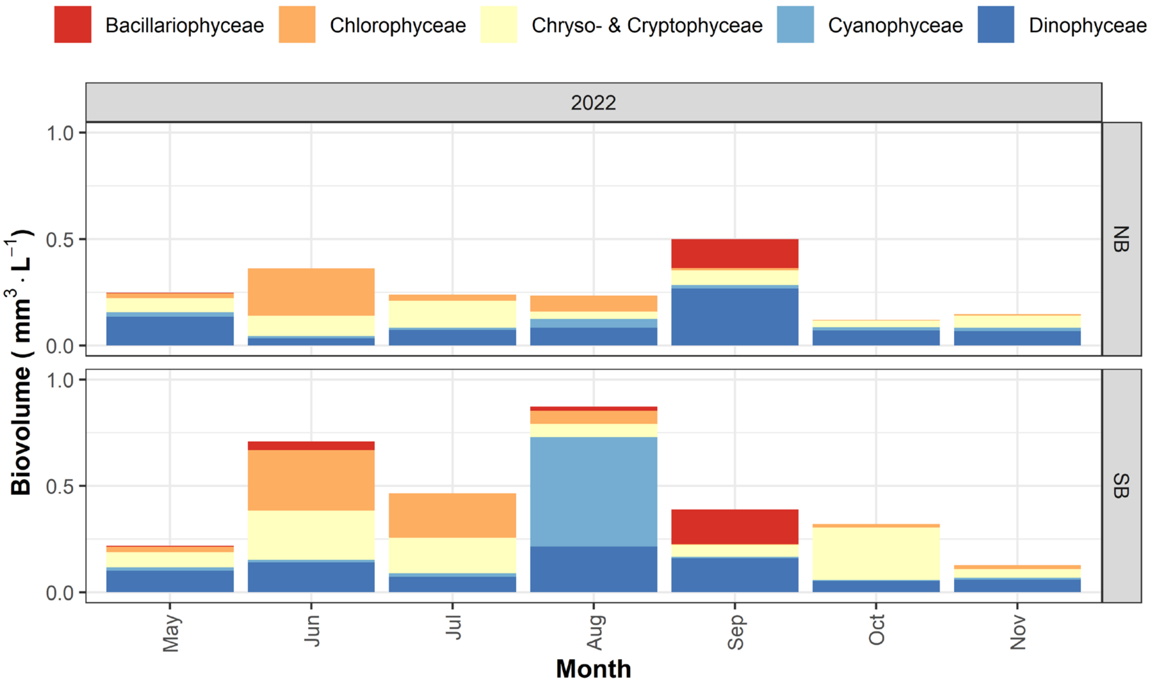

Figure 21. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by class at the north basin (NB) and south basin (SB) limnology stations May to November 2022, Wahleach Reservoir, BC.

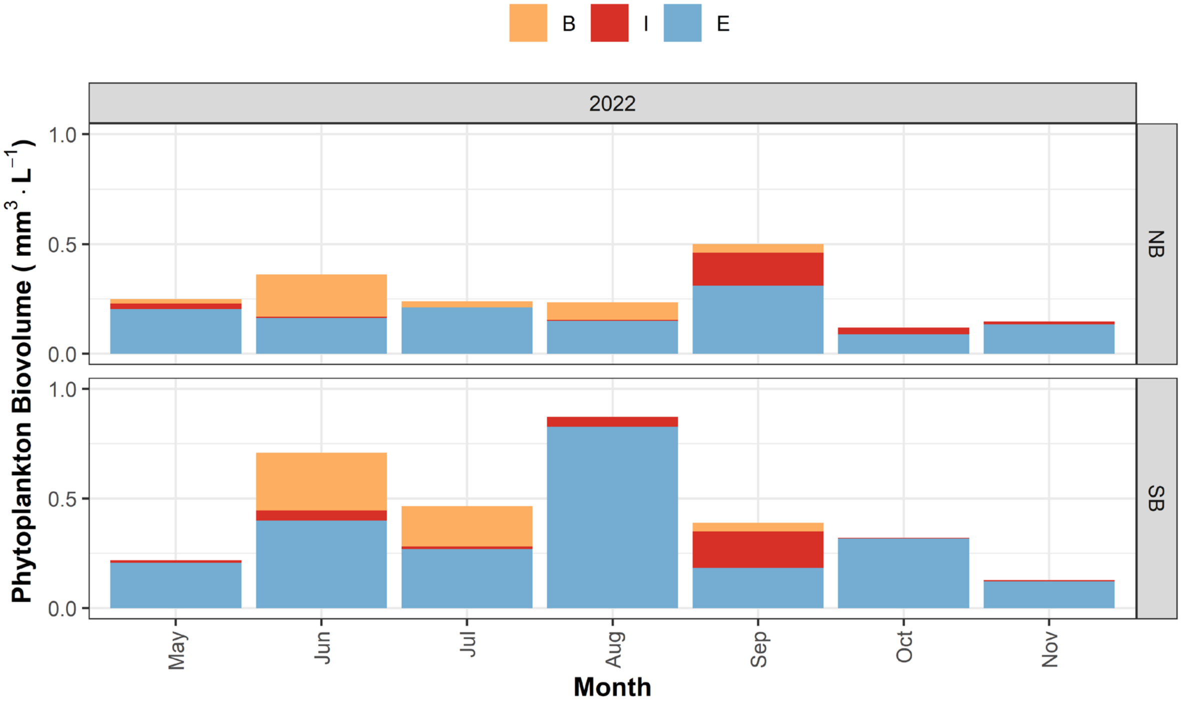

Figure 22. Seasonal phytoplankton biovolume (mm^3·L^{-1}) by edibility (E=edible, I=inedible, B=both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to November 2022, Wahleach Reservoir, BC.

4.5 Zooplankton

The following eight *Cladocera* species and two *Copepoda* species were identified in Wahleach Reservoir in 2022 (53): *Bosmina longirostris* (O.F.M.), *Chydorus sphaericus* (O.F.M.), *Daphnia rosea* (Sars), *Daphnia galeata mendotae (Birge), Holopedium gibberum* (Zaddach), *Leptodora kindtii* (Focke), *Scapholeberis 29ucronate* (O.F.M.), *Polyphemus pediculus* (Linnaeus)*, Cyclops vernalis* (Fischer) and *Leptodiaptomus ashlandi* (Marsh). *Scapholeberis 29ucronate* and *Chydorus sphaericus* are more commonly found in littoral habitats but given the close coupling between littoral and pelagic habitat in Wahleach Reservoir, it is not surprising to find low densities of these two species in the pelagic habitat.

Seasonal zooplankton density in 2022 was 6.0 ± 4.0 individuals·L^{-1} (range 1.1 to 20.4 individuals·L^{-1}) which was greater than densities measured during baseline years (1.0 ± 1.0 individuals·L^{-1}; range 0.1 to 4.5 individuals·L^{-1}). Seasonal zooplankton biomass was 59.1 ± 39.6 µg·L^{-1} (range 3.8 to 143.0 µg·L^{-1}). Early in the season, zooplankton density was largely driven by cladocerans other than *Daphnia*. From August through to October, *Daphnia* were the dominant driver of both density and biomass (Figure 23, Figure 24). It is important to note that during pre-fertilization assessments, *Daphnia* sp. were not detected in the zooplankton community (Inglis, 1995) and the community was dominated by the small cladoceran *Bosmina*. Copepod densities and biomass peaked in August (Figure 23). Seasonal densities and biomass of each major zooplankton group are detailed in Table 5. Overall, in 2022, *Daphnia* made up 33% of the seasonal zooplankton density and 74% of biomass, while other cladocerans made up 57% of density and 25% of biomass (majority of which were *Bosmina longirostris* and *Holopedium*).

Table 5. Summary statistics for seasonal zooplankton density and biomass of each major group (Copepoda, *Daphnia* and other Cladocera), 2022, Wahleach Reservoir, BC.

Taxonomic Group	**Density (individuals·L^{-1})**				**Biomass (µg·L^{-1})**			
	Mean	**SD**	**Max**	**Min**	**Mean**	**SD**	**Max**	**Min**
Copepoda	0.7	0.7	2.9	0.1	1.1	1.2	5.2	0.1
Daphnia	2.2	1.5	5.1	0.01	57.3	41.2	134.4	0.1
Other Cladocera	3.8	4.4	20.3	0.4	19.1	20.4	82.6	2.4

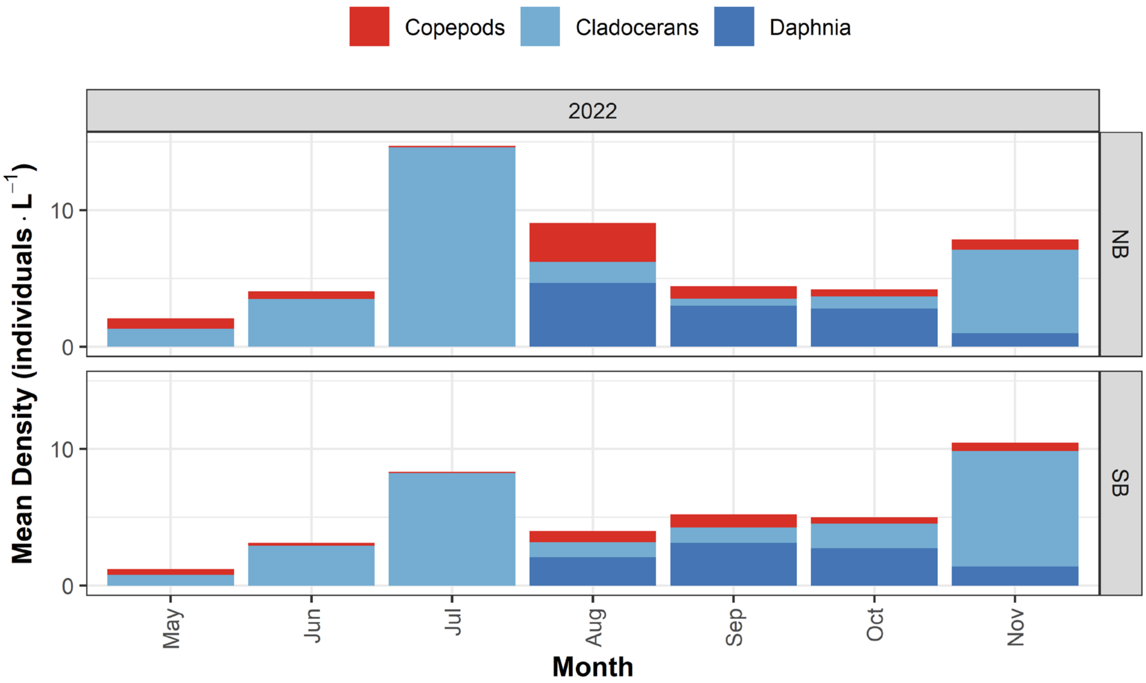

Figure 23. Monthly zooplankton density (individuals·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2022, Wahleach Reservoir, BC.

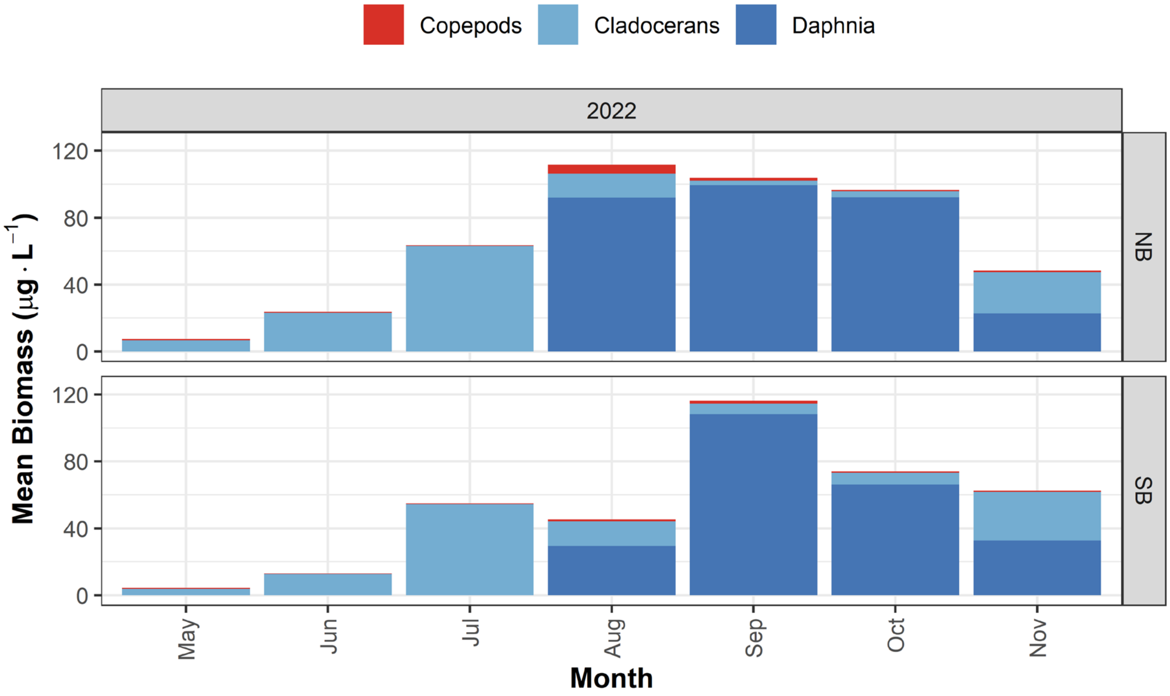

Figure 24. Monthly zooplankton biomass (µg·L^{-1}) by major group (Copepoda, *Daphnia* and other Cladocera) at the north basin (NB) and south basin (SB) limnology stations, 2022, Wahleach Reservoir, BC.

4.6 Fish

4.6.1 Catch & CPUE

Total catch during the nearshore gillnet sampling in 2022 was 214 fish (Table 6). The majority of the catch were Kokanee at 48%, followed by Rainbow Trout at 30% and Cutthroat Trout at 22% (Table 6). Of the total catch, 26% were caught in the 1.25" mesh panels (Table 7). Catch-per-unit-effort (CPUE) for all species combined in the nearshore gillnetting was 0.12 fish$\cdot$100 $m^{-2}\cdot hr^{-1}$. Catch from the minnow trap sampling was 14 Threespine Stickleback; total soak time in 2022 was 110 trap hours with CPUE at 0.13 fish per trap hour.

Table 6. Summary of fall nearshore gillnetting catch and percentage (%), 2022, Wahleach Reservoir, BC. Species include Cutthroat Trout (CT), Rainbow Trout (RB), Kokanee (KO), and unknown Trout (TR) which could not be identified due to consumption by Crayfish (*Pacifastacus leniusculus*).

Species	2022[1]	%
CT	47	22
RB	64	30
KO	102	48
TR	1	<0.5
Total	214	100

1.Includes catch of standard gillnet plus added 1.25" panel

Table 7. Summary of fall nearshore gillnetting catch for standard RISC panels vs. 1.25" panel, 2022, Wahleach Reservoir, BC. The 1.25" panel was added in 2014.

Species	2022 – Standard	2022 – 1.25"
CT	39	8
RB	41	23
KO	77	25
TR	1	0
Total	158	56

4.6.2 Kokanee

A total of 102 Kokanee were captured during fall nearshore gillnetting, ranging in length from 132 to 259 mm and in weight from 23.0 to 207.5 grams. All Kokanee captured were immature and were age 1+ or age 2+ fish, (Table 8, Figure 25) which is expected given the netting program occurred after the Kokanee spawning window. Age 1+ was the dominant age class caught in 2022. When comparing summary statistics of Kokanee size by age class, individuals caught in 2022 were larger and in better condition than during the baseline years, where age 2+ Kokanee had a mean length of 178 mm, mean weight of 55.5 g, and condition factor of 1.0 (data on file). The age 1+ Kokanee captured in 2022 were similar in size to the age 2+ Kokanee from baseline years (Table 8). Most natural salmonid populations have a calculated b value between 2.5 and 3.5 (Carlander, 1969). Kokanee length-weight regressions based on the 2022 fall nearshore gillnetting data (Figure 26, Table 9), had a slope or b value of 3.12; b values near 3 are common for fish (Anderson and Gutreuter, 1983; Cone, 1989) and are indicative of isometric growth (i.e., the shape of the fish is consistent as it grows; Everhart and Youngs, 1981).

Table 8. Summary of Kokanee biometrics by age, 2022, Wahleach Reservoir, BC.

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
1+	182	17	208	132	71.3	20.0	110.5	23.0	1.2	0.07	1.4	1.0	58
2+	220	15	259	182	128.5	25.3	207.5	67.0	1.2	0.06	1.3	1.1	40

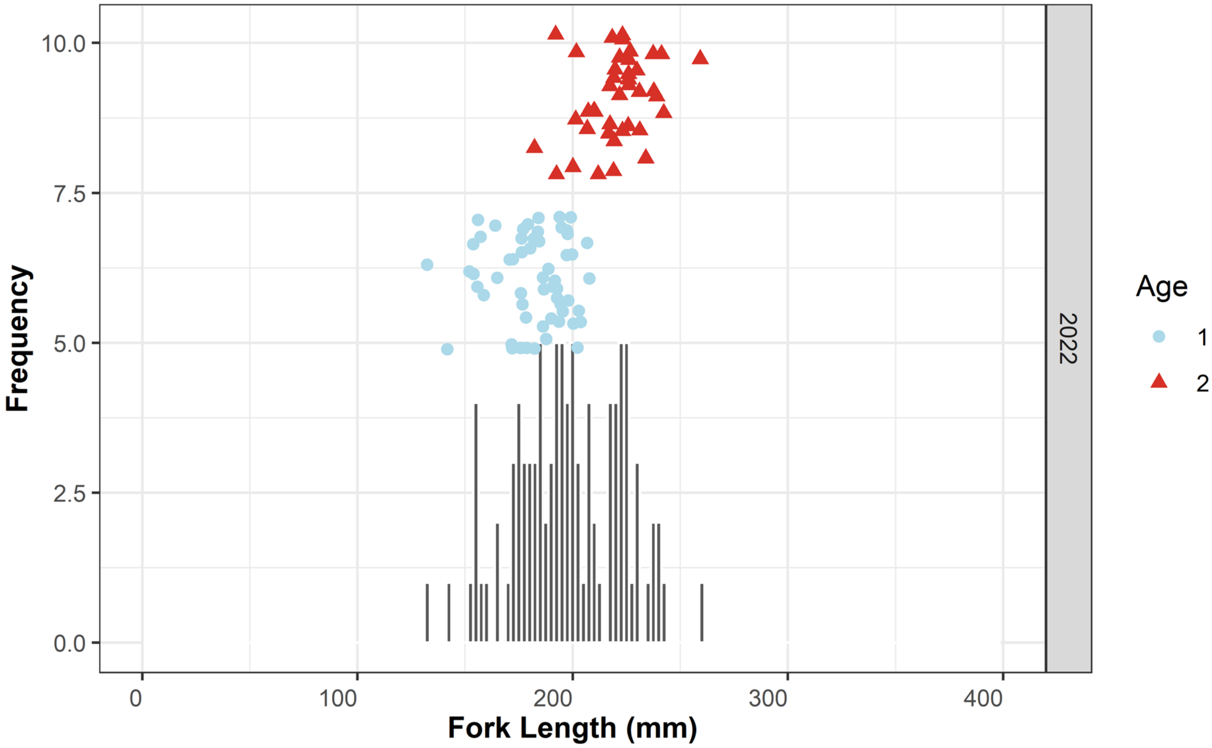

Figure 25. Length frequency distribution by age class of Kokanee, 2022, Wahleach Reservoir, BC.

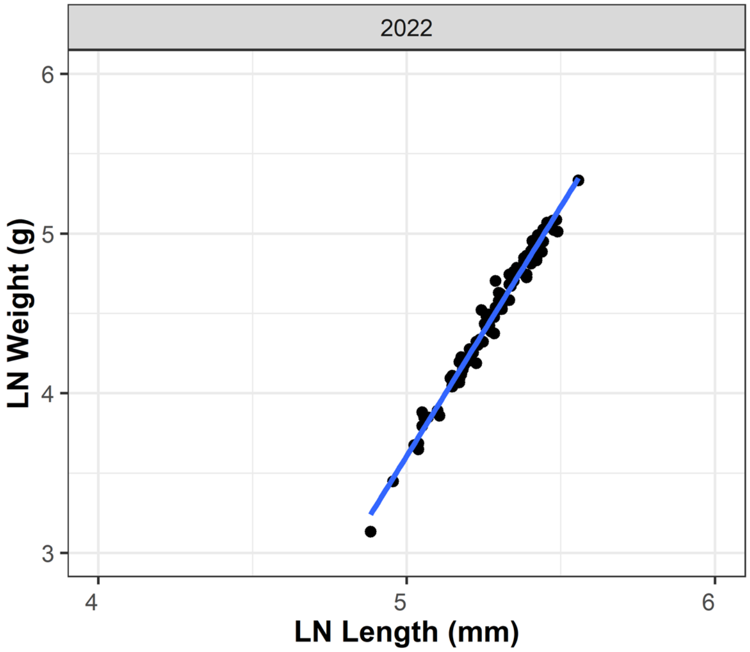

Figure 26. Natural logarithm of length weight linear regression (LN W = LN a * LN Lb) of Kokanee, 2022, Wahleach Reservoir, BC.

Table 9. Summary of variables in R for Kokanee length weight relationships (Ln W = b · Ln L + Ln a), 2022, Wahleach Reservoir, BC.

Year	Equation	R^2
2022	LN.weight.g = 3.12 * LN.length.mm -12.0	0.9800

4.6.2.1 Spawners

Timing of Kokanee spawning in 2022 was similar to previous years where Kokanee were observed in index streams by the first week of September, with peak numbers occurring in mid to late September and most of the spawning completed by mid October (Figure 27). Kokanee escapement in 2022 was the highest on record at 25,758 fish, which was significantly higher than the long-term mean of 8,482 (2006-2022; data on file). Flat Creek had the most spawners (20,185), followed by Jones Creek (5,559), and then Boulder Creek (15). In pre-treatment years, 1993-1994, Kokanee spawning had largely collapsed with only 953 and 568 individuals observed, respectively (data on file).

Kokanee samples taken from index streams via dip netting were generally classified as spawning or spent, so weights were not considered representative and condition factors were not reported. The mean fork length of Kokanee spawners captured was 230 ± 27 mm (range 124 to 286 mm) and ages ranged from age 1+ to 3+, with the majority of spawners aged at 2+ years (Table 10, Figure 28). Length frequency and associated age-at-length data show substantial overlap in the lengths between each of the age classes (Table 11, Figure 29).

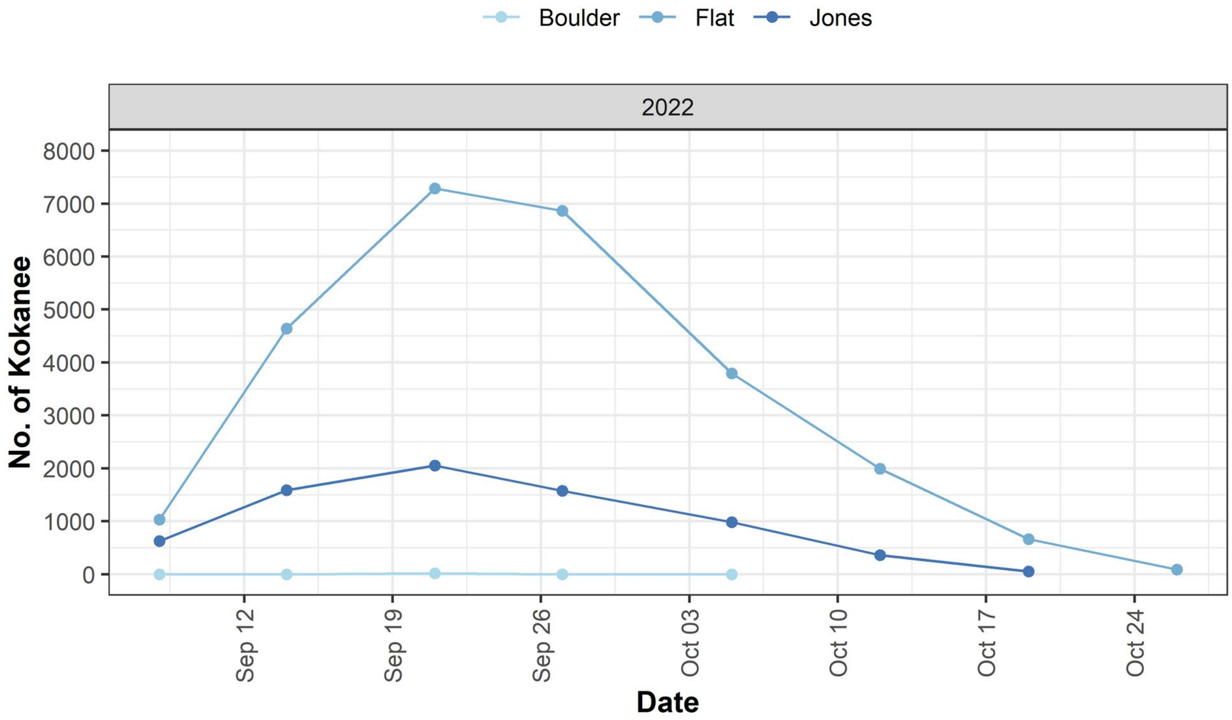

Figure 27. Kokanee spawner counts from each index stream (Boulder Creek, Flat Creek, and Jones Creek), 2022, Wahleach Reservoir, BC.

Table 10. Summary of biometric data from spawning Kokanee collected during spawner surveys, 2022, Wahleach Reservoir, BC. Data for all three index streams (Boulder Creek, Flat Creek, and Jones Creek) were combined as differences between systems were not significant. If fork length (FL) was not measured for an individual, it was calculated based on a regression equation ($y = 1.3775x - 27.748$, $R^2 = 0.9578$) from years (2003-2022) when both POHL and FL were measured.

Year	**Fork Length (mm)**					**Age**				
	Mean	SD	Max	Min	n	Mean	SD	Max	Min	n
2022	230	27	286	124	77	2.1	0.4	3	1	75

Table 11. Summary of Kokanee fork length by age, 2022, Wahleach Reservoir, BC.

Age	**Fork Length (mm)**				
	Mean	SD	Max	Min	n
1+	158	32	211	124	5
2+	231	15	286	199	60
3+	260	11	273	234	10

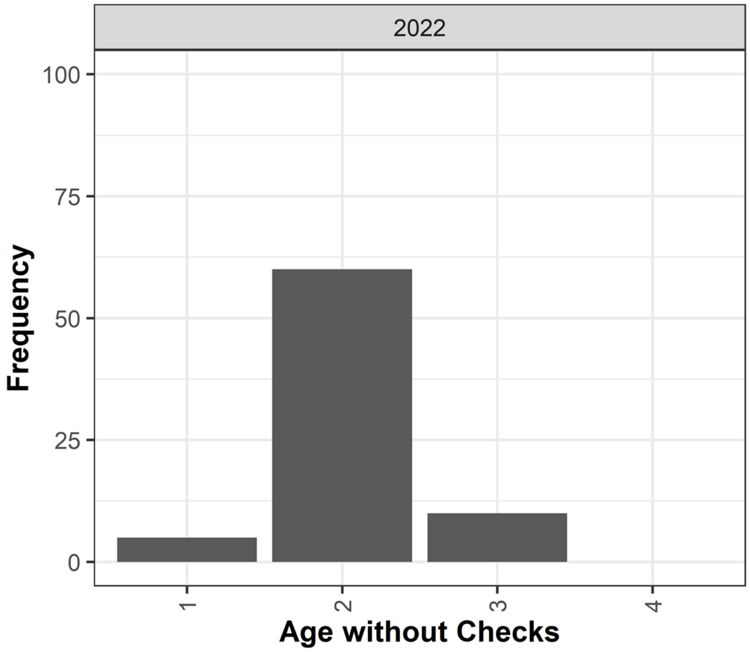

Figure 28. Age frequency of Kokanee spawners in index streams (Boulder Creek, Flat Creek, and Jones Creek), 2022, Wahleach Reservoir, BC.

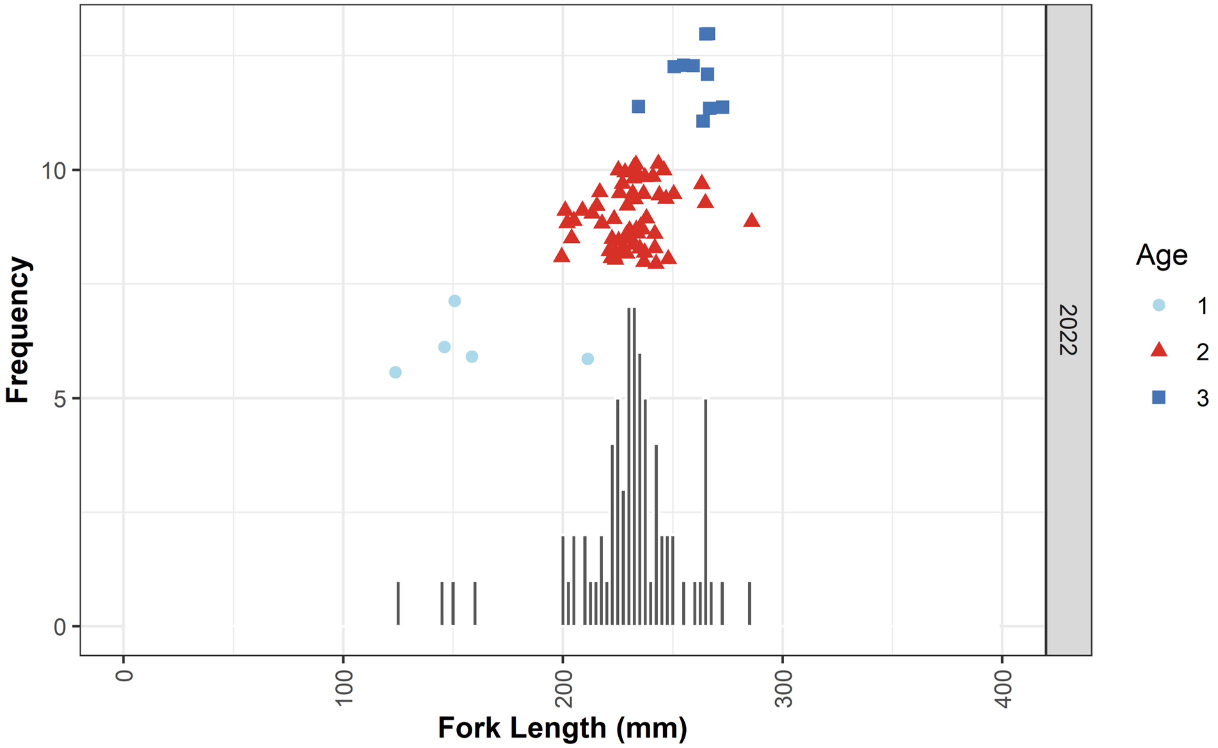

Figure 29. Length frequency distribution by age class of Kokanee spawners in index streams (Boulder Creek, Flat Creek, and Jones Creek), 2022, Wahleach Reservoir, BC.

4.6.3 Rainbow Trout

In 2022, fall nearshore gillnet and minnow trap sampling captured a total of 64 Rainbow Trout, ranging in length from 114 to 310 mm and in weight from 19.0 to 308.5 grams. Length and weight of Rainbow Trout in 2022 was higher than baseline years, when the mean length was 186 ± 45 mm (range 109 to 329 mm) and mean weight was 72 ± 52 g (range 14 to 316 g). The majority of the catch in 2022 was composed of age 2+ fish, closely followed by age 3+, while the remainder of the catch was composed of age 1+ and age 4+ fish (Table 12, Figure 30). Overall, Fulton's condition factor (K) for 2022 Rainbow Trout was 1.1 ± 0.10 indicating healthy somatic growth. Rainbow Trout length-weight regressions based on fall nearshore gillnetting data for 2022 are shown in Figure 31. The 2022 length-weight regression slope (b value) was 2.73 (Figure 31, Table 13); b values near 3 are common for fish (Anderson and Gutreuter, 1983; Cone, 1989) and are indicative of isometric growth (i.e., the shape of the fish is consistent as it grows; Everhart and Youngs, 1981).

Table 12. Summary of Rainbow Trout biometrics by age, 2022, Wahleach Reservoir, BC.

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
1+	147	23	182	114	44.8	19.1	76.0	19.0	1.24	0.15	1.50	1.11	9
2+	184	29	242	148	75.7	37.8	163.5	39.0	1.12	0.10	1.37	0.99	25
3+	249	30	310	155	166.5	52.8	308.5	44.5	1.04	0.07	1.19	0.92	23
4+	301	8	307	295	260.0	9.2	266.5	253.5	0.96	0.05	0.99	0.92	2

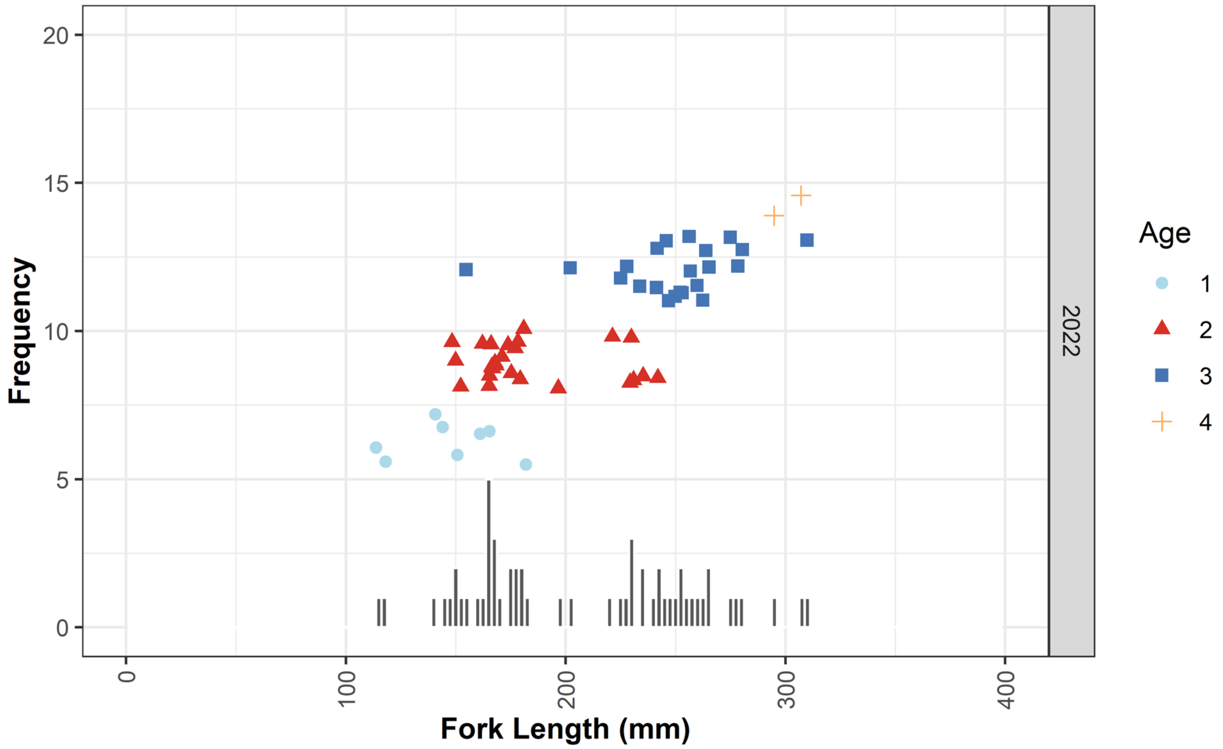

Figure 30. Length frequency by age class of Rainbow Trout in fall nearshore gillnets, 2022, Wahleach Reservoir, BC.

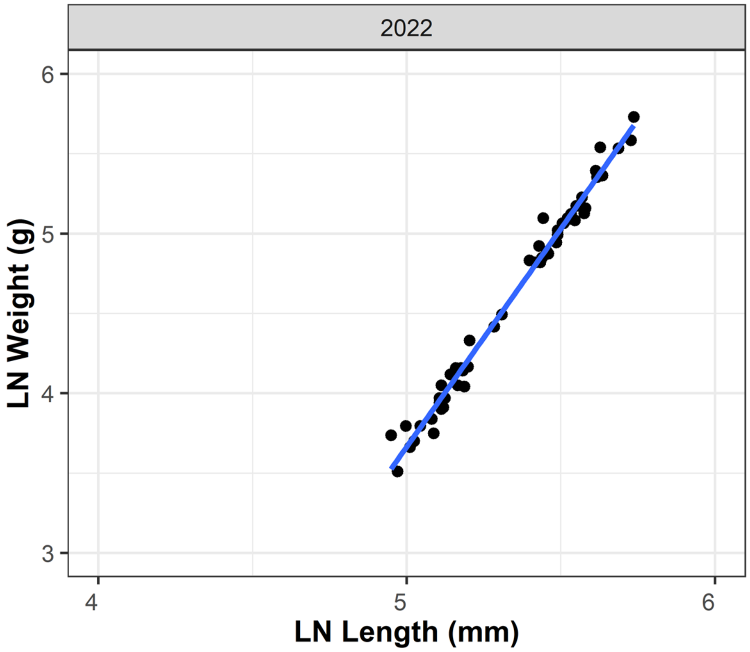

Figure 31. Length weight plot and relationship (Ln W=b · Ln L + Ln a) of Rainbow Trout, 2022, Wahleach Reservoir, BC.

Table 13. Summary of variables in R for Rainbow Trout length weight relationships (Ln W = b · Ln L + Ln a), 2022, Wahleach Reservoir, BC.

Year	Equation	R^2
2022	LN.weight.g = 2.73 *LN.length.mm -9.99	0.9872

4.6.4 Cutthroat Trout

Fall nearshore gillnet sampling in 2022 resulted in the capture of 47 Cutthroat Trout ranging in length from 242 to 525 mm and in weight from 134.0 to 840 grams. Fulton's condition factor (K) had a mean of 0.96 indicating healthy somatic growth. Eleven large, healthy Cutthroat Trout were released alive (ranging in length from 260 to 525 mm); no weight or age data were collected for these fish, therefore they were not included in Table 14. Cutthroat Trout retained during 2022 ranged from age 2+ to age 5+ with age 2+ representing the majority of the catch (Table 14, Figure 32). The length-weight regression slope (b value) for Cutthroat Trout in 2022 was 3 (Figure 33, Table 15); b values near 3 are common for fish (Anderson and Gutreuter, 1983; Cone, 1989).

Table 14. Summary of Cutthroat Trout biometrics by age, 2022, Wahleach Reservoir, BC.

Age	Fork Length (mm)				Weight (g)				Condition Factor (K)				n
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	
2+	277	26	331	242	206.6	62.0	356.5	134.0	0.94	0.08	1.13	0.82	20
3+	310	34	350	260	329.0	93.5	451.0	192.0	1.00	0.08	1.10	0.85	8
4+	398	28	430	368	609.3	163.2	840.0	474.0	0.95	0.07	1.06	0.89	5
5+	372	-	372	372	527.5	-	527.5	527.5	1.02	-	1.02	1.02	1

**Dashes (-) indicate no data.*

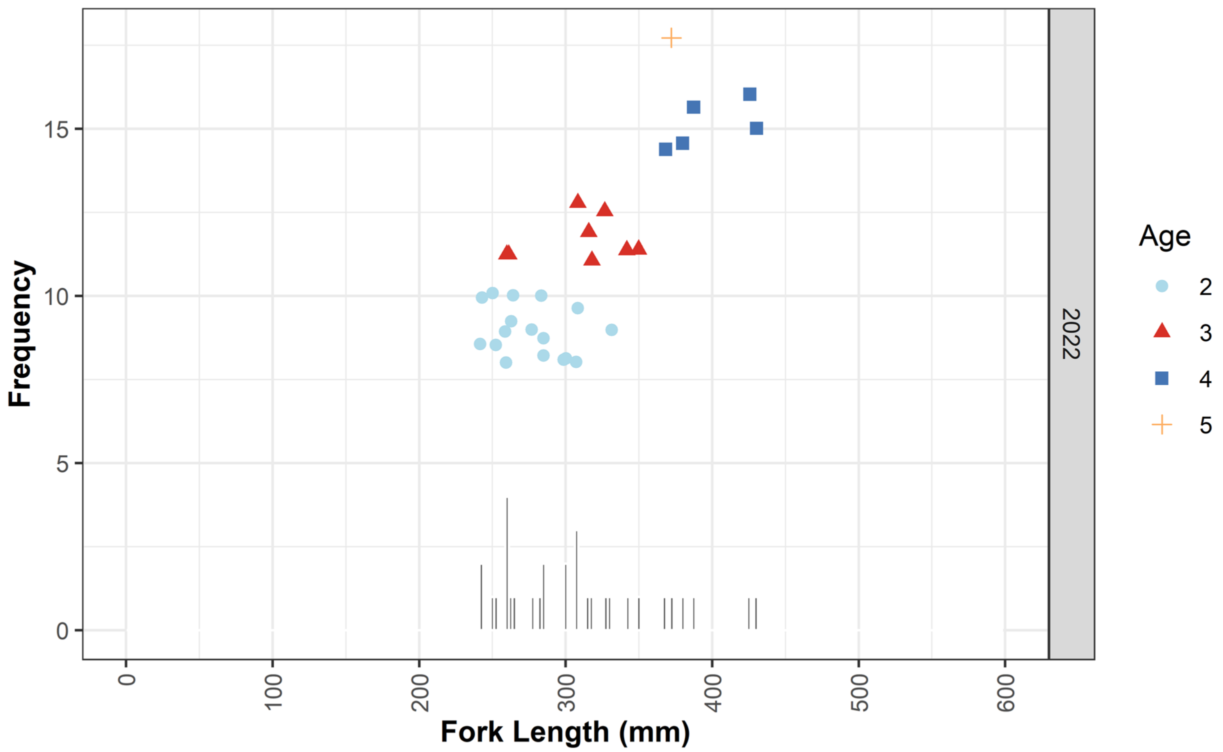

Figure 32. Length frequency of age classes of Cutthroat Trout in fall nearshore gillnets, 2022, Wahleach Reservoir, BC.

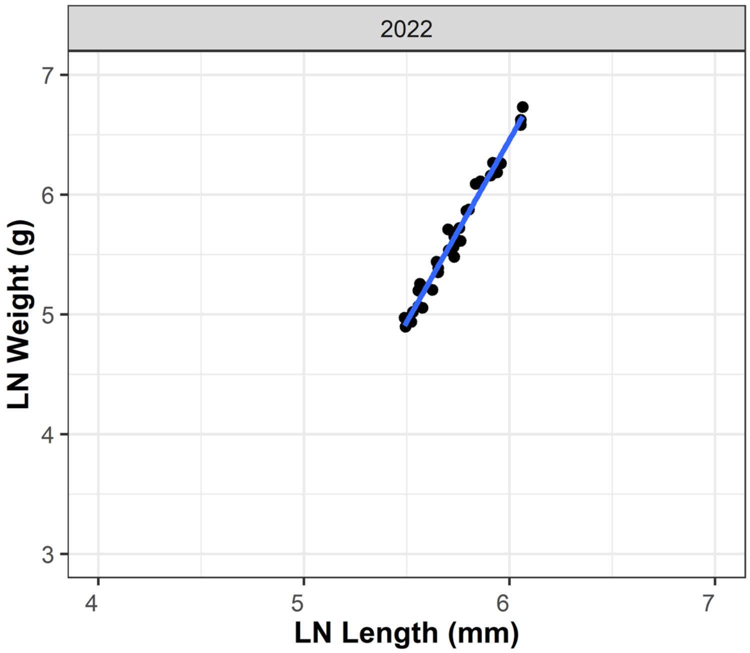

Figure 33. Length weight plot and relationship (Ln W = b · Ln L + Ln a) of Cutthroat Trout, 2022, Wahleach Reservoir, BC.

Table 15. Summary of variables in R for Cutthroat Trout length weight relationships (Ln W = b · Ln L + Ln a), 2022, Wahleach Reservoir, BC. Cutthroat Trout were not present in Wahleach Reservoir prior to nutrient restoration.

Year	Equation	R^2
2022	LN.weight.g = 3.04 *LN.length.mm -11.8	R^2=0.9759

4.6.5 Threespine Stickleback

Littoral minnow traps set in 2022 captured a total of 14 Threespine Stickleback with lengths ranging from 37 to 48 mm and all weighing approximately 0.5 g (Table 16, Figure 34). Threespine Stickleback catch remained lower than the 1994 baseline year (n=65).

Table 16. Summary of Threespine Stickleback length and weight data from minnow trapping, 2022, Wahleach Reservoir, BC.

Year	n	Mean Length (mm)	SD Length (mm)	Mean Weight (g)	SD Weight (g)
2022	14	42	3.2	0.5	0.1

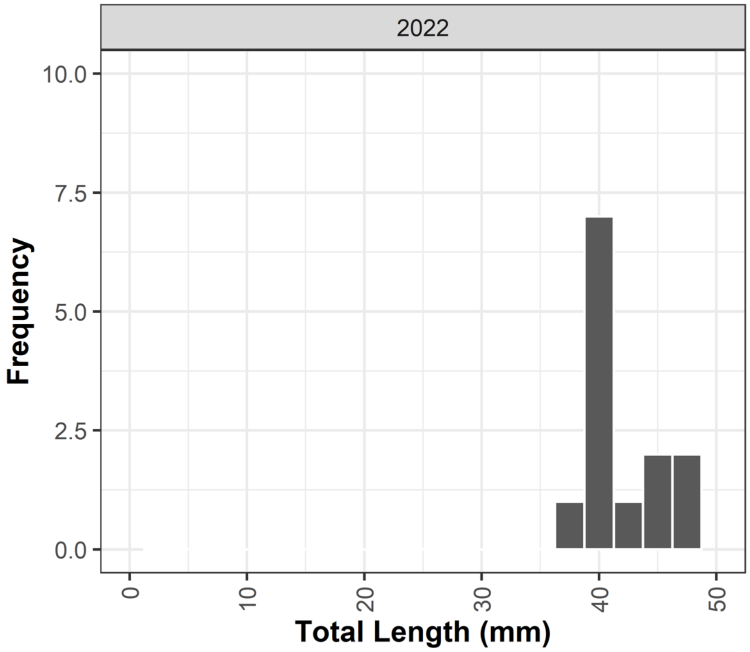

Figure 34. Length frequency of Threespine Stickleback caught in fall 2022, Wahleach Reservoir, BC.

4.6.7 Hydroacoustic Fish Distribution

Smaller sized Kokanee were primarily found in the shallower depth stratum (peak at 6 m layer) while larger Kokanee (age ≥1+) were concentrated deeper in the water column (peak at 8 m layer; Figure 35).

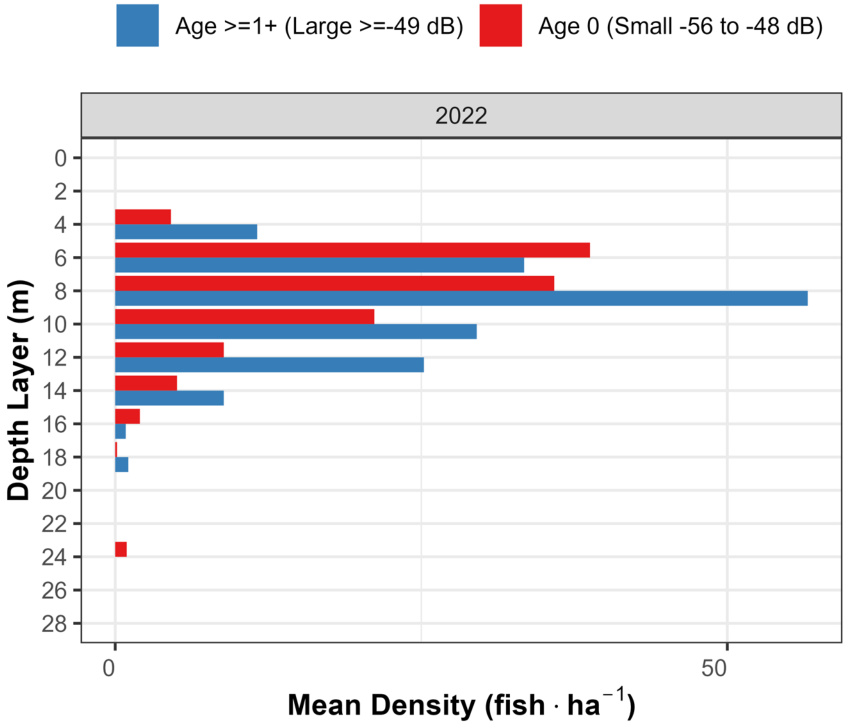

Figure 35. Distribution of Kokanee densities by depth (4-30m) for age 0 (small = -56 to -48 dB) and age ≥1+ fish (large ≥-49 dB) based on hydroacoustic survey, 2022, Wahleach Reservoir, BC.

4.6.8 Population and Biomass Estimates

Kokanee fry (age 0) abundance was ~30,000 individuals (ranging from ~24,000 to 36,000) which was lower than the long-term noise reduction timeseries mean of ~62,000 (2015-2022; Table 17; data on file). Adult Kokanee (age ≥1+) abundance in 2022 was ~42,000 individuals (ranging from ~33,000 to 52,000), which was higher than the long-term noise reduction timeseries mean of ~33,000 (2015-2022; Table 17; data on file). In 2022, total Kokanee biomass was estimated at 1,642 kg, which was above the 2015-2022 mean of 1,425 kg.

Table 17. Population estimates with upper and lower confidence intervals for Kokanee based on hydroacoustic survey, 2022, Wahleach Reservoir, BC.

Analysis Depths (m)	Group	Population Estimate	Lower CI	Upper CI
4-30	All KO	72,760	59,847	85,675
4-30	KO Fry	30,368	24,443	36,325
4-30	Adult KO	42,368	32,912	51,872

In 2022, Threespine Stickleback abundance was 13,982 individuals (Figure 36), which is below baseline and lower than the noise-reduction timeseries (2015-2022) of 30,672 individuals.

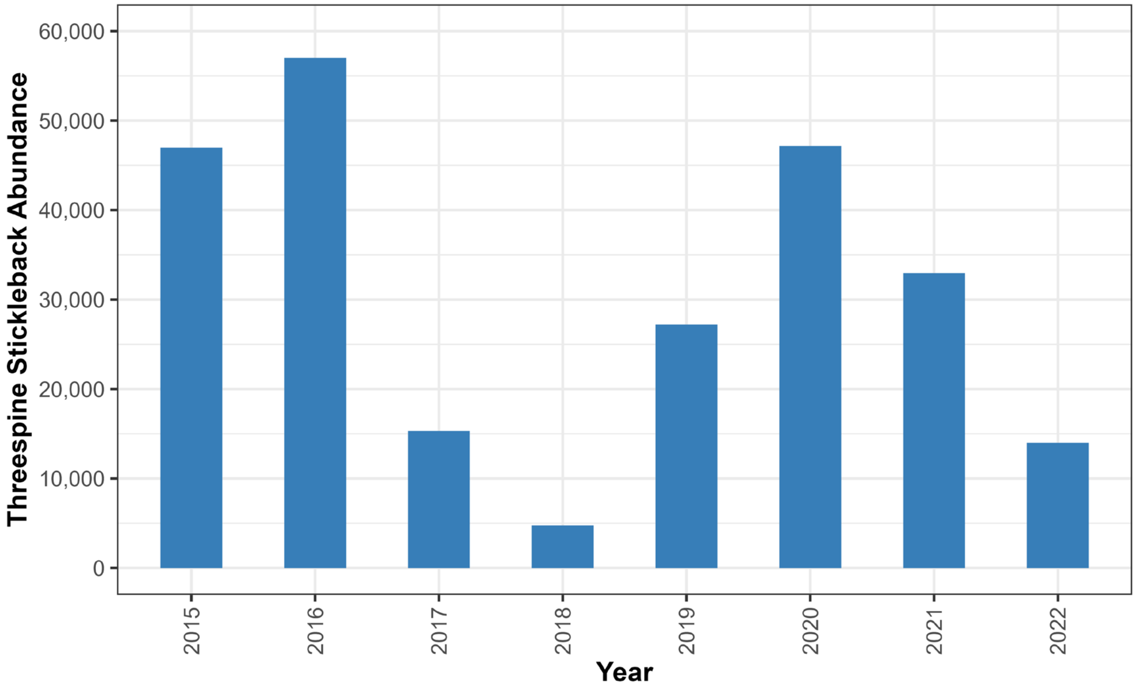

Figure 36. Threespine Stickleback abundance from 2015-2022, Wahleach Reservoir, BC.

5. Discussion

The importance of monitoring to the success of restoration projects has long been recognized. Monitoring allows for adaptive management and evaluation of the effectiveness of chosen restoration strategies. At the outset of the WUP, the key uncertainty identified was whether the nutrient restoration project would be able to maintain the Kokanee population in the reservoir (BC Hydro, 2006).

Trophic State & Nutrient Dynamics

Compelling evidence in the scientific literature supports the relationship between the quantity of nitrogen and phosphorus entering a system and the measured productive response (e.g., D. W. Schindler et al., 1971; Vollenweider, 1968, 1976). The Wahleach Reservoir Nutrient Restoration Project was based on these known links between nutrient availability and productivity. The intent of nutrient additions was to increase productivity, while maintaining the trophic state within the range of ultra-oligotrophic to oligotrophic to mimic conditions typical of coastal British Columbia systems (Northcote and Larkin, 1956; Stockner and Shortreed, 1985). Productivity directly measured through a variety of methods (e.g., radio-labelled carbon, oxygen production or dissolved inorganic carbon uptake measurement) require a high degree of technical expertise and effort and is commonly used to assess the trophic status of lakes and reservoirs including those with nutrient addition programs (e.g., Harris, 2015; E. U. Schindler et al., 2014; Stephens and MacKenzie-Grieve, 1973). The benefit of primary productivity measurements is that they are a direct assessment of primary productivity, and unlike abundance and biomass measurements, are not confounded by losses such as grazing, sinking and transport. In the absence of direct primary productivity data, other parameters were used to assess the reservoir's trophic state and response to nutrient restoration, including total phosphorus, total nitrogen, and Secchi transparency depths.

In 2022, Wahleach Reservoir was characterized by ultra-oligotrophic conditions in terms of nutrient concentrations and exhibited Secchi transparency depths indicative of oligotrophic to mesotrophic conditions, which is normal for nutrient-enriched Wahleach Reservoir (Table 18).

Table 18. Trophic state classification using criteria defined by Wetzel (2001) and Wetzel (1983). Blue shading is indicative of Trophic Classifications during nutrient restoration, 2022, Wahleach Reservoir, BC.

Parameter (Units)	Mean ± SD (Range)	Trophic Classification, Mean (Range)			
	2022	Ultra-Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic
TP (µg·L^{-1})	4.3 ± 1.0 (2.6 to 6.0)	(< 1-5)	8 (3-18)	27 (11-96)	84 (16-386)
TN (µg·L^{-1})	123 ± 35 (88 to 190)	(< 1-250)	661 (307-1,630)	753 (361-1,387)	1,875 (396-6,100)
Secchi (m)	5.3 ± 1.4 (3.4 to 7.8)	-	9.9 (5.4-29.3)	4.2 (1.5-8.1)	2.5 (0.8-7.0)

Patterns and concentrations of nitrogen and phosphorus in the epilimnion were consistent with the seasonal growth of phytoplankton and suggested a rapid uptake and assimilation of useable forms of nutrients by phytoplankton. In terms of nutrient loading from fertilizer additions, actual loads generally followed the annual plan in 2022, with the exception of weeks one and six which were missed due to low reservoir levels and logistical challenges, respectively. Planned nutrient loading strategies will continue to be revised in response to changing reservoir and climatic conditions noted during data reviews, as will actual in-season loading based on current monitoring data. The biological drawdown of NO_3+NO_2 concentrations, seen both seasonally and over the long-term mean, emphasizes the importance of careful monitoring of both phosphorous and nitrogen. Our current nutrient application approach focuses on keeping nitrogen limitation controlled, and continued monitoring is critical to keep on top of this.

Phytoplankton Edibility & Zooplankton Community

Keeping the dynamic nature of phytoplankton and zooplankton communities in mind when interpreting results, monitoring the response of these two trophic levels allows us to assess the efficacy of nutrient addition strategies at stimulating certain species or groups of species that will in turn lead to desired outcomes at higher trophic levels, such as the fish community. Nutrient additions were meant to stimulate the production of edible phytoplankton, so carbon is efficiently transferred to the production of desirable zooplankton species, particularly *Daphnia* – a large bodied zooplankter that is the preferred forage for Kokanee (Thompson, 1999). Ideally, phytoplankton are quickly ingested and assimilated by *Daphnia*, and would therefore leave minimal evidence of enhancement at the phytoplankton trophic level.

The phytoplankton community in 2022 consisted of edible species throughout the season that would support the growth of the zooplankton community. It should be noted that detailed phytoplankton comparisons with previous years are challenging due to the change to a different assessment laboratory in 2019. However, measures were taken to ensure a smooth transition between labs (including having duplicate samples analyzed by the previous and current lab) and we are confident that general conclusions regarding species, edibility and values are comparable. Zooplankton abundance and density across all major taxonomic groups has increased since the nutrient restoration project began (data on file). The most significant result has been the appearance of *Daphnia rosea*. The abundance and biomass of other cladocerans was dominant early in the 2022 season prior to the onset of *Daphnia* growth, which is common in Wahleach and was seen in previous years (data on file). Perhaps due to the late spring in 2022, *Daphnia* density and biomass did not have a strong presence until August, and numbers remained high through the fall and into November. This corresponds with Kokanee spawners leaving the reservoir, indicating that *Daphnia* were likely being heavily grazed down by Kokanee during the summer. Overall, zooplankton densities and biomass in 2022 were high compared to earlier years of the study and demonstrate an increase in food availability for Kokanee. The baseline (1993-94) zooplankton community consisted of *Bosmina longirostris*, *Cyclops* sp., and *Holopedium gibberum* and no *Daphnia* (data on file) were found.

Fish Population Response

In 2022, the hydroacoustic data indicated that age ≥1+ Kokanee (adult) abundance was the highest since 2015 (Figure 37), which is unsurprising given the record number of Kokanee fry recorded in 2021 surveys (Vainionpaa et al., 2022). Kokanee fry abundance in 2022 was lower than the long-term average (2015-2022; data on file). Despite suspected River Otter (*Lontra canadensis*) activity at the nets, the 2022 total gillnet catch was the second highest recorded in more than 10 years (2009-2022; data on file). Overall catch totalled 214 fish, with approximately half of those being Kokanee. Kokanee size and condition in 2022 remained well above baseline years (Perrin and Stables, 2001). Overall, both hydroacoustics and gillnetting data for 2022 showed a healthy Kokanee population in Wahleach Reservoir.

The estimate of Threespine Stickleback abundance from the hydroacoustic surveys was low at 13,982 individuals, which was lower than the long-term average of 30,672 (2015-2022; data on file). Minnow traps in 2022 caught 14 Threespine Stickleback, which was lower than the 1994 baseline catch of 65 Threespine Stickleback.

In order to standardize the methodology among large lakes and increase precision in annual estimates of both age 0 Kokanee and Threespine Stickleback abundances, re-analysis of the acoustic timeseries data (2015-2022) was applied using the method for acoustic noise reduction developed for Kinbasket and Revelstoke acoustic data (see Sebastian and Weir, 2015). This revised approach resulted in slight differences from previous reporting; more precise and robust estimates for both species can be found in Appendix C. The methodology for estimating biomass specific to Kokanee has also been refined and can be found in 55.

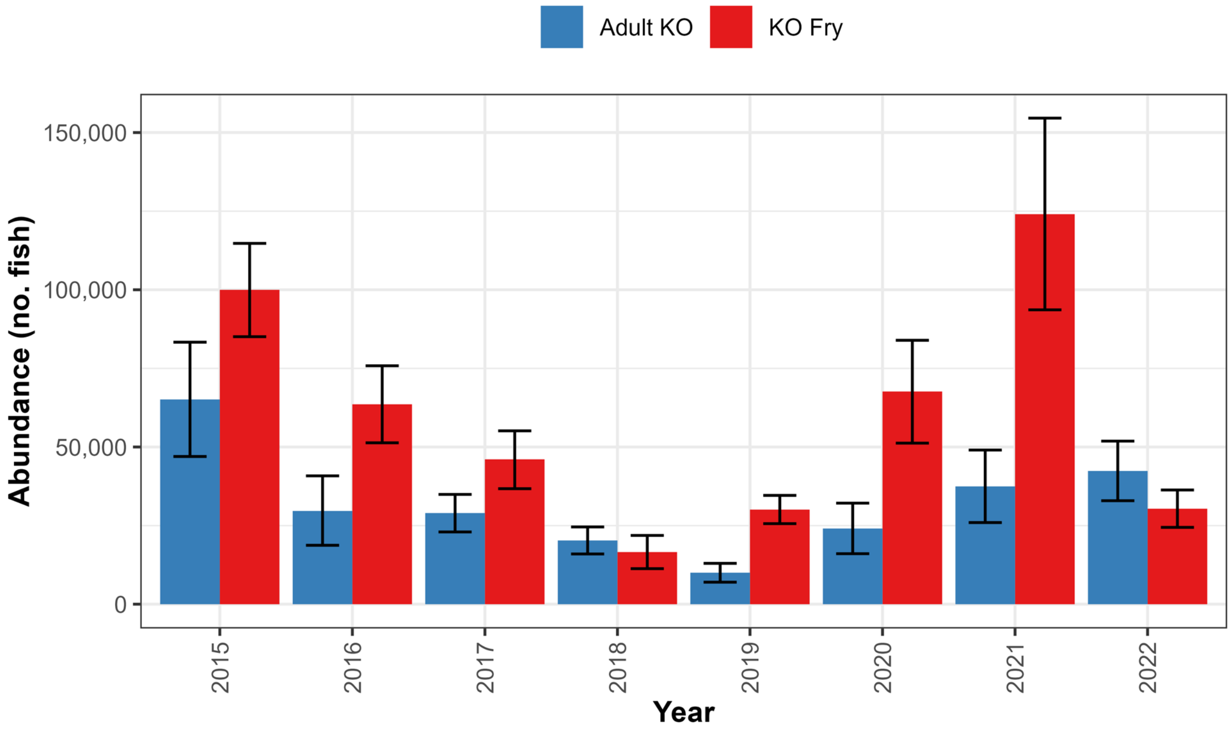

Figure 37. Kokanee adult and fry abundance (revised approach) from 2015-2022, Wahleach Reservoir, BC.

Kokanee spawner escapement in 2022 was the highest recorded since the program began (data on file; Figure 38). Flat Creek had the most spawners, followed by Jones Creek, and then Boulder Creek. Further exploration of Jones and Flat Creek habitats on September 21, 2022, found a potential increase in suitable spawning habitat beyond the original survey end points. This would subsequently underestimate escapement as Kokanee are spawning beyond the traditional survey distances. These numbers were not included in the final escapement to enable comparisons to previous years' data; however, this should be investigated further in subsequent years. Figure 39 shows a closer look at Boulder Creek spawner numbers, which have been steadily declining in recent years. When Kokanee were re-stocked to the reservoir at the inception of this program, they were released as fry nearest to the Boulder Creek tributary; therefore, it is natural that they would initially return to this creek as their spawning grounds. Unsurprisingly, over the next two decades a shift, or "straying" has been observed to Flat and Jones Creeks, which contain more extensive and suitable spawning habitat; straying has been observed in other reservoirs with stocked Kokanee (Shrimpton et al., 2022). As the name indicates, Boulder Creek substrate is mostly composed of larger boulders and cobbles and so typically, the vast majority of Kokanee have spawned in the single large pool that contains ideal spawning gravels. Some infilling of the pool from winter storms coupled with several warm Septembers with lower flows appears to have prevented Kokanee passage to this pool. In 2020 and 2021 it appeared that small falls at the outlet of the pool were too fast and were preventing fish passage. Kokanee were observed at the base of these falls with none further upstream in the more suitable habitat. In 2022, despite some construction by BC Hydro to rebuild the rock weir after the 2021 storm event which reduced the gradient into the pool, no Kokanee were observed spawning in the suitable habitat.

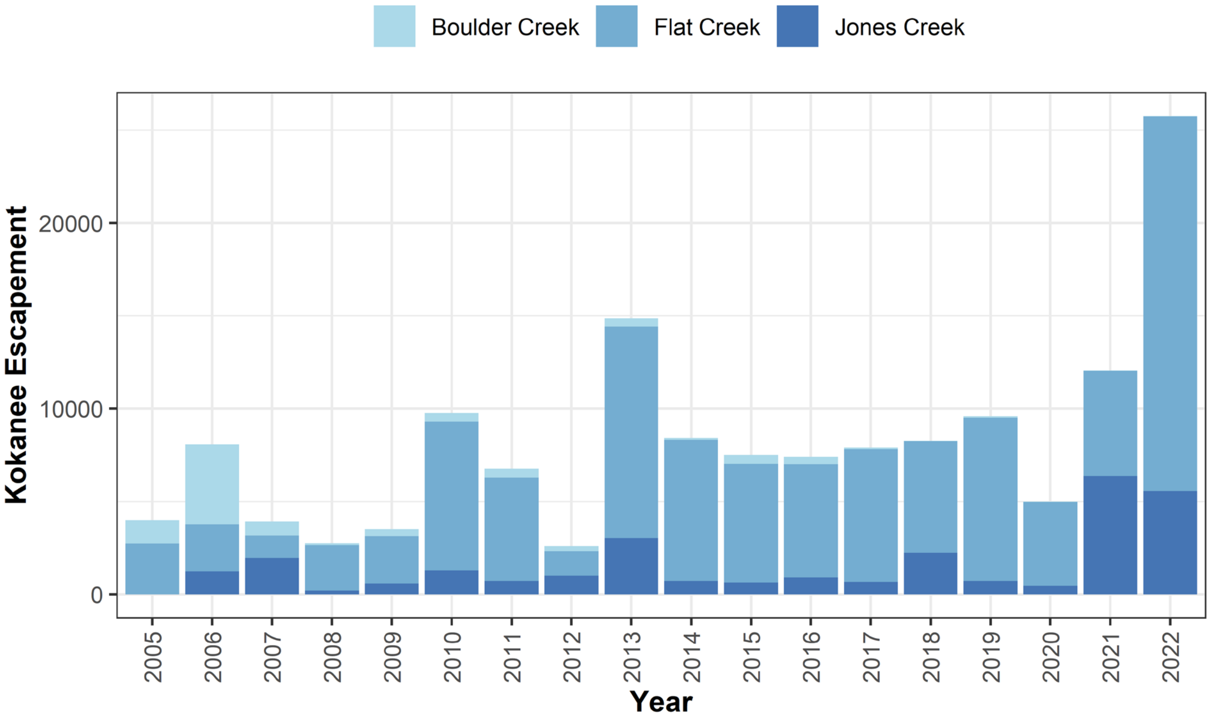

Figure 38. Kokanee spawner escapement from 2005-2022 in each index stream (Boulder Creek, Flat Creek, and Jones Creek), Wahleach Reservoir, BC.

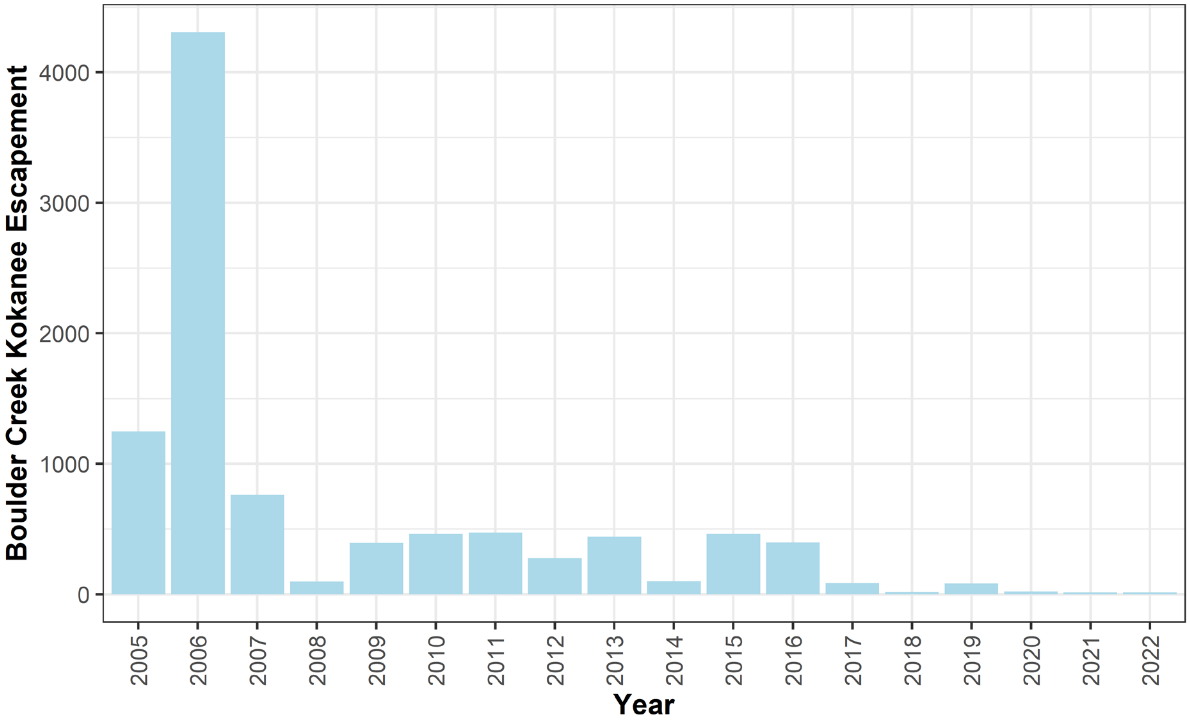

Figure 39. Boulder Creek Kokanee spawner escapement from 2005-2022, Wahleach Reservoir, BC.

When Kokanee return to their natal stream to spawn and die, they carry nutrients back into the ecosystem. As seen on the wildlife cameras, numerous species are benefiting from the spawning Kokanee in the Wahleach tributaries, especially black bears (*Ursus americanus*). Bears are a dominant predator of Salmon (Kokanee), which then provide additional nitrogen to riparian areas (Helfield and Naiman, 2006). In a study conducted by Quinn et al. (2001), it was shown that in smaller streams where Salmon are more easily accessible to bears, spawning Salmon tend to be younger, shorter, less deep-bodied, and spawn quickly once at the spawning grounds. Opportunistic observations of wildlife utilizing the creek corridors and feeding on spawning Kokanee can be found in 56.

6. Conclusion

It is evident from program monitoring data that nutrient addition on Wahleach Reservoir has had a positive effect on the lower trophic levels and has ultimately supported a self-sustaining Kokanee population within the reservoir. The Kokanee, in turn, are providing whole ecosystem benefits within the Wahleach watershed. Perrin et al. (2006) and ongoing program monitoring data confirmed that sterile Cutthroat Trout stocked in Wahleach Reservoir exhibit top-down pressure on the Threespine Stickleback population and have allowed Kokanee to take advantage of improved forage conditions. These combined restoration efforts have maintained Wahleach Reservoir's Kokanee population over the long term. We recommend that both restoration treatments continue to be applied in order to maintain the benefits this program has achieved since its inception thirty years ago.

7. Recommendations

Restoration Treatments

- Continue to apply and adaptively manage seasonal nutrient additions. Evidence from other nutrient restoration programs have shown that stopping or significantly decreasing the nutrient loading of a system can have immediate effects in terms of decreased abundance and biomass at lower trophic levels (Hebert et al., 2016) and would thereby negate the positive bottom-up effects of nutrient restoration on the Kokanee population.

- Continue stocking of sterile Cutthroat Trout at current levels (approximately 2,000) and size (yearling) to maintain top-down pressure on the Threespine Stickleback population. Stocking decisions should continue to be informed by monitoring program data.

Monitoring Programs

Limnology

- Continue monthly limnology sampling to adaptively manage the nutrient restoration strategy. If the reservoir is still thermally stratified in October, consider adding an additional limnology survey in November to ensure the full growing season is captured.

- Depending on in-season sampling results, include an additional limnology sampling trip between normally scheduled June and July trips to allow for closer tracking of nitrogen and phytoplankton concentrations. When phytoplankton are healthy, they double at least once a day and therefore sampling once every four weeks during a dynamic period of the year is inadequate.

Fish Populations

- Continue annual nearshore gillnetting and minnow trapping program in late October to ensure consistency of time-series data for biometric data collection.

- Continue annual Kokanee spawner surveys on index streams on a weekly basis (at minimum) for the entirety of the spawning window. In recent years, habitat use by spawners has been observed beyond the traditional survey end point of Flat Creek, leading to an underestimate of total spawner escapement. We recommend extending surveys to include this additional habitat; spawners counted beyond the original end point would be reported separately to allow for comparisons to previous years.

- Characterize habitat availability in Flat Creek. Spawning habitat was last studied nearly 30 years ago by Inglis (1995) who found only 129 m of suitable spawning habitat in 1,050 m of creek surveyed. Significant changes to the creek and surrounding riparian habitat from forestry operations have been observed and recent record escapements suggest that these findings may no longer be relevant. Documenting the current capacity and habitat quality of Flat Creek is important to ensure resource management decisions are informed by current data.

- Continue with the hydroacoustic surveys in late July or early August in 2023 as field conditions are generally more favorable at that time (i.e., thermal stratification is strongest to best determine fish species distribution and Kokanee spawners are still present in the reservoir). This will ensure consistency of more recent time-series data. It is also recommended that the earlier timeseries (2009-2014) be re-analyzed using a noise reduction method to refine age 0 Kokanee and Threespine Stickleback estimates. This is not expected to change values significantly but will make the estimates more precise. Estimate of completion of this re-analysis is targeted for the 2023 Report.

- Evaluate ability to standardize estimation of age structure and biomass for the Wahleach acoustic dataset with other lakes and reservoirs by applying methodology recently developed and applied to Duncan, Kootenay, Arrow, Kinbasket and Revelstoke Reservoirs. The ability to compare survival and biomass density trends between Wahleach and other systems in BC will add substantial value to the monitoring program and provide new insights into annual and long-term outcomes for Kokanee and the Nutrient Restoration Program in general. In this report biomass was re-analyzed from 2015-2022 using this updated methodology and the remainder of the timeseries will be completed for the 2023 report.

- Maintain temperature loggers in Wahleach Reservoir tributaries to gain knowledge on temperature regimes and long-term climate effects. Temperature data could also be used to gain insight on potential incubation and emergence timing.

Recreational Fishery

- Incorporate creel surveys into regular program monitoring to assess the recreational fishery on Wahleach Reservoir. One creel survey over each five-year cycle should be sufficient to understand how anglers are responding to restoration actions. A creel survey was last completed in 2017.

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9. Appendices

9.1 Appendix A. Phytoplankton species detected during 2022, Wahleach Reservoir, BC.

Species	2022	Species	2022
Amphidinium	+	*Gymnodinium* sp. (medium)	+
Ankistrodesmus sp.	+	*Gymnodinium* sp. (small)	+
Aphanothece minutissimus	+	*Kephyrion* sp.	+
Asterionella formosa	+	*Komma* sp.	+
Chlamydomonas	+	*Merismopedia* sp. (cells)	+
Chromulina sp.	+	*Monomastix sp.*	+
Chroococcus sp. (cells)	+	*Monoraphidium* sp.	+
Chroomonas acuta	+	*Nephroselmis*	+
Chrysococcus	+	*Ochromonas* sp.	+
Coelastrum sp. (cells)	+	*Oocystis* sp. (cells)	+
Cosmarium sp.	+	*Phacus* sp. (small)	+
Cryptomonas sp. (large)	+	*Scenedesmus* sp.	+
Cryptomonas sp. (medium)	+	*Scourfieldia* sp.	+
Cryptomonas sp. (small)	+	Small microflagellates	+
Cyclotella sp.	+	*Synechococcus* sp. (coccoid)	+
Dinobryon sp. (medium)	+	*Synechococcu*s sp. (rod)	+
Euglena	+	*Synechocystis* sp.	+
Fragilaria capucina	+	*Tabellaria fenestrata*	+
Fragilaria crotonensis	+	*Tetraedron* sp.	+
Gloeodinium sp.	+	*Trachelomonas sp.*	+
Gymnodinium sp. (large)	+		+

9.2 Appendix B. Zooplankton species detected during 2022, Wahleach Reservoir, BC.

Order/Species	**2022**
CLADOCERA	
Bosmina longirostris	+
Chydorus sphaericus	r
Daphnia rosea	+
Daphnia galeata mendotae	+
Holopedium gibberum	+
Leptodora kindtii	+
Scapholeberis mucronata	r
Polyphemus pediculus	r
COPEPODA	
Cyclops vernalis	+
Leptodiaptomus ashlandi	r

r = rare species, + = present

9.3 Appendix C. Hydroacoustic noise reduction method results comparing 2021 to the 2022 further refinement, for estimating Kokanee fry abundance 2015-2022, Wahleach Reservoir, BC.

Year	KO abundance 2021 noise reduction	KO abundance 2022 refinement	**% Change**
2015	105,283	99,985	5%
2016	61,797	63,578	3%
2017	45,064	46,071	2%
2018	17,095	16,579	3%
2019	31,242	30,083	4%
2020	71,887	67,649	6%
2021	129,723	124,050	5%
2022	-	30,368	-

9.4 Appendix D. Estimates of Kokanee biomass based on summer hydroacoustic surveys 2015-2022, Wahleach Reservoir, BC.

Year	Dates	KO Biomass (kg) old method	KO Biomass New method	**% Change**
2015	Aug 11	3,093	2,656	14%
2016	Jul 26	1,431	1,378	4%
2017	Jul 26	1,311	1,080	18%
2018	Jul 18	1,011	967	4%
2019	Aug 7	701	731	4%
2020	Aug 19	1,697	1,480	13%
2021	Jul 14	1,748	1,468	16%
2022	Jul 28	-	1,642	-

9.5 Appendix E. Species observed on Wildlife Cameras, September to October, 2022, Wahleach Reservoir, BC.

Common Name	**Scientific Name**
American Dipper	*Cinco mexicanus*
American Marten	*Martes americana*
Bald Eagle	*Haliaeetus leucocephalus*
Barred Owl	*Strix varia*
Black Bear	*Ursus americanus*
Bobcat	*Lynx rufus*
Common Merganser	*Mergus merganser*
Common Raccoon	*Procyon lotor*
Coyote	*Canis latrans*
Douglas's Squirrel	*Tamiasciurus douglasii*
Red-tailed Hawk	*Buteo jamaicensis*